ASME B31.3-2018

(Revision of ASME B31.3-2016)

# Process Piping

## ASME Code for Pressure Piping, B31



AN INTERNATIONAL PIPING CODE®

The American Society of Mechanical Engineers

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AN INTERNATIONAL PIPING CODE®

The American Society of
Mechanical Engineers

Two Park Avenue • New York, NY • 10016 USA

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The next edition of this Code is scheduled for publication in 2020. This Code will become effective 6 months after the Date of Issuance.

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The American Society of Mechanical Engineers
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# FOREWORD

Responding to evident need and at the request of The American Society of Mechanical Engineers (ASME), the American Standards Association initiated Project B31 in March 1926, with ASME as sole administrative sponsor. The breadth of the field involved required that membership of the Sectional Committee be drawn from some 40 engineering societies, industries, government bureaus, institutes, and trade associations.

Initial publication in 1935 was as the American Tentative Standard Code for Pressure Piping. Revisions from 1942 through 1955 were published as American Standard Code for Pressure Piping, ASA B31.1. It was then decided to publish as separate documents the various industry Sections, beginning with ASA B31.8-1955, Gas Transmission and Distribution Piping Systems. The first Petroleum Refinery Piping Code Section was designated ASA B31.3-1959. ASA B31.3 revisions were published in 1962 and 1966.

In 1967–1969, the American Standards Association became first the United States of America Standards Institute, then the American National Standards Institute (ANSI). The Sectional Committee became American National Standards Committee B31 and the Code was renamed the American National Standard Code for Pressure Piping. The next B31.3 revision was designated ANSI B31.3-1973. Addenda were published through 1975.

A draft Code Section for Chemical Plant Piping, prepared by Section Committee B31.6, was ready for approval in 1974. It was decided, rather than have two closely related Code Sections, to merge the Section Committees and develop a joint Code Section, titled Chemical Plant and Petroleum Refinery Piping. The first edition was published as ANSI B31.3-1976.

In this Code, responsibility for piping design was conceptually integrated with that for the overall processing facility, with safeguarding recognized as an effective safety measure. Three categories of Fluid Service were identified, with a separate Chapter for Category M Fluid Service. Coverage for nonmetallic piping was introduced. New concepts were better defined in five Addenda, the fourth of which added Appendix M, a graphic aid to selection of the proper Fluid Service category.

The Standards Committee was reorganized in 1978 as a Committee operating under ASME procedures with ANSI accreditation. It is now the ASME Code for Pressure Piping, B31 Committee. Section committee structure remains essentially unchanged.

The second edition of Chemical Plant and Petroleum Refinery Piping was compiled from the 1976 Edition and its five Addenda, with nonmetal requirements editorially relocated to a separate Chapter. Its new designation was ANSI/ASME B31.3-1980.

Section Committee B31.10 had a draft Code for Cryogenic Piping ready for approval in 1981. Again, it was decided to merge the two Section Committees and develop a more inclusive Code with the same title. The work of consolidation was partially completed in the ANSI/ASME B31.3-1984 Edition.

Significant changes were made in Addenda to the 1984 Edition: integration of cryogenic requirements was completed; a new stand-alone Chapter on high-pressure piping was added; and coverage of fabrication, inspection, testing, and allowable stresses was reorganized. The new Edition was designated as ASME/ANSI B31.3-1987 Edition.

Addenda to the subsequent five Editions, published at three-year intervals, were primarily used to keep the Code up to date. New Appendices were added, however, on requirements for bellows expansion joints, estimating service life, submittal of Inquiries, aluminum flanges, and quality control in the 1990, 1993, 1999, and 2002 Editions, all designated as ASME B31.3.

In a program to clarify the application of all Sections of the Code for Pressure Piping, changes were made in the Introduction and Scope statements of the 1996 Edition, and its title was changed to Process Piping.

Under direction of ASME Codes and Standards management, SI (metric) units of measurement were emphasized. With certain exceptions, SI units were listed first in the 1996 Edition and were designated as the standard. Instructions for conversion were given where SI units data were not available. U.S. Customary units also were given. By agreement, either system may have been used.

Beginning with the 2004 Edition, the publication cycle of ASME B31.3 was changed to biennial. Other changes made in the 2004 Edition included the introduction of the weld joint strength reduction factor, *W*, and the additions of Appendix P, Alternative Rules for Evaluating Stress Range, and Appendix S, Piping System Stress Analysis Examples.

Changes that were made to the 2006 and 2008 Editions of ASME B31.3 included the requirement that valves have blowout-proof stems and the addition of a definition for elevated temperature fluid service, respectively. The most significant change that was made to the 2010 Edition of ASME B31.3 was the addition of Chapter X, High Purity

Piping. In the 2012 Edition, Tables A-1M and A-2M were added to Appendix A that give allowable design values in SI units, and Appendix N, Application of ASME B31.3 Internationally, was also added.

For the 2016 Edition, the allowable design values in SI units as shown in Tables A-1M and A-2M were changed from for information only to values that may be used to meet the requirements of the Code.

In this Edition, SI units are given first, with U.S. Customary units in parentheses. Table K-1 in Appendix K is an exception, containing only U.S. Customary units. The allowable design values in Tables A-1 and A-2 are given in U.S. Customary units, and the SI values are given in Tables A-1M and A-2M. Either the U.S. Customary units or the SI units for these allowable design values may be used. Except for Tables A-1, A-1M, A-2, A-2M, C-1, C-1M, C-6, C-6M, and K-1, values in SI units are to be regarded as the standard, unless otherwise agreed between the contracting parties. Instructions are given in Table K-1 for converting tabular data in U.S. Customary units to appropriate SI units.

Interpretations, Code Cases, and errata to the B31.3 Code on Process Piping are published on the following ASME web page: *https://cstools.asme.org/csconnect/CommitteePages.cfm?Committee=N10020400.*

ASME B31.3-2018 was approved by the American National Standards Institute on August 8, 2018.

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# Code for Pressure Piping

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# INTRODUCTION

The ASME B31 Code for Pressure Piping consists of a number of individually published Sections, each an American National Standard, under the direction of ASME Committee B31, Code for Pressure Piping.

Rules for each Section reflect the kinds of piping installations considered during its development, as follows:

| | |
|---|---|
| B31.1 | Power Piping: piping typically found in electric power generating stations, in industrial and institutional plants, geothermal heating systems, and central and district heating and cooling systems |
| B31.3 | Process Piping: piping typically found in petroleum refineries; onshore and offshore petroleum and natural gas production facilities; chemical, pharmaceutical, textile, paper, ore processing, semiconductor, and cryogenic plants; food and beverage processing facilities; and related processing plants and terminals |
| B31.4 | Pipeline Transportation Systems for Liquids and Slurries: piping transporting products that are predominately liquid between plants and terminals and within terminals, pumping, regulating, and metering stations |
| B31.5 | Refrigeration Piping and Heat Transfer Components: piping for refrigerants and secondary coolants |
| B31.8 | Gas Transmission and Distribution Piping Systems: piping transporting products that are predominately gas between sources and terminals, including compressor, regulating, and metering stations; gas gathering pipelines |
| B31.9 | Building Services Piping: piping typically found in industrial, institutional, commercial, and public buildings, and in multi-unit residences, which does not require the range of sizes, pressures, and temperatures covered in B31.1 |
| B31.12 | Hydrogen Piping and Pipelines: piping in gaseous and liquid hydrogen service and pipelines in gaseous hydrogen service |

This is the B31.3 Process Piping Code Section. Hereafter, in this Introduction and in the text of this Code Section B31.3, where the word *Code* is used without specific identification, it means this Code Section.

It is the owner's responsibility to select the Code Section that most nearly applies to a proposed piping installation. Factors to be considered by the owner include limitations of the Code Section; jurisdictional requirements; and the applicability of other codes and standards. All applicable requirements of the selected Code Section shall be met. For some installations, more than one Code Section may apply to different parts of the installation. The owner is also responsible for imposing requirements supplementary to those of the Code if necessary to assure safe piping for the proposed installation.

Certain piping within a facility may be subject to other codes and standards, including but not limited to

— ANSI Z223.1 National Fuel Gas Code: piping for fuel gas from the point of delivery to the connection of each fuel utilization device

— NFPA Fire Protection Standards: fire protection systems using water, carbon dioxide, halon, foam, dry chemicals, and wet chemicals

— NFPA 99 Health Care Facilities: medical and laboratory gas systems

— building and plumbing codes, as applicable, for potable hot and cold water, and for sewer and drain systems

The Code specifies engineering requirements deemed necessary for safe design and construction of pressure piping. While safety is the primary consideration, this factor alone will not necessarily govern the final specifications for any piping installation. The Code is not a design handbook. Many decisions that must be made to produce a sound piping installation are not specified in detail within this Code. The Code does not serve as a substitute for sound engineering judgments by the owner and the designer.

To the greatest possible extent, Code requirements for design are stated in terms of basic design principles and formulas. These are supplemented as necessary with specific requirements to ensure uniform application of principles and to guide selection and application of piping elements. The Code prohibits designs and practices known to be unsafe and contains warnings where caution, but not prohibition, is warranted.

This Code Section includes the following:

*(a)* references to acceptable material specifications and component standards, including dimensional requirements and pressure–temperature ratings

*(b)* requirements for design of components and assemblies, including piping supports

*(c)* requirements and data for evaluation and limitation of stresses, reactions, and movements associated with pressure, temperature changes, and other forces

*(d)* guidance and limitations on the selection and application of materials, components, and joining methods

*(e)* requirements for the fabrication, assembly, and erection of piping

*(f)* requirements for examination, inspection, and testing of piping

ASME Committee B31 is organized and operates under procedures of The American Society of Mechanical Engineers that have been accredited by the American National Standards Institute. The Committee is a continuing one, and keeps all Code Sections current with new developments in materials, construction, and industrial practice. New editions are published at intervals of two years.

Code users will note that paragraphs in the Code are not necessarily numbered consecutively. Such discontinuities result from following a common outline, insofar as practical, for all Code Sections. In this way, corresponding material is correspondingly numbered in most Code Sections, thus facilitating reference by those who have occasion to use more than one Section.

This edition of Code Section B31.3 is not retroactive. Normally, agreement is made between contracting parties to use a specific edition, considering requirements of the authority having jurisdiction. When specified as the latest edition and when no edition is specified, the specific edition is the one issued at least 6 months prior to the original contract date for the first design activity.

Users of this Code are cautioned against making use of Code revisions without assurance that they are acceptable to the proper authorities in the jurisdiction where the piping is to be installed.

The B31 Committee has established an orderly procedure to consider requests for interpretation and revision of Code requirements. To receive consideration, such request must be in writing and must give full particulars in accordance with Appendix Z.

The approved reply to an inquiry will be sent directly to the inquirer. In addition, the question and reply will be published as part of an Interpretation supplement.

A Case is the prescribed form of reply when study indicates that the Code wording needs clarification, or when the reply modifies existing requirements of the Code or grants permission to use new materials or alternative constructions. The Case will be published as part of a Case supplement.

Code Cases remain available for use until annulled by the ASME B31 Standards Committee.

A request for revision of the Code will be placed on the Committee's agenda. Further information or active participation on the part of the proponent may be requested during consideration of a proposed revision.

Materials ordinarily are listed in the stress tables only when sufficient usage in piping within the scope of the Code has been shown. Requests for listing shall include evidence of satisfactory usage and specific data to permit establishment of allowable stresses, maximum and minimum temperature limits, and other restrictions. Additional criteria can be found in the guidelines for addition of new materials in the ASME Boiler and Pressure Vessel Code, Section II. (To develop usage and gain experience, unlisted materials may be used in accordance with para. 323.1.2.)

# ASME B31.3-2018
# SUMMARY OF CHANGES

Following approval by the ASME B31 Committee and ASME, and after public review, ASME B31.3-2018 was approved by the American National Standards Institute on August 8, 2018.

ASME B31.3-2018 includes the following changes identified by a margin note, **(18)**.

| *Page* | *Location* | *Change* |
|---|---|---|
| xx | Introduction | Revised |
| 1 | 300 | Subparagraphs (b)(1) and (c)(4) revised |
| 2 | 300.1 | Revised |
| 2 | 300.1.3 | Footnote 2 revised |
| 2 | 300.1.4 | Revised |
| 3 | 300.2 | (1) Footnote 3 revised |
| | | (2) *indication, linear; indication, rounded*; and *stress ratio* revised |
| | | (3) *owner, readily accessible (for visual examination)*, and *representative* added |
| 9 | Table 300.4 | Entry for W added |
| 11 | 301.5 | First paragraph deleted |
| 11 | 301.5.1 | Revised |
| 11 | 301.5.4 | Revised |
| 12 | 302.2.3 | Revised in its entirety |
| 12 | 302.2.4 | First paragraph and subpara. (c) revised |
| 14 | 302.3.2 | Revised in its entirety |
| 15 | 302.3.5 | Subparagraphs (c), (e), and (f) revised |
| 18 | 302.3.6 | Subparagraph (a) revised |
| 20 | Table 302.3.5 | (1) Second column head revised |
| | | (2) First row added |
| | | (3) General Note (b) and Notes (2), (3), and (9) revised |
| 29 | 304.5.1 | Subparagraph (b) revised |
| 32 | 306.3.2 | Revised |
| 32 | 306.3.3 | Revised |
| 33 | 306.4.4 | Subparagraph (b) revised |
| 33 | 306.5.2 | Revised |
| 33 | Table 308.2.1 | General Note revised |
| 34 | 308.3 | Revised |
| 34 | 308.4 | Revised |
| 34 | 309.2.3 | First paragraph revised |
| 35 | 310 | Revised |
| 35 | 311.1 | Revised |
| 35 | 311.2 | Paragraphs 311.2.1, 311.2.2, and 311.2.3 deleted, and subsequent paragraphs redesignated |

| | | |
|---|---|---|
| 35 | 312 | First paragraph added |
| 36 | Table 314.2.1 | Revised in its entirety |
| 36 | 314.2.1 | Subparagraphs (a) and (b) revised |
| 36 | 315.2 | Subparagraph (a) revised |
| 36 | 315.3 | Revised |
| 37 | 318.2.3 | Revised |
| 39 | 319.3.6 | Second paragraph revised |
| 40 | 319.4.4 | Subparagraph (c) revised |
| 43 | 320.2 | Second paragraph revised |
| 45 | 321.3.2 | (1) First paragraph revised<br>(2) Last paragraph and footnote 10 added |
| 47 | 323.2.2 | Revised in its entirety |
| 48 | Table 323.2.2 | (1) Last two column heads revised<br>(2) Under Type of Material, third entry revised<br>(3) Notes (1), (3), (4), (6), and (7) revised |
| 50 | Figure 323.2.2A | Previous Note (6) redesignated as (1) and revised; other Notes renumbered |
| 51 | Table 323.2.2A | In seventh group of rows, in fourth row, entries under Nominal Thickness revised |
| 52 | Figure 323.2.2B | (1) Fahrenheit values corrected by errata and moved to bottom of illustration<br>(2) General Notes replaced by one General Note |
| 54 | 323.3.5 | Subparagraphs (b) and (c) revised |
| 57 | Table 323.3.5 | In first column, last entry revised |
| 60 | Table 326.1 | (1) ASME B18.31.2 added<br>(2) Notes (4) and (5) revised |
| 72 | Table 330.1.1 | For P-No. 5B, first two entries in third row revised |
| 72 | 331.1.1 | Subparagraph (a) revised |
| 79 | 335.3.1 | Revised |
| 81 | 340.4 | Subparagraph (b)(3) revised |
| 82 | 341.4.1 | Subparagraphs (a)(2) and (a)(3) revised |
| 84 | Table 341.3.2 | (1) Under Weld Imperfection, fifth entry revised<br>(2) For Criteria F and G, main entry under Measure revised |
| 85 | Criterion Value Notes for Table 341.3.2 | Note (2) [formerly Note (10)] revised |
| 89 | 344.2.1 | Revised |
| 89 | 344.2.2 | Revised |
| 89 | 344.5.1 | Revised |
| 90 | 344.6.2 | Subparagraph (b) corrected by errata |
| 91 | 345.2.1 | Subparagraph (a) revised |
| 91 | 345.2.5 | Revised |
| 93 | 345.8 | (1) Paragraph 345.8.1 added<br>(2) Existing text moved to new para. 345.8.2 and subpara. (a) revised |
| 95 | A302.2.3 | Revised |
| 96 | A302.3.2 | Footnote 1 revised |

| | | |
|---|---|---|
| 97 | A302.3.4 | Subparagraph (a) revised |
| 101 | A319.2.1 | Revised in its entirety |
| 102 | A319.2.2 | Subparagraph (a) revised |
| 107 | Table A326.1 | (1) ASTM F1545 and AWWA C900 revised<br>(2) Note (4) added |
| 114 | Table A341.3.2 | Revised |
| 119 | M323.2 | Revised |
| 120 | M335.1.1 | First cross-reference corrected by errata to read 335.1 |
| 124 | K300 | Subparagraphs (a), (b)(1), and (e) revised |
| 124 | K300.1 | Revised in its entirety |
| 124 | K300.4 | Revised |
| 124 | K301 | (1) First paragraph revised<br>(2) Paragraph K301.1 deleted<br>(3) Paragraph K301.2.1 revised<br>(4) Paragraphs K301.4.2 and K301.7.3 added |
| 125 | K302.2.3 | Revised in its entirety |
| 125 | K302.2.4 | Revised |
| 126 | K302.3.3 | First paragraph revised |
| 127 | K302.3.5 | Subparagraph (c) revised |
| 127 | K302.3.6 | Subparagraph (a) revised |
| 128 | K304.1.2 | (1) Equations (34a), (34b), (34c), and (34d) revised<br>(2) Footnote 3 deleted and subsequent footnotes renumbered |
| 130 | K304.7.4 | Revised |
| 131 | K306.1.1 | Revised |
| 133 | K314 | Revised in its entirety |
| 133 | K315 | Revised in its entirety |
| 134 | K318 | Revised |
| 134 | K319 | Revised |
| 134 | K320 | Added |
| 135 | K323.2 | Revised |
| 135 | K323.2.1 | Revised |
| 136 | K323.2.4 | Subparagraph (a) revised |
| 139 | K326.4 | Revised in its entirety |
| 144 | Table K341.3.2 | Under Type of Imperfection, fifth entry revised |
| 145 | Criterion Value Notes for Table K341.3.2 | For Symbol C, Measure revised |
| 146 | K344.6.3 | Subparagraph (b) revised |
| 148 | K346.2 | Subparagraph (d) revised |
| 151 | U328.4 | Revised |
| 152 | U341.3.2 | Revised |
| 157 | Specification Index for Appendix A | Revised in its entirety |
| 161 | Notes for Tables A-1, A-1M, A-1A, A-1B, A-2, and A-2M | (1) General Note (a) and Notes (6), (30), and (65) revised<br>(2) Note (79) added |
| 165 | Table A-1 | (1) All Note (2) references deleted |

(2) Under Carbon Steel — Forgings and Fittings, A694 F42, F46, F52, F56, F60, F65, and F70; A707 L1, L2, and L3; and A860 WPHY 42, WPHY 46, WPHY 52, WPHY 60, WPHY 65, and WPHY 70 added

(3) Under Low and Intermediate Alloy Steel — Pipes, for A671 CFB70 and CFE70, Type/Grade revised

(4) Under Low and Intermediate Alloy Steel — Plates, for A387 9, P-No. revised

(5) Under Stainless Steel — Pipes and Tubes, A312 TP321, A312 TP321H, A376 TP321, and A376 TP321H revised

(6) A270 TP304L and TP316L added

(7) A358 321 and A409 TP321 revised

(8) A358 321H added

(9) A270 TP316 added

(10) A270 TP304 added

(11) A789 and A790 S82441 added

(12) A789 and A790 S32003 revised

(13) For A928 S32003, Size revised

(14) A789 and A790 S32760 revised

(15) Under Stainless Steel — Plates and Sheets, A240 321 and 321H revised

(16) A240 S82441 added

(17) For A240 S32003, Size revised

(18) A240 S32760 revised

(19) Under Stainless Steel — Forgings and Fittings, A182 F321 and F321H revised

(20) A403 WP321 and WP321H revised

(21) Under Stainless Steel — Bar, for A479 304, 304H, 304L, 316, 316H, and 316L, Notes revised

(22) For A479 321 and 321H, stress value for 650°F and font for stress values revised

(23) A479 S82441 added

(24) Under Stainless Steel — Castings, for A351 CF8C, Notes and stress values revised

(25) Under Nickel and Nickel Alloy — Pipes and Tubes, N08825 B163, B474, and B704 added

(26) For N08825 B423 and B705, fonts for stress values corrected by errata

(27) N06690 B163 and B167 added

(28) N08120 B163, B407, B514, and B515 added

(29) Under Nickel and Nickel Alloy — Plates and Sheets, for N08825 B424, fonts for stress values corrected by errata

(30) N06690 B168 added

(31) N08120 B409 added

(32) Under Nickel and Nickel Alloy — Forgings and Fittings, for N02200 B366, stress value revised

(33) N02200 B564 deleted

(34) For N08825 B366 and B564, fonts for stress values corrected by errata

(35) N06690 B564 added

(36) N08120 B366 and B564 added

(37) Under Nickel and Nickel Alloy — Rod and Bar, for N08825 B425, fonts for stress values corrected by errata

(38) N06690 B166 added

(39) N08120 B408 added

(40) For the titanium and titanium alloys, Product Form and Class/Condition/Temper entries added, and stress values revised

(41) Under Titanium and Titanium Alloy — Pipes and Tubes, R50250, R50400, R50550, R52400, and R53400 B338 added

(42) R53400 B861 and B862 added

(43) Under Titanium and Titanium Alloy — Plates, Sheet, and Strips (formerly Plates and Sheets), for R50250 B265, Specified Min. Yield Strength revised

(44) R52400 and R53400 B265 added

(45) Under Titanium and Titanium Alloy — Forgings and Fittings (formerly Forgings), R50250, R50400, R50550, R52400, and R53400 B363 added

(46) For R50250 B381, Type/Grade and Specified Min. Yield Strength revised

(47) For R50400 and R50550 B381, Type/Grade revised

(48) R52400 and R53400 B381 added

(49) Under Titanium and Titanium Alloy — Bars, R50250, R50400, R50550, R52400, and R53400 B348 added

(50) Under Titanium and Titanium Alloy — Castings, R52550 and R52700 B367 added

(51) Under Aluminum Alloy — Seamless Pipes and Tubes, A83003, A91060, A93003, A95083, A95086, A96061, and A96063 B345 deleted

(52) Under Aluminum Alloy — Castings, for A03560 B26, P-Nos. added

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| 240 | Table A-1M | (1) All Note (2) references deleted |

(2) A694 F42, F46, F52, F56, F60, F65, and F70; A707 L1, L2, and L3; and A860 WPHY 42, WPHY 46, WPHY 52, WPHY 60, WPHY 65, and WPHY 70 added

(3) For A671 CFB70 and CFE70, Type/Grade revised

(4) For A387 9, P-No. revised

(5) A270 TP304L and TP316L added

(6) A312 TP321, A312 TP321H, A358 321, A376 TP321, A376 TP321H, and A409 TP321 revised

(7) A358 321H added

(8) A270 TP304, TP304L, TP316, and TP316L added

(9) A789 and A790 S82441 added

(10) A789 and A790 S32003 revised

(11) For A928 S32003, Size revised

(12) A789 and A790 S32760 revised

(13) A358 S34565 revised

(14) A240 321 and 321H revised

(15) A240 S82441 added

(16) For A240 S32003, Size revised

(17) A240 S32760 revised

(18) A182 F321 and F321H revised

(19) A403 WP321 and WP321H revised

(20) A182 and A815 S32760 revised

(21) For A479 304, 304H, 304L, 316, 316H, and 316L, Notes revised

(22) A479 321 and 321H revised

(23) A479 S82441 added

(24) A351 CF8C revised

(25) N08825 B163 added

(26) For N08825 B423, Notes revised

(27) N08825 B474 and B704 added

(28) N08825 B705 revised

(29) N06690 B163 and B167 added

(30) N08120 B163, B407, B514, and B515 added

(31) For N06230 B619, B622, and B626, font for stress values revised

(32) N06690 B168 added

(33) N08120 B409 added

(34) For N06230 B435, font for stress values revised

(35) N06230 B435 added

(36) For N02200 B366, stress values revised

(37) N02200 B564 deleted

(38) N06690 B564 added

(39) N08120 B366 and B564 added

(40) For N06230 B366, font for stress values revised

(41) N06690 B166 added

(42) N08120 B408 added

(43) For N06230 B572, font for stress values revised

(44) For titanium and titanium alloy materials, Product Form and Class/Condition/Temper entries added; and Min. Tensile Strength, Min. Yield Strength, and stress values revised

(45) R50250, R50400, R50550, R52400, and R53400 B338 added

(46) R53400 B861 and B862 added

(47) R52400 and R53400 B265 added

(48) R50250, R50400, R50550, R52400, and R53400 B363 and B381 added

(49) R50250, R50400, R50550, R52400, and R53400 B348 added

(50) R52550 and R52700 B367 added

(51) A83003, A91060, A93003, A95083, A95086, A96061, and A96063 B345 deleted

(52) For A03560 B26, P-Nos. added

| | | |
|---|---|---|
| 350 | Table A-1A | B367 added |
| 351 | Table A-1B | (1) A105, A181, A350, A182, A487, B160, B164, B564, B247, and B345 deleted |
| | | (2) A813, A814, B517, and B862 revised |
| | | (3) A270, B163, B515, B704, and B338 added |
| 356 | Table A-2 | (1) A325 deleted |
| | | (2) F3125 A325 added |
| | | (3) A354 BC and BD lines revised and new BC line added |
| | | (4) For last B150 HR50, Size Range corrected by errata |
| 366 | Table A-2M | (1) For A307 B, Min. Yield Strength deleted by errata |
| | | (2) A325 deleted |
| | | (3) F3125 A325 added |
| | | (4) A354 BC and BD lines revised and new BC line added |
| | | (5) For last B150 HR50, Size Range corrected by errata |
| 396 | Table C-1M | Table C-2 redesignated as Table C-1M |
| 403 | Table C-6 | Revised in its entirety |
| 407 | Table C-6M | Added |
| 413 | Table D300 | General Note (b) added |
| 417 | Appendix E | Revised in its entirety |
| 423 | F300.1.4 | Added |
| 423 | F301 | (1) Paragraph F301.5.1 added |
| | | (2) Paragraph F301.11 deleted |
| 424 | F308.4 | Revised |
| 425 | F312.1 | Subparagraph (b) revised |
| 426 | F323.2.2 | Revised |
| 426 | F323.4 | Subparagraphs (a) and (c)(4) revised |
| 428 | FK300 | Added |
| 439 | Appendix J | (1) Entry for *X* deleted by errata |
| | | (2) Appendix revised |
| 455 | Appendix K | ASTM A789, A790, and A815 added to Specification Index |
| 457 | Notes for Table K-1 | (1) General Note (b) revised |
| | | (2) Notes (9) and (10) deleted |
| | | (3) Notes (19) and (20) added |
| 458 | Table K-1 | (1) Under Carbon Steel — Pipes and Tubes, API 5L lines revised |
| | | (2) Under Carbon Steel — Forgings and Fittings, for A694 F42 through F70, stress values for highest temperatures deleted |
| | | (3) For Stainless Steel entries, UNS Nos. added |
| | | (4) Under Stainless Steel — Pipes and Tubes, A789 and A790 S32750 added |
| | | (5) Under Stainless Steel — Forgings and Fittings, A182 and A815 S32750 added |
| | | (6) Titanium and Titanium Alloy entries revised, and entries in columns for 350°C, 450°F, and 550°F added |
| 474 | Figure M300 | Cross-references in Col. 1 revised |
| 476 | Appendix Q | Footnote 1 revised |
| 477 | R300 | Subparagraph (a) corrected by errata |

| | | |
|---|---|---|
| 480 | Appendix S | Footnote 1 added |
| 482 | S301.6 | First paragraph revised |
| 492 | V303.1.1 | Subparagraph (b) revised |
| 493 | V303.1.3 | Revised |
| 495 | Appendix W | Added |
| 502 | X302.2.1 | In subparagraph (d), last cross-reference corrected by errata to read Table 331.1.1 |
| 502 | X302.2.3 | Subparagraph (a) revised |
| 504 | Appendix Z | Revised in its entirety |

NOTES:
(1) The ASME B31.3 Interpretations Volume will no longer be published with the Code.
(2) The B31.3 Code Cases will no longer be published with the Code.

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# Chapter I
# Scope and Definitions

## (18) 300 GENERAL STATEMENTS

*(a) Identification.* This Process Piping Code is a Section of The American Society of Mechanical Engineers Code for Pressure Piping, ASME B31, an American National Standard. It is published as a separate document for convenience of Code users.

*(b) Responsibilities*

*(1) Owner.* The owner of a piping installation shall have overall responsibility for compliance with this Code, and for establishing the requirements for design, construction, examination, inspection, and testing that will govern the entire fluid handling or process installation of which the piping is a part. The owner is also responsible for designating piping in Category D, Category M, High Pressure, and High Purity Fluid Services, and for determining if a specific Quality System is to be employed. [See paras. 300(d)(4) through (7) and Appendix Q.] Where applicable, the owner shall consider requirements imposed by the authority having jurisdiction regarding the piping installation. The owner may designate a representative to carry out selected responsibilities required by this Code, but the owner retains ultimate responsibility for the actions of the representative.

*(2) Designer.* The designer is responsible to the owner for assurance that the engineering design of piping complies with the requirements of this Code and with any additional requirements established by the owner.

*(3) Manufacturer, Fabricator, and Erector.* The manufacturer, fabricator, and erector of piping are responsible for providing materials, components, and workmanship in compliance with the requirements of this Code and of the engineering design.

*(4) Owner's Inspector.* The owner's Inspector (see para. 340) is responsible to the owner for ensuring that the requirements of this Code for inspection, examination, and testing are met. If a Quality System is specified by the owner to be employed, the owner's Inspector is responsible for verifying that it is implemented.

*(c) Intent of the Code*

*(1)* It is the intent of this Code to set forth engineering requirements deemed necessary for safe design and construction of piping installations.

*(2)* This Code is not intended to apply to the operation, examination, inspection, testing, maintenance, or repair of piping that has been placed in service. See para. F300.1 for examples of standards that may apply in these situations. The provisions of this Code may optionally be applied for those purposes, although other considerations may also be necessary.

*(3)* The Code generally specifies a simplified approach for many of its requirements. A designer may choose to use a more rigorous analysis to develop design and construction requirements. When the designer decides to take this approach, the designer shall provide to the owner details and calculations demonstrating that design, construction, examination, and testing are consistent with the design criteria of this Code. These details shall be adequate for the owner to verify the validity and shall be approved by the owner. The details shall be documented in the engineering design.

*(4)* Piping elements shall conform to the specifications and standards listed in this Code or, if not prohibited by this Code, shall be qualified for use as set forth in applicable Chapters of this Code.

*(5)* The engineering design shall specify any unusual requirements for a particular service. Where service requirements necessitate measures beyond those required by this Code, such measures shall be specified by the engineering design. Where so specified, the Code requires that they be accomplished.

*(6)* Compatibility of materials with the service and hazards from instability of contained fluids are not within the scope of this Code. See para. F323.

*(d) Determining Code Requirements*

*(1)* Code requirements for design and construction include fluid service requirements, which affect selection and application of materials, components, and joints. Fluid service requirements include prohibitions, limitations, and conditions, such as temperature limits or a requirement for safeguarding (see Appendix G). Code requirements for a piping system are the most restrictive of those that apply to any of its elements.

*(2)* For metallic piping not designated by the owner as Category M, High Pressure, or High Purity Fluid Service (see para. 300.2 and Appendix M), Code requirements are found in Chapters I through VI (the base Code) and fluid service requirements are found in

*(-a)* Chapter III for materials

*(-b)* Chapter II, Part 3, for components

*(-c)* Chapter II, Part 4, for joints

*(3)* For nonmetallic piping and piping lined with nonmetals, all requirements are found in Chapter VII. Paragraph designations begin with "A."

*(4)* For piping in a fluid service designated as Category M, all requirements are found in Chapter VIII. Paragraph designations begin with "M."

*(5)* For piping in a fluid service designated as Category D, piping elements restricted to Category D Fluid Service in Chapters I through VII, as well as elements suitable for other fluid services, may be used.

*(6)* For piping designated as High Pressure Fluid Service, all requirements are found in Chapter IX. These rules apply only when specified by the owner. Paragraph designations begin with "K."

*(7)* For piping designated as High Purity Fluid Service, all requirements are found in Chapter X. Paragraph designations begin with "U."

*(8)* Requirements for Normal Fluid Service in Chapters I through VI are applicable under severe cyclic conditions unless alternative requirements for severe cyclic conditions are stated.

*(9)* Requirements for Normal Fluid Service in Chapters I through VI are applicable for Elevated Temperature Fluid Service unless alternative requirements for Elevated Temperature Fluid Service are invoked.

*(e)* *Appendices.* Appendices of this Code contain Code requirements, supplementary guidance, or other information. See para. 300.4 for a description of the status of each Appendix.

*(f)* *Code Cases.* ASME issues Code Cases that are applicable to this Code. The Code Cases

*(1)* modify the requirements of this Code

*(2)* are applicable from the issue date until the Cases are annulled

*(3)* may be used only when approved by the owner. When so approved, the Code Cases shall be specified in the engineering design and become requirements of this Code.

(18) **300.1 Scope**

Rules for the Process Piping Code Section B31.3[1] have been developed considering piping typically found in petroleum refineries; onshore and offshore petroleum and natural gas production facilities; chemical, pharmaceutical, textile, paper, ore processing, semiconductor, and cryogenic plants; food and beverage processing facilities; and related processing plants and terminals.

**300.1.1 Content and Coverage**

*(a)* This Code prescribes requirements for materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping.

*(b)* This Code applies to piping for all fluids, including

*(1)* raw, intermediate, and finished chemicals

*(2)* petroleum products

*(3)* gas, steam, air, and water

*(4)* fluidized solids

*(5)* refrigerants

*(6)* cryogenic fluids

*(c)* See Figure 300.1.1 for a diagram illustrating the application of B31.3 piping at equipment. The joint connecting piping to equipment is within the scope of B31.3.

**300.1.2 Packaged Equipment Piping.** Also included within the scope of this Code is piping that interconnects pieces or stages within a packaged equipment assembly.

**300.1.3 Exclusions.** This Code excludes the following: (18)

*(a)* piping systems designed for internal gage pressures at or above zero but less than 105 kPa (15 psi), provided the fluid handled is nonflammable, nontoxic, and not damaging to human tissues as defined in 300.2, and its design temperature is from −29°C (−20°F) through 186°C (366°F)

*(b)* power boilers in accordance with ASME BPVC,[2] Section I and boiler external piping that is required to conform to ASME B31.1

*(c)* tubes, tube headers, crossovers, and manifolds of fired heaters that are internal to the heater enclosure

*(d)* pressure vessels, heat exchangers, pumps, compressors, and other fluid handling or processing equipment, including internal piping and connections for external piping

**300.1.4 Rounding.** The rules described in this paragraph apply unless otherwise specified in the Code or the engineering design. For purposes of determining conformance with specified limits in this Code, an observed value or a calculated value shall be rounded "to the nearest unit" in the last right-hand significant digit used in expressing the requirement, in accordance with the rounding method of ASTM E29, Using Significant Digits in Test Data to Determine Conformance with Specifications. ASTM E29 requires that when rounding a number to one having a specified number of significant digits, choose that which is nearest. If two choices are possible, as when the digits dropped are exactly a 5 or a 5 followed only by zeros, choose that ending in an even digit. See Appendix F, para. F300.1.4. (18)

[1] B31 references here and elsewhere in this Code are to the ASME B31 Code for Pressure Piping and its various Sections, which are identified and briefly described in the Introduction.

[2] ASME BPVC references here and elsewhere in this Code are to the ASME Boiler and Pressure Vessel Code and its various Sections as follows:

Section I, Rules for Construction of Power Boilers

Section II, Materials, Parts C and D

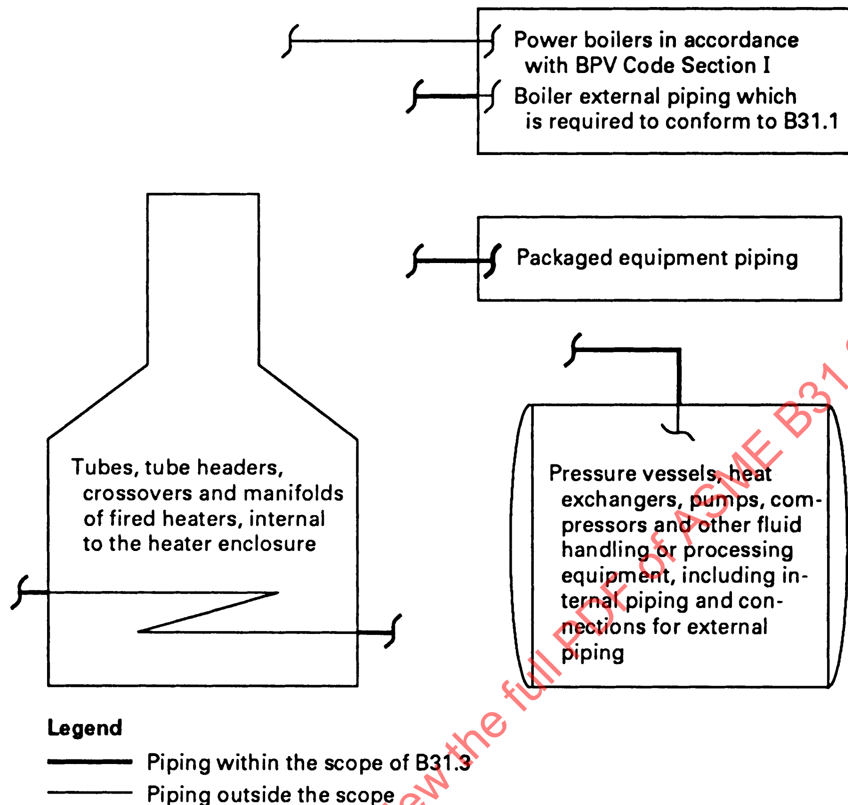
Section III, Rules for Construction of Nuclear Facility Components, Division 1, Subsection NH

Section V, Nondestructive Examination

Section VIII, Rules for Construction of Pressure Vessels, Divisions 1, 2, and 3

Section IX, Welding, Brazing, and Fusing Qualifications

**Figure 300.1.1 Diagram Illustrating Application of B31.3 Piping at Equipment**




GENERAL NOTE: The means by which piping is attached to equipment is within the scope of the applicable piping code.



(18) **300.2 Definitions**

Some of the terms relating to piping are defined below. For welding, brazing, and soldering terms not shown here, definitions in accordance with AWS Standard A3.0[3] apply.

*air-hardened steel:* a steel that hardens during cooling in air from a temperature above its transformation range.

*anneal heat treatment:* see *heat treatment.*

*arc cutting:* a group of cutting processes wherein the severing or removing of metals is effected by melting with the heat of an arc between an electrode and the base metal. (Includes carbon-arc cutting, metal-arc cutting, gas metal-arc cutting, gas tungsten-arc cutting, plasma-arc cutting, and air carbon-arc cutting.) See also *oxygen-arc cutting.*

*arc welding (AW):* a group of welding processes that produces coalescence of metals by heating them with an arc or arcs, with or without the application of pressure and with or without the use of filler metal.

*assembly:* the joining together of two or more piping components by bolting, welding, bonding, screwing, brazing, soldering, cementing, or use of packing devices as specified by the engineering design.

*autogenous weld:* a weld made by fusion of the base metal without the addition of filler metal [see also *gas tungsten-arc welding (GTAW)*].

*automatic welding:* welding with equipment that performs the welding operation without adjustment of the controls by an operator. The equipment may or may not perform the loading and unloading of the work.

*backing filler metal:* see *consumable insert.*

*backing ring:* material in the form of a ring used to support molten weld metal.

*balanced piping system:* see para. 319.2.2(a).

*base material:* the material to be brazed, soldered, welded, or otherwise fused.

*basic allowable stress:* see *stress terms frequently used.*

*bolt design stress:* see *stress terms frequently used.*

[3] AWS A3.0M/A3.0, Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting and Thermal Spraying

*bonded joint:* a permanent joint in nonmetallic piping made by one of the following methods:

*(a) adhesive joint:* a joint made by applying an adhesive to the surfaces to be joined and pressing them together

*(b) butt-and-wrapped joint:* a joint made by butting together the joining surfaces and wrapping the joint with plies of reinforcing fabric saturated with resin

*(c) heat fusion joint:* a joint made by heating the surfaces to be joined and pressing them together to achieve fusion

*(d) hot gas welded joint:* a joint made by simultaneously heating the surfaces to be joined and a filler material with a stream of hot air or hot inert gas, then pressing the surfaces together and applying the filler material to achieve fusion

*(e) solvent cemented joint:* a joint made by using a solvent cement to soften the surfaces to be joined and pressing them together

*(f) electrofusion joint:* a joint made by heating the surfaces to be joined using an electrical resistance wire coil that remains embedded in the joint.

*bonder:* one who performs a manual or semiautomatic bonding operation.

*bonding operator:* one who operates machine or automatic bonding equipment.

*bonding procedure:* the detailed methods and practices involved in the production of a bonded joint.

*bonding procedure specification (BPS):* the document that lists the parameters to be used in the construction of bonded joints in accordance with the requirements of this Code.

*borescopic examination:* a visual examination aided by a mechanical or electromechanical device to examine the inside diameter of inaccessible welds.

*branch connection fitting:* an integrally reinforced fitting welded to a run pipe and connected to a branch pipe by a buttwelding, socket welding, threaded, or flanged joint; includes a branch outlet fitting conforming to MSS SP-97.

*brazing:* a metal joining process wherein coalescence is produced by use of a nonferrous filler metal having a melting point above 427°C (800°F), but lower than that of the base metals being joined. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

*butt joint:* a joint between two members aligned approximately in the same plane.

*Category D:* see *fluid service*.

*Category M:* see *fluid service*.

*caulked joint:* a joint in which suitable material (or materials) is either poured or compressed by the use of tools into the annular space between a bell (or hub) and spigot (or plain end), thus comprising the joint seal.

*chemical plant:* an industrial plant for the manufacture or processing of chemicals, or of raw materials or intermediates for such chemicals. A chemical plant may include supporting and service facilities, such as storage, utility, and waste treatment units.

*cold spring:* see para. 319.2.4.

*compression type tube fittings:* tube fittings consisting of a flareless, mechanical grip connection, including a body, nut, and single or dual ferrules. See also para. U306.6.

*connections for external piping:* those integral parts of individual pieces of equipment that are designed for attachment of external piping.

*consumable insert:* preplaced filler metal that is completely fused into the root of the joint and becomes part of the weld.

*damaging to human tissues:* for the purposes of this Code, this phrase describes a fluid service in which exposure to the fluid, caused by leakage under expected operating conditions, can harm skin, eyes, or exposed mucous membranes so that irreversible damage may result unless prompt restorative measures are taken. (Restorative measures may include flushing with water, administration of antidotes, or medication.)

*design minimum temperature:* see para. 301.3.1.

*design pressure:* see para. 301.2.

*design temperature:* see para. 301.3.

*designer:* the person or organization in responsible charge of the engineering design.

*displacement stress range:* see para. 319.2.3.

*elements:* see *piping elements*.

*engineering design:* the detailed design governing a piping system, developed from process and mechanical requirements, conforming to Code requirements, and including all necessary specifications, drawings, and supporting documents.

*equipment connection:* see *connections for external piping*.

*erection:* the complete installation of a piping system in the locations and on the supports designated by the engineering design including any field assembly, fabrication, examination, inspection, and testing of the system as required by this Code.

*examination, examiner:* see paras. 341.1 and 341.2.

*examination, types of:* see para. 344.1.3 for the following:

*(a)* 100% examination
*(b)* random examination
*(c)* spot examination
*(d)* random spot examination

*extruded outlet header:* see para. 304.3.4.

*fabrication:* the preparation of piping for assembly, including cutting, threading, grooving, forming, bending, and joining of components into subassemblies. Fabrication may be performed in the shop or in the field.

*face of weld:* the exposed surface of a weld on the side from which the welding was done.

*face seal fitting:* a High Purity Fluid Service fitting that incorporates two machined faces and a metallic gasket within an external/internal nut configuration to attain a high leak integrity seal. See also para. U315.3(b).

*filler material:* the material to be added in making metallic or nonmetallic joints.

*fillet weld:* a weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, tee joint, or corner joint. (See also *size of weld* and *throat of a fillet weld*.)

*flammable:* for the purposes of this Code, describes a fluid that under ambient or expected operating conditions is a vapor or produces vapors that can be ignited and continue to burn in air. The term thus may apply, depending on service conditions, to fluids defined for other purposes as flammable or combustible.

*fluid service:* a general term concerning the application of a piping system, considering the combination of fluid properties, operating conditions, and other factors that establish the basis for design of the piping system. See Appendix M.

*(a) Category D Fluid Service:* a fluid service in which all of the following apply:

*(1)* the fluid handled is nonflammable, nontoxic, and not damaging to human tissues as defined in para. 300.2

*(2)* the design gage pressure does not exceed 1 035 kPa (150 psi)

*(3)* the design temperature is not greater than 186°C (366°F)

*(4)* the fluid temperature caused by anything other than atmospheric conditions is not less than −29°C (−20°F)

*(b) Category M Fluid Service:* a fluid service in which both of the following apply:

*(1)* the fluid is so highly toxic that a single exposure to a very small quantity of the fluid, caused by leakage, can produce serious irreversible harm to persons on breathing or bodily contact, even when prompt restorative measures are taken

*(2)* after consideration of piping design, experience, service conditions, and location, the owner determines that the requirements for Normal Fluid Service do not sufficiently provide the leak tightness required to protect personnel from exposure

*(c) Elevated Temperature Fluid Service:* a fluid service in which the piping metal temperature is sustained equal to or greater than $T_{cr}$ as defined in Table 302.3.5, General Note (b).

*(d) High Pressure Fluid Service:* a fluid service for which the owner specifies the use of Chapter IX for piping design and construction; see also para. K300.

*(e) High Purity Fluid Service:* a fluid service that requires alternative methods of fabrication, inspection, examination, and testing not covered elsewhere in the Code, with the intent to produce a controlled level of cleanness. The term thus applies to piping systems defined for other purposes as high purity, ultra high purity, hygienic, or aseptic.

*(f) Normal Fluid Service:* a fluid service pertaining to most piping covered by this Code, i.e., not subject to the rules for Category D, Category M, Elevated Temperature, High Pressure, or High Purity Fluid Service.

*full fillet weld:* a fillet weld whose size is equal to the thickness of the thinner member joined.

*fusion:* the melting together of filler material and base material, or of base material only, that results in coalescence.

*gas metal-arc welding (GMAW):* an arc-welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is obtained entirely from an externally supplied gas, or gas mixture. Some variations of this process are called MIG or $CO_2$ welding (nonpreferred terms).

*gas tungsten-arc welding (GTAW):* an arc-welding process that produces coalescence of metals by heating them with an arc between a single tungsten (nonconsumable) electrode and the work. Shielding is obtained from a gas or gas mixture. Pressure may or may not be used and filler metal may or may not be used. (This process has sometimes been called TIG welding.)

*gas welding:* a group of welding processes wherein coalescence is produced by heating with a gas flame or flames, with or without the application of pressure, and with or without the use of filler material.

*groove weld:* a weld made in the groove between two members to be joined.

*heat affected zone:* that portion of the base material which has not been melted, but whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, forming, or cutting.

*heat treatment:* the following terms describe various types and processes of heat treatment:

*(a) annealing:* heating to and holding at a suitable temperature above the transformation temperature range, followed by slow cooling to well below the transformation temperature range.

*(b) normalizing:* heating a ferrous metal to a temperature above the transformation temperature range, followed by cooling in room-temperature still air to well below the transformation temperature range.

*(c) quenching:* when used as a part of a heat-treating operation, a rapid cooling process that results in microstructural stabilization or changes in material properties that would not have occurred without rapid cooling.

*(d) recommended or required heat treatment:* the application of heat to a metal section subsequent to a cutting, forming, or welding operation, as provided in para. 331.

*(e) solution heat treatment:* heating an alloy to a suitable temperature, holding at that temperature long enough to allow one or more constituents to enter into solid solution, and then cooling rapidly enough to hold the constituents in solution.

*(f) stress-relief:* uniform heating of a structure or portion thereof to a sufficient temperature below the transformation temperature range to relieve the major portion of the residual stresses, followed by uniform cooling slowly enough to minimize development of new residual stresses.

*(g) tempering:* reheating a hardened metal to a temperature below the transformation range to improve toughness.

*(h) transformation range:* the temperature range over which a phase change occurs.

*(i) transformation temperature:* the temperature at which a phase change begins or ends. In metals, phase changes can be solid-state changes.

*High Pressure Fluid Service:* see *fluid service*.

*High Purity Fluid Service:* see *fluid service.*

*hygienic clamp joint:* a tube outside-diameter union consisting of two neutered ferrules having flat faces with a concentric groove and mating gasket that is secured with a clamp, providing a nonprotruding, recessless product contact surface. See also para. U315.3(b).

*indication, linear:* in nondestructive examination, an indication having a length greater than 3 times its width.

*indication, rounded:* in nondestructive examination, an indication with a length equal to or less than 3 times its width. These indications may be circular, elliptical, conical, or irregular in shape and may have tails.

*inline portions of instruments:* pressure-containing portions of instruments that are in direct contact with the fluid when installed in a piping system. Permanently sealed fluid-filled tubing systems furnished with instruments as temperature- or pressure-responsive devices, e.g., pressure gages, pressure transmitters, and transducers, are excluded.

*in-process examination:* see para. 344.7.

*inspection, Inspector:* see para. 340.

*integrally reinforced branch connection fitting:* see *branch connection fitting.*

*joint design:* the joint geometry together with the required dimensions of the welded joint.

*listed:* for the purposes of this Code, describes a material or component that conforms to a specification in Appendix A, Appendix B, or Appendix K or to a standard in Table 326.1, A326.1, or K326.1.

*manual welding:* a welding operation performed and controlled completely by hand.

*may:* a term that indicates a provision is neither required nor prohibited.

*mechanical joint:* a joint for the purpose of mechanical strength or leak resistance, or both, in which the mechanical strength is developed by threaded, grooved, rolled, flared, or flanged pipe ends; or by bolts, pins, toggles, or rings; and the leak resistance is developed by threads and compounds, gaskets, rolled ends, caulking, or machined and mated surfaces.

*miter or miter bend:* for the purposes of this Code, two or more straight sections of pipe matched and joined in a plane bisecting the angle of junction so as to produce a change in direction greater than 3 deg.

*nominal:* a numerical identification of dimension, capacity, rating, or other characteristic used as a designation, not as an exact measurement.

*Normal Fluid Service:* see *fluid service*.

*normalizing:* see *heat treatment*.

*notch-sensitive:* describes a metal subject to reduction in strength in the presence of stress concentration. The degree of notch sensitivity is usually expressed as the strength determined in a notched specimen divided by the strength determined in an unnotched specimen, and can be obtained from either static or dynamic tests.

*NPS:* nominal pipe size (followed, when appropriate, by the specific size designation number without an inch symbol).

*orbital welding:* automatic or machine welding in which the electrode rotates (orbits) around the circumference of a stationary pipe or tube.

*owner:* the person, partnership, organization, or business ultimately responsible for design, construction, operation, and maintenance of a facility.

*oxygen-arc cutting (OAC):* an oxygen-cutting process that uses an arc between the workpiece and a consumable electrode, through which oxygen is directed to the workpiece. For oxidation-resistant metals, a chemical flux or metal powder is used to facilitate the reaction.

*oxygen cutting (OC):* a group of thermal cutting processes that severs or removes metal by means of the chemical reaction between oxygen and the base metal at elevated temperature. The necessary temperature is maintained by the heat from an arc, an oxyfuel gas flame, or other source.

*oxygen gouging:* thermal gouging that uses an oxygen cutting process variation to form a bevel or groove.

*packaged equipment:* an assembly of individual pieces or stages of equipment, complete with interconnecting piping and connections for external piping. The assembly may be mounted on a skid or other structure prior to delivery.

*petroleum refinery:* an industrial plant for processing or handling of petroleum and products derived directly from petroleum. Such a plant may be an individual gasoline recovery plant, a treating plant, a gas processing plant (including liquefaction), or an integrated refinery having various process units and attendant facilities.

*pipe:* a pressure-tight cylinder used to convey a fluid or to transmit a fluid pressure, ordinarily designated "pipe" in applicable material specifications. Materials designated "tube" or "tubing" in the specifications are treated as pipe when intended for pressure service. Types of pipe, according to the method of manufacture, are defined as follows:

*(a) electric resistance-welded pipe:* pipe produced in individual lengths or in continuous lengths from coiled skelp and subsequently cut into individual lengths, having a longitudinal butt joint wherein coalescence is produced by the heat obtained from resistance of the pipe to the flow of electric current in a circuit of which the pipe is a part, and by the application of pressure.

*(b) furnace butt welded pipe, continuous welded:* pipe produced in continuous lengths from coiled skelp and subsequently cut into individual lengths, having its longitudinal butt joint forge welded by the mechanical pressure developed in passing the hot-formed and edge-heated skelp through a set of round pass welding rolls.

*(c) electric-fusion welded pipe:* pipe having a longitudinal butt joint wherein coalescence is produced in the preformed tube by manual or automatic electric-arc welding. The weld may be single (welded from one side) or double (welded from inside and outside) and may be made with or without the addition of filler metal.

*(d) double submerged-arc welded pipe:* pipe having a longitudinal butt joint produced by at least two passes, one of which is on the inside of the pipe. Coalescence is produced by heating with an electric arc or arcs between the bare metal electrode or electrodes and the work. The welding is shielded by a blanket of granular fusible material on the work. Pressure is not used and filler metal for the inside and outside welds is obtained from the electrode or electrodes.

*(e) seamless pipe:* pipe produced by piercing a billet followed by rolling or drawing, or both.

*(f) spiral (helical seam) welded pipe:* pipe having a helical seam with a butt, lap, or lock-seam joint that is welded using an electrical resistance, electric fusion, or double-submerged arc welding process.

*pipe-supporting elements:* pipe-supporting elements consist of fixtures and structural attachments as follows:

*(a) fixtures:* fixtures include elements that transfer the load from the pipe or structural attachment to the supporting structure or equipment. They include hanging type fixtures, such as hanger rods, spring hangers, sway braces, counterweights, turnbuckles, struts, chains, guides, and anchors; and bearing type fixtures, such as saddles, bases, rollers, brackets, and sliding supports.

*(b) structural attachments:* structural attachments include elements that are welded, bolted, or clamped to the pipe, such as clips, lugs, rings, clamps, clevises, straps, and skirts.

*piping:* assemblies of piping components used to convey, distribute, mix, separate, discharge, meter, control, or snub fluid flows. Piping also includes pipe-supporting elements, but does not include support structures, such as building frames, bents, foundations, or any equipment excluded from this Code (see para. 300.1.3).

*piping components:* mechanical elements suitable for joining or assembly into pressure-tight fluid-containing piping systems. Components include pipe, tubing, fittings, flanges, gaskets, bolting, valves, and devices such as expansion joints, flexible joints, pressure hoses, traps, strainers, inline portions of instruments, and separators.

*piping elements:* any material or work required to plan and install a piping system. Elements of piping include design specifications, materials, components, supports, fabrication, examination, inspection, and testing.

*piping installation:* designed piping systems to which a selected Code edition and addenda apply.

*piping subassembly:* a portion of a piping system that consists of one or more piping components.

*piping system:* interconnected piping subject to the same set or sets of design conditions.

*plasma arc cutting (PAC):* an arc cutting process that uses a constricted arc and removes molten metal with a high velocity jet of ionized gas issuing from the constricting orifice.

*postweld heat treatment:* see *heat treatment*.

*preheating:* the application of heat to the base material immediately before or during a forming, welding, or cutting process. See para. 330.

*procedure qualification record (PQR):* a document listing all pertinent data, including the essential variables employed and the test results, used in qualifying the procedure specification.

*process unit:* an area whose boundaries are designated by the engineering design within which reactions, separations, and other processes are carried out. Examples of installations that are *not* classified as process units are loading areas or terminals, bulk plants, compounding plants, and tank farms and storage yards.

*quench annealing:* see *solution heat treatment* under *heat treatment.*

*quenching:* see *heat treatment*.

*readily accessible (for visual examination):* those surfaces that can be examined from a distance of not more than 600 mm (24 in.) and at an angle of not less than 30 deg to the surface to be examined.

*reinforcement:* see paras. 304.3 and A304.3. See also *weld reinforcement.*

*representative:* a person, partnership, organization, or business designated by the owner to carry out selected responsibilities on the owner's behalf.

*room temperature:* temperature between 10°C and 38°C (50°F and 100°F).

*root opening:* the separation between the members to be joined, at the root of the joint.

*safeguarding:* provision of protective measures of the types outlined in Appendix G, where deemed necessary. See Appendix G for detailed discussion.

*seal bond:* a bond intended primarily to provide joint tightness against leakage in nonmetallic piping.

*seal weld:* a weld intended primarily to provide joint tightness against leakage in metallic piping.

*semiautomatic arc welding:* arc welding with equipment that controls only the filler metal feed. The advance of the welding is manually controlled.

*severe cyclic conditions:* conditions applying to specific piping components or joints for which the owner or the designer determines that construction to better resist fatigue loading is warranted. See Appendix F, para. F301.10.3 for guidance on designating piping as being under severe cyclic conditions.

*shall:* a term that indicates a provision is a Code requirement.

*shielded metal-arc welding (SMAW):* an arc welding process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

*should:* a term that indicates a provision is recommended as good practice but is not a Code requirement.

*size of weld:*

*(a) fillet weld:* the leg lengths (the leg length for equal-leg welds) of the sides, adjoining the members welded, of the largest triangle that can be inscribed within the weld cross section. For welds between perpendicular members, the definitions in Figure 328.5.2A apply.

NOTE: When the angle between members exceeds 105 deg, size is of less significance than effective throat (see also *throat of a fillet weld*).

*(b) groove weld:* the joint penetration (depth of bevel plus the root penetration when specified). The size of a groove weld and its effective throat are the same.

*slag inclusion:* nonmetallic solid material entrapped in weld metal or between weld metal and base metal.

*soldering:* a metal joining process wherein coalescence is produced by heating to suitable temperatures and by using a nonferrous alloy fusible at temperatures below 427°C (800°F) and having a melting point below that of the base metals being joined. The filler metal is distributed between closely fitted surfaces of the joint by capillary attraction. In general, solders are lead-tin alloys and may contain antimony, bismuth, and other elements.

*solution heat treatment:* see *heat treatment*.

*stress ratio:* see para. 323.2.2(b).

*stress relief:* see *heat treatment*.

*stress terms frequently used:*

*(a) basic allowable stress:* this term, symbol *S*, represents the stress value for any material determined by the appropriate stress basis in para. 302.3.2

*(b) bolt design stress:* this term represents the design stress used to determine the required cross-sectional area of bolts in a bolted joint

*(c) hydrostatic design basis:* selected properties of plastic piping materials to be used in accordance with ASTM D2837 or D2992 to determine the HDS [see (d) below] for the material

*(d) hydrostatic design stress (HDS):* the maximum continuous stress due to internal pressure to be used in the design of plastic piping, determined from the hydrostatic design basis by use of a service (design) factor

*submerged arc welding (SAW):* an arc welding process that produces coalescence of metals by heating them with an arc or arcs between a bare metal electrode or electrodes and the work. The arc is shielded by a blanket of granular, fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

*tack weld:* a weld made to hold parts of a weldment in proper alignment until the final welds are made.

*tempering:* see *heat treatment*.

*thermoplastic:* a plastic that is capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature.

*thermosetting resin:* a resin capable of being changed into a substantially infusible or insoluble product when cured at room temperature, or by application of heat, or by chemical means.

*throat of a fillet weld:*

*(a) theoretical throat:* the perpendicular distance from the hypotenuse of the largest right triangle that can be inscribed in the weld cross section to the root of the joint

*(b) actual throat:* the shortest distance from the root of a fillet weld to its face

*(c) effective throat:* the minimum distance, minus any reinforcement (convexity), between the weld root and the face of a fillet weld

*toe of weld:* the junction between the face of a weld and the base material.

*tube:* see *pipe*.

*tungsten electrode:* a nonfiller-metal electrode used in arc welding or cutting, made principally of tungsten.

*unbalanced piping system:* see para. 319.2.2(b).

*undercut:* a groove melted into the base material adjacent to the toe or root of a weld and left unfilled by weld material.

*visual examination:* see para. 344.2.1.

*weld:* a localized coalescence of material wherein coalescence is produced either by heating to suitable temperatures, with or without the application of pressure, or by application of pressure alone, and with or without the use of filler material.

(18) **Table 300.4 Status of Appendices in B31.3**

| Appendix | Title | Status |
|---|---|---|
| A | Allowable Stresses and Quality Factors for Metallic Piping and Bolting Materials | Requirements |
| B | Stress Tables and Allowable Pressure Tables for Nonmetals | Requirements |
| C | Physical Properties of Piping Materials | Requirements (1) |
| D | Flexibility and Stress Intensification Factors | Requirements (1) |
| E | Reference Standards | Requirements |
| F | Guidance and Precautionary Considerations | Guidance (2) |
| G | Safeguarding | Guidance (2) |
| H | Sample Calculations for Branch Reinforcement | Guidance |
| J | Nomenclature | Information |
| K | Allowable Stresses for High Pressure Piping | Requirements (3) |
| L | Aluminum Alloy Pipe Flanges | Specification (4) |
| M | Guide to Classifying Fluid Services | Guidance (2) |
| N | Application of ASME B31.3 Internationally | Guidance (2) |
| Q | Quality System Program | Guidance (2) |
| R | Use of Alternative Ultrasonic Acceptance Criteria | Requirements (5) |
| S | Piping System Stress Analysis Examples | Guidance (2) |
| V | Allowable Variations in Elevated Temperature Service | Guidance (2) |
| W | High-Cycle Fatigue Assessment of Piping Systems | Requirements |
| X | Metallic Bellows Expansion Joints | Requirements |
| Z | Preparation of Technical Inquiries | Requirements (5) |

NOTES:
(1) Contains default requirements, to be used unless more directly applicable data are available.
(2) Contains no requirements but Code user is responsible for considering applicable items.
(3) Contains requirements applicable only when use of Chapter IX is specified.
(4) Contains pressure–temperature ratings, materials, dimensions, and markings of forged aluminum alloy flanges.
(5) Contains administrative requirements.



*weld coupon:* a sample weld used to determine weld acceptance. Types of weld coupons are defined as follows:

*(a) primary weld coupon:* made prior to the start of production welding to establish a benchmark of weld acceptance

*(b) production weld coupon:* made when any of the conditions in para. U341.4.5 exist and used to compare against a corresponding primary weld coupon to demonstrate continued acceptability of welds during production welding

*weld coupon examination:* see para. U344.8.1.

*weld reinforcement:* weld material in excess of the specified weld size.

*welder:* one who performs a manual or semi-automatic welding operation. (This term is sometimes erroneously used to denote a welding machine.)

*welding operator:* one who operates machine or automatic welding equipment.

*welding procedure:* the detailed methods and practices involved in the production of a weldment.

*welding procedure specification (WPS):* the document that lists the parameters to be used in construction of weldments in accordance with requirements of this Code.

*weldment:* an assembly whose component parts are joined by welding.

## 300.3 Nomenclature

Dimensional and mathematical symbols used in this Code are listed in Appendix J, with definitions and location references to each. Uppercase and lowercase English letters are listed alphabetically, followed by Greek letters.

## 300.4 Status of Appendices

Table 300.4 indicates for each Appendix of this Code whether it contains Code requirements, guidance, or supplemental information. See the first page of each Appendix for details.

# Chapter II
# Design

## PART 1
## CONDITIONS AND CRITERIA

### 301 DESIGN CONDITIONS

Paragraph 301 states the qualifications of the Designer, defines the temperatures, pressures, and forces applicable to the design of piping, and states the consideration that shall be given to various effects and their consequent loadings. See also Appendix F, para. F301.

### 301.1 Qualifications of the Designer

The Designer is the person(s) in charge of the engineering design of a piping system and shall be experienced in the use of this Code. The qualifications and experience required of the Designer will depend on the complexity and criticality of the system and the nature of the individual's experience. The owner's approval is required if the individual does not meet at least one of the following criteria:

*(a)* Completion of a degree, accredited by an independent agency [such as ABET (U.S. and international), NBA (India), CTI (France), and CNAP (Chile)], in engineering, science, or technology, requiring the equivalent of at least 4 years of full-time study that provides exposure to fundamental subject matter relevant to the design of piping systems, plus a minimum of 5 years experience in the design of related pressure piping.

*(b)* Professional Engineering registration, recognized by the local jurisdiction, and experience in the design of related pressure piping.

*(c)* Completion of an accredited engineering technician or associates degree, requiring the equivalent of at least 2 years of study, plus a minimum of 10 years experience in the design of related pressure piping.

*(d)* Fifteen years experience in the design of related pressure piping.

Experience in the design of related pressure piping is satisfied by piping design experience that includes design calculations for pressure, sustained and occasional loads, and piping flexibility.

### 301.2 Design Pressure

#### 301.2.1 General

*(a)* The design pressure of each component in a piping system shall be not less than the pressure at the most severe condition of coincident internal or external pressure and temperature (minimum or maximum) expected during service, except as provided in para. 302.2.4.

*(b)* The most severe condition is that which results in the greatest required component thickness and the highest component rating.

*(c)* When more than one set of pressure–temperature conditions exist for a piping system, the conditions governing the rating of components conforming to listed standards may differ from the conditions governing the rating of components designed in accordance with para. 304.

*(d)* When a pipe is separated into individualized pressure-containing chambers (including jacketed piping, blanks, etc.), the partition wall shall be designed on the basis of the most severe coincident temperature (minimum or maximum) and differential pressure between the adjoining chambers expected during service, except as provided in para. 302.2.4.

#### 301.2.2 Required Pressure Containment or Relief

*(a)* Provision shall be made to safely contain or relieve (see para. 322.6.3) any expected pressure to which the piping may be subjected. Piping not protected by a pressure-relieving device, or that can be isolated from a pressure-relieving device, shall be designed for at least the highest expected pressure.

*(b)* Sources of pressure to be considered include ambient influences, pressure oscillations and surges, improper operation, decomposition of unstable fluids, static head, and failure of control devices.

*(c)* The allowances of para. 302.2.4(f) are permitted, provided that the other requirements of para. 302.2.4 are also met.

### 301.3 Design Temperature

The design temperature of each component in a piping system is the temperature at which, under the coincident pressure, the greatest thickness or highest component rating is required in accordance with para. 301.2. (To satisfy the requirements of para. 301.2, different components in the same piping system may have different design temperatures.)

In establishing design temperatures, consider at least the fluid temperatures, ambient temperatures, solar radiation, heating or cooling medium temperatures, and the applicable provisions of paras. 301.3.2, 301.3.3, and 301.3.4.

**301.3.1 Design Minimum Temperature.** The design minimum temperature is the lowest component temperature expected in service. This temperature may establish special design requirements and material qualification requirements. See also paras. 301.4.4 and 323.2.2.

#### 301.3.2 Uninsulated Components

*(a)* For fluid temperatures below 65°C (150°F), the component temperature shall be taken as the fluid temperature unless solar radiation or other effects result in a higher temperature.

*(b)* For fluid temperatures 65°C (150°F) and above, unless a lower average wall temperature is determined by test or heat transfer calculation, the temperature for uninsulated components shall be no less than the following values:

*(1)* valves, pipe, lapped ends, welding fittings, and other components having wall thickness comparable to that of the pipe — 95% of the fluid temperature

*(2)* flanges (except lap joint) including those on fittings and valves — 90% of the fluid temperature

*(3)* lap joint flanges — 85% of the fluid temperature

*(4)* bolting — 80% of the fluid temperature

**301.3.3 Externally Insulated Piping.** The component design temperature shall be the fluid temperature unless calculations, tests, or service experience based on measurements support the use of another temperature. Where piping is heated or cooled by tracing or jacketing, this effect shall be considered in establishing component design temperatures.

**301.3.4 Internally Insulated Piping.** The component design temperature shall be based on heat transfer calculations or tests.

### 301.4 Ambient Effects

See Appendix F, para. F301.4.

**301.4.1 Cooling — Effects on Pressure.** The cooling of a gas or vapor in a piping system may reduce the pressure sufficiently to create an internal vacuum. In such a case, the piping shall be capable of withstanding the external pressure at the lower temperature, or provision shall be made to break the vacuum.

**301.4.2 Fluid Expansion Effects.** Provision shall be made in the design either to withstand or to relieve increased pressure caused by the heating of static fluid in a piping component. See also para. 322.6.3(b)(2).

**301.4.3 Atmospheric Icing.** Where the design minimum temperature of a piping system is below 0°C (32°F), the possibility of moisture condensation and buildup of ice shall be considered and provisions made in the design to avoid resultant malfunctions. This applies to surfaces of moving parts of shutoff valves, control valves, pressure-relief devices including discharge piping, and other components.

**301.4.4 Low Ambient Temperature.** Consideration shall be given to low ambient temperature conditions for displacement stress analysis.

### 301.5 Dynamic Effects (18)

**301.5.1 Impact.** Impact forces caused by external or (18) internal conditions (including changes in flow rate, hydraulic shock, liquid or solid slugging, flashing, and geysering) shall be taken into account in the design of piping. See Appendix F, para. F301.5.1.

**301.5.2 Wind.** The effect of wind loading shall be taken into account in the design of exposed piping. The analysis considerations and loads may be as described in ASCE 7. Authoritative local meteorological data may also be used to define or refine the design wind loads.

**301.5.3 Earthquake.** The effect of earthquake loading shall be taken into account in the design of piping. The analysis considerations and loads may be as described in ASCE 7. Authoritative local seismological data may also be used to define or refine the design earthquake loads.

**301.5.4 Vibration.** Piping shall be designed, arranged, (18) and supported to eliminate excessive and harmful effects of vibration that may arise from such sources as impact, pressure pulsation, turbulent flow vortices, resonance in compressors, external vortex shedding (e.g., wind), and acoustically induced vibration.

**301.5.5 Discharge Reactions.** Piping shall be designed, arranged, and supported so as to withstand reaction forces due to let-down or discharge of fluids.

### 301.6 Weight Effects

The following weight effects, combined with loads and forces from other causes, shall be taken into account in the design of piping.

**301.6.1 Live Loads.** These loads include the weight of the medium transported or the medium used for test. Snow and ice loads due to both environmental and operating conditions shall be considered.

**301.6.2 Dead Loads.** These loads consist of the weight of piping components, insulation, and other superimposed permanent loads supported by the piping.

## 301.7 Thermal Expansion and Contraction Effects

The following thermal effects, combined with loads and forces from other causes, shall be taken into account in the design of piping. See also Appendix F, para. F301.7.

**301.7.1 Thermal Loads Due to Restraints.** These loads consist of thrusts and moments that arise when free thermal expansion and contraction of the piping are prevented by restraints or anchors.

**301.7.2 Loads Due to Temperature Gradients.** These loads arise from stresses in pipe walls resulting from large rapid temperature changes or from unequal temperature distribution as may result from a high heat flux through a comparatively thick pipe or stratified two-phase flow causing bowing of the line.

**301.7.3 Loads Due to Differences in Expansion Characteristics.** These loads result from differences in thermal expansion where materials with different thermal expansion coefficients are combined, as in bimetallic, lined, jacketed, or metallic–nonmetallic piping.

## 301.8 Effects of Support, Anchor, and Terminal Movements

The effects of movements of piping supports, anchors, and connected equipment shall be taken into account in the design of piping. These movements may result from the flexibility and/or thermal expansion of equipment, supports, or anchors; and from settlement, tidal movements, or wind sway.

## 301.9 Reduced Ductility Effects

The harmful effects of reduced ductility shall be taken into account in the design of piping. The effects may, for example, result from welding, heat treatment, forming, bending, or low operating temperatures, including the chilling effect of sudden loss of pressure on highly volatile fluids. Low ambient temperatures expected during operation shall be considered.

## 301.10 Cyclic Effects

Fatigue due to pressure cycling, thermal cycling, and other cyclic loadings shall be considered in the design of piping. See Appendix F, para. F301.10.

## 301.11 Air Condensation Effects

At operating temperatures below −191°C (−312°F) in ambient air, condensation and oxygen enrichment occur. These shall be considered in selecting materials, including insulation, and adequate shielding and/or disposal shall be provided.



# 302 DESIGN CRITERIA

## 302.1 General

Paragraph 302 states pressure–temperature ratings, stress criteria, design allowances, and minimum design values together with permissible variations of these factors as applied to the design of piping.

## 302.2 Pressure–Temperature Design Criteria

**302.2.1 Listed Components Having Established Ratings.** Except as limited elsewhere in the Code, pressure–temperature ratings contained in standards for piping components listed in Table 326.1 are acceptable for design pressures and temperatures in accordance with this Code. When the owner approves, provisions of this Code may be used to extend the pressure–temperature ratings of a component beyond the ratings contained in the listed standard.

**302.2.2 Listed Components Not Having Specific Ratings**

*(a)* Some of the standards for fittings in Table 326.1 (e.g., ASME B16.9 and B16.11) state that pressure–temperature ratings are based on straight seamless pipe. Such fittings shall be rated as calculated for straight seamless pipe with the same allowable stresses as the fitting and the nominal thickness corresponding to the wall thickness or class designation of the fitting, less all applicable allowances (e.g., thread depth and corrosion allowance), and considering the manufacturing undertolerances of the fittings and the pipe.

*(b)* For components with straight or spiral (helical seam) longitudinal welded joints, the pressure rating as determined for seamless pipe shall be multiplied by the weld joint strength reduction factor, $W$, as defined in para. 302.3.5(e).

*(c)* Other listed components not addressed in para. 302.2.1 or 302.2.2(a) shall have their pressure–temperature ratings established in accordance with the rules in para. 304.

**302.2.3 Unlisted Components.** Piping components not listed in Table 326.1 may be used subject to all of the following requirements: (18)

*(a)* The material shall comply with para. 323.

*(b)* The designer shall be satisfied that the design is suitable for the intended service.

*(c)* Pressure–temperature ratings shall be established in accordance with the rules in para. 304.

**302.2.4 Allowances for Pressure and Temperature Variations.** Occasional variations of pressure, temperature, or both may occur in a piping system. Such variations shall be considered in selecting design pressure (para. 301.2) and design temperature (para. 301.3). The most severe coincident pressure and temperature (18) shall determine the design conditions unless all of the following criteria are met:

*(a)* The piping system shall have no pressure-containing components of gray iron or other nonductile metal.

*(b)* Circumferential pressure stresses (based on minimum pipe wall thickness, less allowances) shall not exceed the yield strength at temperature (see para. 302.3 of this Code and $S_y$ data in ASME BPVC, Section II, Part D, Table Y-1).

*(c)* Combined stresses shall not exceed the limits established in para. 302.3.6.

*(d)* The total number of pressure–temperature variations above the design conditions shall not exceed 1 000 during the life of the piping system.

*(e)* In no case shall the increased pressure exceed the test pressure used under para. 345 for the piping system.

*(f)* Occasional variations above design conditions shall remain within one of the following limits for pressure design.

*(1)* Subject to the owner's approval, it is permissible to exceed the pressure rating or the allowable stress for pressure design at the temperature of the increased condition by not more than

*(-a)* 33% for no more than 10 h at any one time and no more than 100 h/y, or

*(-b)* 20% for no more than 50 h at any one time and no more than 500 h/y

The effects of such variations shall be determined by the designer to be safe over the service life of the piping system by methods acceptable to the owner. (See Appendix V.)

*(2)* When the variation is self-limiting (e.g., due to a pressure-relieving event), and lasts no more than 50 h at any one time and not more than 500 h/y, it is permissible to exceed the pressure rating or the allowable stress for pressure design at the temperature of the increased condition by not more than 20%.

*(g)* The combined effects of the sustained and cyclic variations on the serviceability of all components in the system shall have been evaluated.

*(h)* Temperature variations below the minimum temperature shown in Appendix A are not permitted unless the requirements of para. 323.2.2 are met for the lowest temperature during the variation.

*(i)* The application of pressures exceeding pressure–temperature ratings of valves may under certain conditions cause loss of seat tightness or difficulty of operation. The differential pressure on the valve closure element should not exceed the maximum differential pressure rating established by the valve manufacturer. Such applications are the owner's responsibility.

**302.2.5 Ratings at Junction of Different Services.** When two services that operate at different pressure–temperature conditions are connected, the valve segregating the two services shall be rated for the more severe service condition. Where multiple valves are used (e.g., in a double block and bleed arrangement), all of the valves shall be rated for the more severe service condition. If the valve(s) will operate at a different temperature due to remoteness from a header or piece of equipment, the valve(s) (and any mating flanges) may be selected on the basis of the different temperature. For piping on either side of the valve, however, each system shall be designed for the conditions of the service to which it is connected.

### 302.3 Allowable Stresses and Other Stress Limits

**302.3.1 General.** The allowable stresses defined in paras. 302.3.1(a), (b), and (c) shall be used in design calculations unless modified by other provisions of this Code.

*(a) Tension.* Basic allowable stresses, *S*, in tension for metals listed in Tables A-1 and A-1M, and design stresses, *S*, for bolting materials listed in Tables A-2 and A-2M were determined in accordance with para. 302.3.2.

In equations elsewhere in the Code where the product *SE* appears, the value *S* is multiplied by one of the following quality factors:[1]

*(1)* casting quality factor $E_c$ as defined in para. 302.3.3 and tabulated for various material specifications in Table A-1A, and for various levels of supplementary examination in Table 302.3.3C, or

*(2)* longitudinal weld joint factor $E_j$ as defined in 302.3.4 and tabulated for various material specifications and classes in Table A-1B, and for various types of joints and supplementary examinations in Table 302.3.4

The stress values in Tables A-1, A-1M, A-2, and A-2M are grouped by materials and product forms, and are for stated temperatures up to the limit provided in para. 323.2.1(a). Straight-line interpolation between temperatures is permissible. The temperature intended is the design temperature (see para. 301.3).

*(b) Shear and Bearing.* Allowable stresses in shear shall be 0.80 times the basic allowable stress in tension tabulated in Appendix A. Allowable stress in bearing shall be 1.60 times that value.

*(c) Compression.* Allowable stresses in compression shall be no greater than the basic allowable stresses in tension as tabulated in Appendix A. Consideration shall be given to structural stability.

[1] If a component is made of castings joined by longitudinal welds, both a casting and a weld joint quality factor shall be applied. The equivalent quality factor *E* is the product of $E_c$, Table A-1A, and $E_j$, Table A-1B.

(18) **302.3.2 Bases for Design Stresses.**[2] The bases for establishing design stress values for bolting materials and basic allowable stress values for other metallic materials in this Code are specified in (a), (b), (c), and (d). In the application of these criteria, the yield strength at temperature is considered to be $S_Y R_Y$ and the tensile strength at temperature is considered to be $1.1 S_T R_T$, where

$R_T$ = ratio of the average temperature-dependent trend curve value of tensile strength to the room temperature tensile strength

$R_Y$ = ratio of the average temperature-dependent trend curve value of yield strength to the room temperature yield strength

$S_T$ = specified minimum tensile strength at room temperature

$S_Y$ = specified minimum yield strength at room temperature

*(a) Bolting Materials.* Design stress values at temperature for bolting materials shall not exceed the lowest of the following:

*(1)* at temperatures below the creep range, for bolting materials whose strength has not been enhanced by heat treatment or strain hardening, the lowest of one-fourth of $S_T$, one-fourth of tensile strength at temperature, two-thirds of $S_Y$, and two-thirds of yield strength at temperature

*(2)* at temperatures below the creep range, for bolting materials whose strength has been enhanced by heat treatment or strain hardening, the lowest of one-fifth of $S_T$, one-fourth of the tensile strength at temperature, one-fourth of $S_Y$, and two-thirds of the yield strength at temperature (unless these values are lower than corresponding values for annealed material, in which case the annealed values shall be used)

*(3)* 100% of the average stress for a creep rate of 0.01% per 1 000 h

*(4)* 67% of the average stress for rupture at the end of 100 000 h

*(5)* 80% of minimum stress for rupture at the end of 100 000 h

*(b) Gray Iron.* Basic allowable stress values at temperature for gray iron shall not exceed the lower of the following:

*(1)* one-tenth of $S_T$

*(2)* one-tenth of the tensile strength at temperature

*(c) Malleable Iron.* Basic allowable stress values at temperature for malleable iron shall not exceed the lower of the following:

*(1)* one-fifth of $S_T$

*(2)* one-fifth of the tensile strength at temperature

*(d) Other Materials.* Basic allowable stress values at temperature for materials other than bolting materials, gray iron, and malleable iron shall not exceed the lowest of the following:

*(1)* the lower of one-third of $S_T$ and one-third of tensile strength at temperature.

*(2)* except as provided in (3) below, the lower of two-thirds of $S_Y$ and two-thirds of yield strength at temperature.

*(3)* for austenitic stainless steels and nickel alloys having similar stress–strain behavior, the lower of two-thirds of $S_Y$ and 90% of yield strength at temperature [see (e)].

*(4)* 100% of the average stress for a creep rate of 0.01% per 1 000 h.

*(5)* for temperatures up to and including 815°C (1,500°F), 67% of the average stress for rupture at the end of 100 000 h.

*(6)* for temperatures higher than 815°C (1,500°F), $(100 \times F_{avg})$% times the average stress for rupture at the end of 100 000 h. $F_{avg}$ is determined from the slope, $n$, of the log time-to-rupture versus log stress plot at 100 000 h such that $\log F_{avg} = 1/n$. $F_{avg}$ shall not exceed 0.67.

*(7)* 80% of the minimum stress for rupture at the end of 100 000 h.

For structural grade materials, the basic allowable stress shall be 0.92 times the lowest value determined in (d)(1) through (7).

*(e) Application Limits.* Application of stress values determined in accordance with (d)(3) is not recommended for flanged joints and other components in which slight deformation can cause leakage or malfunction.

*(1)* These values are shown in italics or boldface in Table A-1, as explained in Note (4a) to Appendix A Tables. Instead, either 75% of the stress value in Table A-1 or two-thirds of the yield strength at temperature listed in ASME BPVC, Section II, Part D, Table Y-1 should be used.

*(2)* Stress values determined in accordance with (d)(3) are not identified in Table A-1M. See Note (4b) to Appendix A. When using Table A-1M, two-thirds of the yield strength at temperature listed in ASME BPVC, Section II, Part D, Table Y-1 should be used.

**302.3.3 Casting Quality Factor, $E_c$**

*(a) General.* The casting quality factors, $E_c$, defined herein shall be used for cast components not having pressure–temperature ratings established by standards in Table 326.1.

[2] These bases are the same as those for ASME BPVC, Section III, Class 1 materials, given in ASME BPVC, Section II, Part D. Stress values in B31.3, Appendix A, at temperatures below the creep range generally are the same as those listed in ASME BPVC, Section II, Part D, Tables 2A and 2B, and in Table 3 for bolting, corresponding to those bases. They have been adjusted as necessary to exclude casting quality factors and longitudinal weld joint quality factors. Stress values at temperatures in the creep range generally are the same as those in ASME BPVC, Section II, Part D, Tables 1A and 1B, corresponding to the bases for ASME BPVC, Section VIII, Division 1.

**Table 302.3.3C Increased Casting Quality Factors, $E_c$**

| Supplementary Examination in Accordance With Note(s) | Factor, $E_c$ |
|---|---|
| (1) | 0.85 |
| (2)(a) or (2)(b) | 0.85 |
| (3)(a) or (3)(b) | 0.95 |
| (1) and (2)(a) or (2)(b) | 0.90 |
| (1) and (3)(a) or (3)(b) | 1.00 |
| (2)(a) or (2)(b) and (3)(a) or (3)(b) | 1.00 |

GENERAL NOTE: Titles of standards referenced in this Table's Notes are as follows:

| | |
|---|---|
| ASME B46.1 | Surface Texture (Surface Roughness, Waviness and Lay) |
| ASTM E94 | Guide for Radiographic Examination |
| ASTM E114 | Practice for Ultrasonic Pulse-Echo Straight-Beam Contact Testing |
| ASTM E125 | Reference Photographs for Magnetic Particle Indications on Ferrous Castings |
| ASTM E165 | Practice for Liquid Penetrant Examination for General Industry |
| ASTM E709 | Guide for Magnetic Particle Testing |
| MSS SP-53 | Quality Standard for Steel Castings and Forgings for Valves, Flanges, Fittings, and Other Piping Components — Magnetic Particle Examination Method |
| MSS SP-93 | Quality Standard for Steel Castings and Forgings for Valves, Flanges, Fittings, and Other Piping Components — Liquid Penetrant Examination Method |

NOTES:

(1) Machine all surfaces to a finish of 6.3 μm $R_a$ (250 μin. $R_a$ in accordance with ASME B46.1), thus increasing the effectiveness of surface examination.

(2)

*(a)* Examine all surfaces of each casting (ferromagnetic material only) by the magnetic particle method in accordance with ASTM E709. Judge acceptability in accordance with MSS SP-53, Table 1.

*(b)* Examine all surfaces of each casting by the liquid penetrant method, in accordance with ASTM E165. Judge acceptability in accordance with SP-93, Table 1.

(3)

*(a)* Fully examine each casting ultrasonically in accordance with ASTM E114, accepting a casting only if there is no evidence of depth of defects in excess of 5% of wall thickness.

*(b)* Fully radiograph each casting in accordance with ASTM E94. Judge in accordance with the stated acceptance levels in Table 302.3.3D.



*(b) Basic Quality Factors.* Castings of gray and malleable iron, conforming to listed specifications, are assigned a basic casting quality factor, $E_c$, of 1.00 (due to their conservative allowable stress basis). For most other metals, static castings that conform to the material specification and have been visually examined as required by MSS SP-55, Quality Standard for Steel Castings for Valves, Flanges and Fittings and Other Piping Components — Visual Method, are assigned a basic casting quality factor, $E_c$, of 0.80. Centrifugal castings that meet specification requirements only for chemical analysis, tensile, hydrostatic, and flattening tests, and visual examination are assigned a basic casting quality factor of 0.80. Basic casting quality factors are tabulated for listed specifications in Table A-1A.

*(c) Increased Quality Factors.* Casting quality factors may be increased when supplementary examinations are performed on each casting. Table 302.3.3C states the increased casting quality factors, $E_c$, that may be used for various combinations of supplementary examination. Table 302.3.3D states the acceptance criteria for the examination methods specified in the Notes to Table 302.3.3C. Quality factors higher than those shown in Table 302.3.3C do not result from combining tests (2)(a) and (2)(b), or (3)(a) and (3)(b). In no case shall the quality factor exceed 1.00.

Several of the specifications in Appendix A require machining of all surfaces and/or one or more of these supplementary examinations. In such cases, the appropriate increased quality factor is shown in Table A-1A.

### 302.3.4 Weld Joint Quality Factor, $E_j$

*(a) Basic Quality Factors.* The weld joint quality factors, $E_j$, tabulated in Table A-1B are basic factors for straight or spiral (helical seam) welded joints for pressure-containing components as shown in Table 302.3.4.

*(b) Increased Quality Factors.* Table 302.3.4 also indicates higher joint quality factors that may be substituted for those in Table A-1B for certain kinds of welds if additional examination is performed beyond that required by the product specification.

### 302.3.5 Limits of Calculated Stresses Due to Sustained Loads and Displacement Strains (18)

*(a) Internal Pressure Stresses.* Stresses due to internal pressure shall be considered safe when the wall thickness of the piping component, including any reinforcement, meets the requirements of para. 304.

*(b) External Pressure Stresses.* Stresses due to external pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of para. 304.

*(c) Stresses Due to Sustained Loads, $S_L$.* The stresses due to sustained loads, $S_L$, in any component in a piping system (see para. 320), shall not exceed $S_h$, where $S_h$ is the basic allowable stress provided in Table A-1 or Table A-1M at

## Table 302.3.3D Acceptance Levels for Castings

| Material Examined Thickness, $T$ | Applicable Standard | Acceptance Level (or Class) | Acceptable Discontinuities |
|---|---|---|---|
| Steel $T \le 25$ mm (1 in.) | ASTM E446 | 1 | Types A, B, C |
| Steel $T > 25$ mm, $\le 51$ mm (2 in.) | ASTM E446 | 2 | Types A, B, C |
| Steel $T > 51$ mm, $\le 114$ mm ($4\frac{1}{2}$ in.) | ASTM E186 | 2 | Categories A, B, C |
| Steel $T > 114$ mm, $\le 305$ mm (12 in.) | ASTM E280 | 2 | Categories A, B, C |
| Aluminum and magnesium | ASTM E155 | ... | Shown in reference radiographs |
| Copper, Ni–Cu | ASTM E272 | 2 | Codes A, Ba, Bb |
| Bronze | ASTM E310 | 2 | Codes A and B |

GENERAL NOTE: Titles of ASTM standards referenced in this Table are as follows:

E155 Reference Radiographs for Inspection of Aluminum and Magnesium Castings
E186 Reference Radiographs for Heavy-Walled (2 to 4-½-in. (50.8 to 114 mm)) Steel Castings
E272 Reference Radiographs for High-Strength Copper-Base and Nickel-Copper Alloy Castings
E280 Reference Radiographs for Heavy-Walled (4-½ to 12-in. (114 to 305 mm)) Steel Castings
E310 Reference Radiographs for Tin Bronze Castings
E446 Reference Radiographs for Steel Castings Up to 2 in. (50.8 mm) in Thickness

the metal temperature for the operating condition being considered.

*(d) Allowable Displacement Stress Range, $S_A$.* The computed displacement stress range, $S_E$, in a piping system (see para. 319.4.4) shall not exceed the allowable displacement stress range, $S_A$ (see paras. 319.2.3 and 319.3.4), calculated by eq. (1a)

$$S_A = f(1.25S_c + 0.25S_h) \tag{1a}$$

When $S_h$ is greater than $S_L$, the difference between them may be added to the term $0.25S_h$ in eq. (1a). In that case, the allowable stress range is calculated by eq. (1b)

$$S_A = f[1.25(S_c + S_h) - S_L] \tag{1b}$$

For eqs. (1a) and (1b)

$f$ = stress range factor,[3] calculated by eq. (1c)[4]

$$f \text{ (see Fig. 302.3.5)} = 6.0(N)^{-0.2} \le f_m \tag{1c}$$

$f_m$ = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤517 MPa (75 ksi) and at metal temperatures ≤371°C (700°F); otherwise $f_m$ = 1.0
$N$ = equivalent number of full displacement cycles during the expected service life of the piping system[5]
$S_c$ = basic allowable stress[6] at minimum metal temperature expected during the displacement cycle under analysis
= 138 MPa (20 ksi) maximum
$S_h$ = basic allowable stress[6] at maximum metal temperature expected during the displacement cycle under analysis
= 138 MPa (20 ksi) maximum
$S_L$ = stress due to sustained loads; in systems where supports may be active in some conditions and inactive in others, the maximum value of sustained stress, considering all support conditions, shall be used

When the computed stress range varies, whether from thermal expansion or other conditions, $S_E$ is defined as the greatest computed displacement stress range. The value of $N$ in such cases can be calculated by eq. (1d)

$$N = N_E + \sum \left(r_i^5 N_i\right) \text{ for } i = 1, 2, \ldots, n \tag{1d}$$

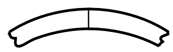
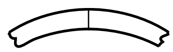
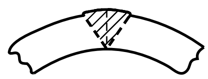
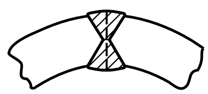
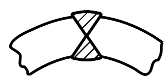
where

$N_E$ = number of cycles of maximum computed displacement stress range, $S_E$
$N_i$ = number of cycles associated with displacement stress range, $S_i$
$r_i$ = $S_i/S_E$
$S_i$ = any computed displacement stress range smaller than $S_E$

When the total number of significant stress cycles due to all causes exceeds 100 000, and with the owner's approval, the designer may elect to apply the alternative fatigue assessment rules in Appendix W to satisfy the displacement stress range requirements of this paragraph and of

[3] Applies to essentially noncorroded piping. Corrosion can sharply decrease cyclic life; therefore, corrosion resistant materials should be considered where a large number of major stress cycles is anticipated.
[4] The minimum value for $f$ is 0.15, which results in an allowable displacement stress range, $S_A$, for an indefinitely large number of cycles.
[5] The designer is cautioned that the fatigue life of materials operated at elevated temperature may be reduced.
[6] For castings, the basic allowable stress shall be multiplied by the applicable casting quality factor, $E_c$. For longitudinal welds, the basic allowable stress need not be multiplied by the weld quality factor, $E_j$.

### Table 302.3.4 Longitudinal Weld Joint Quality Factor, $E_j$

| No. | Type of Joint | | Type of Seam | Examination | Factor, $E_j$ |
|---|---|---|---|---|---|
| 1 | Furnace butt weld, continuous weld |  | Straight | As required by listed specification | 0.60 [Note (1)] |
| 2 | Electric resistance weld |  | Straight or spiral (helical seam) | As required by listed specification | 0.85 [Note (1)] |
| 3 | Electric fusion weld | | | | |
| | (a) Single butt weld (with or without filler metal) |  | Straight or spiral (helical seam) | As required by listed specification or this Code | 0.80 |
| | | | | Additionally spot radiographed in accordance with para. 341.5.1 | 0.90 |
| | | | | Additionally 100% radiographed in accordance with para. 344.5.1 and Table 341.3.2 | 1.00 |
| | (b) Double butt weld (with or without filler metal) |  | Straight or spiral (helical seam) (except as provided in 4 below) | As required by listed specification or this Code | 0.85 |
| | | | | Additionally spot radiographed in accordance with para. 341.5.1 | 0.90 |
| | | | | Additionally 100% radiographed in accordance with para. 344.5.1 and Table 341.3.2 | 1.00 |
| 4 | Specific specification | | | | |
| | API 5L, electric fusion weld, double butt seam |  | Straight (with one or two seams) or spiral (helical seam) | As required by specification | 0.95 |
| | | | | Additionally 100% radiographed in accordance with para. 344.5.1 and Table 341.3.2 | 1.00 |

NOTE: (1) It is not permitted to increase the joint quality factor by additional examination for joint 1 or 2.



para. 319. A significant stress cycle is defined in para. W300. When the alternative rules of Appendix W are applied, the calculations shall be documented in the engineering design.

*(e) Weld Joint Strength Reduction Factor, W.* At elevated temperatures, the long-term strength of weld joints may be lower than the long-term strength of the base material.

The weld joint strength reduction factor, $W$, is the ratio of the nominal stress to cause failure of a weld joint to that of the corresponding base material for an elevated temperature condition of the same duration. It only applies at weld locations in longitudinal or spiral (helical seam) welded piping components. The designer is responsible for the application of weld joint strength reduction factors to other welds (e.g., circumferential).

When determining the required wall thickness for internal pressure in accordance with para. 304, for each coincident operating pressure–temperature condition under consideration, the product of the *basic* allowable stress and the applicable weld quality factor, $SE$, shall be multiplied by $W$.

$W$ is equal to 1.0 when evaluating occasional loads, e.g., wind and earthquake, or when evaluating permissible variations in accordance with para. 302.2.4. Application of $W$ is not required when determining the pressure rating for the occasional load or *permissible* variation condition. It is also not required when calculating the allowable stress range for displacement stresses, $S_A$, in (d).

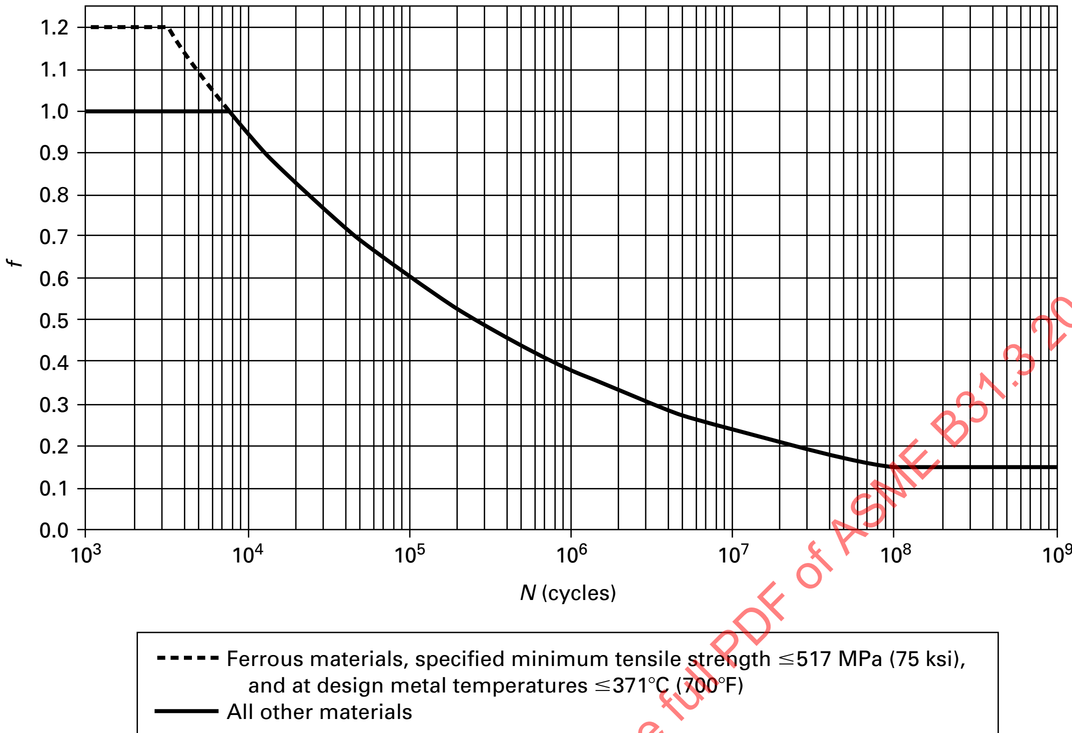
For other than occasional loads or permissible variations, $W$ shall be in accordance with Table 302.3.5 except as provided in (f).

*(f) Alternative Weld Strength Reduction Factors.* A weld strength reduction factor other than that listed in Table 302.3.5 may be used in accordance with one of the following criteria:

*(1)* Creep test data may be used to determine the weld joint strength reduction factor, $W$. However, the use of creep test data to increase the factor $W$ above that shown in Table 302.3.5 is not permitted for the CrMo and Creep Strength Enhanced Ferritic (CSEF) steels materials, as defined in Table 302.3.5. Creep testing of weld joints to determine weld joint strength reduction factors, when permitted, should be full thickness cross-weld specimens with test durations of at least 1 000 h. Full thickness tests shall be used unless the designer otherwise considers effects such as stress redistribution across the weld.

*(2)* With the owner's approval, extensive successful experience may be used to justify the factor $W$ above that shown in Table 302.3.5. Successful experience must

**Figure 302.3.5 Stress Range Factor, *f***






include same or like material, weld metal composition, and welding process under equivalent, or more severe, sustained operating conditions.

(18) **302.3.6 Limits of Calculated Stresses Due to Occasional Loads**

*(a) Operation.* Stresses due to occasional loads may be calculated using the equations for stress due to sustained loads in para. 320.2.

*(1)* Subject to the limits of para. 302.2.4, the sum of the stresses due to sustained loads, such as pressure and weight, $S_L$, and of the stresses produced by occasional loads, such as wind and earthquake, may be as much as 1.33 times the basic allowable stress provided in Table A-1 or Table A-1M at the metal temperature for the occasional condition being considered. Wind and earthquake forces need not be considered as acting concurrently.

*(2)* For Elevated Temperature Fluid Service (see definition in para. 300.2) of materials having ductile behavior, as an alternative to the use of 1.33 times the basic allowable stress provided in Table A-1 or Table A-1M, the allowable stress for occasional loads of short duration, e.g., surge, extreme wind, or earthquake, may be taken as the lowest of the following:

*(-a)* the weld strength reduction factor times 90% of the yield strength at the metal temperature for the occasional condition being considered

*(-b)* four times the basic allowable stress provided in Appendix A

*(-c)* for occasional loads that exceed 10 h over the life of the piping system, the stress resulting in a 20% creep usage factor in accordance with Appendix V

For (-a), the yield strength shall be as listed in ASME BPVC, Section II, Part D, Table Y-1 or determined in accordance with para. 302.3.2. The strength reduction factor represents the reduction in yield strength with long-term exposure of the material to elevated temperatures and, in the absence of more-applicable data, shall be taken as 1.0 for austenitic stainless steel and 0.8 for other materials.

For (-b), the basic allowable stress for castings shall also be multiplied by the casting quality factor, $E_c$. Where the allowable stress value exceeds two-thirds of yield strength at temperature, the allowable stress value must be reduced as specified in para. 302.3.2(e).

*(b) Test.* Stresses due to test conditions are not subject to the limitations in para. 302.3. It is not necessary to consider other occasional loads, e.g., wind and earthquake, as occurring concurrently with test loads.

### 302.4 Allowances

In determining the minimum required thickness of a piping component, allowances shall be included for corrosion, erosion, and thread depth or groove depth. See definition for $c$ in para. 304.1.1(b).

### 302.5 Mechanical Strength

*(a)* Designs shall be checked for adequacy of mechanical strength under applicable loadings. When necessary, the wall thickness shall be increased to prevent overstress, damage, collapse, or buckling due to superimposed loads from supports, ice formation, backfill, transportation, handling, or other loads enumerated in para. 301.

*(b)* Where increasing the thickness would excessively increase local stresses or the risk of brittle fracture, or is otherwise impracticable, the impact of applied loads may be mitigated through additional supports, braces, or other means without requiring an increased wall thickness. Particular consideration should be given to the mechanical strength of small pipe connections to piping or equipment.

## PART 2
## PRESSURE DESIGN OF PIPING COMPONENTS

### 303 GENERAL

Components manufactured in accordance with standards listed in Table 326.1 shall be considered suitable for use at pressure–temperature ratings in accordance with para. 302.2.1 or para. 302.2.2, as applicable. The rules in para. 304 are intended for pressure design of components not covered in Table 326.1, but may be used for a special or more-rigorous design of such components, or to satisfy requirements of para. 302.2.2. Designs shall be checked for adequacy of mechanical strength as described in para. 302.5.

### 304 PRESSURE DESIGN OF COMPONENTS

### 304.1 Straight Pipe

#### 304.1.1 General

*(a)* The required thickness of straight sections of pipe shall be determined in accordance with eq. (2)

$$t_m = t + c \tag{2}$$

The minimum thickness, $T$, for the pipe selected, considering manufacturer's minus tolerance, shall be not less than $t_m$.

*(b)* The following nomenclature is used in the equations for pressure design of straight pipe:

$c$ = sum of the mechanical allowances (thread or groove depth) plus corrosion and erosion allowances. For threaded components, the nominal thread depth (dimension $h$ of ASME B1.20.1, or equivalent) shall apply. For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.

$D$ = outside diameter of pipe as listed in tables of standards or specifications or as measured

$d$ = inside diameter of pipe. For pressure design calculation, the inside diameter of the pipe is the maximum value allowable under the purchase specification.

$E$ = quality factor from Table A-1A or Table A-1B

$P$ = internal design gage pressure

$S$ = stress value for material from Table A-1 or Table A-1M

$T$ = pipe wall thickness (measured or minimum in accordance with the purchase specification)

$t$ = pressure design thickness, as calculated in accordance with para. 304.1.2 for internal pressure or as determined in accordance with para. 304.1.3 for external pressure

$t_m$ = minimum required thickness, including mechanical, corrosion, and erosion allowances

$W$ = weld joint strength reduction factor in accordance with para. 302.3.5(e)

$Y$ = coefficient from Table 304.1.1, valid for $t < D/6$ and for materials shown. The value of $Y$ may be interpolated for intermediate temperatures. For $t \geq D/6$,

$$Y = \frac{d + 2c}{D + d + 2c}$$

#### 304.1.2 Straight Pipe Under Internal Pressure

*(a)* For $t < D/6$, the internal pressure design thickness for straight pipe shall be not less than that calculated in accordance with either eq. (3a) or eq. (3b)

$$t = \frac{PD}{2(SEW + PY)} \tag{3a}$$

$$t = \frac{P(d + 2c)}{2[SEW - P(1 - Y)]} \tag{3b}$$

*(b)* For $t \geq D/6$ or for $P/SE > 0.385$, calculation of pressure design thickness for straight pipe requires special consideration of factors such as theory of failure, effects of fatigue, and thermal stress.

**304.1.3 Straight Pipe Under External Pressure.** To determine wall thickness and stiffening requirements for straight pipe under external pressure, the procedure outlined in ASME BPVC, Section VIII, Division 1, UG-28 through UG-30 shall be followed, using as the design length, $L$, the running centerline length between any two sections stiffened in accordance with UG-29. As an exception, for pipe with $D_o/t < 10$, the value of $S$ to be

(18)

## Table 302.3.5 Weld Joint Strength Reduction Factor, *W*

| Steel Group | Component Temperature, $T_i$, °C (°F) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ≤427 (≤800) | 454 (850) | 482 (900) | 510 (950) | 538 (1,000) | 566 (1,050) | 593 (1,100) | 621 (1,150) | 649 (1,200) | 677 (1,250) | 704 (1,300) | 732 (1,350) | 760 (1,400) | 788 (1,450) | 816 (1,500) |
| Carbon Steel | 1 | 1 | 1 | 1 | 1 | 1 | 1 | ... | ... | ... | ... | ... | ... | ... | ... |
| CrMo [Notes (1)–(3)] | 1 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | 0.73 | 0.68 | 0.64 | ... | ... | ... | ... | ... | ... |
| CSEF (N + T) [Notes (3)–(5)] | ... | ... | ... | 1 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | ... | ... | ... | ... | ... | ... |
| CSEF [Notes (3) and (4)] (Subcritical PWHT) | ... | ... | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | ... | ... | ... | ... | ... | ... |
| Autogenous welds in austenitic stainless grade 3xx, and N088xx and N066xx nickel alloys [Note (6)] | ... | ... | ... | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Austenitic stainless grade 3xx and N088xx nickel alloys [Notes (7) and (8)] | ... | ... | ... | 1 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | 0.73 | 0.68 | 0.64 | 0.59 | 0.55 | 0.5 |
| Other materials [Note (9)] | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

GENERAL NOTES:

(a) Weld joint strength reduction factors at temperatures above the upper temperature limit listed in Appendix A for the base metal or outside of the applicable range in Table 302.3.5 are the responsibility of the designer. At temperatures below those where weld joint strength reduction factors are tabulated, a value of 1.0 shall be used for the factor *W* where required; however, the additional rules of this Table and Notes do not apply.

(b) $T_{cr}$ = temperature 25°C (50°F) below the temperature identifying the start of time-dependent properties listed under "NOTES - TIME-DEPENDENT PROPERTIES" (Txx) in the Notes to ASME BPVC, Section II, Part D, Tables 1A and 1B for the base metals joined by welding. For materials not listed in Section II, Part D, $T_{cr}$ shall be the temperature where the creep rate or stress rupture criteria in paras. 302.3.2(d)(4), (5), (6), and (7) governs the basic allowable stress value of the metals joined by welding. When the base metals differ, the lower value of $T_{cr}$ shall be used for the weld joint.

(c) $T_i$ = temperature, °C (°F), of the component for the coincident operating pressure–temperature condition, $i$, under consideration.

(d) CAUTIONARY NOTE: There are many factors that may affect the life of a welded joint at elevated temperature and all of those factors cannot be addressed in a table of weld strength reduction factors. For example, fabrication issues such as the deviation from a true circular form in pipe (e.g., "peaking" at longitudinal weld seams) or offset at the weld joint can cause an increase in stress that may result in reduced service life and control of these deviations is recommended.

(e) The weld joint strength reduction factor, *W*, may be determined using linear interpolation for intermediate temperature values.

NOTES:

(1) The Cr–Mo Steels include: $^1/_2$Cr–$^1/_2$Mo, 1Cr–$^1/_2$Mo, 1$^1/_4$Cr–$^1/_2$Mo–Si, 2$^1/_4$Cr–1Mo, 3Cr–1Mo, 5Cr–$^1/_2$Mo, 9Cr–1Mo. Longitudinal and spiral (helical seam) welds shall be normalized, normalized and tempered, or subjected to proper subcritical postweld heat treatment (PWHT) for the alloy. Required examination is in accordance with para. 341.4.4 or 305.2.4.

(2) Longitudinal and spiral (helical seam) seam fusion welded construction is not permitted for C–$^1/_2$Mo steel above 454°C (850°F).

(3) The required carbon content of the weld filler metal shall be ≥0.05 C wt. %. See para. 341.4.4(b) for examination requirements. The basicity index of SAW flux shall be ≥1.0.

(4) The CSEF (Creep Strength Enhanced Ferritic) steels include grades 91, 92, 911, 122, and 23.

(5) N + T = Normalizing + Tempering PWHT.

(6) Autogenous welds without filler metal in austenitic stainless steel (grade 3xx) and austenitic nickel alloys UNS Nos. N066xx and N088xx. A solution anneal after welding is required for use of the factors in the Table. See para. 341.4.3(b) for examination requirements.

(7) Alternatively, the 100,000 hr Stress Rupture Factors listed in ASME BPVC, Section III, Division 1, Subsection NH, Tables I-14.10 A-xx, B-xx, and C-xx may be used as the weld joint strength reduction factor for the materials and welding consumables specified.

### Table 302.3.5 Weld Joint Strength Reduction Factor, *W* (Cont'd)

NOTES: (Cont'd)

(8) Certain heats of the austenitic stainless steels, particularly for those grades whose creep strength is enhanced by the precipitation of temper-resistant carbides and carbonitrides, can suffer from an embrittlement condition in the weld heat affected zone that can lead to premature failure of welded components operating at elevated temperatures. A solution annealing heat treatment of the weld area mitigates this susceptibility.

(9) For materials other than carbon steel, CrMo, CSEF, and the austenitic alloys listed in Table 302.3.5, $W$ shall be as follows: For $T_i \le T_{cr}$, $W = 1.0$. For SI units, for $T_{cr} < T_i \le 816°C$, $W = 1 - 0.00164(T_i - T_{cr})$. For U.S. Customary units, for $T_{cr} < T_i \le 1{,}500°F$, $W = 1 - 0.000909(T_i - T_{cr})$. If $T_i$ exceeds the upper temperature for which an allowable stress value is listed in Appendix A for the base metal, the value for $W$ is the responsibility of the designer.

**Table 304.1.1 Values of Coefficient *Y* for *t* < *D*/6**

| | Temperature, °C (°F) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Material | 482 (900) and Below | 510 (950) | 538 (1,000) | 566 (1,050) | 593 (1,100) | 621 (1,150) | 649 (1,200) | 677 (1,250) and Above |
| Ferritic steels | 0.4 | 0.5 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Austenitic steels | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 | 0.7 | 0.7 |
| Nickel alloys UNS Nos. N06617, N08800, N08810, and N08825 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 |
| Gray iron | 0.0 | ... | ... | ... | ... | ... | ... | ... |
| Other ductile metals | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |

used in determining $P_{a2}$ shall be the lesser of the following values for pipe material at design temperature:

*(a)* 1.5 times the stress value from Table A-1 or Table A-1M of this Code, or

*(b)* 0.9 times the yield strength tabulated in ASME BPVC, Section II, Part D, Table Y-1 for materials listed therein

(The symbol $D_o$ in ASME BPVC, Section VIII is equivalent to $D$ in this Code.)

## 304.2 Curved and Mitered Segments of Pipe

**304.2.1 Pipe Bends.** The minimum required thickness, $t_m$, of a bend, after bending, in its finished form, shall be determined in accordance with eqs. (2) and (3c)

$$t = \frac{PD}{2[(SEW/I) + PY]} \tag{3c}$$

where at the intrados (inside bend radius)

$$I = \frac{4(R_1/D) - 1}{4(R_1/D) - 2} \tag{3d}$$

and at the extrados (outside bend radius)

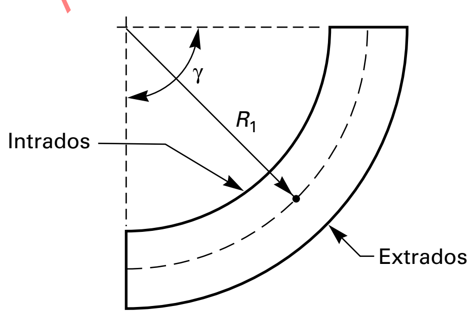
$$I = \frac{4(R_1/D) + 1}{4(R_1/D) + 2} \tag{3e}$$

and at the sidewall on the bend centerline radius, $I$ = 1.0, and where

$R_1$ = bend radius of welding elbow or pipe bend

Thickness variations from the intrados to the extrados and along the length of the bend shall be gradual. The thickness requirements apply at the mid-span of the bend, $\gamma/2$, at the intrados, extrados, and bend centerline radius. The minimum thickness at the end tangents shall not be less than the requirements of para. 304.1 for straight pipe (see Figure 304.2.1).

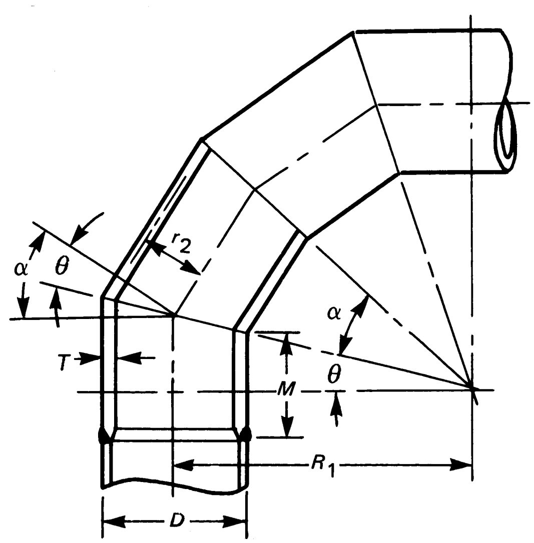
**Figure 304.2.1 Nomenclature for Pipe Bends**




**304.2.2 Elbows.** Manufactured elbows not in accordance with para. 303 shall be qualified as required by para. 304.7.2 or designed in accordance with para. 304.2.1, except as provided in para. 328.4.2(b)(6).

**304.2.3 Miter Bends.** An angular offset of 3 deg or less (angle $\alpha$ in Figure 304.2.3) does not require design consideration as a miter bend. Acceptable methods for pressure design of multiple and single miter bends are given in (a) and (b) below.

**Figure 304.2.3 Nomenclature for Miter Bends**



*(a) Multiple Miter Bends.* The maximum allowable internal pressure shall be the lesser value calculated from eqs. (4a) and (4b). These equations are not applicable when $\theta$ exceeds 22.5 deg.

$$P_m = \frac{SEW(T-c)}{r_2}\left(\frac{T-c}{(T-c)+0.643\tan\theta\sqrt{r_2(T-c)}}\right) \tag{4a}$$

$$P_m = \frac{SEW(T-c)}{r_2}\left(\frac{R_1-r_2}{R_1-0.5r_2}\right) \tag{4b}$$

*(b) Single Miter Bends*

*(1)* The maximum allowable internal pressure for a single miter bend with angle $\theta$ not greater than 22.5 deg shall be calculated by eq. (4a).

*(2)* The maximum allowable internal pressure for a single miter bend with angle $\theta$ greater than 22.5 deg shall be calculated by eq. (4c)

$$P_m = \frac{SEW(T-c)}{r_2}\left(\frac{T-c}{(T-c)+1.25\tan\theta\sqrt{r_2(T-c)}}\right) \tag{4c}$$

*(c)* The miter pipe wall thickness, $T$, used in eqs. (4a), (4b), and (4c) shall extend a distance not less than $M$ from the inside crotch of the end miter welds where

$M$ = the larger of $2.5(r_2T)^{0.5}$ or $\tan\theta\,(R_1 - r_2)$

The length of taper at the end of the miter pipe may be included in the distance, $M$.

*(d)* The following nomenclature is used in eqs. (4a), (4b), and (4c) for the pressure design of miter bends:

$c$ = same as defined in para. 304.1.1
$E$ = same as defined in para. 304.1.1
$P_m$ = maximum allowable internal pressure for miter bends
$R_1$ = effective radius of miter bend, defined as the shortest distance from the pipe centerline to the intersection of the planes of adjacent miter joints
$r_2$ = mean radius of pipe using nominal wall $\overline{T}$
$S$ = same as defined in para. 304.1.1
$T$ = miter pipe wall thickness (measured or minimum in accordance with the purchase specification)
$W$ = same as defined in para. 304.1.1
$\alpha$ = angle of change in direction at miter joint = $2\theta$
$\theta$ = angle of miter cut

For compliance with this Code, the value of $R_1$ shall be not less than that given by eq. (5)

$$R_1 = \frac{A}{\tan\theta} + \frac{D}{2} \tag{5}$$

where $A$ has the following empirical values:

*(1)* For SI units

| $(T - c)$, mm | $A$ |
|---|---|
| $\leq 13$ | 25 |
| $13 < (T - c) < 22$ | $2(T - c)$ |
| $\geq 22$ | $[2(T - c)/3] + 30$ |

*(2)* For U.S. Customary units

| $(T - c)$, in. | $A$ |
|---|---|
| $\leq 0.5$ | 1.0 |
| $0.5 < (T - c) < 0.88$ | $2(T - c)$ |
| $\geq 0.88$ | $[2(T - c)/3] + 1.17$ |

**304.2.4 Curved and Mitered Segments of Pipe Under External Pressure.** The wall thickness of curved and mitered segments of pipe subjected to external pressure may be determined as specified for straight pipe in para. 304.1.3.

## 304.3 Branch Connections

### 304.3.1 General

*(a)* Except as provided in (b) below, the requirements in paras. 304.3.2 through 304.3.4 are applicable to branch connections made in accordance with the following methods:

*(1)* fittings (tees, extruded outlets, branch outlet fittings in accordance with MSS SP-97, laterals, crosses)

*(2)* unlisted cast or forged branch connection fittings (see para. 300.2), and couplings not over DN 80 (NPS 3), attached to the run pipe by welding

*(3)* welding the branch pipe directly to the run pipe, with or without added reinforcement, as covered in para. 328.5.4

*(b)* The rules in paras. 304.3.2 through 304.3.4 are minimum requirements, valid only for branch connections in which (using the nomenclature of Figure 304.3.3)

*(1)* the run pipe diameter-to-thickness ratio ($D_h/T_h$) is less than 100 and the branch-to-run diameter ratio ($D_b/D_h$) is not greater than 1.0

*(2)* for run pipe with $D_h/T_h \geq 100$, the branch diameter, $D_b$, is less than one-half the run diameter, $D_h$

*(3)* angle $\beta$ is at least 45 deg

*(4)* the axis of the branch intersects the axis of the run

*(c)* Where the provisions of (a) and (b) above are not met, pressure design shall be qualified as required by para. 304.7.2.

*(d)* Other design considerations relating to branch connections are stated in para. 304.3.5.

**304.3.2 Strength of Branch Connections.** A pipe having a branch connection is weakened by the opening that must be made in it and, unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide added reinforcement. The amount of reinforcement required to sustain the pressure shall be determined in accordance with para. 304.3.3 or 304.3.4. There are, however, certain branch connections that have adequate pressure strength or reinforcement as constructed. It may be assumed without calculation that a branch connection has adequate strength to sustain the internal and external pressure that will be applied to it if

*(a)* the branch connection is made with a listed branch type fitting such as an ASME B16.9 or ASME B16.11 tee, or MSS SP-97 branch connection fitting. See para. 303.

*(b)* the branch connection is made by welding a listed threaded or socket welding coupling or listed half coupling directly to the run in accordance with para. 328.5.4, provided the size of the branch does not exceed DN 50 (NPS 2) nor one-fourth the nominal size of the run. The minimum wall thickness of the coupling anywhere in the reinforcement zone (if threads are in the zone, wall thickness is measured from root of thread to minimum outside diameter) shall be not less than that of the unthreaded branch pipe. In no case shall a coupling or half coupling have a rating less than Class 3000 in accordance with ASME B16.11.

*(c)* the branch connection utilizes an unlisted branch connection fitting (see para. 300.2), provided the fitting is made from materials listed in Table A-1 or Table A-1M and provided that the branch connection is qualified as required by para. 304.7.2.

**304.3.3 Reinforcement of Welded Branch Connections.** Added reinforcement is required to meet the criteria in (b) and (c) when it is not inherent in the components of the branch connection. Sample problems illustrating the calculations for branch reinforcement are shown in Appendix H.

*(a) Nomenclature.* The nomenclature below is used in the pressure design of branch connections. It is illustrated in Figure 304.3.3, which does not indicate details for construction or welding. Some of the terms defined in Appendix J are subject to further definitions or variations, as follows:

$b$ = subscript referring to branch

$d_1$ = effective length removed from pipe at branch. For branch intersections where the branch opening is a projection of the branch pipe inside diameter (e.g., pipe-to-pipe fabricated branch), $d_1 = [D_b - 2(T_b - c)]/\sin\beta$

$d_2$ = "half width" of reinforcement zone
= $d_1$ or $(T_b - c) + (T_h - c) + d_1/2$, whichever is greater, but in any case not more than $D_h$

$h$ = subscript referring to run or header

$L_4$ = height of reinforcement zone outside of run pipe
= $2.5(T_h - c)$ or $2.5(T_b - c) + T_r$, whichever is less

$T_b$ = branch pipe thickness (measured or minimum in accordance with the purchase specification) except for branch connection fittings (see para. 300.2). For such connections the value of $T_b$ for use in calculating $L_4$, $d_2$, and $A_3$ is the thickness of the reinforcing barrel (minimum per purchase specification), provided that the barrel thickness is uniform (see Figure K328.5.4) and extends at least to the $L_4$ limit (see Figure 304.3.3).

$T_r$ = minimum thickness of reinforcing ring or saddle made from pipe (use nominal thickness if made from plate)
= 0 if there is no reinforcing ring or saddle

$t$ = pressure design thickness of pipe, according to the appropriate wall thickness equation or procedure in para. 304.1. For welded pipe, when the branch does not intersect the longitudinal weld of the run, the basic allowable stress, $S$, for the pipe may be used in determining $t_h$ for the purpose of reinforcement calculation only. When the branch does intersect the longitudinal weld of the run, the product $SEW$ (of the stress value, $S$; the appropriate weld joint quality factor, $E_j$, from Table A-1B; and the weld joint strength reduction factor, $W$; see para. 302.3.5) for the run pipe shall be used in the calculation. The product $SEW$ of the branch shall be used in calculating $t_b$.

$\beta$ = smaller angle between axes of branch and run

*(b) Required Reinforcement Area.* The reinforcement area, $A_1$, required for a branch connection under internal pressure is

$$A_1 = t_h d_1(2 - \sin\beta) \tag{6}$$

For a branch connection under external pressure, area $A_1$ is one-half the area calculated by eq. (6), using as $t_h$ the thickness required for external pressure.

*(c) Available Area.* The area available for reinforcement is defined as

$$A_2 + A_3 + A_4 \geq A_1 \tag{6a}$$

These areas are all within the reinforcement zone and are further defined below.

*(1)* Area $A_2$ is the area resulting from excess thickness in the run pipe wall

$$A_2 = (2d_2 - d_1)(T_h - t_h - c) \tag{7}$$

*(2)* Area $A_3$ is the area resulting from excess thickness in the branch pipe wall

$$A_3 = 2L_4(T_b - t_b - c)/\sin\beta \tag{8}$$

If the allowable stress for the branch pipe wall is less than that for the run pipe, its calculated area must be reduced in the ratio of allowable stress values of the branch to the run in determining its contributions to area $A_3$.

*(3)* Area $A_4$ is the area of other metal provided by welds and properly attached reinforcement. [See (f).] Weld areas shall be based on the minimum dimensions specified in para. 328.5.4, except that larger dimensions may be used if the welder has been specifically instructed to make the welds to those dimensions.

*(d) Reinforcement Zone.* The reinforcement zone is a parallelogram whose length extends a distance, $d_2$, on each side of the centerline of the branch pipe and whose width starts at the inside surface of the run pipe (in its corroded condition) and extends beyond the outside surface of the run pipe a perpendicular distance, $L_4$.

*(e) Multiple Branches.* When two or more branch connections are so closely spaced that their reinforcement zones overlap, the distance between centers of the openings should be at least $1\frac{1}{2}$ times their average diameter, and the area of reinforcement between any two openings shall be not less than 50% of the total that both require. Each opening shall have adequate reinforcement in accordance with (b) and (c). No part of the metal cross section may apply to more than one opening or be evaluated more than once in any combined area. (Consult PFI Standard ES-7, Minimum Length and Spacing for Branch Connections, for detailed recommendations on spacing of welded nozzles.)

*(f) Added Reinforcement*

*(1)* Reinforcement added in the form of a ring or saddle as part of area $A_4$ shall be of reasonably constant width.

*(2)* Material used for reinforcement may differ from that of the run pipe provided it is compatible with run and branch pipes with respect to weldability, heat treatment requirements, galvanic corrosion, thermal expansion, etc.

*(3)* If the allowable stress for the reinforcement material is less than that for the run pipe, its calculated area must be reduced in the ratio of allowable stress values in determining its contribution to area $A_4$.

*(4)* No additional credit may be taken for a material having higher allowable stress value than the run pipe.

### 304.3.4 Reinforcement of Extruded Outlet Headers

*(a)* The principles of reinforcement stated in para. 304.3.3 are essentially applicable to extruded outlet headers. An extruded outlet header is a length of pipe in which one or more outlets for branch connection have been formed by extrusion, using a die or dies to control the radii of the extrusion. The extruded outlet projects above the surface of the header a distance $h_x$ at least equal to the external radius of the outlet $r_x$ (i.e., $h_x \geq r_x$).

*(b)* The rules in this paragraph are minimum requirements, valid only within the limits of geometry shown in Figure 304.3.4, and only where the axis of the outlet intersects and is perpendicular to the axis of the header. Where these requirements are not met, or where nonintegral material such as a ring, pad, or saddle has been added to the outlet, pressure design shall be qualified as required by para. 304.7.2.

*(c) Nomenclature.* The nomenclature used herein is illustrated in Figure 304.3.4. Note the use of subscript $x$ signifying extruded. Refer to para. 304.3.3(a) for nomenclature not listed here.

$d_x$ = the design inside diameter of the extruded outlet, measured at the level of the outside surface of the header. This dimension is taken after removal of all mechanical and corrosion allowances, and all thickness tolerances.

$d_2$ = half width of reinforcement zone (equal to $d_x$)

$h_x$ = height of the extruded outlet. This must be equal to or greater than $r_x$ [except as shown in illustration (b) in Figure 304.3.4].

$L_5$ = height of reinforcement zone
= $0.7\sqrt{D_b T_x}$

$r_x$ = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch

$T_x$ = corroded finished thickness of extruded outlet, measured at a height equal to $r_x$ above the outside surface of the header

*(d) Limitations on Radius $r_x$.* The external contour radius, $r_x$, is subject to the following limitations:

*(1)* minimum $r_x$ — the lesser of $0.05D_b$ or 38 mm (1.50 in.)

*(2)* maximum $r_x$ shall not exceed

*(a)* for $D_b$ < DN 200 (NPS 8), 32 mm (1.25 in.)

*(b)* for $D_b \geq$ DN 200, $0.1D_b$ + 13 mm (0.50 in.)

*(3)* for an external contour with multiple radii, the requirements of (1) and (2) above apply, considering the best-fit radius over a 45-deg arc as the maximum radius

*(4)* machining shall not be employed in order to meet the above requirements

*(e) Required Reinforcement Area.* The required area of reinforcement is defined by

$$A_1 = K t_h d_x \tag{9}$$

where $K$ is determined as follows:

*(1)* For $D_b/D_h > 0.60$, $K = 1.00$.

*(2)* For $0.60 \geq D_b/D_h > 0.15$, $K = 0.6 + \frac{2}{3}(D_b/D_h)$.

*(3)* For $D_b/D_h \leq 0.15$, $K = 0.70$.

*(f) Available Area.* The area available for reinforcement is defined as

$$A_2 + A_3 + A_4 \geq A_1 \tag{9a}$$

These areas are all within the reinforcement zone and are further defined below.

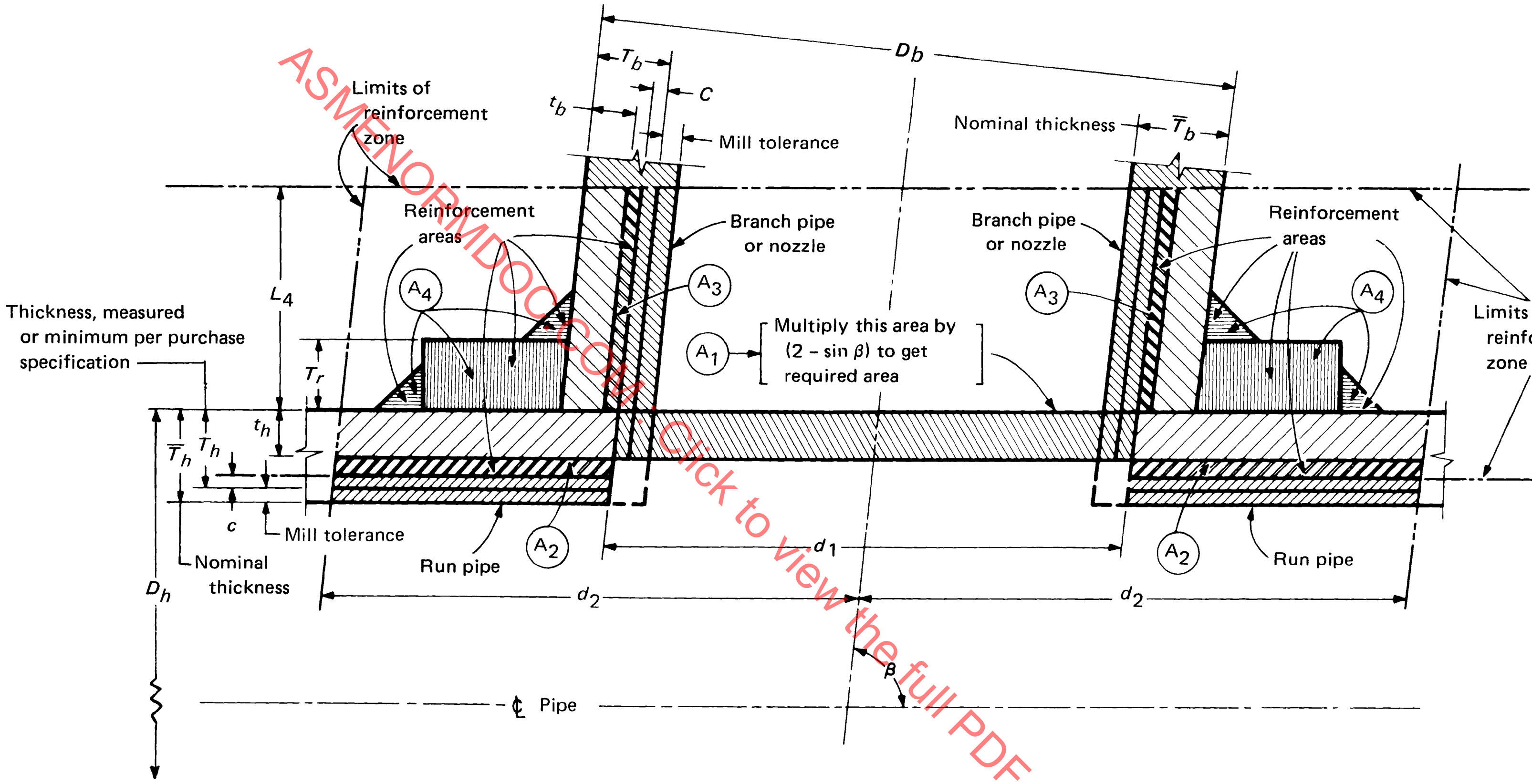
*(1)* Area $A_2$ is the area resulting from excess thickness in the header wall

$$A_2 = (2d_2 - d_x)(T_h - t_h - c) \tag{10}$$

*(2)* Area $A_3$ is the area resulting from excess thickness in the branch pipe wall

$$A_3 = 2L_5(T_b - t_b - c) \tag{11}$$

**Figure 304.3.3 Branch Connection Nomenclature**




GENERAL NOTE: This Figure illustrates the nomenclature of para. 304.3.3. It does not indicate complete welding details or a preferred method of construction. For typical weld details, see Figure 328.5.4D and Figure 328.5.4F.

*(3)* Area $A_4$ is the area resulting from excess thickness in the extruded outlet lip

$$A_4 = 2r_x[T_x - (T_b - c)] \tag{12}$$

*(g)* *Reinforcement of Multiple Openings.* The rules of para. 304.3.3(e) shall be followed, except that the required area and reinforcement area shall be as given in this paragraph.

*(h)* *Identification.* The manufacturer shall establish the design pressure and temperature for each extruded outlet header and shall mark the header with this information, together with the symbol "B31.3" (indicating the applicable Code Section) and the manufacturer's name or trademark.

**304.3.5 Additional Design Considerations.** The requirements of paras. 304.3.1 through 304.3.4 are intended to ensure satisfactory performance of a branch connection subject only to pressure. The designer shall also consider the following:

*(a)* In addition to pressure loadings, external forces and movements are applied to a branch connection by thermal expansion and contraction, dead and live loads, and movement of piping terminals and supports. Special consideration shall be given to the design of a branch connection to withstand these forces and movements.

*(b)* Branch connections made by welding the branch pipe directly to the run pipe should be avoided under the following circumstances:

*(1)* when branch size approaches run size, particularly if pipe formed by more than 1.5% cold expansion, or expanded pipe of a material subject to work hardening, is used as the run pipe

*(2)* where repetitive stresses may be imposed on the connection by vibration, pulsating pressure, temperature cycling, etc.

In such cases, it is recommended that the design be conservative and that consideration be given to the use of tee fittings or complete encirclement types of reinforcement.

*(c)* Adequate flexibility shall be provided in a small line that branches from a large run, to accommodate thermal expansion and other movements of the larger line (see para. 319.6).

*(d)* If ribs, gussets, or clamps are used to stiffen the branch connection, their areas cannot be counted as contributing to the reinforcement area determined in para. 304.3.3(c) or 304.3.4(f). However, ribs or gussets may be used for pressure-strengthening a branch connection in lieu of reinforcement covered in paras. 304.3.3 and 304.3.4 if the design is qualified as required by para. 304.7.2.

*(e)* For branch connections that do not meet the requirements of para. 304.3.1(b), integral reinforcement, complete encirclement reinforcement, or other means of reinforcement should be considered.

**304.3.6 Branch Connections Under External Pressure.** Pressure design for a branch connection subjected to external pressure may be determined in accordance with para. 304.3.1, using the reinforcement area requirement stated in para. 304.3.3(b).

## 304.4 Closures

### 304.4.1 General

*(a)* Closures not in accordance with para. 303 or (b) shall be qualified as required by para. 304.7.2.

*(b)* For materials and design conditions covered therein, closures may be designed in accordance with rules in ASME BPVC, Section VIII, Division 1, calculated from eq. (13)

$$t_m = t + c \tag{13}$$

where

$c$ = sum of allowances defined in para. 304.1.1

$t$ = pressure design thickness, calculated for the type of closure and direction of loading, shown in Table 304.4.1, except that the symbols used to determine $t$ shall be as follows:

- $E$ = same as defined in para. 304.1.1
- $P$ = design gage pressure
- $S$ = $S$ times $W$, with $S$ and $W$ as defined in para. 304.1.1

$t_m$ = minimum required thickness, including mechanical, corrosion, and erosion allowance

### 304.4.2 Openings in Closures

*(a)* The rules in (b) through (g) apply to openings not larger than one-half the inside diameter of the closure as defined in the ASME BPVC, Section VIII, Division 1, UG-36. A closure with a larger opening should be designed as a reducer in accordance with para. 304.6 or, if the closure is flat, as a flange in accordance with para. 304.5.

*(b)* A closure is weakened by an opening and, unless the thickness of the closure is sufficiently in excess of that required to sustain pressure, it is necessary to provide added reinforcement. The need for and amount of reinforcement required shall be determined in accordance with the subparagraphs below except that it shall be considered that the opening has adequate reinforcement if the outlet connection meets the requirements in para. 304.3.2(b) or (c).

*(c)* Reinforcement for an opening in a closure shall be so distributed that reinforcement area on each side of an opening (considering any plane through the center of the opening normal to the surface of the closure) will equal at least one-half the required area in that plane.

*(d)* The total cross-sectional area required for reinforcement in any given plane passing through the center of the opening shall not be less than that defined in ASME BPVC, Section VIII, Division 1, UG-37 (b), UG-38, and UG-39.

## Figure 304.3.4 Extruded Outlet Header Nomenclature

**This Figure illustrates the nomenclature of para. 304.3.4. It does not indicate complete details or a preferred method of construction.**

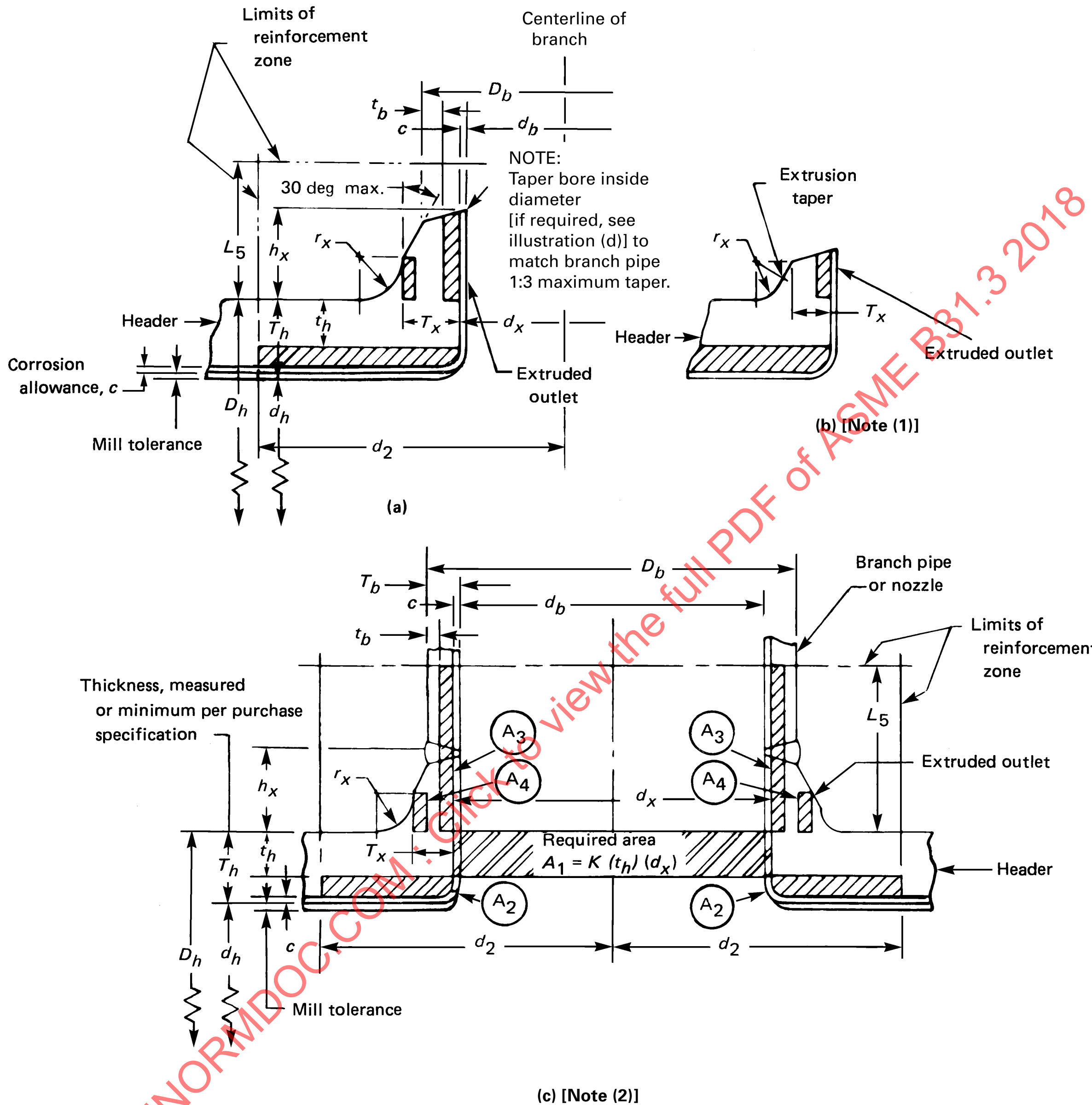
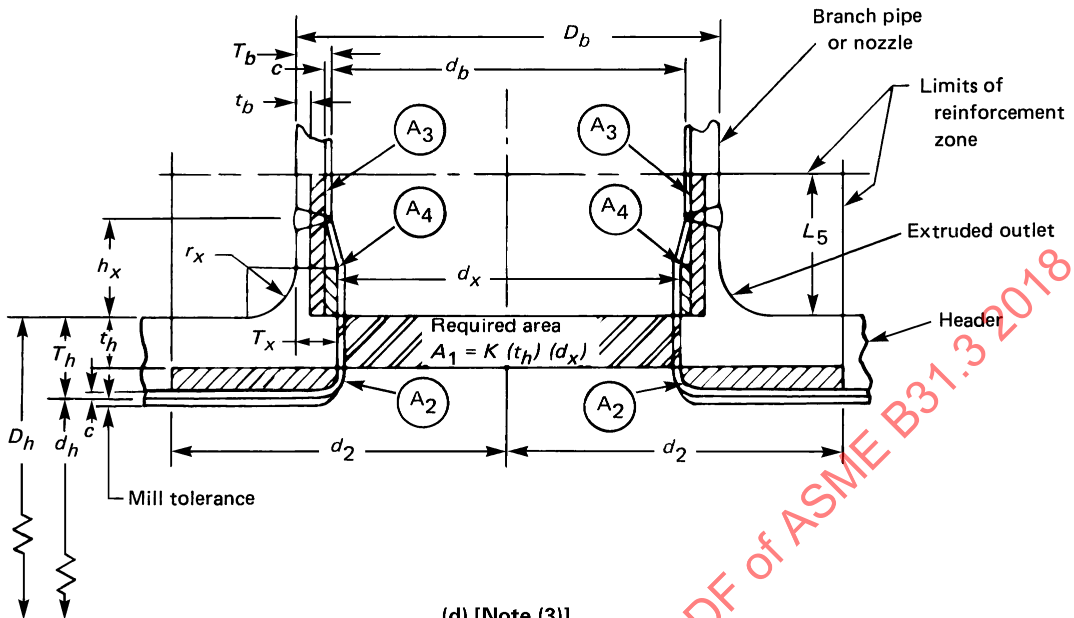


**Figure 304.3.4 Extruded Outlet Header Nomenclature (Cont'd)**




(d) [Note (3)]



NOTES:
(1) Illustration to show method of establishing $T_x$ when the taper encroaches on the crotch radius.
(2) Illustration is drawn for condition where $K$ = 1.00.
(3) Illustration is drawn for condition where $K$ = 1.00 and $d_x < d_b$.

**Table 304.4.1 ASME BPVC References for Closures**

| Type of Closure | Concave to Pressure | Convex to Pressure |
|---|---|---|
| Ellipsoidal | UG-32(d) | UG-33(d) |
| Torispherical | UG-32(e) | UG-33(e) |
| Hemispherical | UG-32(f) | UG-33(c) |
| Conical (no transition to knuckle) | UG-32(g) | UG-33(f) |
| Toriconical | UG-32(h) | UG-33(f) |
| Flat (pressure on either side) | UG-34 | |

GENERAL NOTE: Paragraph numbers are from ASME BPVC, Section VIII, Division 1.

*(e)* The reinforcement area and reinforcement zone shall be calculated in accordance with para. 304.3.3 or 304.3.4, considering the subscript *h* and other references to the run or header pipe as applying to the closure. Where the closure is curved, the boundaries of the reinforcement zone shall follow the contour of the closure, and dimensions of the reinforcement zone shall be measured parallel to and perpendicular to the closure surface.

*(f)* If two or more openings are to be located in a closure, the rules in paras. 304.3.3 and 304.3.4 for the reinforcement of multiple openings apply.

*(g)* The additional design considerations for branch connections discussed in para. 304.3.5 apply equally to openings in closures.

## 304.5 Pressure Design of Flanges and Blanks

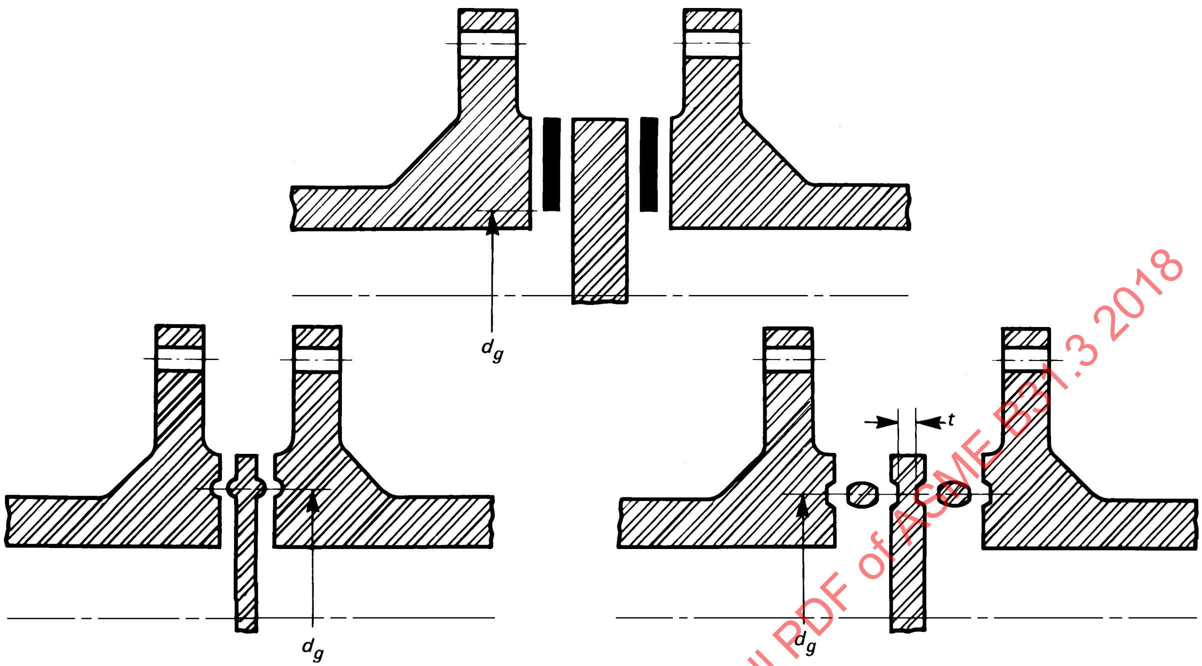
### 304.5.1 Flanges — General (18)

*(a)* Flanges not in accordance with para. 303, or 304.5.1(b) or (d), shall be qualified as required by para. 304.7.2.

*(b)* A flange may be designed in accordance with ASME BPVC, Section VIII, Division 1, Mandatory Appendix 2 (Rules for Bolted Flange Connections with Ring Type Gaskets) or ASME BPVC, Section VIII, Division 2, 4.16 (Design Rules for Flanged Joints), using the allowable stresses and temperature limits of this Code. Nomenclature shall be as defined in Appendix 2, except as follows:

$P$ = design gage pressure
$S_a$ = bolt design stress at atmospheric temperature
$S_b$ = bolt design stress at design temperature
$S_f$ = product $SEW$ [of the stress value, $S$; the appropriate quality factor, $E$, from Table A-1A or Table A-1B; and weld joint strength reduction

**Figure 304.5.3 Blanks**




factor in accordance with para. 302.3.5(e)] for flange or pipe material. See para. 302.3.2(e).

*(c)* The rules in (b) above are not applicable to a flanged joint having a gasket that extends outside the bolts (usually to the outside diameter of the flange).

*(d)* For flanges that make solid contact outside the bolts, ASME BPVC, Section VIII, Division 1, Appendix Y should be used.

*(e)* See Section VIII, Division 1, Appendix S, for considerations applicable to bolted joint assembly.

### 304.5.2 Blind Flanges

*(a)* Blind flanges not in accordance with para. 303 or 304.5.2(b) shall be qualified as required by para. 304.7.2.

*(b)* A blind flange may be designed in accordance with eq. (14). The minimum thickness, considering the manufacturer's minus tolerance, shall be not less than $t_m$

$$t_m = t + c \tag{14}$$

To calculate $t$, the rules of ASME BPVC, Section VIII, Division 1, UG-34 may be used with the following changes in nomenclature:

$c$ = sum of allowances defined in para. 304.1.1
$P$ = internal or external design gage pressure
$S_f$ = product $SEW$ [of the stress value, $S$; the appropriate quality factor, $E$, from Table A-1A or Table A-1B; and weld joint strength reduction factor per para. 302.3.5(e)] for flange material. See para. 302.3.2(e).
$t$ = pressure design thickness, as calculated for the given styles of blind flange, using the appropriate equations for bolted flat cover plates in UG-34

### 304.5.3 Blanks

*(a)* Blanks not in accordance with para. 303 or 304.5.3(b) shall be qualified as required by para. 304.7.2.

*(b)* The minimum required thickness of a permanent blank (representative configurations shown in Figure 304.5.3) shall be calculated in accordance with eq. (15)

$$t_m = d_g \sqrt{\frac{3P}{16SEW}} + c \tag{15}$$

where

$c$ = sum of allowances defined in para. 304.1.1
$d_g$ = inside diameter of gasket for raised or flat face flanges, or the gasket pitch diameter for ring joint and fully retained gasketed flanges
$E$ = same as defined in para. 304.1.1
$P$ = design gage pressure
$S$ = same as defined in para. 304.1.1
$W$ = same as defined in para. 304.1.1

### 304.6 Reducers

**304.6.1 Concentric Reducers**

*(a)* Concentric reducers not in accordance with para. 303 or 304.6.1(b) shall be qualified as required by para. 304.7.2.

*(b)* Concentric reducers made in a conical or reversed curve section, or a combination of such sections, may be designed in accordance with the rules for conical and toriconical closures stated in para. 304.4.1.

**304.6.2 Eccentric Reducers.** Eccentric reducers not in accordance with para. 303 shall be qualified as required by para. 304.7.2.

### 304.7 Pressure Design of Other Components

**304.7.1 Listed Components.** Other pressure-containing components manufactured in accordance with standards in Table 326.1 may be utilized in accordance with para. 303.

**304.7.2 Unlisted Components.** Pressure design of unlisted components to which the rules elsewhere in para. 304 do not apply shall be based on the pressure design criteria of this Code. The designer shall ensure that the pressure design has been substantiated through one or more of the means stated in (a) through (d). Note that designs are also required to be checked for adequacy of mechanical strength as described in para. 302.5. Documentation showing compliance with this paragraph shall be available for the owner's approval.

*(a)* extensive, successful service experience under comparable conditions with similarly proportioned components of the same or like material.

*(b)* experimental stress analysis, such as described in ASME BPVC, Section VIII, Division 2, Annex 5.F.

*(c)* proof test in accordance with ASME B16.9, MSS SP-97, or ASME BPVC, Section VIII, Division 1, UG-101.

*(d)* detailed stress analysis (e.g., finite element method) with results evaluated as described in ASME BPVC, Section VIII, Division 2, Part 5. The basic allowable stress from Table A-1 or Table A-1M shall be used in place of the allowable stress, *S*, in Division 2 where applicable. Load design factors used in a Division 2 evaluation shall be consistent with the design bases in para. 302.3.2. At design temperatures in the creep range, additional considerations beyond the scope of Division 2 may be necessary.

*(e)* For any of the above, the designer may interpolate between sizes, wall thicknesses, and pressure classes, and may determine analogies among related materials.

**304.7.3 Metallic Components With Nonmetallic Pressure Parts.** Components not covered by standards listed in Table 326.1, in which both metallic and nonmetallic parts contain the pressure, shall be evaluated by applicable requirements of para. A304.7.2 as well as those of para. 304.7.2.

**304.7.4 Expansion Joints**

*(a) Metallic Bellows Expansion Joints.* The design of bellows type expansion joints shall be in accordance with Appendix X. See also Appendix F, para. F304.7.4 for further design considerations.

*(b) Slip Type Expansion Joints*

*(1)* Pressure-containing elements shall be in accordance with para. 318 and other applicable requirements of this Code.

*(2)* External piping loads shall not impose excessive bending on the joint.

*(3)* The effective pressure thrust area shall be computed using the outside diameter of the pipe.

*(c) Other Types of Expansion Joint.* The design of other types of expansion joint shall be qualified as required by para. 304.7.2.



# PART 3
# FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

## 305 PIPE

Pipe includes components designated as "tube" or "tubing" in the material specification, when intended for pressure service.

### 305.1 General

Listed pipe may be used in Normal Fluid Service except as stated in paras. 305.2.1 and 305.2.2. Unlisted pipe may be used only as provided in para. 302.2.3.

### 305.2 Specific Requirements

**305.2.1 Pipe for Category D Fluid Service.** The following carbon steel pipe may be used only for Category D Fluid Service:

API 5L continuous welded (furnace butt-welded)
ASTM A53, Type F
ASTM A134 made from other than ASTM A285 plate

**305.2.2 Pipe Requiring Safeguarding.** When used for other than Category D Fluid Service, the following carbon steel pipe shall be safeguarded:

ASTM A134 made from ASTM A285 plate
ASTM A139

**305.2.3 Pipe for Severe Cyclic Conditions**

*(a)* Except as limited in (b) through (d), only the following pipe may be used under severe cyclic conditions:

*(1)* pipe listed in Table A-1A, where $E_c \geq 0.90$,[7] or

*(2)* pipe listed in Table A-1B, where $E_j \geq 0.90$[7]

*(b)* For API 5L pipe, only the following materials may be used:

[7] See para. 302.3.3.

Grade A or B, seamless
Grade A or B, SAW, str. seam, $E_j \geq 0.95$
Grade X42, seamless
Grade X46, seamless
Grade X52, seamless
Grade X56, seamless
Grade X60, seamless

*(c)* For copper pipe, only ASTM B42 may be used.

*(d)* For copper alloy pipe, only ASTM B466 may be used.

*(e)* For aluminum alloy pipe, only ASTM B210 and B241, both in tempers O and H112, may be used.

**305.2.4 Elevated Temperature Fluid Service.** In Elevated Temperature Fluid Service, all longitudinal or spiral (helical seam) welds in P-No. 4 or P-No. 5 materials shall be examined by 100% radiography or 100% ultrasonic examination. Acceptance criteria are as stated in para. 341.3.2 and in Table 341.3.2, for Normal Fluid Service, unless otherwise specified.

## 306 FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

Fittings, bends, miters, laps, and branch connections may be used in accordance with paras. 306.1 through 306.5. Pipe and other materials used in such components shall be suitable for the manufacturing or fabrication process and the fluid service.

### 306.1 Pipe Fittings

**306.1.1 Listed Fittings.** Listed fittings may be used in Normal Fluid Service in accordance with para. 303.

**306.1.2 Unlisted Fittings.** Unlisted fittings may be used only in accordance with para. 302.2.3.

#### 306.1.3 Specific Fittings

*(a)* Proprietary welding branch outlet fittings that have been design proof tested successfully as prescribed in ASME B16.9, MSS SP-97, or ASME BPVC, Section VIII, Division 1, UG-101 may be used within their established ratings.

*(b)* The lap thickness of a proprietary "Type C" lap-joint stub-end buttwelding fitting shall conform to the requirements of para. 306.4.2 for flared laps.

#### 306.1.4 Fittings for Severe Cyclic Conditions

*(a)* Only the following fittings may be used under severe cyclic conditions:

*(1)* forged.

*(2)* wrought, seamless or welded. If welded, requires 100% radiograph of welds in accordance with para. 344.5.1 and Table 341.3.2.

*(3)* cast, with factor $E_c \geq 0.90$.[7]

*(b)* Fittings conforming to MSS SP-43, MSS SP-119, and proprietary "Type C" lap-joint stub-end welding fittings shall not be used under severe cyclic conditions.

### 306.2 Pipe Bends

#### 306.2.1 General

*(a)* A pipe bend made in accordance with paras. 332.2.1 and 332.2.2, and verified for pressure design in accordance with para. 304.2.1, is suitable for the same service as the pipe from which it is made.

*(b)* A pipe bend made in accordance with para. 332.2.2, but not meeting the flattening limits of para. 332.2.1, may be qualified for pressure design by para. 304.7.2 and shall not exceed the rating of the straight pipe from which it is made.

**306.2.2 Corrugated and Other Bends.** Bends of other designs (such as creased or corrugated) shall be qualified for pressure design as required by para. 304.7.2.

**306.2.3 Bends for Severe Cyclic Conditions.** A pipe bend designed as creased or corrugated shall not be used under severe cyclic conditions.

### 306.3 Miter Bends

**306.3.1 General.** Except as stated in para. 306.3.2, a miter bend made in accordance with para. 304.2.3 and welded in accordance with para. 311.1 is suitable for use in Normal Fluid Service.

**306.3.2 Miter Bends for Category D Fluid Service.** A (18)
miter bend that makes a change in direction at a single joint (angle $\alpha$ in Figure 304.2.3) greater than 45 deg, or is welded in accordance with para. 311.1, may be used only for Category D Fluid Service.

**306.3.3 Miter Bends for Severe Cyclic Conditions.** A (18)
miter bend to be used under severe cyclic conditions shall be made in accordance with para. 304.2.3 and welded in accordance with para. 311.1, and shall have an angle $\alpha$ (see Figure 304.2.3) $\leq$ 22.5 deg.

### 306.4 Laps

The following requirements do not apply to fittings conforming to para. 306.1, specifically lap-joint stub ends conforming to ASME B16.9, nor to laps integrally hot-forged on pipe ends, except as noted in paras. 306.4.3 and 306.4.4(a).

**306.4.1 Fabricated Laps.** A fabricated lap is suitable for use in Normal Fluid Service, provided that all of the following requirements are met:

*(a)* The outside diameter of the lap shall be within the dimensional tolerances of the corresponding ASME B16.9 lap-joint stub end.

*(b)* The lap thickness shall be at least equal to the nominal wall thickness of the pipe to which it is attached.

*(c)* The lap material shall have an allowable stress at least as great as that of the pipe.

*(d)* Welding shall be in accordance with para. 311.1 and fabrication shall be in accordance with para. 328.5.5.

**306.4.2 Flared Laps.** See para. 308.2.5 for requirements of lapped flanges for use with flared laps. A flared lap is suitable for use in Normal Fluid Service, provided that all of the following requirements are met:

*(a)* The pipe used shall be of a specification and grade suitable for forming without cracks, surface buckling, or other defects.

*(b)* The outside diameter of the lap shall be within the dimensional tolerances of the corresponding ASME B16.9 lap-joint stub end.

*(c)* The radius of fillet shall not exceed 3 mm ($\frac{1}{8}$ in.).

*(d)* The lap thickness at any point shall be at least 95% of the minimum pipe wall thickness, *T*, multiplied by the ratio of the pipe outside diameter to the diameter at which the lap thickness is measured.

*(e)* Pressure design shall be qualified as required by para. 304.7.2.

**306.4.3 Forged Laps.** A lap integrally hot-forged on a pipe end is suitable for Normal Fluid Service only when the requirements of para. 332 are met. Its dimensions shall conform to those for lap-joint stub ends given in ASME B16.9.

(18) **306.4.4 Laps for Severe Cyclic Conditions**

*(a)* A forged lap-joint stub end in accordance with para. 306.1 or a lap integrally hot-forged on a pipe end in accordance with para. 306.4.3 may be used under severe cyclic conditions.

*(b)* A fabricated lap to be used under severe cyclic conditions shall conform to the requirements of para. 306.4.1, except that welding shall be in accordance with para. 311.1. A fabricated lap shall conform to a detail shown in Figure 328.5.5, illustration (d) or (e).

*(c)* A flared lap is not permitted under severe cyclic conditions.

### 306.5 Fabricated Branch Connections

The following requirements do not apply to fittings conforming to para. 306.1.

**306.5.1 General.** A fabricated branch connection made and verified for pressure design in accordance with para. 304.3, and welded in accordance with para. 311.1, is suitable for use in Normal Fluid Service.

(18) **306.5.2 Fabricated Branch Connections for Severe Cyclic Conditions.** A fabricated branch connection to be used under severe cyclic conditions shall conform to the requirements of para. 306.5.1, except that welding shall be in accordance with para. 311.1, with fabrication limited to a detail equivalent to Figure 328.5.4D, illustration (2) or (4), or to Figure 328.5.4E.

### 306.6 Thermowells

Thermowells shall comply with ASME PTC 19.3 TW where applicable.

## 307 VALVES AND SPECIALTY COMPONENTS

The following requirements for valves shall also be met as applicable by other pressure-containing piping components, such as traps, strainers, and separators. See also Appendix F, paras. F301.4 and F307.

### 307.1 General

**307.1.1 Listed Valves.** A listed valve is suitable for use in Normal Fluid Service, except as stated in para. 307.2.

**307.1.2 Unlisted Valves.** Unlisted valves may be used only in accordance with para. 302.2.3. Unless pressure–temperature ratings are established by the method set forth in ASME B16.34, pressure design shall be qualified as required by para. 304.7.2.

### 307.2 Specific Requirements

**307.2.1 Bonnet Bolting.** A bolted bonnet valve whose bonnet is secured to the body by less than four bolts, or by a U-bolt, may be used only for Category D Fluid Service.

**307.2.2 Stem Retention.** Valves shall be designed so that the stem seal retaining fasteners (e.g., packing, gland fasteners) alone do not retain the stem. Specifically, the design shall be such that the stem shall not be capable of removal from the valve, while the valve is under pressure, by the removal of the stem seal retainer (e.g., gland) alone.

## 308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

### 308.1 General

**308.1.1 Listed Components.** A listed flange, blank, or gasket is suitable for use in Normal Fluid Service, except as stated elsewhere in para. 308.

**308.1.2 Unlisted Components.** Unlisted flanges, blanks, and gaskets may be used only in accordance with para. 302.2.3.

### 308.2 Specific Requirements for Flanges

See Appendix F, paras. F308.2 and F312.

**Table 308.2.1 Permissible Sizes/Rating Classes for Slip-On Flanges Used as Lapped Flanges** (18)

| | Maximum Flange Size | |
|---|---|---|
| Rating Class | DN | NPS |
| 150 | 300 | 12 |
| 300 | 200 | 8 |

GENERAL NOTE: Actual thickness of the slip-on flange at the bolt circle shall be at least equal to the minimum required flange thickness for lapped flanges in ASME B16.5.

#### 308.2.1 Slip-On Flanges

*(a)* A slip-on flange shall be double-welded as shown in Figure 328.5.2B when the service is

*(1)* subject to severe erosion, crevice corrosion, or cyclic loading

*(2)* flammable, toxic, or damaging to human tissue

*(3)* under severe cyclic conditions

*(4)* at temperatures below −101°C (−150°F)

*(b)* The use of slip-on flanges should be avoided where many large temperature cycles are expected, particularly if the flanges are not insulated.

*(c)* *Slip-on Flanges as Lapped Flanges.* A slip-on flange may be used as a lapped flange only as shown in Table 308.2.1 unless pressure design is qualified in accordance with para. 304.5.1. A corner radius or bevel shall conform to one of the following as applicable:

*(1)* For an ASME B16.9 lap joint stub end or a forged lap (see para. 306.4.3), the corner radius shall be as specified in ASME B16.5, Tables 9 and 12, dimension *r*.

*(2)* For a fabricated lap, the corner bevel shall be at least half the nominal thickness of the pipe to which the lap is attached (see Figure 328.5.5).

*(3)* For a flared lap see para. 308.2.5.

**308.2.2 Expanded-Joint Flanges.** A flange having an expanded-joint insert is subject to the requirements for expanded joints in para. 313.

**308.2.3 Socket Welding and Threaded Flanges.** A socket welding flange is subject to the requirements for socket welds in para. 311.2.2. A threaded flange is subject to the requirements for threaded joints in para. 314.

**308.2.4 Flanges for Severe Cyclic Conditions.** Unless it is safeguarded, a flange to be used under severe cyclic conditions shall be welding neck conforming to ASME B16.5 or ASME B16.47, or a similarly proportioned flange designed in accordance with para. 304.5.1.

**308.2.5 Flanges for Flared Metallic Laps.** For a flange used with a flared metallic lap (para. 306.4.2), the intersection of face and bore shall be beveled or rounded approximately 3 mm ($\frac{1}{8}$ in.). See also para. 308.2.1(c).

### (18) 308.3 Flange Facings

The flange facing shall be compatible with the gasket and bolting employed.

### (18) 308.4 Gaskets

Gaskets shall be selected so that the required seating load is compatible with the flange rating and facing, the strength of the flange, and its bolting. See Appendix F, para. F308.4.

## 309 BOLTING

Bolting includes bolts, bolt studs, studs, cap screws, nuts, and washers. See also Appendix F, para. F309.

### 309.1 General

**309.1.1 Listed Bolting.** Listed bolting is suitable for use in Normal Fluid Service, except as stated elsewhere in para. 309.

**309.1.2 Unlisted Bolting.** Unlisted bolting may be used only in accordance with para. 302.2.3.

**309.1.3 Bolting for Components.** Bolting for components conforming to a listed standard shall be in accordance with that standard if specified therein.

**309.1.4 Selection Criteria.** Bolting selected shall be adequate to seat the gasket and maintain joint tightness under all design conditions.

### 309.2 Specific Bolting

**309.2.1 Low Yield Strength Bolting.** Bolting having not more than 207 MPa (30 ksi) specified minimum yield strength shall not be used for flanged joints rated ASME B16.5 Class 400 and higher, nor for flanged joints using metallic gaskets, unless calculations have been made showing adequate strength to maintain joint tightness.

**309.2.2 Carbon Steel Bolting.** Except where limited by other provisions of this Code, carbon steel bolting may be used with nonmetallic gaskets in flanged joints rated ASME B16.5 Class 300 and lower for bolt metal temperatures at −29°C to 204°C (−20°F to 400°F), inclusive. If these bolts are galvanized, heavy hexagon nuts, threaded to suit, shall be used.

**309.2.3 Bolting for Metallic Flange Combinations.** (18)
Any bolting that meets the requirements of para. 309 may be used with any combination of flange material and facing. If either flange is to the ASME B16.1, ASME B16.24 manufactured from an ASTM B61 or an ASTM B62 casting, MSS SP-42, or MSS SP-51 specification, the bolting material shall be no stronger than low yield strength bolting unless

*(a)* both flanges have flat faces and a full-face gasket is used, or

*(b)* sequence and torque limits for bolt-up are specified, with consideration of sustained loads, displacement strains, occasional loads (see paras. 302.3.5 and 302.3.6), and strength of the flanges

**309.2.4 Bolting for Severe Cyclic Conditions.** Low yield strength bolting (see para. 309.2.1) shall not be used for flanged joints under severe cyclic conditions.

### 309.3 Tapped Holes

Tapped holes for pressure-retaining bolting in metallic piping components shall be of sufficient depth that the thread engagement will be at least seven-eighths times the nominal thread diameter.

## PART 4
## FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS

### (18) 310 GENERAL

Piping joints shall be selected considering joint tightness and mechanical strength under expected service and test conditions of pressure, temperature, and external loading. See para. 302.5.

### 311 WELDED JOINTS

Joints may be made by welding in any material for which it is possible to qualify welding procedures, welders, and welding operators in conformance with the rules in Chapter V.

### (18) 311.1 General

Welds shall conform to the following:

*(a)* Welding shall be in accordance with para. 328.

*(b)* Preheating and heat treatment shall be in accordance with paras. 330 and 331, respectively.

*(c)* Examination shall be in accordance with para. 341.4.

*(d)* Acceptance criteria shall be in accordance with para. 341.3.2.

### (18) 311.2 Specific Requirements

#### 311.2.1 Backing Rings and Consumable Inserts

*(a)* If a backing ring is used where the resulting crevice is detrimental (e.g., subject to corrosion, vibration, or severe cyclic conditions), it should be removed and the internal joint face ground smooth. When it is impractical to remove the backing ring in such a case, consideration shall be given to welding without backing rings or to the use of consumable inserts or removable nonmetallic backing rings.

*(b)* Split backing rings shall not be used under severe cyclic conditions.

#### 311.2.2 Socket Welds

*(a)* Socket welded joints (para. 328.5.2) should be avoided in any service where crevice corrosion or severe erosion may occur.

*(b)* Socket welded joints shall conform to the following:

*(1)* Socket dimensions shall conform to ASME B16.5 for flanges and ASME B16.11 or MSS SP-119 for other socket-welding components.

*(2)* Weld dimensions shall not be less than those shown in Figures 328.5.2B and 328.5.2C.

*(c)* Socket welds larger than DN 50 (NPS 2) shall not be used under severe cyclic conditions.

*(d)* A drain or bypass in a component may be attached by socket welding, provided the socket dimensions conform to Figure 4 in ASME B16.5.

#### 311.2.3 Fillet Welds

*(a)* Fillet welds in accordance with para. 328.5.2 may be used as primary welds to attach socket welding components and slip-on flanges.

*(b)* Fillet welds may also be used to attach reinforcement and structural attachments, to supplement the strength or reduce stress concentration of primary welds, and to prevent disassembly of joints.

**311.2.4 Seal Welds.** Seal welds (para. 328.5.3) may be used only to prevent leakage of threaded joints and shall not be considered as contributing any strength to the joints.

### 312 FLANGED JOINTS (18)

See Appendix F, para. F312.1.

### 312.1 Joints Using Flanges of Different Ratings

Where flanges of different ratings are bolted together, the rating of the joint shall not exceed that of the lower rated flange. Bolting torque shall be limited so that excessive loads will not be imposed on the lower rated flange in obtaining a tight joint.

### 312.2 Metal to Nonmetal Flanged Joints

Where a metallic flange is bolted to a nonmetallic flange, both should be flat-faced. A full-faced gasket is preferred. If a gasket extending only to the inner edge of the bolts is used, bolting torque shall be limited so that the nonmetallic flange is not overloaded.

### 312.3 Flanged Joint Assembly

See para. 335.2.5.

### 313 EXPANDED JOINTS

*(a)* Expanded joints shall not be used under severe cyclic conditions. For other services, adequate means shall be provided to prevent separation of the joint. If the fluid is toxic or damaging to human tissue, safeguarding is required.

(18) **Table 314.2.1 Minimum Schedule of Components With External Threads**

| Fluid Service | Notch-Sensitive Material [Note (1)] | Size Range [Note (2)] DN | Size Range [Note (2)] NPS | Minimum Schedule [Note (3)] |
|---|---|---|---|---|
| Normal | Yes | ≤40 | $\leq 1\frac{1}{2}$ | 80 |
| | | 50–150 | 2–6 | 40 |
| | | >150 | >6 | None |
| | No | ≤150 | ≤6 | 40 |
| | | >150 | >6 | None |
| Category D | Either | All | All | None |

NOTES:
(1) Carbon steel is generally considered to be notch sensitive, whereas stainless steel is generally considered to be not notch sensitive.
(2) For sizes over DN 50 (NPS 2), the joint shall be safeguarded (see Appendix G) for a fluid service that is flammable, toxic, or damaging to human tissue.
(3) Minimum schedules 40 and 80 are listed in ASME B36.10M, which are identical to schedules 40S and 80S listed in ASME B36.19M for DN 150 (NPS 6) and smaller.

*(b)* Consideration shall be given to the tightness of expanded joints when subjected to vibration, differential expansion or contraction due to temperature cycling, or external mechanical loads.

## 314 THREADED JOINTS

### 314.1 General

Threaded joints are suitable for Normal Fluid Service except as stated elsewhere in para. 314. They may be used under severe cyclic conditions only as provided in paras. 314.2.1(c) and 314.2.2.

*(a)* Threaded joints should be avoided in any service where crevice corrosion, severe erosion, or cyclic loading may occur.

*(b)* When threaded joints are intended to be seal welded, thread sealing compound shall not be used.

*(c)* Layout of piping employing threaded joints should, insofar as possible, minimize stress on joints, giving special consideration to stresses due to thermal expansion and operation of valves (particularly a valve at a free end). Provision should be made to counteract forces that would tend to unscrew the joints.

*(d)* Except for specially designed joints employing lens rings or similar gaskets, threaded flanges in which the pipe ends project through to serve as the gasket surface may be used only for Category D Fluid Service.

### 314.2 Specific Requirements

**314.2.1 Taper-Threaded Joints.** For joints in which the threads of both mating components conform to ASME B1.20.1, (18)

*(a)* the minimum thickness of components with external threads shall be the greater of $t_m$ in accordance with para. 304.1.1 and the schedule shown in Table 314.2.1

*(b)* threaded components shall be checked for adequacy of mechanical strength as described in para. 302.5

*(c)* threaded components of a specialty nature that are not subject to external moment loading, such as thermometer wells, may be used under severe cyclic conditions

A coupling having straight threads may be used only for Category D Fluid Service, and only with taper-threaded mating components.

**314.2.2 Straight-Threaded Joints.** Threaded joints in which the tightness of the joint is provided by a seating surface other than the threads (e.g., a union comprising male and female ends joined with a threaded union nut, or other constructions shown typically in Figure 335.3.3) may be used. If such joints are used under severe cyclic conditions and are subject to external moment loadings, safeguarding is required.

## 315 TUBING JOINTS

### 315.1 General

In selecting and applying flared, flareless, and compression type tubing fittings, the designer shall consider the possible adverse effects on the joints of such factors as assembly and disassembly, cyclic loading, vibration, shock, and thermal expansion and contraction.

### 315.2 Joints Conforming to Listed Standards (18)

Joints using flared, flareless, or compression type tubing fittings covered by listed standards may be used in Normal Fluid Service provided that

*(a)* the fittings and joints are compatible with the tubing with which they are to be used (considering maximum and minimum wall thickness) and are used within the pressure–temperature limitations of the fitting and the joint

*(b)* the joints are safeguarded when used under severe cyclic conditions

### 315.3 Joints Not Conforming to Listed Standards (18)

Joints using flared, flareless, or compression type tubing fittings not listed in Table 326.1 may be used in accordance with para. 315.2 provided that the design is qualified in accordance with para. 304.7.2.

## 316 CAULKED JOINTS

Caulked joints such as bell type joints shall be limited to Category D Fluid Service and to a temperature not over 93°C (200°F). They shall be used within the pressure–temperature limitations of the joint and pipe. Provisions shall be made to prevent disengagement of joints, to prevent buckling of the piping, and to sustain lateral reactions produced by branch connections or other causes.

## 317 SOLDERED AND BRAZED JOINTS

### 317.1 Soldered Joints

Soldered joints shall be made in accordance with the provisions of para. 333 and may be used only in Category D fluid service. Fillet joints made with solder metal are not permitted. The low melting point of solder shall be considered where possible exposure to fire or elevated temperature is involved.

### 317.2 Brazed and Braze Welded Joints

*(a)* Brazed and braze welded joints made in accordance with the provisions in para. 333 are suitable for Normal Fluid Service. They shall be safeguarded in fluid services that are flammable, toxic, or damaging to human tissue. They shall not be used under severe cyclic conditions. The melting point of brazing alloys shall be considered where possible exposure to fire is involved.

*(b)* Fillet joints made with brazing filler metal are not permitted.

## 318 SPECIAL JOINTS

Special joints are those not covered elsewhere in Chapter II, Part 4, such as bell type and packed gland type joints.

### 318.1 General

**318.1.1 Listed Joints.** Joints using listed components are suitable for Normal Fluid Service.

**318.1.2 Unlisted Joints.** For joints that utilize unlisted components, pressure design shall be qualified as required by para. 304.7.2.

### 318.2 Specific Requirements

**318.2.1 Joint Integrity.** Separation of the joint shall be prevented by a means that has sufficient strength to withstand anticipated conditions of service.

**318.2.2 Joint Interlocks.** Either mechanical or welded interlocks shall be provided to prevent separation of any joint used for a fluid service that is flammable, toxic, or damaging to human tissues, of any joint to be used under severe cyclic conditions, and of any joint exposed to temperatures in the creep range.

**318.2.3 Bell and Gland Type Joints.** Bell-type and gland-type joints used under severe cyclic conditions shall be safeguarded. (18)

# PART 5
# FLEXIBILITY AND SUPPORT

## 319 PIPING FLEXIBILITY

### 319.1 Requirements

**319.1.1 Basic Requirements.** Piping systems shall have sufficient flexibility to prevent thermal expansion or contraction or movements of piping supports and terminals from causing

*(a)* failure of piping or supports from overstress or fatigue

*(b)* leakage at joints

*(c)* detrimental stresses or distortion in piping and valves or in connected equipment (e.g., pumps and turbines), resulting from excessive thrusts and moments in the piping

**319.1.2 Specific Requirements.** In para. 319, concepts, data, and methods are given for determining the requirements for flexibility in a piping system and for assuring that the system meets all of these requirements. In brief, these requirements are that

*(a)* the computed stress range at any point due to displacements in the system shall not exceed the allowable stress range established in para. 302.3.5

*(b)* reaction forces computed in para. 319.5 shall not be detrimental to supports or connected equipment

*(c)* computed movement of the piping shall be within any prescribed limits, and properly accounted for in the flexibility calculations

If it is determined that a piping system does not have adequate inherent flexibility, means for increasing flexibility shall be provided in accordance with para. 319.7.

### 319.2 Concepts

Concepts characteristic of piping flexibility analysis are covered in the following paragraphs. Special consideration is given to displacements (strains) in the piping system, and to resultant axial, bending, and torsional displacement stress ranges.

**319.2.1 Displacement Strains**

*(a) Thermal Displacements.* A piping system will undergo dimensional changes with any change in temperature. If it is constrained from free expansion or contraction by connected equipment and restraints such as guides and anchors, it will be displaced from its unrestrained position.

(b) *Restraint Flexibility.* If restraints are not considered rigid, their flexibility may be considered in determining displacement stress range and reactions.

(c) *Externally Imposed Displacements.* Externally caused movement of restraints will impose displacements on the piping in addition to those related to thermal effects. Movements may result from tidal changes (dock piping), wind sway (e.g., piping supported from a tall slender tower), or temperature changes in connected equipment.

Movement due to earth settlement, since it is a single cycle effect, will not significantly influence fatigue life. A displacement stress range greater than that permitted by para. 302.3.5(d) may be allowable if due consideration is given to avoidance of excessive localized strain and end reactions.

(d) *Total Displacement Strains.* Thermal displacements, reaction displacements, and externally imposed displacements all have equivalent effects on the piping system, and shall be considered together in determining the total displacement strains (proportional deformation) in various parts of the piping system.

#### 319.2.2 Displacement Stresses

(a) *Elastic Behavior.* Stresses may be considered proportional to the total displacement strains in a piping system in which the strains are well-distributed and not excessive at any point (a balanced system). Layout of systems should aim for such a condition, which is assumed in flexibility analysis methods provided in this Code.

(b) *Overstrained Behavior.* Stresses cannot be considered proportional to displacement strains throughout a piping system in which an excessive amount of strain may occur in localized portions of the system (an unbalanced system). Operation of an unbalanced system in the creep range may aggravate the deleterious effects due to creep strain accumulation in the most susceptible regions of the system. Unbalance may result from one or more of the following:

(1) highly stressed small size pipe runs in series with large or relatively stiff pipe runs.

(2) a local reduction in size or wall thickness, or local use of material having reduced yield strength (for example, girth welds of substantially lower strength than the base metal).

(3) a line configuration in a system of uniform size in which the expansion or contraction must be absorbed largely in a short offset from the major portion of the run.

(4) variation of piping material or temperature in a line. When differences in the elastic modulus within a piping system will significantly affect the stress distribution, the resulting displacement stresses shall be computed based on the actual elastic moduli at the respective operating temperatures for each segment in the system and then multiplied by the ratio of the elastic modulus at ambient temperature to the modulus used in the analysis for each segment.

Unbalance should be avoided or minimized by design and layout of piping systems, particularly those using materials of low ductility. Many of the effects of unbalance can be mitigated by selective use of cold spring. If unbalance cannot be avoided, the designer shall use appropriate analytical methods in accordance with para. 319.4 to assure adequate flexibility as defined in para. 319.1.

#### 319.2.3 Displacement Stress Range

(a) In contrast with stresses from sustained loads, such as internal pressure or weight, displacement stresses may be permitted to attain sufficient magnitude to cause local yielding in various portions of a piping system. When the system is initially operated at the condition of greatest displacement (highest or lowest temperature, or greatest imposed movement) from its installed condition, any yielding or creep brings about a reduction or relaxation of stress. When the system is later returned to its original condition (or a condition of opposite displacement), a reversal and redistribution of stresses occurs that is referred to as self-springing. It is similar to cold springing in its effects.

(b) While stresses resulting from displacement strains diminish with time due to yielding or creep, the algebraic difference between strains in the extreme displacement condition and the original (as-installed) condition (or any anticipated condition with a greater differential effect) remains substantially constant during any one cycle of operation. This difference in strains produces a corresponding stress differential, the displacement stress range, that is used as the criterion in the design of piping for flexibility. In evaluating systems where supports may be active in some conditions and not others (e.g., pipes lifting off supports), this difference in strains may be influenced by the changing distribution of sustained load. In such cases, the displacement strain range is based on the algebraic difference between the calculated positions of the pipe that define the range. In addition to the displacement strain, each calculated position shall include the sustained loads present in the condition under evaluation. See para. 302.3.5(d) for the allowable stress range, $S_A$, and para. 319.4.4(a) for the computed displacement stress range, $S_E$.

**319.2.4 Cold Spring.** Cold spring is the intentional deformation of piping during assembly to produce a desired initial displacement and reaction. Cold spring is beneficial in that it serves to balance the magnitude of the reaction under initial and extreme displacement conditions. When cold spring is properly applied there is less likelihood of overstrain during initial operation; hence, it is recommended especially for piping materials of limited ductility. There is also less deviation from as-installed dimensions during initial operation, so that hangers will not be displaced as far from their original settings.

Inasmuch as the service life of a piping system is affected more by the range of stress variation than by the magnitude of stress at a given time, no credit for cold spring is permitted in stress range calculations. However, in calculating the thrusts and moments where actual reactions as well as their range of variations are significant, credit is given for cold spring.

## 319.3 Properties for Flexibility Analysis

The following paragraphs deal with properties of piping materials and their application in piping flexibility stress analysis.

### 319.3.1 Thermal Expansion Data

*(a) Values for Stress Range.* Values of thermal displacements to be used in determining total displacement strains for computing the stress range shall be determined from Appendix C as the algebraic difference between the value at maximum metal temperature and that at the minimum metal temperature for the thermal cycle under analysis.

*(b) Values for Reactions.* Values of thermal displacements to be used in determining total displacement strains for computation of reactions on supports and connected equipment shall be determined as the algebraic difference between the value at maximum (or minimum) temperature for the thermal cycle under analysis and the value at the temperature expected during installation.

**319.3.2 Modulus of Elasticity.** The reference modulus of elasticity at 21°C (70°F), $E_a$, and the modulus of elasticity at maximum or minimum temperature, $E_m$, shall be taken as the values shown in Appendix C for the temperatures determined in para. 319.3.1(a) or (b). For materials not included in Appendix C, reference shall be made to authoritative source data, such as publications of the National Institute of Standards and Technology.

**319.3.3 Poisson's Ratio.** Poisson's ratio may be taken as 0.3 at all temperatures for all metals. More accurate and authoritative data may be used if available.

### 319.3.4 Allowable Stresses

*(a)* The allowable displacement stress range, $S_A$, and permissible additive stresses shall be as specified in para. 302.3.5(d) for systems primarily stressed in bending and/or torsion.

*(b)* The stress intensification factors in Appendix D have been developed from fatigue tests of representative piping components and assemblies manufactured from ductile ferrous materials. The allowable displacement stress range is based on tests of carbon and austenitic stainless steels. Caution should be exercised when using eqs. (1a) and (1b) (para. 302.3.5) for allowable displacement stress range for some nonferrous materials (e.g., certain copper and aluminum alloys) for other than low cycle applications.

**319.3.5 Dimensions.** Nominal thicknesses and outside diameters of pipe and fittings shall be used in flexibility calculations.

**319.3.6 Flexibility and Stress Intensification Factors.** (18)
The flexibility factors, $k$, and stress intensification factors, $i$, shall not be less than unity. In the absence of more directly applicable data, the flexibility factor, $k$, and stress intensification factor, $i$, shown in Appendix D shall be used for flexibility calculations described in para. 319.4.

Flexibility factors and stress intensification factors may be developed in accordance with ASME B31J, Nonmandatory Appendices B and A, respectively.

For piping components or attachments (such as valves, strainers, anchor rings, or bands) not covered in Table D300, suitable stress intensification factors may be assumed by comparison of their significant geometry with that of the components shown. The validity of any assumptions is the responsibility of the designer. If two or more of the geometries shown in Appendix D are combined, their combined $k$ and $i$ might be significantly different from the values shown. Examples include trunnions on elbows and branch connection fittings welded to anything other than straight pipe.

## 319.4 Flexibility Analysis

**319.4.1 Formal Analysis Not Required.** No formal analysis of adequate flexibility is required for a piping system that

*(a)* duplicates, or replaces without significant change, a system operating with a successful service record

*(b)* can readily be judged adequate by comparison with previously analyzed systems

*(c)* is of uniform size, has no more than two points of fixation, no intermediate restraints, and falls within the limitations of empirical eq. (16)[8]

$$\frac{Dy}{(L - U)^2} \le K_1 \tag{16}$$

where

$D$ = outside diameter of pipe, mm (in.)

$E_a$ = reference modulus of elasticity at 21°C (70°F), MPa (ksi)

$K_1$ = 208 000 $S_A/E_a$, (mm/m)$^2$
= 30 $S_A/E_a$, (in./ft)$^2$

[8] *WARNING*: No general proof can be offered that this equation will yield accurate or consistently conservative results. It is not applicable to systems used under severe cyclic conditions. It should be used with caution in configurations such as unequal leg U-bends or near-straight "sawtooth" runs, or for large thin-wall pipe ($i \ge 5$), or where extraneous displacements (not in the direction connecting anchor points) constitute a large part of the total displacement. There is no assurance that terminal reactions will be acceptably low, even if a piping system falls within the limitations of eq. (16).

$L$ = developed length of piping between anchors, m (ft)
$S_A$ = allowable displacement stress range in accordance with eq. (1a), MPa (ksi)
$U$ = anchor distance, straight line between anchors, m (ft)
$y$ = resultant of total displacement strains, mm (in.), to be absorbed by the piping system

**319.4.2 Formal Analysis Requirements**

*(a)* Any piping system that does not meet the criteria in para. 319.4.1 shall be analyzed by a simplified, approximate, or comprehensive method of analysis, as appropriate.

*(b)* A simplified or approximate method may be applied only if used within the range of configurations for which its adequacy has been demonstrated.

*(c)* Acceptable comprehensive methods of analysis include analytical and chart methods that provide an evaluation of the forces, moments, and stresses caused by displacement strains (see para. 319.2.1).

*(d)* Comprehensive analysis shall take into account stress intensification factors for any component other than straight pipe. Credit may be taken for the extra flexibility of such a component.

**319.4.3 Basic Assumptions and Requirements.** Standard assumptions specified in para. 319.3 shall be followed in all cases. In calculating the flexibility of a piping system between anchor points, the system shall be treated as a whole. The significance of all parts of the line and of all restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, and also the restraint introduced by support friction, shall be recognized. Consider all displacements, as outlined in para. 319.2.1, over the temperature range defined by para. 319.3.1.

(18) **319.4.4 Flexibility Stresses**

*(a)* The axial, bending, and torsional displacement stress ranges shall be computed using the reference modulus of elasticity at 21°C (70°F), $E_a$, except as provided in para. 319.2.2(b)(4), and then combined in accordance with eq. (17) to determine the computed displacement stress range, $S_E$, which shall not exceed the allowable displacement stress range, $S_A$, in para. 302.3.5(d). See also eq. (1d) and Appendix S, Example 3 for the greatest computed displacement stress range.

$$S_E = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \tag{17}$$

where

$A_p$ = cross-sectional area of pipe; see para. 319.3.5
$F_a$ = axial force range between any two conditions being evaluated
$i_a$ = axial stress intensification factor. In the absence of more-applicable data, $i_a$ = 1.0 for elbows, pipe bends, and miter bends (single, closely spaced, and widely spaced), and $i_a = i_o$ (or $i$ when listed) in Appendix D for other components; see also para. 319.3.6.
$i_t$ = torsional stress intensification factor. In the absence of more-applicable data, $i_t$ = 1.0; also see para. 319.3.6.
$M_t$ = torsional moment range between any two conditions being evaluated
$S_a$ = axial stress range due to displacement strains
 = $i_aF_a/A_p$
$S_b$ = bending stress range due to displacement strains
$S_t$ = torsional stress range due to displacement strains
 = $i_tM_t/2Z$
$Z$ = section modulus of pipe; see para. 319.3.5

*(b)* The bending stress range, $S_b$, to be used in eq. (17) for elbows, miter bends, and full size outlet branch connections (Legs 1, 2, and 3) shall be calculated in accordance with eq. (18), with moments as shown in Figures 319.4.4A and 319.4.4B.

$$S_b = \frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2}}{Z} \tag{18}$$

where

$i_i$ = in-plane stress intensification factor; see para. 319.3.6
$i_o$ = out-plane stress intensification factor; see para. 319.3.6
$M_i$ = in-plane bending moment range between any two conditions being evaluated
$M_o$ = out-plane bending moment range between any two conditions being evaluated

*(c)* The bending stress range, $S_b$, to be used in eq. (17) for reducing outlet branch connections shall be calculated in accordance with eqs. (19) and (20), with moments as shown in Figure 319.4.4B.

For header (Legs 1 and 2)

$$S_b = \frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2}}{Z} \tag{19}$$

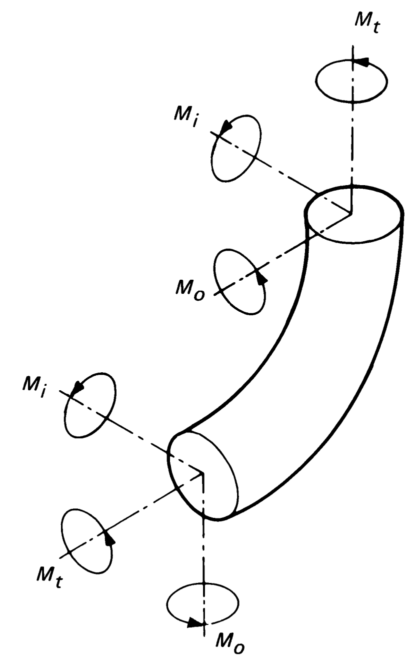
For branch (Leg 3), use eq. (20) when $i_i$ or $i_o$ is taken from Appendix D; when both $i_i$ and $i_o$ are taken from ASME B31J or determined by experimental or analytical means, e.g., ASME B31J, Nonmandatory Appendix A, use eq. (19)

$$S_b = \frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2}}{Z_e} \tag{20}$$

where

$r_2$ = mean branch cross-sectional radius
$\bar{T}_b$ = thickness of pipe matching branch

**Figure 319.4.4A Moments in Bends**




$\overline{T}_h$ = thickness of pipe matching run of tee or header exclusive of reinforcing elements

$T_S$ = effective branch wall thickness, lesser of $\overline{T}_h$ and ($i_i$)($\overline{T}_b$)

$Z_e$ = effective section modulus of branch
= $\pi r_2{}^2 T_S$; see para. 319.3.5

## 319.5 Reactions

Reaction forces and moments used to design restraints and supports for a piping system, and to evaluate the effects of piping displacement on connected equipment, shall be based on the maximum load from operating conditions, including weight, pressure, and other sustained loads; thermal displacement; and, where applicable, occasional loads. The reactions shall be calculated using the modulus of elasticity at the temperature of the condition, $E_m$ ($E_a$ may be used instead of $E_m$ when it provides a more conservative result). The temperature of the condition may differ in different locations within the piping system.

Where cold spring is used in the piping system, experience has shown that it cannot be fully assured. Therefore, the reactions shall be computed both with the assumption that only two-thirds of the design cold spring is present, and with four-thirds of the design cold spring present.

If it is necessary to determine the reactions at ambient temperature, the designer shall consider loads at that condition, including the design cold spring and self springing of piping. Self springing may occur if the operating stress in the piping system exceeds the yield strength of the material or if the piping operates at temperatures in the creep range of the material.

**319.5.1 Maximum Reactions for Simple Systems.** For a two-anchor piping system without intermediate restraints, the maximum instantaneous values of reaction forces and moments may be estimated from eqs. (21) and (22).

*(a) For Extreme Displacement Conditions, $R_m$.* The temperature for this computation is the maximum or minimum metal temperature defined in para. 319.3.1(b), whichever produces the larger reaction.

$$R_m = R\left(1 - \frac{2C}{3}\right)\frac{E_m}{E_a} \tag{21}$$

where

$C$ = cold-spring factor varying from zero for no cold spring to 1.0 for 100% cold spring. (The factor two-thirds is based on experience showing that specified cold spring cannot be fully assured, even with elaborate precautions.)

$E_a$ = reference modulus of elasticity at 21°C (70°F)

$E_m$ = modulus of elasticity at maximum or minimum metal temperature

$R$ = range of reaction forces or moments (derived from flexibility analysis) corresponding to the full displacement stress range and based on $E_a$

$R_m$ = estimated instantaneous maximum reaction force or moment at maximum or minimum metal temperature

*(b) For Original Condition, $R_a$.* The temperature for this computation is the expected temperature at which the piping is to be assembled.

$R_a = CR$ or $C_1R$, whichever is greater, where nomenclature is as in para. 319.5.1(a) and

$$C_1 = 1 - \frac{S_h E_a}{S_E E_m} \tag{22}$$

= estimated self-spring or relaxation factor; use zero if value of $C_1$ is negative

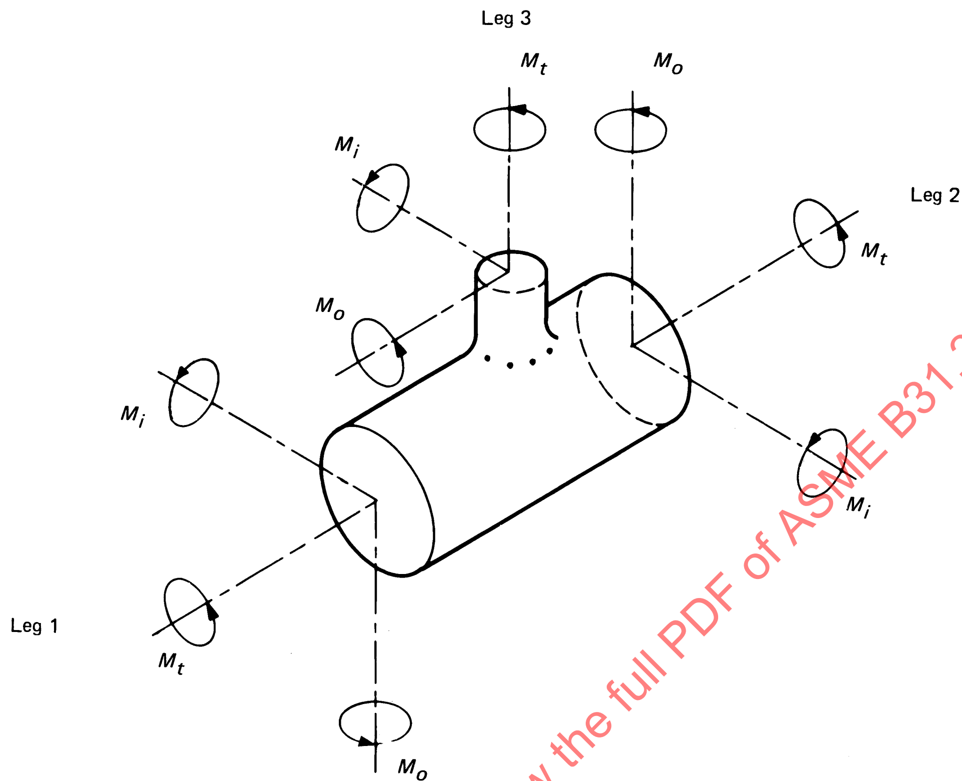
$R_a$ = estimated instantaneous reaction force or moment at installation temperature

$S_E$ = computed displacement stress range (see para. 319.4.4)

$S_h$ = see definition in para. 302.3.5(d)

**319.5.2 Maximum Reactions for Complex Systems.** For multianchor piping systems and for two-anchor systems with intermediate restraints, eqs. (21) and (22) are not applicable. Each case must be studied to estimate location, nature, and extent of local overstrain, and its effect on stress distribution and reactions.

**Figure 319.4.4B Moments in Branch Connections**






### 319.6 Calculation of Movements

Calculations of displacements and rotations at specific locations may be required where clearance problems are involved. In cases where small-size branch pipes attached to stiffer run pipes are to be calculated separately, the linear and angular movements of the junction point must be calculated or estimated for proper analysis of the branch.

### 319.7 Means of Increasing Flexibility

The layout of piping often provides inherent flexibility through changes in direction, so that displacements produce chiefly bending and torsional strains within prescribed limits. The amount of axial tension or compression strain (which produces large reactions) usually is small.

Where the piping lacks built-in changes of direction, or where it is unbalanced [see para. 319.2.2(b)], large reactions or detrimental overstrain may be encountered. The designer should consider adding flexibility by one or more of the following means: bends, loops, or offsets; swivel joints; corrugated pipe; expansion joints of the bellows or slip-joint type; or other devices permitting angular, rotational, or axial movement. Suitable anchors, ties, or other devices shall be provided as necessary to resist end forces produced by fluid pressure, frictional resistance to movement, and other causes. When expansion joints or other similar devices are provided, the stiffness of the joint or device should be considered in any flexibility analysis of the piping.

## 320 ANALYSIS OF SUSTAINED LOADS

### 320.1 Basic Assumptions and Requirements

Sustained conditions may be evaluated by detailed analysis, approximate methods, or simplified means such as span tables. When detailed analysis is performed, the stress due to sustained loads, $S_L$, shall be computed and combined as described in this paragraph and shall not exceed the allowable described in para. 302.3.5(c). See Appendix S, Example 2 for guidance on loading conditions and support scenarios that result in the greatest $S_L$ for each operating condition being considered. The loads due to weight should be based on the nominal thickness of all system components unless otherwise justified in a more rigorous analysis. Section moduli used to compute the stresses in this paragraph shall be based on nominal pipe dimensions less allowances, i.e., the sum of mechanical (thread or groove depth), internal and external corrosion, and erosion allowances. Areas used to compute the stresses in this paragraph assume nominal pipe dimensions less allowances affecting the inside diameter of the pipe, i.e., the sum of mechanical and internal corrosion and erosion allowances. It is the responsibility of the designer to determine sustained stress indices, $I_a$, $I_i$, $I_o$, and $I_t$, when a piping component is not explicitly addressed in Appendix D, e.g., base-ells, reducing elbows, crosses, close proximity findings, etc., as well as elbows, pipe bends, or miters other than 90 deg or supported by a trunnion. Sustained stress indices shall not be lower than 1.00.

## (18) 320.2 Stress Due to Sustained Loads

The equation for the stress due to sustained loads, such as pressure and weight, $S_L$, is provided in eq. (23a). Equations for the stress due to sustained bending moments, $S_b$, are presented in eqs. (23b1) and (23b2).

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \tag{23a}$$

$$S_b = \frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z} \tag{23b1}$$

For branch (Leg 3 in Figure 319.4.4B), use eq. (23b2) only when $I_i$ or $I_o$ is based upon $i$, $i_i$, or $i_o$ taken from Appendix D; when both $I_i$ and $I_o$ are taken from ASME B31J or determined by experimental or analytical means, e.g., ASME B31J, Nonmandatory Appendix D, use eq. (23b1).

$$S_b = \frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_e} \tag{23b2}$$

where

$I_i$ = sustained in-plane moment index. In the absence of more-applicable data, $I_i$ is taken as the greater of $0.75i_i$ or 1.00.

$I_o$ = sustained out-plane moment index. In the absence of more-applicable data, $I_o$ is taken as the greater of $0.75i_o$ or 1.00.

$M_i$ = in-plane moment due to sustained loads, e.g., pressure and weight

$M_o$ = out-plane moment due to sustained loads, e.g., pressure and weight

$Z$ = sustained section modulus. $Z$ in eqs. (23b1) and (23c) is described in para. 319.4.4 but is computed in this paragraph using nominal pipe dimensions less allowances; see para. 320.1.

$Z_e$ = sustained effective section modulus. $Z_e$ in eq. (23b2) is described in para. 319.4.4, using $i_i$ from Appendix D in $T_s$ calculation, but $Z_e$ is computed in this paragraph using nominal pipe dimensions less allowances; see para. 320.1.

The equation for the stress due to sustained torsional moment, $S_t$, is

$$S_t = \frac{I_t M_t}{2Z} \tag{23c}$$

where

$I_t$ = sustained torsional moment index. In the absence of more-applicable data, $I_t$ is taken as 1.00.

$M_t$ = torsional moment due to sustained loads, e.g., pressure and weight

The equation for the stress due to sustained longitudinal force, $S_a$, is

$$S_a = \frac{I_a F_a}{A_p} \tag{23d}$$

where

$A_p$ = cross-sectional area of the pipe, considering nominal pipe dimensions less allowances; see para. 320.1

$F_a$ = longitudinal force due to sustained loads, e.g., pressure and weight

$I_a$ = sustained longitudinal force index. In the absence of more-applicable data, $I_a$ is taken as 1.00.

The sustained longitudinal force, $F_a$, includes the sustained force due to pressure, which is $P_j A_f$ unless the piping system includes an expansion joint that is not designed to carry this force itself, where $P_j$ is the internal operating pressure for the condition being considered, $A_f = \pi d^2/4$, and $d$ is the pipe inside diameter considering pipe wall thickness less applicable allowances; see para. 320.1. For piping systems that contain expansion joints, it is the responsibility of the designer to determine the sustained longitudinal force due to pressure in the piping system.

# 321 PIPING SUPPORT

## 321.1 General

The design of support structures (not covered by this Code) and of supporting elements (see definitions of piping and pipe supporting elements in para. 300.2) shall be based on all concurrently acting loads transmitted into such supports. These loads, defined in para. 301, include weight effects, loads introduced by service pressures and temperatures, vibration, wind, earthquake, shock, and displacement strain (see para. 319.2.2).

For piping containing gas or vapor, weight calculations need not include the weight of liquid if the designer has taken specific precautions against entrance of liquid into the piping, and if the piping is not to be subjected to hydrostatic testing at initial construction or subsequent inspections.

**321.1.1 Objectives.** The layout and design of piping and its supporting elements shall be directed toward preventing the following:

(a) piping stresses in excess of those permitted in this Code
(b) leakage at joints
(c) excessive thrusts and moments on connected equipment (such as pumps and turbines)
(d) excessive stresses in the supporting (or restraining) elements
(e) resonance with imposed or fluid-induced vibrations
(f) excessive interference with thermal expansion and contraction in piping which is otherwise adequately flexible
(g) unintentional disengagement of piping from its supports
(h) excessive piping sag in piping requiring drainage slope
(i) excessive distortion or sag of piping (e.g., thermoplastics) subject to creep under conditions of repeated thermal cycling
(j) excessive heat flow, exposing supporting elements to temperature extremes outside their design limits

**321.1.2 Analysis.** In general, the location and design of pipe supporting elements may be based on simple calculations and engineering judgment. However, when a more refined analysis is required and a piping analysis, which may include support stiffness, is made, the stresses, moments, and reactions determined thereby shall be used in the design of supporting elements.

**321.1.3 Stresses for Pipe Supporting Elements.** Allowable stresses for materials used for pipe supporting elements, except springs, shall be in accordance with para. 302.3.1. Longitudinal weld joint factors, $E_j$, however, need not be applied to the allowable stresses for welded piping components that are to be used for pipe supporting elements.

**321.1.4 Materials**

(a) Permanent supports and restraints shall be of material suitable for the service conditions. If steel is cold-formed to a centerline radius less than twice its thickness, it shall be annealed or normalized after forming.
(b) Gray, ductile, and malleable iron may be used for rollers, roller bases, anchor bases, and other supporting elements subject chiefly to compressive loading. Gray iron is not recommended if the piping may be subject to impact-type loading resulting from pulsation or vibration. Ductile and malleable iron may be used for pipe and beam clamps, hanger flanges, clips, brackets, and swivel rings.
(c) Steel of an unknown specification may be used for pipe supporting elements that are not welded directly to pressure-containing piping components. (Compatible intermediate materials of known specification may be welded directly to such components.) Basic allowable stress in tension or compression shall not exceed 82 MPa (12 ksi) and the support temperature shall be within the range of −29°C to 343°C (−20°F to 650°F). For stress values in shear and bearing, see para. 302.3.1(b).
(d) Wood or other materials may be used for pipe supporting elements, provided the supporting element is properly designed, considering temperature, strength, and durability.
(e) Attachments welded or bonded to the piping shall be of a material compatible with the piping and service. For other requirements, see para. 321.3.2.

**321.1.5 Threads.** Screw threads shall conform to ASME B1.1 unless other threads are required for adjustment under heavy loads. Turnbuckles and adjusting nuts shall have the full length of internal threads engaged. Any threaded adjustment shall be provided with a locknut, unless locked by other means.

### 321.2 Fixtures

#### 321.2.1 Anchors and Guides

(a) A supporting element used as an anchor shall be designed to maintain an essentially fixed position.
(b) To protect terminal equipment or other (weaker) portions of the system, restraints (such as anchors and guides) shall be provided where necessary to control movement or to direct expansion into those portions of the system that are designed to absorb them. The design, arrangement, and location of restraints shall ensure that expansion joint movements occur in the directions for which the joint is designed. In addition to the other thermal forces and moments, the effects of friction in other supports of the system shall be considered in the design of such anchors and guides.
(c) Piping layout, anchors, restraints, guides, and supports for all types of expansion joints shall be designed in accordance with para. X301.2 of Appendix X.

#### 321.2.2 Inextensible Supports Other Than Anchors and Guides[9]

(a) Supporting elements shall be designed to permit the free movement of piping caused by thermal expansion and contraction.
(b) Hangers include pipe and beam clamps, clips, brackets, rods, straps, chains, and other devices. They shall be proportioned for all required loads. Safe loads for threaded parts shall be based on the root area of the threads.
(c) *Sliding Supports.* Sliding supports (or shoes) and brackets shall be designed to resist the forces due to friction in addition to the loads imposed by bearing. The dimensions of the support shall provide for the expected movement of the supported piping.

[9] Various types of inextensible (solid) and resilient supports are illustrated in MSS SP-58.

**321.2.3 Resilient Supports**[9]

*(a)* Spring supports shall be designed to exert a supporting force, at the point of attachment to the pipe, equal to the load as determined by weight balance calculations. They shall be provided with means to prevent misalignment, buckling, or eccentric loading of the springs, and to prevent unintentional disengagement of the load.

*(b)* Constant-support spring hangers provide a substantially uniform supporting force throughout the range of travel. The use of this type of spring hanger is advantageous at locations subject to appreciable movement with thermal changes. Hangers of this type should be selected so that their travel range exceeds expected movements.

*(c)* Means shall be provided to prevent overstressing spring hangers due to excessive deflections. It is recommended that all spring hangers be provided with position indicators.

**321.2.4 Counterweight Supports.** Counterweights shall be provided with stops to limit travel. Weights shall be positively secured. Chains, cables, hangers, rocker arms, or other devices used to attach the counterweight load to the piping shall be subject to the requirements of para. 321.2.2.

**321.2.5 Hydraulic Supports.** An arrangement utilizing a hydraulic cylinder may be used to give a constant supporting force. Safety devices and stops shall be provided to support the load in case of hydraulic failure.

### 321.3 Structural Attachments

External and internal attachments to piping shall be designed so that they will not cause undue flattening of the pipe, excessive localized bending stresses, or harmful thermal gradients in the pipe wall. It is important that attachments be designed to minimize stress concentration, particularly in cyclic services.

**321.3.1 Nonintegral Attachments.** Nonintegral attachments, in which the reaction between the piping and the attachment is by contact, include clamps, slings, cradles, U-bolts, saddles, straps, and clevises. If the weight of a vertical pipe is supported by a clamp, it is recommended to prevent slippage that the clamp be located below a flange, fitting, or support lugs welded to the pipe.

(18) **321.3.2 Integral Attachments.** Integral attachments include plugs, ears, shoes, plates, trunnions, stanchions, structural shapes, and angle clips, cast on or welded to the piping. The material for integral attachments attached by welding shall be of good weldable quality. [See para. 321.1.4(e) for material requirements.] Preheating, welding, and heat treatment requirements shall be in accordance with Chapter V. Consideration shall be given to the localized stresses induced in the piping component by welding the integral attachment, as well as differential thermal displacement strains between the attachment and the component to which it is attached. Welds shall be proportioned so that the shear stresses meet the requirements of para. 302.3.1(b). If the allowed stress values differ between the piping component and the attachment material, the lower of the two values shall be used. Where postweld heat treatment of the piping is required by para. 331, welds for structural attachments made directly to pressure-containing materials shall be postweld heat treated. Welds for structural attachments not made directly to pressure-containing materials do not require postweld heat treatment.

*(a)* Integral reinforcement, complete encirclement reinforcement, or intermediate pads of suitable alloy and design may be used to reduce contamination or undesirable heat effects in alloy piping.

*(b)* Intermediate pads, integral reinforcement, complete encirclement reinforcement, or other means of reinforcement may be used to distribute stresses.

The design of pipe-supporting elements and the local effects on the piping component are the responsibility of the designer. Nonmandatory guidance on the design of supports and attachments may be found as referenced in ASME BPVC, Section VIII, Division 1, Nonmandatory Appendix G, G-9. The designer is cautioned that not all the listed standards and bulletins in G-9 are well suited for use on branch-diameter-to-run-diameter and run-diameter-to-run-thickness ratios typical for pipe support component analyses (e.g., Appendix A of WRC Bulletin 537[10] lists the limitations to WRC Bulletin 537).

### 321.4 Structural Connections

The load from piping and pipe supporting elements (including restraints and braces) shall be suitably transmitted to a pressure vessel, building, platform, support structure, foundation, or to other piping capable of bearing the load without deleterious effects. See Appendix F, para. F321.4.

## PART 6
## SYSTEMS

## 322 SPECIFIC PIPING SYSTEMS

### 322.3 Instrument Piping

**322.3.1 Definition.** Instrument piping within the scope of this Code includes all piping and piping components used to connect instruments to other piping or equipment, and control piping used to connect air or hydraulically operated control apparatus. It does not include

[10] WRC (Welding Research Council) 537-2010, "Precision Equations and Enhanced Diagrams for Local Stresses in Spherical and Cylindrical Shells Due to External Loadings for Implementation of WRC Bulletin 107."

instruments, or permanently sealed fluid-filled tubing systems furnished with instruments as temperature or pressure responsive devices.

**322.3.2 Requirements.** Instrument piping shall meet the applicable requirements of the Code and the following:

*(a)* The design pressure and temperature for instrument piping shall be determined in accordance with para. 301. If more severe conditions are experienced during blowdown of the piping, they may be treated as occasional variations in accordance with para. 302.2.4.

*(b)* Consideration shall be given to the mechanical strength (including fatigue) of small instrument connections to piping or apparatus (see para. 304.3.5).

*(c)* Instrument piping containing fluids that are normally static and subject to freezing shall be protected by heat tracing or other heating methods, and insulation.

*(d)* If it will be necessary to blow down (or bleed) instrument piping containing toxic or flammable fluids, consideration shall be given to safe disposal.

## 322.6 Pressure-Relieving Systems

Pressure-relieving systems within the scope of this Code shall conform to the following requirements. See also Appendix F, para. F322.6.

**322.6.1 Stop Valves in Pressure Relief Piping.** If one or more stop valves are installed between the piping being protected and its protective device or devices, or between the protective device or devices and the point of discharge, they shall meet the requirements of (a) and either (b) or (c), below.

*(a)* A full-area stop valve may be installed on the inlet side of a pressure-relieving device. A full area stop valve may be placed on the discharge side of a pressure-relieving device when its discharge is connected to a common header with other discharge lines from other pressure-relieving devices. Stop valves of less than full area may be used on both the inlet side and discharge side of pressure-relieving devices as outlined herein if the stop valves are of such type and size that the increase in pressure drop will not reduce the relieving capacity below that required, nor adversely affect the proper operation of the pressure-relieving device.

*(b)* Stop valves to be used in pressure relief piping shall be so constructed or positively controlled that the closing of the maximum number of block valves possible at one time will not reduce the pressure-relieving capacity provided by the unaffected relieving devices below the required relieving capacity.

*(c)* As an alternative to (b) above, stop valves shall be so constructed and arranged that they can be locked or sealed in either the open or closed position. See Appendix F, para. F322.6.

**322.6.2 Pressure Relief Discharge Piping.** Discharge lines from pressure-relieving safety devices shall be designed to facilitate drainage. When discharging directly to the atmosphere, discharge shall not impinge on other piping or equipment and shall be directed away from platforms and other areas used by personnel. Reactions on the piping system due to actuation of safety relief devices shall be considered, and adequate strength shall be provided to withstand these reactions.

**322.6.3 Pressure-Relieving Devices**

*(a)* Pressure-relieving devices required by para. 301.2.2(a) shall be in accordance with ASME BPVC, Section VIII, Division 1, UG-125(c), UG-126, UG-127, and UG-132 through UG-136, excluding UG-135(e) and UG-136(c). The terms *design pressure*[11] and *piping system* shall be substituted for *maximum allowable working pressure* and *vessel,* respectively, in these paragraphs. The required relieving capacity of any pressure-relieving device shall include consideration of all piping systems that it protects.

*(b)* Relief set pressure[12] shall be in accordance with Section VIII, Division 1, with the exceptions stated in alternatives (1) and (2), below.

*(1)* With the owner's approval, the set pressure may exceed the limits in Section VIII, Division 1, provided that the limit on maximum relieving pressure stated in (c) below will not be exceeded.

*(2)* For a liquid thermal expansion relief device that protects only a blocked-in portion of a piping system, the set pressure shall not exceed the lesser of the system test pressure or 120% of design pressure.

*(c)* The maximum relieving pressure[13] shall be in accordance with Section VIII, Division 1, with the exception that the allowances in para. 302.2.4(f) are permitted, provided that all other requirements of para. 302.2.4 are also met.



[11] The *design pressure* for pressure relief is the maximum design pressure permitted, considering all components in the piping system.

[12] *Set pressure* is the pressure at which the device begins to relieve, e.g., lift pressure of a spring-actuated relief valve, bursting pressure of a rupture disk, or breaking pressure of a breaking pin device.

[13] *Maximum relieving pressure* is the maximum system pressure during a pressure-relieving event.

# Chapter III
# Materials

## 323 GENERAL REQUIREMENTS

Chapter III states limitations and required qualifications for materials based on their inherent properties. Their use in piping is also subject to requirements and limitations in other parts of this Code [see para. 300(d)]. See also para. 321.1.4 for support materials, and Appendix F, para. F323, for precautionary considerations.

### 323.1 Materials and Specifications

**323.1.1 Listed Materials.** Any material used in pressure-containing piping components shall conform to a listed specification except as provided in para. 323.1.2.

**323.1.2 Unlisted Materials.** Unlisted materials may be used provided they conform to a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control, and otherwise meet the requirements of this Code. See also ASME BPVC, Section II, Part D, Appendix 5. Allowable stresses shall be determined in accordance with the applicable allowable stress basis of this Code or a more conservative basis.

**323.1.3 Unknown Materials.** Materials of unknown specification shall not be used for pressure-containing piping components.

**323.1.4 Reclaimed Materials.** Reclaimed pipe and other piping components may be used, provided they are properly identified as conforming to a listed or published specification (para. 323.1.1 or 323.1.2) and otherwise meet the requirements of this Code. Sufficient cleaning and inspection shall be made to determine minimum wall thickness and freedom from imperfections that would be unacceptable in the intended service.

### 323.2 Temperature Limitations

The designer shall verify that materials that meet other requirements of the Code are suitable for service throughout the operating temperature range.

**323.2.1 Upper Temperature Limits, Listed Materials.** A listed material may be used at a temperature above the maximum for which a stress value or rating is shown, only if

*(a)* there is no prohibition in Appendix A or elsewhere in the Code

*(b)* the designer verifies the serviceability of the material in accordance with para. 323.2.4

**323.2.2 Lower Temperature Limits, Listed Materials.** (18)
Listed materials shall be tested as described in Table 323.2.2 except as exempted by (d) through (j). See Appendix F, para. F323.2.2.

*(a)* The allowable stress or component rating at any temperature colder than the minimum shown in Table A-1, Table A-1M, or Figure 323.2.2A shall not exceed the stress value or rating at the minimum temperature in Table A-1, Table A-1M, or the component standard.

*(b)* The stress ratio is used in Figure 323.2.2B to determine the allowable reduction in the impact test exemption temperature. The stress ratio is defined as the maximum of the following:

*(1)* circumferential pressure stress for the condition under consideration (based on minimum pipe wall thickness less allowances) divided by the basic allowable stress at the condition under consideration.

*(2)* for piping components with pressure ratings, the pressure for the condition under consideration divided by the pressure rating at the condition under consideration.

*(3)* combined stress due to pressure, dead loads, live loads, and displacement strain for the condition under consideration divided by the basic allowable stress at the condition under consideration. In calculating this combined stress, the forces and moments in the piping system for these combined sustained loads and displacement strains shall be calculated using nominal dimensions, and the stresses shall be calculated using eqs. (23a) through (23d) with all of the stress indices taken as 1.0 ($I_a = I_i \; I_o = I_t = 1.0$) and using section properties based on the nominal dimensions less corrosion, erosion, and mechanical allowances. Also see Appendix F, para. F323.2.2.

*(c)* Minimum impact test exemption temperature reduction may be used only when all of the following apply:

*(1)* The piping is not in Elevated Temperature Fluid Service.

*(2)* Local stresses caused by shock loading, thermal bowing, and differential expansion between dissimilar metals (e.g., austenitic welded to ferritic) are less than 10% of the basic allowable stresses at the condition under consideration.

*(3)* The piping is safeguarded from maintenance loads, e.g., using a valve wheel wrench on a small bore valve.

*(d)* Impact testing of the base metal is not required if the design minimum temperature is warmer than or equal to the temperature listed in the Min. Temp. column of

(18)

## Table 323.2.2 Requirements for Low Temperature Toughness Tests for Metals

These Toughness Test Requirements Are in Addition to Tests Required by the Material Specification

| | Type of Material | Column A Design Minimum Temperature at or Warmer Than Minimum Temperature in Table A-1, Table A-1M, or Figure 323.2.2A or as Described in Para. 323.2.2(h) | | Column B Design Minimum Temperature Colder Than Minimum Temperature in Table A-1, Table A-1M, or Figure 323.2.2A or as Described in Para. 323.2.2(h) |
|---|---|---|---|---|
| **Listed Materials** | **1** Gray iron | **A-1** No additional requirements | | **B-1** No additional requirements |
| | **2** Malleable and ductile iron; carbon steel in accordance with Note (1) | **A-2** No additional requirements | | **B-2** Materials designated in Box 2 shall not be used. |
| | | **(a) Base Metal** | **(b) Weld Metal and Heat Affected Zone (HAZ) [Note (2)]** | |
| | **3** Other carbon steels; low and intermediate alloy steels; and ferritic, martensitic, and duplex stainless steels | **A-3** (a) No additional requirements | **A-3** (b) Weld metal deposits shall be impact tested in accordance with para. 323.3 if design minimum temperature <−29°C (−20°F), except as provided in Notes (3) and (4), and except as follows: for materials listed for Curves C and D of Figure 323.2.2A, where corresponding welding consumables are qualified by impact testing at the design minimum temperature or lower in accordance with the applicable AWS specification, additional testing is not required. | **B-3** Except as provided in Notes (3) and (4), heat treat base metal in accordance with applicable ASTM specification listed in para. 323.3.2; then impact test base metal, weld deposits, and HAZ in accordance with para. 323.3 [see Note (2)]. When materials are used at temperature below the assigned curve as permitted by Notes (2) and (3) of Figure 323.2.2A, weld deposits and HAZ shall be impact tested [see Note (2)]. |
| | **4** Austenitic stainless steels | **A-4** (a) If (1) carbon content by analysis >0.1% or (2) material is not in solution heat treated condition, then impact test in accordance with para. 323.3 for design minimum temperature <−29°C (−20°F) except as provided in Notes (5) and (6) | **A-4** (b) Weld metal deposits shall be impact tested in accordance with para. 323.3 if design minimum temperature <−29°C (−20°F) except as provided in para. 323.2.2 and in Notes (5) and (6) | **B-4** Base metal and weld metal deposits shall be impact tested in accordance with para. 323.3. See Notes (2), (5), and (6). |
| | **5** Austenitic ductile iron, ASTM A571 | **A-5** (a) No additional requirements | **A-5** (b) Welding is not permitted | **B-5** Base metal shall be impact tested in accordance with para. 323.3. Do not use <−196°C (−320°F). Welding is not permitted. |
| | **6** Aluminum, copper, nickel, and their alloys; unalloyed titanium | **A-6** (a) No additional requirements | **A-6** (b) No additional requirements unless filler metal composition is outside the range for base metal composition; then test in accordance with item B-6 | **B-6** Designer shall be assured by suitable tests [see Note (7)] that base metal, weld deposits, and HAZ are suitable at the design minimum temperature |
| **Unlisted Materials** | **7** An unlisted material shall conform to a published specification. Where composition, heat treatment, and product form are comparable to those of a listed material, requirements for the corresponding listed material shall be met. Other unlisted materials shall be qualified as required in the applicable section of column B. | | | |

NOTES:

(1) Carbon steels conforming to the following are subject to the limitations in Box B-2: plates in accordance with ASTM A36, A283, and A1011; pipe in accordance with ASTM A134 when made from these plates; structural shapes in accordance with ASTM A992; and pipe in accordance with ASTM A53 Type F and API 5L Gr. A25 butt weld.

(2) Impact tests that meet the requirements of Table 323.3.1, which are performed as part of the weld procedure qualification, will satisfy all requirements of para. 323.2.2, and need not be repeated for production welds.

(3) See paras. 323.2.2(g) through (i).

(4) Impact tests are not required when the maximum obtainable Charpy specimen has a width along the notch of less than 2.5 mm (0.098 in.). Under these conditions, and where the stress ratio defined in para. 323.2.2(b) is greater than 0.3, the design minimum temperature shall not be colder than the lower of −48°C (−55°F) or the minimum temperature for the material in Table A-1 or Table A-1M. See also para. 323.2.2(g).

(5) Impact tests are not required when the maximum obtainable Charpy specimen has a width along the notch of less than 2.5 mm (0.098 in.).

**Table 323.2.2 Requirements for Low Temperature Toughness Tests for Metals (Cont'd)**

NOTES: (Cont'd)

(6) For austenitic stainless steels, impact testing is not required if the design minimum temperature is warmer than or equal to −104°C (−155°F), and the stress ratio as defined in para. 323.2.2(b) is 0.3 or less. See also para. 323.2.2(g).

(7) Tests may include tensile elongation, sharp-notch tensile strength (to be compared with unnotched tensile strength), or other tests, conducted at or colder than design minimum temperature. See also para. 323.3.4.

Table A-1, or Table A-1M, except as provided in Table 323.2.2, Box A-4(a) for austenitic stainless steel base material. In some cases, welds will require either impact testing or testing as described in Table 323.2.2, Box B-6 even when the base metal is not required to be tested. See (f) for steels or Table 323.2.2, Box A-6 (b) for other materials.

*(e)* For carbon steels with a letter designation in the Min. Temp. column of Table A-1 or Table A-1M, the minimum temperature is defined by the applicable curve and Notes in Figure 323.2.2A. If a design minimum temperature–thickness combination is on or above the curve, impact testing exemption requirements described in (d) apply.

*(f)* For steel materials, impact testing of welds, including those made in manufacturing (e.g., for seam welded pipe and welded tees), is required if either base material is required to be impact tested or if the design minimum temperature is colder than −29°C (−20°F), except for manufacturing welds in austenitic stainless steel base materials having a carbon content not exceeding 0.10% and supplied in the solution heat treated condition or as provided in Table 323.2.2, Boxes A-3(b) and A-4(b). For impact testing of production welds, see Table 323.2.2, Note (2).

*(g)* For steels, impact testing is not required for material (including welds) if the stress ratio as defined in (b) is 0.3 or less, the design minimum temperature is warmer than or equal to −104°C (−155°F), and when (c) applies.

*(h)* For carbon, low alloy, and intermediate alloy steel materials (including welds) that have not been qualified by impact testing, the minimum temperature from Table A-1, Table A-1M, or Figure 323.2.2A may be reduced to a temperature no colder than −48°C (−55°F) by the temperature reduction provided in Figure 323.2.2B when (c) applies. For carbon, low alloy, and intermediate alloy steel welds that require impact testing in accordance with Table 323.2.2, Box A-3(b), the temperature reduction from Figure 323.2.2B shall be applied to −29°C (−20°F).

*(i)* For carbon, low alloy, and intermediate alloy steel materials (including welds) that have been qualified by impact testing, the permitted design minimum temperature may be reduced to a temperature no colder than −104°C (−155°F) by the temperature reduction from Figure 323.2.2B when (c) applies.

*(j)* Impact testing is not required for the following combinations of weld metals and design minimum temperatures:

*(1)* for austenitic stainless steel base materials having a carbon content not exceeding 0.10%, welded without filler metal, at design minimum temperatures of −104°C (−155°F) and warmer

*(2)* for austenitic weld metal

*(-a)* having a carbon content not exceeding 0.10%, and produced with filler metals conforming to AWS A5.4, A5.9, A5.11, A5.14, or A5.22[1] at design minimum temperatures of −104°C (−155°F) and warmer, or

*(-b)* having a carbon content exceeding 0.10%, and produced with filler metals conforming to AWS A5.4, A5.9, A5.11, A5.14, or A5.22[1] at design minimum temperatures of −48°C (−55°F) and warmer

**323.2.3 Temperature Limits, Unlisted Materials.** An unlisted material, acceptable under para. 323.1.2, shall be qualified for service at all temperatures within a stated range, from design minimum temperature to design maximum temperature, in accordance with para. 323.2.4.

### 323.2.4 Verification of Serviceability

*(a)* When an unlisted material is to be used, or when a listed material is to be used above the highest temperature for which stress values appear in Appendix A, the designer is responsible for demonstrating the validity of the allowable stresses and other limits used in design and of the approach taken in using the material, including the derivation of stress data and the establishment of temperature limits.

*(b)* Data for the development of design limits shall be obtained from a sound scientific program carried out in accordance with recognized technology for both the

[1] Titles of referenced AWS standards are as follows:

AWS A5.4/A5.4M, Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding

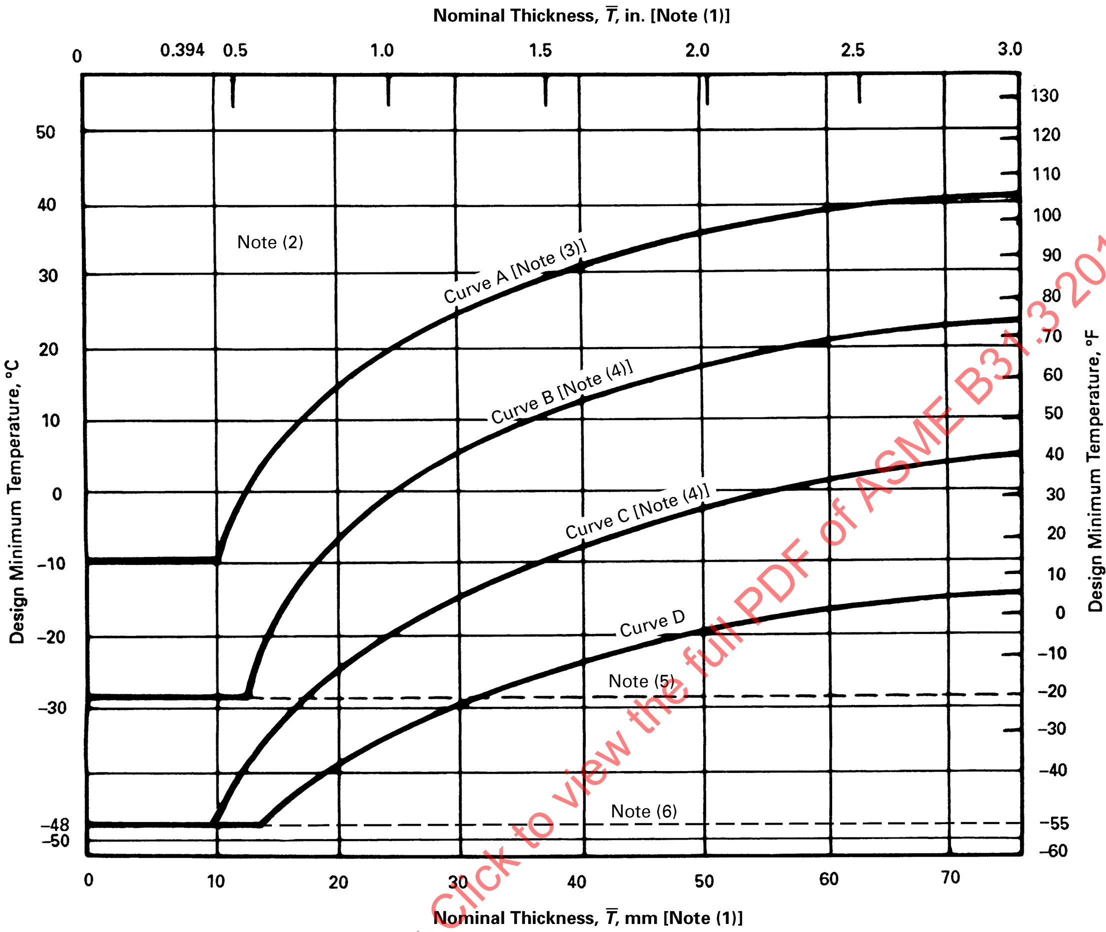
AWS A5.9/A5.9M, Welding Consumables—Wire Electrodes, Strip Electrodes, Wires, and Rods for Arc Welding of Stainless and Heat Resisting Steels—Classification

A5.11/A5.11M, Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding

A5.14/A5.14M, Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods

A5.22/A5.22M, Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods

(18) **Figure 323.2.2A Minimum Temperatures Without Impact Testing for Carbon Steel Materials (See Table A-1 or Table A-1M for Designated Curve for a Listed Material; see Table 323.2.2A for Tabular Values)**




NOTES:

(1) For blind flanges and blanks made from materials with a letter designation in the Min. Temp. column of Table A-1 or Table A-1M, $\overline{T}$ shall be $\frac{1}{4}$ of the total thickness, where the total thickness is the thickness of the blind flange or blank including the thickness of the facing(s), if applicable.

(2) Any carbon steel material may be used to a minimum temperature of −29°C (−20°F) for Category D Fluid Service.

(3) X Grades of API 5L, and ASTM A381 materials, may be used in accordance with Curve B if normalized or quenched and tempered.

(4) The following materials may be used in accordance with Curve D if normalized:
- *(a)* ASTM A516 plate, all grades
- *(b)* ASTM A671 pipe made from A516 plate, all grades
- *(c)* ASTM A672 pipe made from A516 plate, all grades

(5) A welding procedure for the manufacture of pipe or components shall include impact testing of welds and HAZ for any design minimum temperature below −29°C (−20°F), except as provided in Table 323.2.2, A-3(b).

(6) Impact testing in accordance with para. 323.3 is required for any design minimum temperature below −48°C (−55°F), except as permitted by Note (3) in Table 323.2.2.

(18) **Table 323.2.2A Tabular Values for Minimum Temperatures Without Impact Testing for Carbon Steel Materials (See Figure 323.2.2A for Curves)**

| Nominal Thickness, $\overline{T}$ [Note (1)] | | Lowest Exemption Temperature | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Curve A [Note (2)] | | Curve B [Note (3)] | | Curve C [Note (3)] | | Curve D | |
| mm | in. | °C | °F | °C | °F | °C | °F | °C | °F |
| 6.4 | 0.25 | −9.4 | 15 | −28.9 | −20 | −48.3 | −55 | −48.3 | −55 |
| 7.9 | 0.3125 | −9.4 | 15 | −28.9 | −20 | −48.3 | −55 | −48.3 | −55 |
| 9.5 | 0.375 | −9.4 | 15 | −28.9 | −20 | −48.3 | −55 | −48.3 | −55 |
| 10.0 | 0.394 | −9.4 | 15 | −28.9 | −20 | −48.3 | −55 | −48.3 | −55 |
| 11.1 | 0.4375 | −6.7 | 20 | −28.9 | −20 | −41.7 | −43 | −48.3 | −55 |
| 12.7 | 0.5 | −1.1 | 30 | −28.9 | −20 | −37.8 | −36 | −48.3 | −55 |
| 14.3 | 0.5625 | 2.8 | 37 | −21.7 | −7 | −35.0 | −31 | −45.6 | −50 |
| 15.9 | 0.625 | 6.1 | 43 | −16.7 | 2 | −32.2 | −26 | −43.9 | −47 |
| 17.5 | 0.6875 | 8.9 | 48 | −12.8 | 9 | −29.4 | −21 | −41.7 | −43 |
| 19.1 | 0.75 | 11.7 | 53 | −9.4 | 15 | −27.2 | −17 | −40.0 | −40 |
| 20.6 | 0.8125 | 14.4 | 58 | −6.7 | 20 | −25.0 | −13 | −38.3 | −37 |
| 22.2 | 0.875 | 16.7 | 62 | −3.9 | 25 | −23.3 | −10 | −36.7 | −34 |
| 23.8 | 0.9375 | 18.3 | 65 | −1.7 | 29 | −21.7 | −7 | −35.6 | −32 |
| 25.4 | 1.0 | 20.0 | 68 | 0.6 | 33 | −19.4 | −3 | −34.4 | −30 |
| 27.0 | 1.0625 | 22.2 | 72 | 2.2 | 36 | −18.3 | −1 | −33.3 | −28 |
| 28.6 | 1.125 | 23.9 | 75 | 3.9 | 39 | −16.7 | 2 | −32.2 | −26 |
| 30.2 | 1.1875 | 25.0 | 77 | 5.6 | 42 | −15.6 | 4 | −30.6 | −23 |
| 31.8 | 1.25 | 26.7 | 80 | 6.7 | 44 | −14.4 | 6 | −29.4 | −21 |
| 33.3 | 1.3125 | 27.8 | 82 | 7.8 | 46 | −13.3 | 8 | −28.3 | −19 |
| 34.9 | 1.375 | 28.9 | 84 | 8.9 | 48 | −12.2 | 10 | −27.8 | −18 |
| 36.5 | 1.4375 | 30.0 | 86 | 9.4 | 49 | −11.1 | 12 | −26.7 | −16 |
| 38.1 | 1.5 | 31.1 | 88 | 10.6 | 51 | −10.0 | 14 | −25.6 | −14 |
| 39.7 | 1.5625 | 32.2 | 90 | 11.7 | 53 | −8.9 | 16 | −25.0 | −13 |
| 41.3 | 1.625 | 33.3 | 92 | 12.8 | 55 | −8.3 | 17 | −23.9 | −11 |
| 42.9 | 1.6875 | 33.9 | 93 | 13.9 | 57 | −7.2 | 19 | −23.3 | −10 |
| 44.5 | 1.75 | 34.4 | 94 | 14.4 | 58 | −6.7 | 20 | −22.2 | −8 |
| 46.0 | 1.8125 | 35.6 | 96 | 15.0 | 59 | −5.6 | 22 | −21.7 | −7 |
| 47.6 | 1.875 | 36.1 | 97 | 16.1 | 61 | −5.0 | 23 | −21.1 | −6 |
| 49.2 | 1.9375 | 36.7 | 98 | 16.7 | 62 | −4.4 | 24 | −20.6 | −5 |
| 50.8 | 2.0 | 37.2 | 99 | 17.2 | 63 | −3.3 | 26 | −20.0 | −4 |
| 52.4 | 2.0625 | 37.8 | 100 | 17.8 | 64 | −2.8 | 27 | −19.4 | −3 |
| 54.0 | 2.125 | 38.3 | 101 | 18.3 | 65 | −2.2 | 28 | −18.9 | −2 |
| 55.6 | 2.1875 | 38.9 | 102 | 18.9 | 66 | −1.7 | 29 | −18.3 | −1 |
| 57.2 | 2.25 | 38.9 | 102 | 19.4 | 67 | −1.1 | 30 | −17.8 | 0 |
| 58.7 | 2.3125 | 39.4 | 103 | 20.0 | 68 | −0.6 | 31 | −17.2 | 1 |
| 60.3 | 2.375 | 40.0 | 104 | 20.6 | 69 | 0.0 | 32 | −16.7 | 2 |
| 61.9 | 2.4375 | 40.6 | 105 | 21.1 | 70 | 0.6 | 33 | −16.1 | 3 |
| 63.5 | 2.5 | 40.6 | 105 | 21.7 | 71 | 1.1 | 34 | −15.6 | 4 |
| 65.1 | 2.5625 | 41.1 | 106 | 21.7 | 71 | 1.7 | 35 | −15.0 | 5 |
| 66.7 | 2.625 | 41.7 | 107 | 22.8 | 73 | 2.2 | 36 | −14.4 | 6 |
| 68.3 | 2.6875 | 41.7 | 107 | 22.8 | 73 | 2.8 | 37 | −13.9 | 7 |
| 69.9 | 2.75 | 42.2 | 108 | 23.3 | 74 | 3.3 | 38 | −13.3 | 8 |
| 71.4 | 2.8125 | 42.2 | 108 | 23.9 | 75 | 3.9 | 39 | −13.3 | 8 |
| 73.0 | 2.875 | 42.8 | 109 | 24.4 | 76 | 4.4 | 40 | −12.8 | 9 |
| 74.6 | 2.9375 | 42.8 | 109 | 25.0 | 77 | 4.4 | 40 | −12.2 | 10 |
| 76.2 | 3.0 | 43.3 | 110 | 25.0 | 77 | 5.0 | 41 | −11.7 | 11 |

**Table 323.2.2A Tabular Values for Minimum Temperatures Without Impact Testing for Carbon Steel Materials (See Figure 323.2.2A for Curves) (Cont'd)**

NOTES:

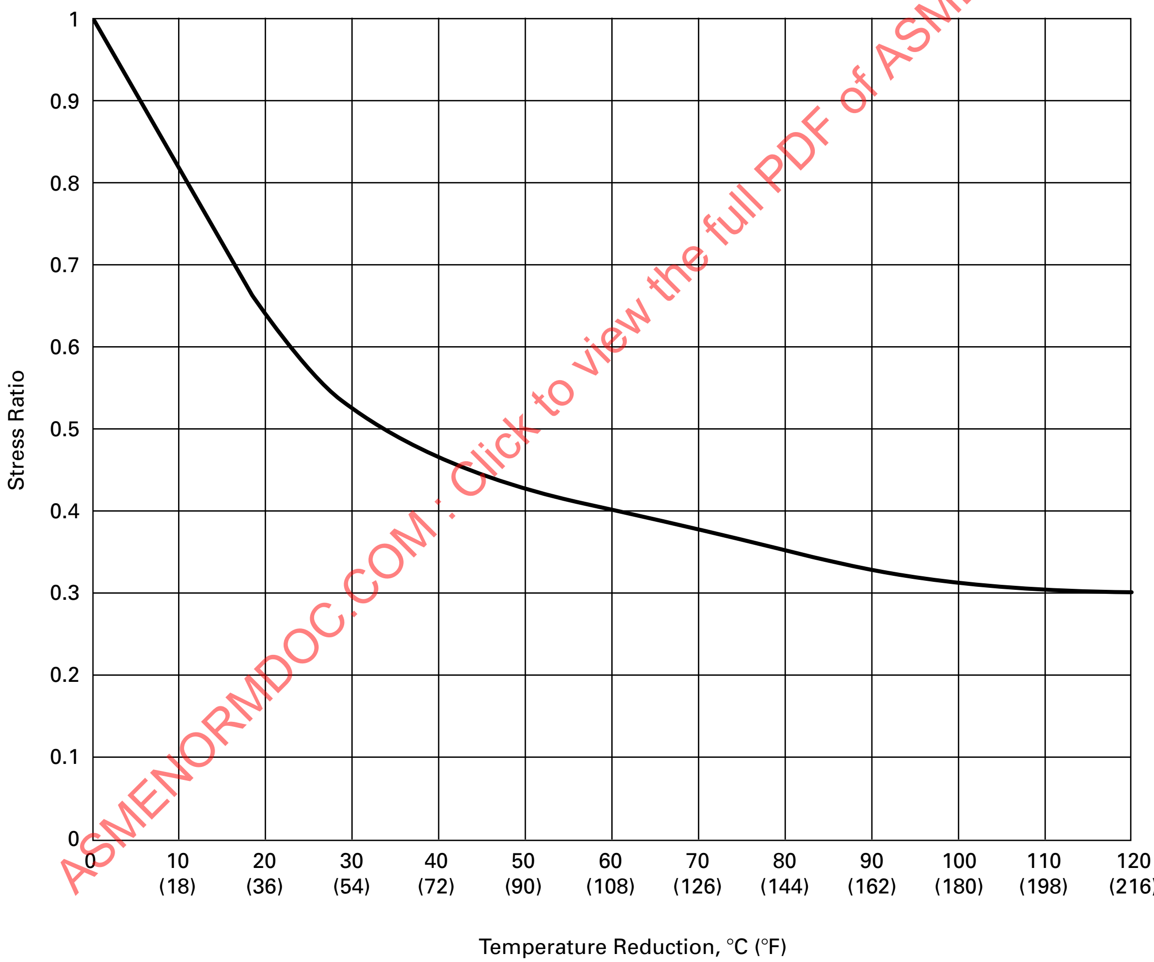
(1) For blind flanges and blanks made from materials with a letter designation in the Min. Temp. column of Table A-1 or Table A-1M, $\overline{T}$ shall be $\frac{1}{4}$ of the total thickness, where the total thickness is the thickness of the blind flange or blank including the thickness of the facing(s), if applicable.

(2) X Grades of API 5L, and ASTM A381 materials, may be used in accordance with Curve B if normalized or quenched and tempered.

(3) The following materials may be used in accordance with Curve D if normalized:

  *(a)* ASTM A516 plate, all grades
  
  *(b)* ASTM A671 pipe made from A516 plate, all grades
  
  *(c)* ASTM A672 pipe made from A516 plate, all grades

(18) **Figure 323.2.2B Reduction in Lowest Exemption Temperature for Steels Without Impact Testing (See Table 323.2.2B for Tabular Values)**




GENERAL NOTE: See para. 323.2.2(b) to determine stress ratio.

**Table 323.2.2B Tabular Values for Reduction in Lowest Exemption Temperature for Steels Without Impact Testing (See Figure 323.2.2B for Curve and Applicable Notes)**

| Stress Ratio | Reduction in Exemption Temperature | | Stress Ratio | Reduction in Exemption Temperature | |
|---|---|---|---|---|---|
| | °C | °F | | °C | °F |
| 1.00 | 0 | 0 | 0.64 | 20 | 36 |
| 0.99 | 1 | 1 | 0.63 | 21 | 37 |
| 0.98 | 1 | 2 | 0.62 | 21 | 38 |
| 0.97 | 2 | 3 | 0.61 | 22 | 40 |
| 0.96 | 2 | 4 | 0.60 | 23 | 41 |
| 0.95 | 3 | 5 | 0.59 | 23 | 42 |
| 0.94 | 3 | 6 | 0.58 | 24 | 44 |
| 0.93 | 4 | 7 | 0.57 | 26 | 46 |
| 0.92 | 4 | 8 | 0.56 | 26 | 47 |
| 0.91 | 5 | 9 | 0.55 | 27 | 49 |
| 0.90 | 6 | 10 | 0.54 | 28 | 51 |
| 0.89 | 6 | 11 | 0.53 | 29 | 53 |
| 0.88 | 7 | 12 | 0.52 | 31 | 56 |
| 0.87 | 7 | 13 | 0.51 | 33 | 59 |
| 0.86 | 8 | 14 | 0.50 | 34 | 61 |
| 0.85 | 8 | 15 | 0.49 | 36 | 65 |
| 0.84 | 9 | 16 | 0.48 | 38 | 68 |
| 0.83 | 9 | 17 | 0.47 | 40 | 72 |
| 0.82 | 10 | 18 | 0.46 | 42 | 76 |
| 0.81 | 11 | 19 | 0.45 | 44 | 80 |
| 0.80 | 11 | 20 | 0.44 | 47 | 85 |
| 0.79 | 12 | 21 | 0.43 | 50 | 90 |
| 0.78 | 12 | 22 | 0.42 | 53 | 96 |
| 0.77 | 13 | 23 | 0.41 | 56 | 101 |
| 0.76 | 13 | 24 | 0.40 | 60 | 108 |
| 0.75 | 14 | 25 | 0.39 | 64 | 115 |
| 0.74 | 14 | 26 | 0.38 | 68 | 122 |
| 0.73 | 15 | 27 | 0.37 | 72 | 130 |
| 0.72 | 16 | 28 | 0.36 | 77 | 138 |
| 0.71 | 16 | 29 | 0.35 | 82 | 147 |
| 0.70 | 17 | 30 | 0.34 | 87 | 156 |
| 0.69 | 17 | 31 | 0.33 | 92 | 166 |
| 0.68 | 18 | 32 | 0.32 | 98 | 177 |
| 0.67 | 18 | 33 | 0.31 | 104 | 188 |
| 0.66 | 18 | 33 | 0.30 | 111 | 200 |
| 0.65 | 19 | 34 | 0.30 | 120 | 217 |

material and the intended service conditions. Factors to be considered include

*(1)* applicability and reliability of the data, especially for extremes of the temperature range

*(2)* resistance of the material to deleterious effects of the fluid service and of the environment throughout the temperature range

*(3)* determination of allowable stresses in accordance with para. 302.3

## 323.3 Impact Testing Methods and Acceptance Criteria

**323.3.1 General.** When impact testing is required by Table 323.2.2, provisions elsewhere in this Code, or the engineering design, it shall be done in accordance with Table 323.3.1 using the testing methods and acceptance criteria described in paras. 323.3.2 through 323.3.5.

**323.3.2 Procedure.** Impact testing of each product form of material for any specification (including welds in the components) shall be done using procedures and apparatus in accordance with ASTM A370. For material forms that are represented by the ASTM specifications listed below, impact tests shall be conducted in conformance with those requirements as well. When conflicts exist between the specific requirements of this Code and the requirements of those specifications, the requirements of this Code shall take precedence.

| Product Form | ASTM Spec. No. |
|---|---|
| Pipe | A333 |
| Tube | A334 |
| Fittings | A420 |
| Forgings | A350 |
| Castings | A352 |
| Bolting | A320 |
| Plate | A20 |

GENERAL NOTE: Titles of referenced standards not listed in the Specifications Index for Appendix A are A20 General Requirements for Steel Plates for Pressure Vessels and A370 Test Methods and Definitions for Mechanical Testing of Steel Products.

**323.3.3 Test Specimens.** Each set of impact test specimens shall consist of three specimen bars. All impact tests shall be made using standard 10 mm (0.394 in.) square cross section Charpy V-notch specimen bars, except when the material shape or thickness does not permit. Charpy impact tests may be performed on specimens of full material thickness, which may be machined to remove surface irregularities. Alternatively, such material may be reduced in thickness to produce the largest possible Charpy subsize specimen. See Table 323.3.4.

**323.3.4 Test Temperatures.** For all Charpy impact tests, the test temperature criteria in (a) or (b) shall be observed. The test specimens, as well as the handling tongs, shall be cooled for a sufficient length of time to reach the test temperature.

*(a) For Materials of Thickness Equal to or Greater Than 10 mm (0.394 in.).* Where the largest attainable Charpy V-notch specimen has a width along the notch of at least 8 mm (0.315 in.), the Charpy test using such a specimen shall be conducted at a temperature not higher than the design minimum temperature. Where the largest possible test specimen has a width along the notch less than 8 mm, the test shall be conducted at a temperature lower than the design minimum temperature by the amount shown in Table 323.3.4 for that specimen width.

*(b) For Materials With Thickness Less Than 10 mm (0.394 in.).* Where the largest attainable Charpy V-notch specimen has a width along the notch of at least 80% of the material thickness, the Charpy test of such a specimen shall be conducted at a temperature not higher than the design minimum temperature. Where the largest possible test specimen has a width along the notch of less than 80% of the material thickness, the test shall be conducted at a temperature lower than the design minimum temperature by an amount equal to the difference (referring to Table 323.3.4) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually tested.

**323.3.5 Acceptance Criteria** (18)

*(a) Minimum Energy Requirements.* Except for bolting materials, the applicable minimum energy requirement for carbon and low alloy steels with specified minimum tensile strengths less than 656 MPa (95 ksi) shall be those shown in Table 323.3.5.

*(b) Lateral Expansion Requirements.* Other carbon and low alloy steels having specified minimum tensile strengths equal to or greater than 656 MPa (95 ksi), all bolting materials, and all high alloy steels (P-Nos. 6, 7, 8, 10H, and 10I) shall have a lateral expansion opposite the notch of not less than 0.38 mm (0.015 in.) for all specimen sizes. The lateral expansion is the increase in width of the broken impact specimen over that of the unbroken specimen measured on the compression side, parallel to the line constituting the bottom of the V-notch (see ASTM A370).

*(c) Weld Impact Test Requirements.* Where two base metals having different required impact test acceptance criteria are joined by welding, the impact test acceptance criteria shall conform to the requirements of the base material having a specified minimum tensile strength most closely matching the specified minimum tensile strength of the weld metal.

## Table 323.3.1 Impact Testing Requirements for Metals

| Test Characteristics | | Column A<br>Materials Tested by the Manufacturer [Note (1)] or Those in Table 323.2.2 Requiring Impact Tests Only on Welds | Column B<br>Materials Not Tested by the Manufacturer or Those Tested But Heat Treated During or After Fabrication |
|---|---|---|---|
| **Tests on Materials** | Number of tests | **A-1** The greater of the number required by<br>(a) the material specification or<br>(b) the applicable specification listed in para. 323.3.2 [Note (2)] | **B-1** The number required by the applicable specification listed in para. 323.3.2 [Note (2)] |
| | Location and orientation of specimens | **2** As required by the applicable specification listed in para. 323.3.2. | |
| | Tests by | **A-3** The manufacturer | **B-3** The fabricator or erector |
| **Tests on Welds in Fabrication or Assembly** | Test piece for preparation of impact specimens | **4** One required for each welding procedure, for each type of filler metal (i.e., AWS E-XXXX classification), and for each flux to be used. Test pieces shall be subjected to essentially the same heat treatment (including time at temperature or temperatures and cooling rate) as the erected piping will have received. | |
| | Number of test pieces [Note (3)] | **A-5**<br>(a) One piece, thickness *T*, for each range of material thickness from $T/2$ to $T + 6$ mm ($^1/_4$ in.)<br>(b) Unless required by the engineering design, pieces need not be made from each lot, nor from material for each job, provided that welds have been tested as required by Section 4 above, for the same type and grade of material (or for the same P-Number and Group Number in the ASME BPVC, Section IX), and of the same thickness range, and that records of the tests are made available | **B-5**<br>(a) One piece from each lot of material in each specification and grade including heat treatment [Note (4)] unless<br>(b) Materials are qualified by the fabricator or erector as specified in items B-1 and 2 above, in which case the requirements of item A-5 apply |
| | Location and orientation of specimens | **6**<br>(a) Weld metal: across the weld, with notch in the weld metal; notch axis shall be normal to material surface, with one face of specimen ≤1.5 mm ($^1/_{16}$ in.) from the material surface.<br>(b) Heat affected zone (HAZ): across the weld and long enough to locate notch in the HAZ after etching; notch axis shall be approximately normal to material surface and shall include as much as possible of the HAZ in the fracture. | |
| | Tests by | **7** The fabricator or erector | |

NOTES:

(1) A certified report of impact tests performed (after being appropriately heat treated as required by Table 323.2.2, item B-3) by the manufacturer shall be obtained as evidence that the material (including any welds used in its manufacture) meets the requirements of this Code and that

*(a)* the tests were conducted on specimens representative of the material delivered to and used by the fabricator or erector, or

*(b)* the tests were conducted on specimens removed from test pieces of the material which received heat treatment separately in the same manner as the material (including heat treatment by the manufacturer) so as to be representative of the finished piping

(2) If welding is used in manufacture, fabrication, or erection, tests of the HAZ will suffice for the tests of the base material.

(3) The test piece shall be large enough to permit preparing three specimens from the weld metal and three from the HAZ (if required) in accordance with para. 323.3. If this is not possible, preparation of additional test pieces is required.

(4) For purposes of this requirement, "lot" means the quantity of material described under the "Number of tests" provision of the specification applicable to the product term (i.e., plate, pipe, etc.) listed in para. 323.3.2.

**Table 323.3.4 Charpy Impact Test Temperature Reduction**

| Actual Material Thickness [See Para. 323.3.4(b)] or Charpy Impact Specimen Width Along the Notch [Note (1)] | | Temperature Reduction Below Design Minimum Temperature | |
|---|---|---|---|
| mm | in. | °C | °F |
| 10 (full size standard bar) | 0.394 | 0 | 0 |
| 9 | 0.354 | 0 | 0 |
| 8 | 0.315 | 0 | 0 |
| 7.5 (3/4 size bar) | 0.295 | 2.8 | 5 |
| 7 | 0.276 | 4.4 | 8 |
| 6.67 (2/3 size bar) | 0.262 | 5.6 | 10 |
| 6 | 0.236 | 8.3 | 15 |
| 5 (1/2 size bar) | 0.197 | 11.1 | 20 |
| 4 | 0.157 | 16.7 | 30 |
| 3.33 (1/3 size bar) | 0.131 | 19.4 | 35 |
| 3 | 0.118 | 22.2 | 40 |
| 2.5 (1/4 size bar) | 0.098 | 27.8 | 50 |

GENERAL NOTE: These temperature reduction criteria do not apply when Table 323.3.5 specifies lateral expansion for minimum required values.

NOTE: (1) Straight-line interpolation for intermediate values is permitted.

*(d) Retests*

*(1) For Absorbed Energy Criteria.* When the average value of the three specimens equals or exceeds the minimum value permitted for a single specimen and the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, a retest of three additional specimens shall be made. The value for each of these retest specimens shall equal or exceed the required average value.

*(2) For Lateral Expansion Criterion.* If the value of lateral expansion for one specimen in a group of three is below 0.38 mm (0.015 in.) but not below 0.25 mm (0.01 in.), and if the average value for three specimens equals or exceeds 0.38 mm (0.015 in.), a retest of three additional specimens may be made, each of which must equal or exceed the specified minimum value of 0.38 mm (0.015 in.). In the case of heat treated materials, if the required values are not obtained in the retest or if the values in the initial test are below the minimum allowed for retest, the material may be reheat treated and retested. After reheat treatment, a set of three specimens shall be made. For acceptance, the lateral expansion of each of the specimens must equal or exceed the specified minimum value of 0.38 mm (0.015 in.).

*(3) For Erratic Test Results.* When an erratic result is caused by a defective specimen or there is uncertainty in the test procedure, a retest will be allowed.

## 323.4 Fluid Service Requirements for Materials

**323.4.1 General.** Requirements in para. 323.4 apply to pressure-containing parts. They do not apply to materials used for supports, gaskets, packing, or bolting. See also Appendix F, para. F323.4.

### 323.4.2 Specific Requirements

*(a) Ductile Iron.* Ductile iron shall not be used for pressure containing parts at temperatures below −29°C (−20°F) (except austenitic ductile iron) or above 343°C (650°F). Austenitic ductile iron conforming to ASTM A571 may be used at temperatures below −29°C (−20°F) down to the temperature of the impact test conducted in accordance with that specification but not below −196°C (−320°F).

Valves having bodies and bonnets or covers made of materials conforming to ASTM A395 and meeting the requirements of ASME B16.42 and additional requirements of ASME B16.34 Standard Class, API 594, API 599, or API 609 may be used within the pressure–temperature ratings given in ASME B16.42.

Welding shall not be performed in the fabrication or repair of ductile iron components nor in assembly of such components in a piping system.

*(b) Other Cast Irons.* The following shall not be used under severe cyclic conditions. If safeguarding is provided against excessive heat and thermal shock and mechanical shock and abuse, they may be used in other services subject to the following requirements:

*(1)* Gray iron shall not be used above ground within process unit limits in hydrocarbon or other flammable fluid service at temperatures above 149°C (300°F) nor at gage pressures above 1 035 kPa (150 psi). In other locations the pressure limit shall be 2 760 kPa (400 psi).

*(2)* Malleable iron shall not be used in any fluid service at temperatures below −29°C (−20°F) or above 343°C (650°F) and shall not be used in flammable fluid service at temperatures above 149°C (300°F) nor at gage pressures above 2 760 kPa (400 psi).

*(3)* High silicon iron (14.5% Si) shall not be used in flammable fluid service. The manufacturer should be consulted for pressure–temperature ratings and for precautionary measures when using this material.

*(c) Other Materials*

*(1)* If welding or thermal cutting is performed on aluminum castings, the stress values in Appendix A and component ratings listed in Table 326.1 are not

(18) **Table 323.3.5 Minimum Required Charpy V-Notch Impact Values**

| Specified Minimum Tensile Strength | Number of Specimens [Note (1)] | Energy [Note (2)] Fully Deoxidized Steels Joules | Energy [Note (2)] Fully Deoxidized Steels ft-lbf | Energy [Note (2)] Other Than Fully Deoxidized Steels Joules | Energy [Note (2)] Other Than Fully Deoxidized Steels ft-lbf |
|---|---|---|---|---|---|
| **(a) Carbon and Low Alloy Steels** | | | | | |
| 448 MPa (65 ksi) and less | Average for 3 specimens | 18 | 13 | 14 | 10 |
| | Minimum for 1 specimen | 14 | 10 | 10 | 7 |
| Over 448 to 517 MPa (75 ksi) | Average for 3 specimens | 20 | 15 | 18 | 13 |
| | Minimum for 1 specimen | 16 | 12 | 14 | 10 |
| Over 517 but not incl. 656 MPa (95 ksi) | Average for 3 specimens | 27 | 20 | ... | ... |
| | Minimum for 1 specimen | 20 | 15 | ... | ... |
| | | Lateral Expansion | | | |
| 656 MPa and over [Note (3)] | Minimum for 3 specimens | 0.38 mm (0.015 in.) | | | |
| **(b) Steels in P-Nos. 6, 7, 8, 10H, and 10I** | Minimum for 3 specimens | 0.38 mm (0.015 in.) | | | |

NOTES:
(1) See para. 323.3.5(d) for permissible retests.
(2) Energy values in this Table are for standard size specimens. For subsize specimens, these values shall be multiplied by the ratio of the actual specimen width to that of a full-size specimen, 10 mm (0.394 in.).
(3) For bolting of this strength level in nominal sizes M 52 (2 in.) and under, the impact requirements of ASTM A320 may be applied. For bolting over M 52, requirements of this Table shall apply.

applicable. It is the designer's responsibility to establish such stresses and ratings consistent with the requirements of this Code.

*(2)* Lead and tin and their alloys shall not be used in flammable fluid services.

**323.4.3 Cladding and Lining Materials.** Materials with metallic cladding or metallic lining may be used in accordance with the following provisions:

*(a)* If piping components are made from integrally clad plate conforming to

*(1)* ASTM A263, Corrosion-Resisting Chromium Steel Clad Plate, Sheet, and Strip

*(2)* ASTM A264, Stainless Chromium-Nickel Steel Clad Plate, Sheet, and Strip

*(3)* ASTM A265, Nickel and Nickel-Base Alloy Clad Plate, Sheet, and Strip

Then pressure design in accordance with rules in para. 304 may be based upon the total thickness of base metal and cladding after any allowance for corrosion has been deducted, provided that both the base metal and the cladding metal are acceptable for Code use under para. 323.1, and provided that the clad plate has been shear tested and meets all shear test requirements of the applicable ASTM specification. The allowable stress for each material (base and cladding) shall be taken from Appendix A, or determined in accordance with the rules in para. 302.3, provided, however, that the allowable stress used for the cladding portion of the design thickness shall never be greater than the allowable stress used for the base portion.

*(b)* For all other metallic clad or lined piping components, the base metal shall be an acceptable Code material as defined in para. 323.1 and the thickness used in pressure design in accordance with para. 304 shall not include the thickness of the cladding or lining. The allowable stress used shall be that for the base metal at the design temperature. For such components, the cladding or lining may be any material that, in the judgment of the user, is suitable for the intended service and for the method of manufacture and assembly of the piping component.

*(c)* Except for components designed in accordance with provisions of para. 323.4.3(a) , fluid service requirements for materials stated in this Code shall not restrict their use as cladding or lining in pipe or other components. Fluid service requirements for the outer material (including those for components and joints) shall govern, except that temperature limitations of both inner and outer materials, and of any bond between them, shall be considered.

*(d)* Fabrication by welding of clad or lined piping components and the inspection and testing of such components shall be done in accordance with applicable provisions of ASME BPVC, Section VIII, Division 1, UCL-30 through UCL-52, or the provisions of Chapters V and VI of this Code, whichever are more stringent.

### 323.5 Deterioration of Materials in Service

Selection of material to resist deterioration in service is not within the scope of this Code. See para. 300(c)(6). Recommendations based on experience are presented for guidance in Appendix F, para. F323.

## 325 MATERIALS — MISCELLANEOUS

### 325.1 Joining and Auxiliary Materials

When selecting materials such as adhesives, cements, solvents, solders, brazing materials, packing, and O-rings for making or sealing joints, the designer shall consider their suitability for the fluid service. (Consideration should also be given to the possible effects of the joining or auxiliary materials on the fluid handled.)

# Chapter IV
# Standards for Piping Components

## 326 DIMENSIONS AND RATINGS OF COMPONENTS

### 326.1 Dimensional Requirements

**326.1.1 Listed Piping Components.** Dimensional standards[1] for piping components are listed in Table 326.1. Dimensional requirements contained in specifications listed in Appendix A shall also be considered requirements of this Code.

**326.1.2 Unlisted Piping Components.** Piping components not listed in Table 326.1 or Appendix A shall meet the pressure design requirements described in para. 302.2.3 and the mechanical strength requirements described in para. 302.5.

**326.1.3 Threads.** The dimensions of piping connection threads not otherwise covered by a governing component standard or specification shall conform to the requirements of applicable standards listed in Table 326.1 or Appendix A.

### 326.2 Ratings of Components

**326.2.1 Listed Components.** The pressure–temperature ratings of components listed in Table 326.1 are accepted for pressure design in accordance with para. 303.

**326.2.2 Unlisted Components.** The pressure–temperature ratings of unlisted piping components shall conform to the applicable provisions of para. 304.

### 326.3 Reference Documents

The documents listed in Table 326.1 contain references to codes, standards, and specifications not listed in Table 326.1. Such unlisted codes, standards, and specifications shall be used only in the context of the listed documents in which they appear.

The design, materials, fabrication, assembly, examination, inspection, and testing requirements of this Code are not applicable to components manufactured in accordance with the documents listed in Table 326.1, unless specifically stated in this Code or the listed document.



[1] It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of sponsoring organizations, are shown in Appendix E.

(18)

## Table 326.1 Component Standards

| Standard or Specification | Designation |
|---|---|
| **Bolting** | |
| Square and Hex Bolts and Screws (Inch Series) | ASME B18.2.1 |
| Square and Hex Nuts (Inch Series) | ASME B18.2.2 |
| Continuous Thread Stud, Double-End Stud, and Flange Bolting Stud (Stud Bolt) (Inch Series) | ASME B18.31.2 |
| **Metallic Fittings, Valves, and Flanges** | |
| Gray Iron Pipe Flanges and Flanged Fittings | ASME B16.1 |
| Malleable Iron Threaded Fittings | ASME B16.3 |
| Gray Iron Threaded Fittings | ASME B16.4 |
| Pipe Flanges and Flanged Fittings | ASME B16.5 |
| Factory-Made Wrought Buttwelding Fittings | ASME B16.9 |
| Face-to-Face and End-To-End Dimensions of Valves | ASME B16.10 |
| Forged Fittings, Socket-Welding and Threaded | ASME B16.11 |
| Ferrous Pipe Plugs, Bushings, and Locknuts With Pipe Threads | ASME B16.14 |
| Cast Bronze Threaded Fittings, Class 125 and 250 [Note (1)] | ASME B16.15 |
| Cast Copper Alloy Solder Joint Pressure Fittings | ASME B16.18 |
| Wrought Copper and Copper Alloy Solder Joint Pressure Fittings | ASME B16.22 |
| Cast Copper Alloy Pipe Flanges, Flanged Fittings, and Valves: Classes 150, 300, 600, 900, 1500, and 2500 | ASME B16.24 |
| Cast Copper Alloy Fittings for Flared Copper Tubes | ASME B16.26 |
| Valves — Flanged, Threaded, and Welding End | ASME B16.34 |
| Orifice Flanges, Class 300, 600, 900, 1500, and 2500 | ASME B16.36 |
| Malleable Iron Threaded Pipe Unions, Class 150, 250, and 300 | ASME B16.39 |
| Ductile Iron Pipe Flanges and Flanged Fittings, Class 150 and 300 | ASME B16.42 |
| Large Diameter Steel Flanges, NPS 26 Through NPS 60 | ASME B16.47 |
| Steel Line Blanks | ASME B16.48 |
| Brazing Joints for Copper and Copper Alloy Pressure Fittings | ASME B16.50 |
| Bioprocessing Equipment [Note (2)] | ASME BPE |
| | |
| Pipeline Valves [Note (3)] | API 6D |
| Flanged Steel Pressure-Relief Valves | API 526 |
| Check Valves: Flanged, Lug, Wafer and Butt-welding | API 594 |
| Metal Plug Valves — Flanged, Threaded, and Welding Ends | API 599 |
| Bolted Bonnet Steel Gate Valves for Petroleum and Natural Gas Industries | API 600 |
| Gate, Globe, and Check Valves for Sizes DN 100 and Smaller for the Petroleum and Natural Gas Industries | API 602 |
| Corrosion-Resistant, Bolted Bonnet Gate Valves — Flanged and Butt-Welding Ends | API 603 |
| Metal Ball Valves — Flanged, Threaded, and Welding End | API 608 |
| Butterfly Valves: Double-flanged, Lug- and Wafer-type | API 609 |
| | |
| Ductile-Iron and Gray-Iron Fittings, 3 Inch Through 48 Inch (75 mm Through 1200 mm), for Water and Other Liquids | AWWA C110 |
| Flanged Ductile-Iron Pipe with Ductile-Iron or Gray-Iron Threaded Flanges | AWWA C115 |
| Steel Pipe Flanges for Waterworks Service, Sizes 4 inch Through 144 inch (100 mm Through 3,600 mm) | AWWA C207 |
| Dimensions for Fabricated Steel Water Pipe Fittings | AWWA C208 |
| Metal-Seated Gate Valves for Water Supply Service | AWWA C500 |
| Rubber-Seated Butterfly Valves | AWWA C504 |
| | |
| Standard Finishes for Contact Faces of Pipe Flanges and Connecting-End Flanges of Valves and Fittings | MSS SP-6 |
| Spot Facing for Bronze, Iron and Steel Flanges | MSS SP-9 |
| Standard Marking Systems for Valves, Fittings, Flanges, and Unions | MSS SP-25 |
| Class 150 (PN 20) Corrosion Resistant Gate, Globe, Angle and Check Valves With Flanged and Butt Weld Ends | MSS SP-42 |
| Wrought Stainless Steel Butt-Welding Fittings Including Reference to Other Corrosion Resistant Materials [Note (4)] | MSS SP-43 |

## Table 326.1 Component Standards (Cont'd)

| Standard or Specification | Designation |
|---|---|
| **Metallic Fittings, Valves, and Flanges (Cont'd)** | |
| Steel Pipeline Flanges | MSS SP-44 |
| Bypass and Drain Connections | MSS SP-45 |
| Class 150LW Corrosion Resistant Flanges and Cast Flanged Fittings | MSS SP-51 |
| High Pressure Chemical Industry Flanges and Threaded Stubs for Use with Lens Gaskets | MSS SP-65 |
| Gray Iron Gate Valves, Flanged and Threaded Ends | MSS SP-70 |
| Gray Iron Swing Check Valves, Flanged and Threaded Ends | MSS SP-71 |
| Ball Valves With Flanged or Buttwelding Ends for General Service | MSS SP-72 |
| Specifications for High Test Wrought Buttwelding Fittings | MSS SP-75 |
| Gray Iron Plug Valves, Flanged and Threaded Ends | MSS SP-78 |
| Socket-Welding Reducer Inserts | MSS SP-79 |
| Bronze Gate, Globe, Angle and Check Valves | MSS SP-80 |
| Stainless Steel, Bonnetless, Flanged, Knife Gate Valves | MSS SP-81 |
| Class 3000 Steel Pipe Unions, Socket-Welding and Threaded | MSS SP-83 |
| Gray Iron Globe and Angle Valves, Flanged and Threaded Ends | MSS SP-85 |
| Diaphragm Type Valves | MSS SP-88 |
| Swage(d) Nipples and Bull Plugs | MSS SP-95 |
| Integrally Reinforced Forged Branch Outlet Fittings — Socket Welding, Threaded, and Buttwelding Ends | MSS SP-97 |
| Instrument Valves for Code Applications | MSS SP-105 |
| Cast Copper Alloy Flanges and Flanged Fittings Class 125, 150, and 300 | MSS SP-106 |
| Factory-Made Wrought Belled End Socket Welding Fittings [Note (5)] | MSS SP-119 |
| | |
| Refrigeration Tube Fittings — General Specifications | SAE J513 |
| Hydraulic Tube Fittings | SAE J514 |
| Hydraulic Flanged Tube, Pipe, and Hose Connections, Four-Bolt Split Flanged Type | SAE J518 |
| | |
| **Metallic Pipe and Tubes [Note (6)]** | |
| Welded and Seamless Wrought Steel Pipe | ASME B36.10M |
| Stainless Steel Pipe | ASME B36.19M |
| Flanged Ductile-Iron Pipe with Ductile-Iron or Gray-Iron Threaded Flanges | AWWA C115 |
| Thickness Design of Ductile-Iron Pipe | AWWA C150 |
| Ductile-Iron Pipe, Centrifugally Cast, for Water | AWWA C151 |
| Steel Water Pipe 6 inches (150 mm) and Larger | AWWA C200 |
| | |
| **Miscellaneous** | |
| Unified Inch Screw Threads (UN and UNR Thread Form) | ASME B1.1 |
| Pipe Threads, General Purpose (Inch) | ASME B1.20.1 |
| Dryseal Pipe Threads (Inch) | ASME B1.20.3 |
| Hose Coupling Screw Threads (Inch) | ASME B1.20.7 |
| Metallic Gaskets for Pipe Flanges — Ring: Joint, Spiral Wound, and Jacketed | ASME B16.20 |
| Nonmetallic Flat Gaskets for Pipe Flanges | ASME B16.21 |
| Buttwelding Ends | ASME B16.25 |
| Surface Texture (Surface Roughness, Waviness, and Lay) | ASME B46.1 |
| Thermowells [Note (7)] | ASME PTC 19.3 TW |
| Specification for Threading, Gaging and Thread Inspection of Casing, Tubing, and Line Pipe Threads | API 5B |
| Rubber Gasket Joints for Ductile-Iron Pressure Pipe and Fittings | AWWA C111 |
| Grooved and Shouldered Joints [Note (8)] | AWWA C606 |
| Flexible Metal Hose [Notes (9) and (10)] | BS 6501, Part 1 |
| Pipe Hangers and Supports — Materials, Design, and Manufacture | MSS SP-58 |

## Table 326.1 Component Standards (Cont'd)

| Standard or Specification | Designation |
|---|---|
| **Metallic Fittings, Valves, and Flanges (Cont'd)** | |
| Standard for Fire Hose Connections . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | NFPA 1963 |

GENERAL NOTES:

(a) It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in Appendix E.

(b) Many of the listed standards allow the use of unlisted materials; see para. 323.1.2.

NOTES:

(1) This standard allows straight pipe threads in sizes ≤ DN 15 (NPS $\frac{1}{2}$); see last paragraph of para. 314.2.1.

(2) Part DT of ASME BPE covers dimensions and tolerances for stainless steel automatic welding and hygienic clamp tube fittings and process components.

(3) API 6D allows design and calculations for pressure-containing elements to be in accordance with various internationally recognized design codes or standards. Only API 6D valves with design and calculations for pressure-containing elements in accordance with ASME B16.34 are considered a "listed component" for the purpose of this Code.

(4) *Cautionary Note:* See MSS SP-43 for special provisions concerning ratings. (In accordance with MSS SP-43, the pressure ratings for Class CR fittings are 30% of those calculated for straight seamless pipe of *minimum* wall thickness.)

(5) MSS SP-119 includes three classes of fittings: MP, MARINE, and CR. Only the MP class fittings are considered a "Listed Component" for the purpose of this Code. *Cautionary Note*: See MSS SP-119 (Section 5) for special provisions concerning ratings. (In accordance with MSS SP-119, the pressure ratings for MP class fittings are 87.5% of those calculated for straight seamless pipe of *minimum* wall thickness.)

(6) See also Appendix A.

(7) ASME PTC 19.3 TW allows mechanical design of thermowells to be in accordance with various design codes. Only PTC 19.3 TW thermowells with design and calculations for pressure-containing elements in accordance with ASME B31.3 are considered a "listed component" for the purpose of this Code.

(8) For use with this Code, the rated pressure of components covered by this standard shall be based on no greater than one-third the hydrostatic test failure pressure (the pressure at fracture or leakage), rather than one-half the hydrostatic test failure pressure specified in AWWA C606.

(9) Welding and brazing to be in accordance with paras. 328 and 333, respectively, in lieu of the referenced specifications in this standard.

(10) This standard contains recommended materials of construction for certain chemical services; the responsibility for the ultimate selection of material is the responsibility of the Owner and is, therefore, not within the scope of this Code.

# Chapter V
# Fabrication, Assembly, and Erection

## 327 GENERAL

Metallic piping materials and components are prepared for assembly and erection by one or more of the fabrication processes covered in paras. 328, 330, 331, 332, and 333. When any of these processes is used in assembly or erection, requirements are the same as for fabrication.

## 328 WELDING AND BRAZING

Welding and brazing shall conform to the requirements of this Chapter and the applicable requirements of para. 311.2.

### 328.1 Responsibility

Each employer is responsible for

*(a)* the welding and brazing performed by personnel of its organization

*(b)* conducting the qualification tests required to qualify the welding or brazing procedure specifications used by personnel in its organization, except as provided in paras. 328.2.1 and 328.2.2

*(c)* conducting the qualification tests required to qualify the welders, brazers, and operators, except as provided in para. 328.2.3

### 328.2 Welding and Brazing Qualification

Welding and brazing procedure specifications (WPSs and BPSs) to be followed in production welding shall be prepared and qualified, and welders, brazers, and operators shall be qualified as required by ASME BPVC, Section IX except as modified by para. 333 for brazing of Category D Fluid Service piping and by the following subparagraphs.

**328.2.1 Standard Welding Procedure Specifications.** Standard welding procedure specifications published by the American Welding Society and listed in ASME BPVC, Section IX, Appendix E are permitted for Code construction within the limitations established by ASME BPVC, Section IX, Article V.

**328.2.2 Procedure Qualification by Others.** In order to avoid duplication of effort and subject to the approval of the owner, WPSs and BPSs qualified by a technically competent group or agency may be used provided the following are met:

*(a)* The procedures meet the requirements of ASME BPVC, Section IX and any additional qualification requirements of this Code.

*(b)* The employer has qualified at least one welder, brazer, or operator following each WPS or BPS.

*(c)* The employer's business name shall be shown on each WPS and BPS, and on each qualification record. In addition, qualification records shall be signed and dated by the employer, thereby accepting responsibility for the qualifications performed by others.

**328.2.3 Performance Qualification by Others.** In order to avoid duplication of effort and subject to the approval of the owner, an employer may accept the performance qualification of a welder, brazer, or operator made by a previous employer. This acceptance is limited to performance qualifications that were made on pipe or tube test coupons. The new employer shall have the WPS or BPS that was followed during qualification or an equivalent WPS or BPS that is within the limits of the essential variables set forth in ASME BPVC, Section IX. An employer accepting such qualification tests shall obtain a copy of the performance qualification test record from the previous employer. The record shall show the name of the employer by whom the welder, brazer, or operator was qualified and the date of that qualification. Evidence shall also be provided that the welder, brazer, or operator has maintained qualification in accordance with QW-322 and QB-322 of ASME BPVC, Section IX, except that this evidence may be provided by an employer responsible for the individual's welding or brazing performance even if not the original qualifying employer. The new employer's business name shall be shown on the qualification record, and it shall be signed and dated by the employer, thereby accepting responsibility for the qualifications performed by others.

**328.2.4 Qualification Records.** The employer shall maintain copies of the procedure and performance qualification records specified by ASME BPVC, Section IX that shall be available to the Inspector at the location where welding is being done.

### 328.3 Welding Materials

**328.3.1 Electrodes and Filler Metal.** Welding electrodes and filler metal, including consumable inserts, shall conform to the requirements of ASME BPVC, Section II, Part C. An electrode or filler metal not conforming to the above may be used provided the WPS and the welders who will follow the WPS have been qualified as required by ASME BPVC, Section IX. Unless otherwise specified by the Designer, welding electrodes and filler metals used shall produce weld metal that complies with the following:

*(a)* The nominal tensile strength of the weld metal shall equal or exceed the minimum specified tensile strength of the base metals being joined, or the weaker of the two if base metals of two different strengths are being joined.

*(b)* The nominal chemical analysis of the weld metal shall be similar to the nominal chemical analysis of the major alloying elements of the base metal (e.g., $2^1/_4$% Cr, 1% Mo steels should be joined using $2^1/_4$% Cr, 1% Mo filler metals).

*(c)* If base metals of different chemical analysis are being joined, the nominal chemical analysis of the weld metal shall be similar to either base metal or an intermediate composition, except as specified below for austenitic steels joined to ferritic steels.

*(d)* When austenitic steels are joined to ferritic steels, the weld metal shall have a predominantly austenitic microstructure.

*(e)* For nonferrous metals, the weld metal shall be that recommended by the manufacturer of the nonferrous base metal or by industry associations for that metal.

**328.3.2 Weld Backing Material.** When backing rings are used, they shall conform to the following:

*(a) Ferrous Metal Backing Rings.* These shall be of weldable quality. Sulfur content shall not exceed 0.05%.

*(b)* If two abutting surfaces are to be welded to a third member used as a backing ring and one or two of the three members are ferritic and the other member or members are austenitic, the satisfactory use of such materials shall be demonstrated by welding procedure qualified as required by para. 328.2.

Backing rings may be of the continuous machined or split-band type. Some commonly used types are shown in Figure 328.3.2.

*(c) Nonferrous and Nonmetallic Backing Rings.* Backing rings of nonferrous or nonmetallic material may be used, provided the designer approves their use and the welding procedure using them is qualified as required by para. 328.2.

**328.3.3 Consumable Inserts.** Consumable inserts may be used, provided they are of the same nominal composition as the filler metal, will not cause detrimental alloying of the weld metal, and the welding procedure using them is qualified as required by para. 328.2. Some commonly used types are shown in Figure 328.3.2.

## 328.4 Preparation for Welding

**328.4.1 Cleaning.** Internal and external surfaces to be thermally cut or welded shall be clean and free from paint, oil, rust, scale, and other material that would be detrimental to either the weld or the base metal when heat is applied.

### 328.4.2 End Preparation

*(a) General*

*(1)* End preparation is acceptable only if the surface is reasonably smooth and true, and slag from oxygen or arc cutting is cleaned from thermally cut surfaces. Discoloration remaining on a thermally cut surface is not considered detrimental oxidation.

*(2)* End preparation for groove welds specified in ASME B16.25, or any other that meets the WPS, is acceptable. [For convenience, the basic bevel angles of ASME B16.25 and some additional J-bevel angles are shown in Figure 328.4.2, illustrations (a) and (b).]

*(b) Circumferential Welds*

*(1)* If component ends are trimmed as shown in Figure 328.3.2, illustration (a) or (b) to fit backing rings or consumable inserts, or as shown in Figure 328.4.3, illustration (a) or (b) to correct internal misalignment, such trimming shall not reduce the finished wall thickness below the required minimum wall thickness, $t_m$.

*(2)* Component ends may be bored to allow for a completely recessed backing ring, provided the remaining net thickness of the finished ends is not less than $t_m$.

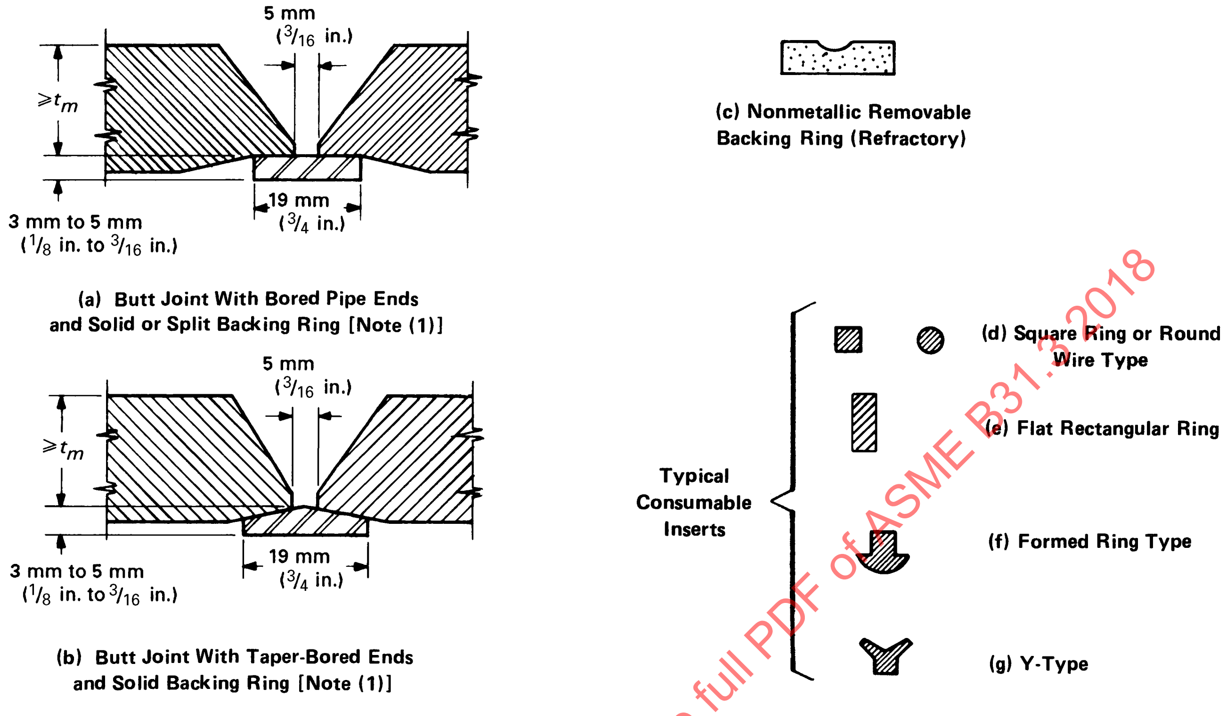
*(3)* It is permissible to size pipe ends of the same nominal size to improve alignment if wall thickness requirements are maintained.

*(4)* Where necessary, weld metal may be deposited inside or outside of the component to permit alignment or provide for machining to ensure satisfactory seating of rings or inserts.

*(5)* When a girth or miter groove weld joins components of unequal wall thickness and one is more than $1^1/_2$ times the thickness of the other, end preparation and geometry shall be in accordance with acceptable designs for unequal wall thickness in ASME B16.25.

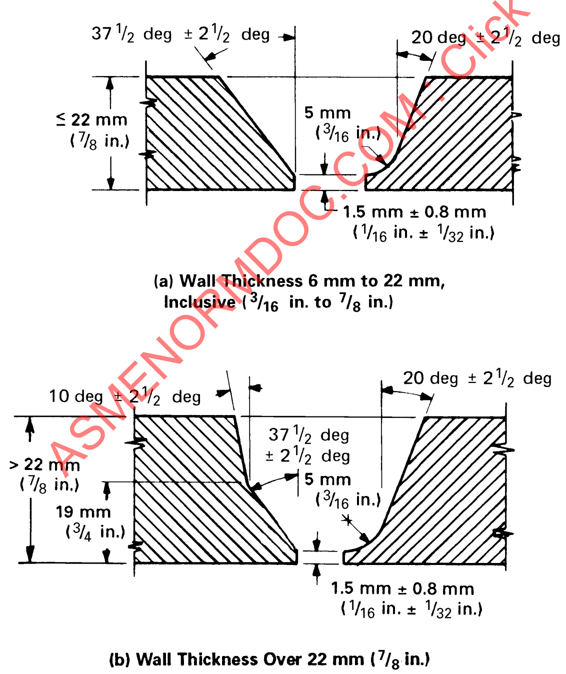
*(6)* Butt-weld fittings manufactured in accordance with ASME B16.9 may be trimmed to produce an angular joint offset in their connections to pipe or to other butt-weld fittings without being subject to design qualifications in accordance with para. 304.7.2, provided the total angular offset produced between the two jointed parts does not exceed 3 deg.

**Figure 328.3.2 Typical Backing Rings and Consumable Inserts**




NOTE: (1) Refer to ASME B16.25 for detailed dimensional information on welding ends.

**Figure 328.4.2 Typical Butt Weld End Preparation**




### 328.4.3 Alignment

*(a) Circumferential Welds*

*(1)* Inside surfaces of components at ends to be joined in girth or miter groove welds shall be aligned within the dimensional limits in the WPS and the engineering design.

*(2)* If the external surfaces of the components are not aligned, the weld shall be tapered between them.

*(b) Longitudinal Welds.* Alignment of longitudinal groove welds (not made in accordance with a standard listed in Table A-1, Table A-1M, or Table 326.1) shall conform to the requirements of para. 328.4.3(a).

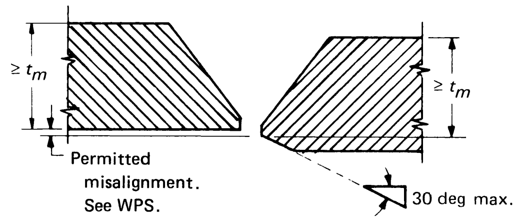
*(c) Branch Connection Welds*

*(1)* Branch connections that abut the outside surface of the run pipe shall be contoured for groove welds that meet the WPS requirements [see Figure 328.4.4, illustrations (a) and (b)].

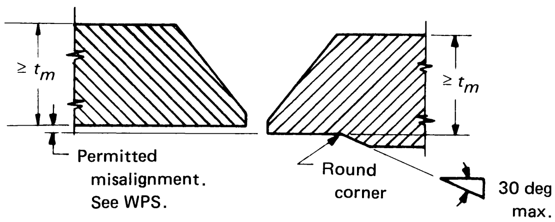
*(2)* Branch connections that are inserted through a run opening shall be inserted at least as far as the inside surface of the run pipe at all points [see Figure 328.4.4, illustration (c)] and shall otherwise conform to para. 328.4.3(c)(1).

*(3)* Run openings for branch connections shall not deviate from the required contour more than the dimension *m* in Figure 328.4.4. In no case shall deviations of the shape of the opening cause the root spacing tolerance

**Figure 328.4.3 Trimming and Permitted Misalignment**




(a) Thicker Pipe Taper-Bored to Align




(b) Thicker Pipe Bored for Alignment

limits in the WPS to be exceeded. Weld metal may be added and refinished if necessary for compliance.

*(d)* *Spacing.* The root opening of the joint shall be within the tolerance limits in the WPS.

## 328.5 Welding Requirements

### 328.5.1 General

*(a)* Welds, including addition of weld metal for alignment [paras. 328.4.2(b)(4) and 328.4.3(c)(3)], shall be made in accordance with a qualified procedure and by qualified welders or welding operators.

*(b)* Each qualified welder and welding operator shall be assigned an identification symbol. Unless otherwise specified in the engineering design, each pressure-containing weld or adjacent area shall be marked with the identification symbol of the welder or welding operator. In lieu of marking the weld, appropriate records shall be filed.

*(c)* Tack welds at the root of the joint shall be made with filler metal equivalent to that used in the root pass. Tack welds shall be made by a qualified welder or welding operator. Tack welds shall be fused with the root pass weld, except that those that have cracked shall be removed. Bridge tacks (above the weld) shall be removed.

*(d)* Peening is prohibited on the root pass and final pass of a weld.

*(e)* No welding shall be done if there is impingement on the weld area of rain, snow, sleet, or excessive wind, or if the weld area is frosted or wet.

*(f)* *Welding End Valves.* The welding sequence and procedure and any heat treatment for a welding end valve shall be such as to preserve the seat tightness of the valve.

**328.5.2 Fillet and Socket Welds.** Fillet welds (including socket welds) may vary from convex to concave. The size of a fillet weld is determined as shown in Figure 328.5.2A.

*(a)* Typical weld details for slip-on and socket welding flanges are shown in Figure 328.5.2B; minimum welding dimensions for other socket welding components are shown in Figure 328.5.2C or MSS SP-119.

*(b)* If slip-on flanges are single welded, the weld shall be at the hub.

**328.5.3 Seal Welds.** Seal welding shall be done by a qualified welder. Seal welds shall cover all exposed threads.

### 328.5.4 Welded Branch Connections

*(a)* Figures 328.5.4A through 328.5.4F show acceptable details of branch connections with and without added reinforcement, in which the branch pipe is connected directly to the run pipe. The illustrations are typical and are not intended to exclude acceptable types of construction not shown.

*(b)* Figure 328.5.4D shows basic types of weld attachments used in the fabrication of branch connections. The location and minimum size of attachment welds shall conform to the requirements herein. Welds shall be calculated in accordance with para. 304.3.3 but shall be not less than the sizes shown in Figure 328.5.4D. Figure 328.5.4F shows the basic types of attachment welds used with integrally reinforced branch connection fittings. The location and the minimum size of the attachment welds shall conform to the requirements of (i) below.

*(c)* The nomenclature and symbols used herein, in Figure 328.5.4D, and in Figure 328.5.4F are

$\overline{T}_b$ = nominal thickness of branch

$\overline{T}_h$ = nominal thickness of header

$\overline{T}_m$ = nominal thickness of the branch weld for integrally reinforced branch connection fittings

*(1)* as specified by the manufacturer of the branch connection fitting

*(2)* the full depth of the resultant weld groove, after fit-up, if no manufacturer's weld thickness is specified

*(3)* as documented and specified in the engineering design in accordance with para. 300(c)(3), or

*(4)* calculated and documented in accordance with the requirements of para. 304.7.2

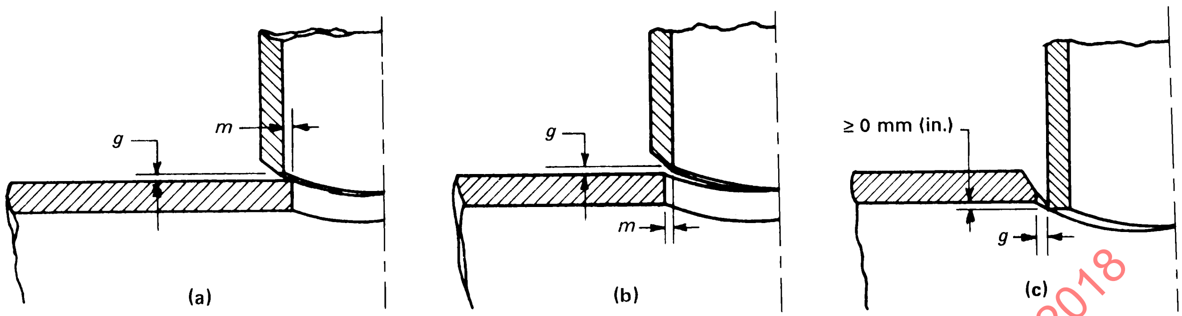
$\overline{T}_r$ = nominal thickness of reinforcing pad or saddle

$t_c$ = lesser of 0.7 $\overline{T}_b$ or 6 mm ($^1\!/_4$ in.)

$t_{min}$ = lesser of $\overline{T}_b$ or $\overline{T}_r$

*(d)* Branch connections, including branch connection fittings (see paras. 300.2 and 304.3.2), that abut the outside of the run or that are inserted in an opening in

## Figure 328.4.4 Preparation for Branch Connections




$g$ = root gap per welding specification
$m$ = the lesser of 3.2 mm ($^1/_8$ in.) or 0.5 $\overline{T}_b$

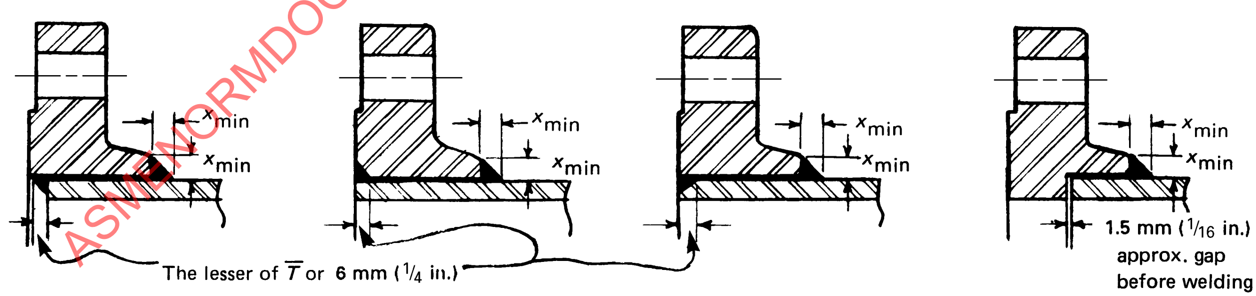
## Figure 328.5.2A Fillet Weld Size


Equal Leg Fillet Weld [Note (1)]

Unequal Leg Fillet Weld [Note (2)]

NOTES:
(1) The size of an equal leg fillet weld is the leg length of the largest inscribed isosceles right triangle (theoretical throat = 0.707 × size).
(2) The size of unequal leg fillet weld is the leg lengths of the largest right triangle that can be inscribed within the weld cross section [e.g., 13 mm × 19 mm ($^1\!/_2$ in. × $^3\!/_4$ in.)].

## Figure 328.5.2B Typical Details for Double-Welded Slip-On and Socket Welding Flange Attachment Welds



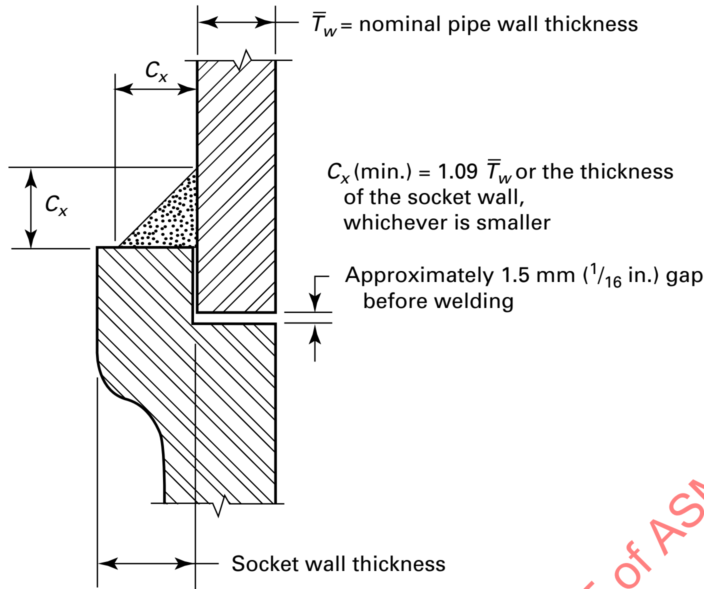

(a) Front and Back Welds

(b) Face and Back Welds

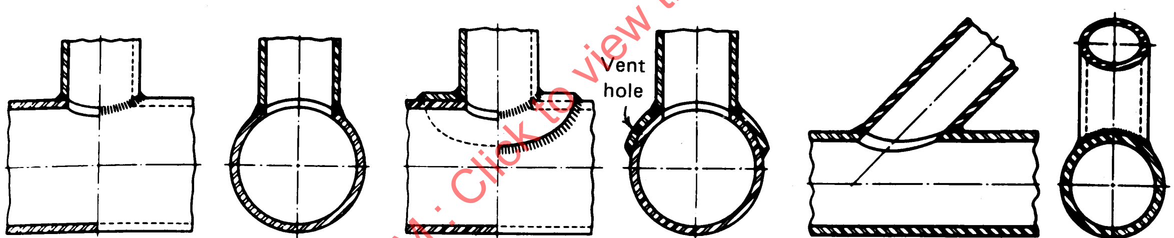
(c) Socket Welding Flange

$x_{min}$ = the lesser of 1.4 $\overline{T}$ or the thickness of the hub

**Figure 328.5.2C Minimum Welding Dimensions for Socket Welding Components Other Than Flanges**




**Figures 328.5.4A, B, C Typical Welded Branch Connections**




**(a) Without Added Reinforcement**

**(b) With Added Reinforcement**

**(c) Angular Branch Without Added Reinforcement**



the run shall be attached by fully penetrated groove welds. The welds shall be finished with cover fillet welds having a throat dimension not less than $t_c$. See Figure 328.5.4D, illustrations (1) and (2).

*(e)* A reinforcing pad or saddle shall be attached to the branch pipe by either

*(1)* a fully penetrated groove weld finished with a cover fillet weld having a throat dimension not less than $t_c$, or

*(2)* a fillet weld having a throat dimension not less than $0.7t_{min}$. See Figure 328.5.4D, illustration (5).

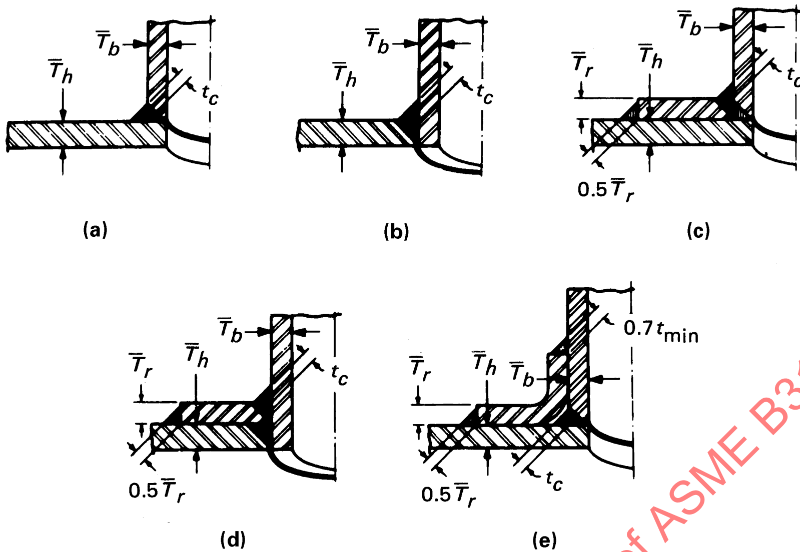
*(f)* The outer edge of a reinforcing pad or saddle shall be attached to the run pipe by a fillet weld having a throat dimension not less than 0.5 $\overline{T}_r$. See Figure 328.5.4D, illustrations (3), (4), and (5).

*(g)* Reinforcing pads and saddles shall have a good fit with the parts to which they are attached. A vent hole shall be provided at the side (not at the crotch) of any pad or saddle to reveal leakage in the weld between branch and run and to allow venting during welding and heat treatment. A pad or saddle may be made in more than one piece if joints between pieces have strength equivalent to pad or saddle parent metal, and if each piece has a vent hole.

*(h)* Examination and any necessary repairs of the completed weld between branch and run shall be made before adding a pad or saddle.

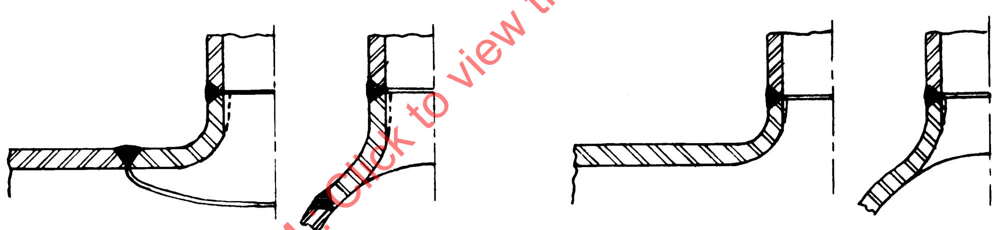
*(i)* Figure 328.5.4F shows additional integrally reinforced branch connections typical of MSS SP-97 fittings that abut the outside of the run attached by a full penetration groove weld. The welds shall be finished with cover fillets having a throat dimension not less than $t_c$. The cover

**Figure 328.5.4D Acceptable Details for Branch Attachment Welds**




GENERAL NOTE: These illustrations show minimum acceptable welds. Welds may be larger than those shown here.

**Figure 328.5.4E Acceptable Details for Branch Attachment Suitable for 100% Radiography**



**(a) Contour Outlet Fitting** **(b) Extruded Header Outlet**



fillet weld shall fill and smoothly transition to the attachment weld and run pipe or fitting.

**328.5.5 Fabricated Laps.** Figure 328.5.5 shows typical fabricated laps. Fabrication shall be in accordance with the applicable requirements of para. 328.5.4.

**328.5.6 Welding for Severe Cyclic Conditions.** A welding procedure shall be employed that provides a smooth, regular, fully penetrated inner surface.

## 328.6 Weld Repair

A weld defect to be repaired shall be removed to sound metal. Repair welds shall be made using a welding procedure qualified in accordance with para. 328.2.1, recognizing that the cavity to be repaired may differ in contour and dimensions from the original joint. Repair welds shall be made by welders or welding operators qualified in accordance with para. 328.2.1. Preheating and heat treatment shall be as required for the original welding. See also para. 341.3.3.

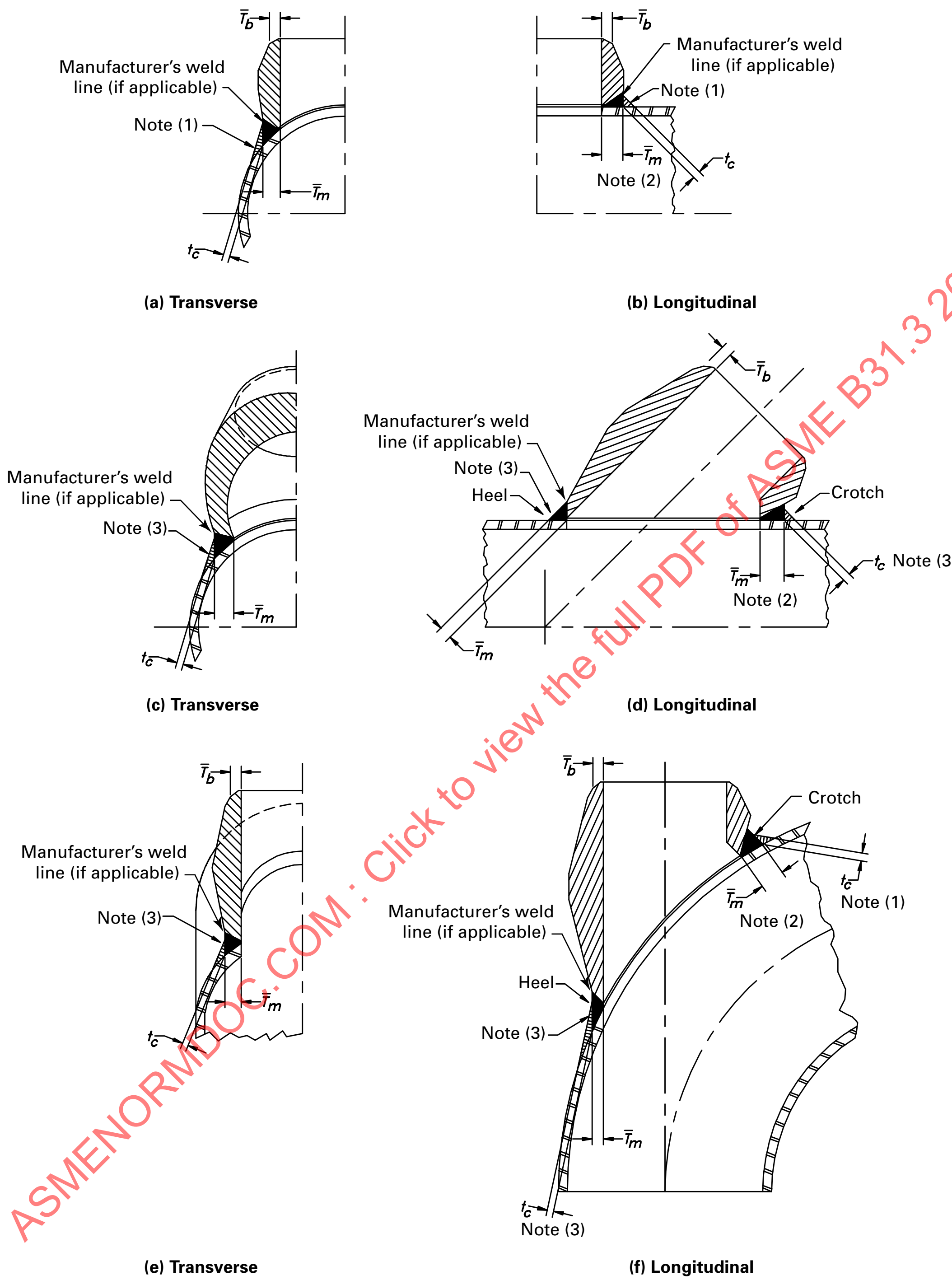
## 328.7 Attachment Welds

Structural attachments may be made by complete penetration, partial penetration, or fillet welds.

Low energy capacitor discharge welding may be used for welding temporary attachments (e.g., thermocouples) and permanent nonstructural attachments without preheat above 10°C (50°F) or subsequent postweld heat treatment on P-No. 1 through P-No. 5B and P-No. 15E materials, provided

*(a)* a Welding Procedure Specification is prepared, describing the low energy capacitor discharge equipment, the combination of materials to be joined, and the

## Figure 328.5.4F Acceptable Details for Integrally Reinforced Branch Connections




(a) Transverse

(b) Longitudinal

(c) Transverse

(d) Longitudinal

(e) Transverse

(f) Longitudinal



GENERAL NOTE: Welds shall be in accordance with para. 328.5.4(i).

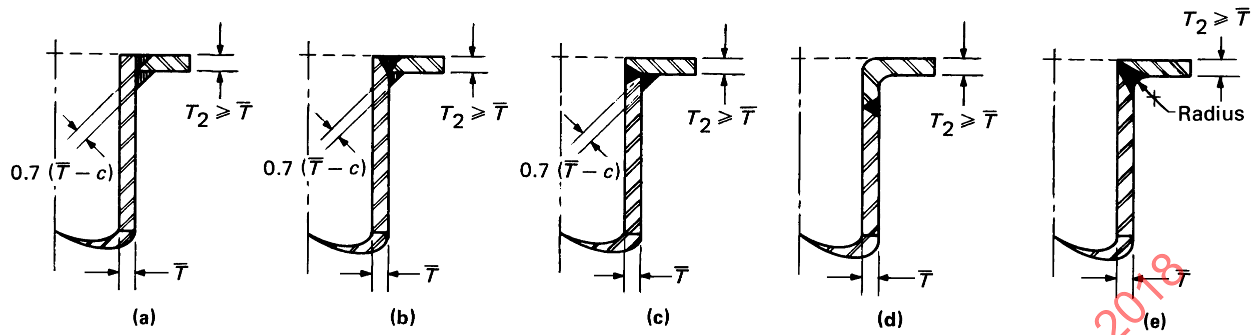
NOTES:

(1) Cover fillet weld shall provide a smooth transition to the run pipe with an equal leg fillet at the longitudinal section to an equal leg fillet, unequal (oblique) leg fillet, or groove butt joint at the transverse section (depending on branch connection size).

(2) Heat treatment requirements shall be in accordance with para. 331.1.3(a).

(3) Cover fillet weld shall provide a smooth transition to the run pipe with an equal leg fillet at the crotch in the longitudinal section to an equal leg fillet, unequal (oblique) leg fillet, or groove butt joint at the transverse section (depending on branch connection size) to nothing at the heel of the branch connection fitting in the longitudinal section.

Figure 328.5.5 Typical Fabricated Laps




GENERAL NOTE: Laps shall be machined (front and back) or trued after welding. Plate flanges in accordance with para. 304.5 or lap joint flanges in accordance with ASME B16.5 may be used. Welds may be machined to radius, as in illustration (e), if necessary to match ASME B16.5 lap joint flanges.



technique of application; qualification of the welding procedure is not required

*(b)* the energy output of the welding process is limited to 125 W-sec

*(c)* for P-No. 5A, P-No. 5B, and P-No. 15E materials, the maximum carbon content of the material is 0.15%

*(d)* after thermocouples are removed, the areas shall be visually examined for evidence of defects to be repaired

## 330 PREHEATING

### 330.1 General

The preheat requirements herein apply to all types of welding, including tack welds, repair welds, and seal welds on threaded joints.

**330.1.1 Requirements.** Unless specified otherwise in the engineering design, the minimum preheat temperatures for materials of various P-Numbers are given in Table 330.1.1. The thickness intended in Table 330.1.1 is that of the nominal thickness of the thicker component [as defined in para. 331.1.3(c)]. Higher minimum preheat temperatures may be required by the WPS or by the engineering design.

**330.1.2 Unlisted Materials.** Preheat requirements for an unlisted material shall be specified in the WPS.

**330.1.3 Preheat Temperature Verification**

*(a)* Preheat temperature shall be checked by use of temperature indicating crayons, thermocouple pyrometers, or other suitable means to ensure that the temperature specified in the WPS is obtained prior to and maintained during welding.

*(b)* Thermocouples may be temporarily attached directly to pressure-containing parts using the low energy capacitor discharge method of welding in accordance with para. 328.7.

**330.1.4 Preheat Zone.** The preheat zone shall be at or above the specified minimum temperature in all directions from the point of welding for a distance of the larger of 75 mm (3 in.) or 1.5 times the greater nominal thickness.

The base metal temperature for tack welds shall be at or above the specified minimum temperature for a distance not less than 25 mm (1 in.) in all directions from the point of welding.

### 330.2 Specific Requirements

**330.2.1 Different P-No. Materials.** When welding two different P-No. materials, the preheat temperature shall be the higher temperature for the material being welded as shown in Table 330.1.1.

**330.2.2 Interruption of Welding.** After welding commences, the minimum preheat temperature shall be maintained until any required PWHT is performed on P-Nos. 3, 4, 5A, 5B, 6, and 15E, except when all of the following conditions are satisfied:

*(a)* A minimum of at least 10 mm ($^3/_8$ in.) thickness of weld is deposited or 25% of the welding groove is filled, whichever is less (the weld shall be sufficiently supported to prevent overstressing the weld if the weldment is to be moved or otherwise loaded). Caution is advised that the surface condition prior to cooling should be smooth and free of sharp discontinuities.

*(b)* For P-Nos. 3, 4, and 5A materials, the weld is allowed to cool slowly to room temperature.

*(c)* For P-Nos. 5B, 6, and 15E materials, the weld is subjected to an adequate intermediate heat treatment with a controlled rate of cooling. The preheat temperature may be reduced to 95°C (200°F) (minimum) for the purpose of root examination without performing an intermediate heat treatment. Intermediate heat treatment for P-No. 5B or P-No. 15E materials may be omitted when using low-hydrogen electrodes and filler metals classified

(18) **Table 330.1.1 Preheat Temperatures**

| Base Metal P-No. [Note (1)] | Base Metal Group | Greater Material Thickness | | Additional Limits [Note (2)] | Required Minimum Temperature | |
|---|---|---|---|---|---|---|
| | | mm | in. | | °C | °F |
| 1 | Carbon steel | ≤25 | ≤1 | None | 10 | 50 |
| | | >25 | >1 | %C ≤ 0.30 [Note (3)] | 10 | 50 |
| | | >25 | >1 | %C > 0.30 [Note (3)] | 95 | 200 |
| 3 | Alloy steel, Cr ≤ ½% | ≤13 | ≤½ | SMTS ≤ 450 MPa (65 ksi) | 10 | 50 |
| | | >13 | >½ | SMTS ≤ 450 MPa (65 ksi) | 95 | 200 |
| | | All | All | SMTS > 450 MPa (65 ksi) | 95 | 200 |
| 4 | Alloy steel, ½% < Cr ≤ 2% | All | All | None | 120 | 250 |
| 5A | Alloy steel | All | All | SMTS ≤ 414 MPa (60 ksi) | 150 | 300 |
| | | All | All | SMTS > 414 MPa (60 ksi) | 200 | 400 |
| 5B | Alloy steel | All | All | SMTS ≤ 414 MPa (60 ksi) | 150 | 300 |
| | | All | All | SMTS > 414 MPa (60 ksi) | 200 | 400 |
| | | >13 | >½ | %Cr > 6.0 [Note (3)] | 200 | 400 |
| 6 | Martensitic stainless steel | All | All | None | 200 [Note (4)] | 400 [Note (4)] |
| 9A | Nickel alloy steel | All | All | None | 120 | 250 |
| 9B | Nickel alloy steel | All | All | None | 150 | 300 |
| 10I | 27Cr steel | All | All | None | 150 [Note (5)] | 300 [Note (5)] |
| 15E | 9Cr–1Mo–V CSEF steel | All | All | None | 200 | 400 |
| ... | All other materials | ... | ... | None | 10 | 50 |

NOTES:
(1) P-Nos. and Group Nos. from ASME BPVC, Section IX, QW/QB-422.
(2) SMTS = Specified Minimum Tensile Strength.
(3) Composition may be based on ladle or product analysis or in accordance with specification limits.
(4) Maximum interpass temperature 315°C (600°F).
(5) Maintain interpass temperature between 150°C and 230°C (300°F and 450°F).



by the filler metal specification with an optional supplemental diffusible-hydrogen designator of H4 or lower and suitably controlled by maintenance procedures to avoid contamination by hydrogen-producing sources. The surface of the base metal prepared for welding shall be free of contaminants.

*(d)* After cooling and before welding is resumed, visual examination of the weld shall be performed to assure that no cracks have formed.

*(e)* Required preheat shall be applied before welding is resumed.

## 331 HEAT TREATMENT

### 331.1 General

#### 331.1.1 Postweld Heat Treatment Requirements (18)

*(a)* PWHT shall be in accordance with the material groupings (P-Nos. and Group Nos.) and ranges in Table 331.1.1 except as provided in Table 331.1.2 and Table 331.1.3. See Appendix F, para. F331.1. The P-Numbers and Group Numbers are defined in ASME BPVC, Section IX, Table QW/QB-422. (Note that the P-Nos. are also listed in Appendix A.)

*(b)* The PWHT to be used after production welding shall be specified in the WPS and shall be used in qualifying the welding procedure.

*(c)* The engineering design shall specify the examination and/or other production quality control (not less than the requirements of this Code) to ensure that the final welds are of adequate quality.

**331.1.2 Other Heat Treatments**

*(a)* Heat treatment for bending and forming shall be in accordance with para. 332.4.

*(b)* See Table 302.3.5 for special heat treatment requirements for longitudinal or spiral (helical seam) welds in Elevated Temperature Fluid Service.

**331.1.3 Definition of Thicknesses Governing PWHT**

*(a)* The term *control thickness* as used in Table 331.1.1 and Table 331.1.3 is the lesser of

*(1)* the thickness of the weld

*(2)* the thickness of the materials being joined at the weld or the thickness of the pressure-containing material if the weld is attaching a nonpressure-containing material to a pressure-containing material.

*(b)* Thickness of the weld, which is a factor in determining the control thickness, is defined as follows:

*(1)* groove welds (girth and longitudinal) — the thicker of the two abutting ends after weld preparation, including I.D. machining

*(2)* fillet welds — the throat thickness of the weld

*(3)* partial penetration welds — the depth of the weld groove

*(4)* material repair welds — the depth of the cavity to be repaired

*(5)* branch welds — the dimension existing in the plane intersecting the longitudinal axes, calculated as indicated for each detail using the thickness through the weld for the details shown in Figure 328.5.4D and Figure 328.5.4F. This thickness shall be computed using the following formulas:

*(-a)* for Figure 328.5.4D use

$$\text{illustration (1)} = \overline{T}_b + t_c$$

$$\text{illustration (2)} = \overline{T}_h + t_c$$

$$\text{illustration (3)} = \text{greater of } \overline{T}_b + t_c \text{ or } \overline{T}_r + t_c$$

$$\text{illustration (4)} = \overline{T}_h + \overline{T}_r + t_c$$

$$\text{illustration (5)} = \overline{T}_b + t_c$$

*(-b)* for Figure 328.5.4F use $\overline{T}_m + t_c$ for all illustrations

*(c)* The term *nominal material thickness* as used in Table 331.1.3 is the thicker of the materials being joined at the weld.

**331.1.4 Heating and Cooling.** The heating method shall provide the required metal temperature, metal temperature uniformity, and temperature control, and may include an enclosed furnace, local flame heating, electric resistance, electric induction, or exothermic chemical reaction. Above 315°C (600°F), the rate of heating and cooling shall not exceed 335°C/h (600°F/hr) divided by one-half the maximum material thickness in inches at the weld, but in no case shall the rate exceed 335°C/h (600°F/hr). See Table 331.1.1 for cooling rate requirements for P-Nos. 7, 10I, 11A, and 62 materials.

**331.1.6 Temperature Verification.** Heat treatment temperature shall be checked by thermocouple pyrometers or other suitable methods to ensure that the WPS requirements are met. See para. 328.7 for attachment of thermocouples by the low energy capacitor discharge method of welding.

*(a)* If used, the heat treatment furnace shall be calibrated such that the PWHT can be controlled within the required temperature range.

*(b)* Any required PWHT shall be as required by the qualified WPS.

*(c)* For welds that require PWHT in accordance with Table 331.1.1, the temperature of the material during PWHT shall be within the range specified. However, if specified by the designer, the range may be extended as permitted by Table 331.1.2, provided the lower critical temperature of the material is not exceeded.

## 331.2 Specific Requirements

Where warranted by experience or knowledge of service conditions, alternative methods of heat treatment or exceptions to the basic heat treatment provisions of para. 331.1 may be adopted as provided in paras. 331.2.1 and 331.2.2.

**331.2.1 Alternative Heat Treatment.** Normalizing, or normalizing and tempering, or annealing may be applied in lieu of the required heat treatment after welding, bending, or forming, provided that the mechanical properties of any affected weld and base metal meet specification requirements after such treatment and that the substitution is approved by the designer.

**331.2.2 Exceptions to Basic Requirements.** As indicated in para. 331, the basic practices therein may require modification to suit service conditions in some cases. In such cases, the designer may specify more-stringent requirements in the engineering design, including heat treatment and hardness limitations for lesser thickness, or may specify less stringent heat treatment and hardness requirements, including none.

When provisions less stringent than those in para. 331 are specified, the designer must demonstrate to the owner's satisfaction the adequacy of those provisions by comparable service experience, considering service

### Table 331.1.1 Postweld Heat Treatment

| P-No. and Group No. (ASME BPVC, Section IX, QW/QB-420) | Holding Temperature Range, °C (°F) [Note (1)] | Minimum Holding Time at Temperature for Control Thickness [Note (2)] | |
|---|---|---|---|
| | | Up to 50 mm (2 in.) | Over 50 mm (2 in.) |
| P-No. 1, Group Nos. 1–3 | 595 to 650 (1,100 to 1,200) | 1 h/25 mm (1 hr/in.); 15 min min. | 2 hr plus 15 min for each additional 25 mm (in.) over 50 mm (2 in.) |
| P-No. 3, Group Nos. 1 and 2 | 595 to 650 (1,100 to 1,200) | | |
| P-No. 4, Group Nos. 1 and 2 | 650 to 705 (1,200 to 1,300) | | |
| P-No. 5A, Group No. 1 | 675 to 760 (1,250 to 1,400) | | |
| P-No. 5B, Group No. 1 | 675 to 760 (1,250 to 1,400) | | |
| P-No. 6, Group Nos. 1–3 | 760 to 800 (1,400 to 1,475) | | |
| P-No. 7, Group Nos. 1 and 2 [Note (3)] | 730 to 775 (1,350 to 1,425) | | |
| P-No. 8, Group Nos. 1–4 | PWHT not required unless required by WPS | | |
| P-No. 9A, Group No. 1 | 595 to 650 (1,100 to 1,200) | | |
| P-No. 9B, Group No. 1 | 595 to 650 (1,100 to 1,200) | | |
| P-No. 10H, Group No. 1 | PWHT not required unless required by WPS. If done, see Note (4). | | |
| P-No. 10I, Group No. 1 [Note (3)] | 730 to 815 (1,350 to 1,500) | | |
| P-No. 11A | 550 to 585 (1,025 to 1,085) [Note (5)] | | |
| P-No. 15E, Group No. 1 | 705 to 775 (1,300 to 1,425) [Notes (6) and (7)] | 1 h/25 mm (1 hr/in.); 30 min min. | 1 h/25 mm (1 hr/in.) up to 125 mm (5 in.) plus 15 min for each additional 25 mm (in.) over 125 mm (5 in.) |
| P-No. 62 | 540 to 595 (1,000 to 1,100) | ... | See Note (8) |
| All other materials | PWHT as required by WPS | In accordance with WPS | In accordance with WPS |

GENERAL NOTE: The exemptions for mandatory PWHT are defined in Table 331.1.3.

NOTES:

(1) The holding temperature range is further defined in para. 331.1.6(c) and Table 331.1.2.

(2) The control thickness is defined in para. 331.1.3.

(3) Cooling rate shall not be greater than 55°C (100°F) per hour in the range above 650°C (1,200°F), after which the cooling rate shall be sufficiently rapid to prevent embrittlement.

(4) If PWHT is performed after welding, it shall be within the following temperature ranges for the specific alloy, followed by rapid cooling:
Alloys S31803 and S32205 — 1 020°C to 1 100°C (1,870°F to 2,010°F)
Alloy S32550 — 1 040°C to 1 120°C (1,900°F to 2,050°F)
Alloy S32750 — 1 025°C to 1 125°C (1,880°F to 2,060°F)
All others — 980°C to 1 040°C (1,800°F to 1,900°F)

(5) Cooling rate shall be >165°C (300°F)/h to 315°C (600°F)/h.

(6) The minimum PWHT holding temperature may be 675°C (1,250°F) for nominal material thicknesses [see para. 331.1.3(c)] ≤13 mm ($\frac{1}{2}$ in.).

(7) The Ni + Mn content of the filler metal shall not exceed 1.2% unless specified by the designer, in which case the maximum temperature to be reached during PWHT shall be the $A_1$ (lower transformation or lower critical temperature) of the filler metal, as determined by analysis and calculation or by test, but not exceeding 800°C (1,470°F). If the 800°C (1,470°F) limit was not exceeded but the $A_1$ of the filler metal was exceeded or if the composition of the filler metal is unknown, the weld must be removed and replaced. It shall then be rewelded with compliant filler metal and subjected to a compliant PWHT. If the 800°C (1,470°F) limit was exceeded, the weld and the entire area affected by the PWHT will be removed and, if reused, shall be renormalized and tempered prior to reinstallation.

(8) Heat treat within 14 days after welding. Hold time shall be increased by 1.2 h for each 25 mm (1 in.) over 25 mm (1 in.) thickness. Cool to 425°C (800°F) at a rate ≤280°C (500°F)/h.

**Table 331.1.2 Alternate Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels, P-Nos. 1 and 3**

| Decrease in Specified Minimum Temperature, °C (°F) | Minimum Holding Time at Decreased Temperature, h [Note (1)] |
|---|---|
| 30 (50) | 2 |
| 55 (100) | 4 |
| 85 (150) [Note (2)] | 10 |
| 110 (200) [Note (2)] | 20 |

NOTES:
(1) Times shown apply to thicknesses ≤25 mm (1 in.). Add 15 min/25 mm (15 min/in.) of thickness for control thicknesses >25 mm (1 in.) (see para. 331.1.3).
(2) A decrease >55°C (100°F) below the minimum specified temperature is allowable only for P-No. 1, Group Nos. 1 and 2 materials.

temperature and its effects, frequency and intensity of thermal cycling, flexibility stress levels, probability of brittle failure, and other pertinent factors. In addition, appropriate tests shall be conducted, including WPS qualification tests.

#### 331.2.3 Dissimilar Materials

*(a)* Heat treatment of welded joints between dissimilar ferritic metals or between ferritic metals using dissimilar ferritic filler metal shall be at the higher of the temperature ranges in Table 331.1.1 for the materials in the joint. This may require the use of material transition joint designs.
*(b)* Heat treatment of welded joints including both ferritic and austenitic components and filler metals shall be as required for the ferritic material or materials unless otherwise specified in the engineering design.

**331.2.4 Delayed Heat Treatment.** If a weldment is allowed to cool prior to heat treatment, the rate of cooling shall be controlled or other means shall be used to prevent detrimental effects in the piping.

**331.2.5 Partial Heat Treatment.** When an entire piping assembly to be heat treated cannot be fitted into the furnace, it is permissible to heat treat in more than one heat, provided there is at least 300 mm (1 ft) overlap between successive heats, and that parts of the assembly outside the furnace are protected from harmful temperature gradients. This method may not be used for austenitizing heat treatments for ferritic materials.

**331.2.6 Local Heat Treatment.** Welds may be locally postweld heat treated by heating a circumferential band around the entire component with the weld located in the center of the band. The width of the band heated to the specified temperature range shall be at least three times the wall thickness at the weld of the thickest part being joined. For nozzle and attachment welds, the width of the band heated to the specified temperature range shall extend beyond the nozzle weld or attachment weld on each side at least two times the run pipe thickness, and shall extend completely around the run pipe. Guidance for the placement of thermocouples on circumferential butt welds is provided in AWS D10.10, Sections 5, 6, and 8. Special consideration shall be given to the placement of thermocouples when heating welds adjacent to large heat sinks such as valves or fittings, or when joining parts of different thicknesses. No part of the materials subjected to the heat source shall exceed the lower critical temperature of the material except as permitted by para. 331.2.1. Particular care must be exercised when the applicable PWHT temperature is close to the material's lower critical temperature, such as for P-No. 15E materials or when materials of different P-Nos. are being joined. This method may not be used for austenitizing heat treatments.

## 332 BENDING AND FORMING

### 332.1 General

Pipe may be bent and components may be formed by any hot or cold method that is suitable for the material, the fluid service, and the severity of the bending or forming process.[1] The finished surface shall be free of cracks and substantially free from buckling. Thickness after bending or forming shall be not less than that required by the design.

### 332.2 Bending

**332.2.1 Bend Flattening.** Flattening of a bend, the difference between maximum and minimum diameters at any cross section, shall not exceed 8% of nominal outside diameter for internal pressure and 3% for external pressure. Removal of metal shall not be used to achieve these requirements.

#### 332.2.2 Bending Temperature

*(a)* Cold bending of ferritic materials shall be done at a temperature below the transformation range.
*(b)* Hot bending shall be done at a temperature above the transformation range and in any case within a temperature range consistent with the material and the intended service.

**332.2.3 Corrugated and Other Bends.** Dimensions and configuration shall conform to the design qualified in accordance with para. 306.2.2.

### 332.3 Forming

The temperature range for forming shall be consistent with material, intended service, and specified heat treatment.

[1] For pipe bending, PFI Standard ES-24, Pipe Bending Methods, Tolerances, Process and Material Requirements, may be used as a guide.

## Table 331.1.3 Exemptions to Mandatory Postweld Heat Treatment

| P-No. and Group No. (ASME BPVC, Section IX, QW/QB-420) [Note (1)] | Control Thickness, mm (in.) [Note (2)] | Type of Weld | Additional Limitations Required for Exemption From PWHT [Notes (3)–(5)] |
|---|---|---|---|
| P-No. 1, all Group Nos. | All | All | A preheat of 95°C (200°F) is applied prior to welding on any nominal material thickness >25 mm (1 in.)<br>Multiple layer welds are used when the nominal material thickness >5 mm ($\frac{3}{16}$ in.) [Note (6)] |
| P-No. 3, Group Nos. 1 and 2 | ≤16 mm ($\frac{5}{8}$ in.) | All | A preheat of 95°C (200°F) is applied prior to welding on any nominal material thickness >13 mm ($\frac{1}{2}$ in.)<br>A specified carbon content of the base materials ≤0.25%<br>Multiple layer welds are used when the nominal material thickness >5 mm ($\frac{3}{16}$ in.) [Note (6)] |
| P-No. 4, Group No. 1 | ≤16 mm ($\frac{5}{8}$ in.) | Groove | Mandatory preheat has been applied<br>Specified carbon content of the base materials ≤0.15%<br>Multiple layer welds are used when the nominal material thickness >5 mm ($\frac{3}{16}$ in.) [Note (6)] |
| | ≤16 mm ($\frac{5}{8}$ in.) except the thickness of a socket weld fitting or flange need not be considered | Socket and fillet welds | Mandatory preheat has been applied<br>Throat thickness of the fillet weld or the socket weld ≤13 mm ($\frac{1}{2}$ in.)<br>Specified carbon content of the pipe material ≤0.15%<br>Nominal material thickness of the pipe ≤16 mm ($\frac{5}{8}$ in.)<br>Multiple layer welds are used when the nominal material thickness >5 mm ($\frac{3}{16}$ in.) [Note (6)] |
| | ≤16 mm ($\frac{5}{8}$ in.) | Seal welds and non-load-carrying attachments [Note (7)] | Mandatory preheat has been applied<br>Multiple layer welds are used when the nominal material thickness >5 mm ($\frac{3}{16}$ in.) [Note (6)] |
| P-No. 5A, Group No. 1 | ≤16 mm ($\frac{5}{8}$ in.) | Groove | Mandatory preheat has been applied<br>Specified carbon content of the base materials ≤0.15%<br>Multiple layer welds are used when the nominal material thickness >5 mm ($\frac{3}{16}$ in.) [Note (6)] |
| | ≤16 mm ($\frac{5}{8}$ in.) except the thickness of a socket weld fitting or flange need not be considered | Socket and fillet welds | Mandatory preheat has been applied<br>Throat thickness of the fillet weld or the socket weld ≤13 mm ($\frac{1}{2}$ in.)<br>Specified carbon content of the pipe material ≤0.15%<br>Nominal thickness of the pipe ≤5 mm ($\frac{3}{16}$ in.)<br>Multiple layer welds are used when the nominal material thickness >5 mm ($\frac{3}{16}$ in.) [Note (6)] |
| | ≤16 mm ($\frac{5}{8}$ in.) | Seal welds and non-load-carrying attachments [Note (7)] | Mandatory preheat has been applied<br>Multiple layer welds are used when the nominal material thickness >5 mm ($\frac{3}{16}$ in.) [Note (6)] |
| P-No. 5B, Group No. 1 | ... | ... | No exemptions from PWHT |
| P-No. 6, Group Nos. 1–3 | All | All | Specified carbon content of the base materials ≤0.08%<br>Nominal material thickness ≤10 mm ($\frac{3}{8}$ in.)<br>Weld filler metal is A-No. 8, A-No. 9, or F-No. 43 composition [Note (8)] |

**Table 331.1.3 Exemptions to Mandatory Postweld Heat Treatment (Cont'd)**

| P-No. and Group No. (ASME BPVC, Section IX, QW/QB-420) [Note (1)] | Control Thickness, mm (in.) [Note (2)] | Type of Weld | Additional Limitations Required for Exemption From PWHT [Notes (3)–(5)] |
|---|---|---|---|
| P-No. 7, Group No. 1 | All | All | Specified carbon content of the base materials ≤0.08%<br>Nominal material thickness ≤10 mm ($^3\!/_8$ in.)<br>Weld filler metal is A-No. 8, A-No. 9, or F-No. 43 composition [Note (8)] |
| P-No. 7, Group No. 2 | ... | ... | No exemptions from PWHT |
| P-No. 8, all Group Nos. | All | All | PWHT neither required nor prohibited |
| P-No. 9A, Group No. 1 | All | All | Specified carbon content of the pipe material ≤0.15%<br>Nominal material thickness ≤13 mm ($^1\!/_2$ in.)<br>Mandatory preheat has been applied |
| P-No. 9B, Group No. 1 | All | All | Nominal material thickness ≤16 mm ($^5\!/_8$ in.) and the WPS has been qualified using a material of equal or greater thickness than used in the production weld |
| P-No. 10H, Group No. 1 | All | All | PWHT neither required nor prohibited |
| P-No. 10I, Group No. 1 | All | All | PWHT neither required nor prohibited for nominal material thickness ≤13 mm ($^1\!/_2$ in.) |
| P-No. 11A | ≤50 mm (2 in.) | All | ... |
| P-No. 15E | ... | ... | No exemptions from PWHT |
| P-No. 62 | ... | ... | No exemptions from PWHT |

NOTES:
(1) If differences with the P-No. listed in Appendix A are found, the P-No. listed in ASME BPVC, Section IX, Table QW/QB-422 applies.
(2) The control thickness is defined in para. 331.1.3.
(3) The nominal material thickness is defined in para. 331.1.3(c).
(4) No exemptions are permitted for PWHTs required by the designer or the WPS.
(5) Additional exemptions for welds made in accordance with para. 328.7 may be taken for the materials addressed.
(6) Single-layer or single-pass welds may be exempted from PWHT, provided the WPS has been qualified using single-pass welds with ±10% heat input and that all other conditions for exemption are met.
(7) Non-load-carrying attachments are defined as items where no pressure loads or significant mechanical loads are transmitted through the attachment to the pipe or pressure-containing material.
(8) The A-Nos. and the F-Nos. are found in ASME BPVC, Section IX, Tables QW-442 and QW-432, respectively.

### 332.4 Required Heat Treatment

Heat treatment shall be performed in accordance with para. 331.1.1 when required by the following.

**332.4.1 Hot Bending and Forming.** After hot bending and forming, heat treatment is required for P-Nos. 3, 4, 5, 6, and 10A materials in all thicknesses. Durations and temperatures shall be in accordance with para. 331.

**332.4.2 Cold Bending and Forming.** After cold bending and forming, heat treatment is required (for all thicknesses, and with temperature and duration as given in Table 331.1.1) when any of the following conditions exist:

*(a)* for P-Nos. 1 through 6 materials, where the maximum calculated fiber elongation after bending or forming exceeds 50% of specified basic minimum elongation (in the direction of severest forming) for the applicable specification, grade, and thickness. This requirement may be waived if it can be demonstrated that the selection of pipe and the choice of bending or forming process provide assurance that, in the finished condition, the most severely strained material retains at least 10% elongation.

*(b)* for any material requiring impact testing, where the maximum calculated fiber elongation after bending or forming will exceed 5%.

*(c)* when specified in the engineering design.

## 333 BRAZING AND SOLDERING

### 333.1 Qualification

**333.1.1 Brazing Qualification.** The qualification of brazing procedures, brazers, and brazing operators shall be in accordance with para. 328.2. For Category D Fluid Service at design temperature not over 93°C (200°F), such qualification is not required unless specified in the engineering design.

**333.1.2 Soldering Qualification.** The qualification of solderers shall be in accordance with the requirements of ASTM B828, Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings.

### 333.2 Brazing and Soldering Materials

**333.2.1 Brazing Filler Metal and Flux.** Brazing filler metal and flux shall comply with AWS A5.8, Specification for Filler Metals for Brazing and Braze Welding, and AWS A5.31, Specification for Fluxes for Brazing and Braze Welding, respectively, or other filler metals and fluxes that have been qualified in accordance with ASME BPVC, Section IX.

**333.2.2 Soldering Filler Metal and Flux.** Soldering filler metal and flux shall comply with ASTM B32, Standard Specification for Solder Metal, and ASTM B813, Standard Specification for Liquid and Paste Fluxes for Soldering of Copper and Copper Alloy Tube, respectively.

### 333.3 Preparation and Cleaning

**333.3.1 Surface Preparation.** The surfaces to be brazed or soldered shall be clean and free from grease, oxides, paint, scale, and dirt of any kind. A suitable chemical or mechanical cleaning method shall be used if necessary to provide a clean wettable surface.

**333.3.2 Joint Clearance.** The clearance between surfaces to be joined by soldering or brazing shall be no larger than necessary to allow complete capillary distribution of the filler metal.

**333.3.3 Flux Removal.** Residual flux shall be removed.

## 335 ASSEMBLY AND ERECTION

### 335.1 Alignment

*(a) Piping Distortions.* Any distortion of piping to bring it into alignment for joint assembly that introduces a detrimental strain in equipment or piping components is prohibited.

*(b) Cold Spring.* Before assembling any joints to be cold sprung, guides, supports, and anchors shall be examined for errors that might interfere with desired movement or lead to undesired movement. The gap or overlap of piping prior to assembly shall be checked against the drawing and corrected if necessary. Heating shall not be used to help in closing the gap because it defeats the purpose of cold springing.

*(c) Flanged Joints.* Unless otherwise specified in the engineering design, flanged joints shall be aligned as described in (1) or (2), and (3).

*(1)* Before bolting, mating gasket contact surfaces shall be aligned to each other within 1 mm in 200 mm ($\frac{1}{16}$ in./ft), measured across any diameter.

*(2)* The flanged joint shall be capable of being bolted such that the gasket contact surfaces bear uniformly on the gasket.

*(3)* Flange bolt holes shall be aligned within 3 mm ($\frac{1}{8}$ in.) maximum offset.

### 335.2 Flanged Joints

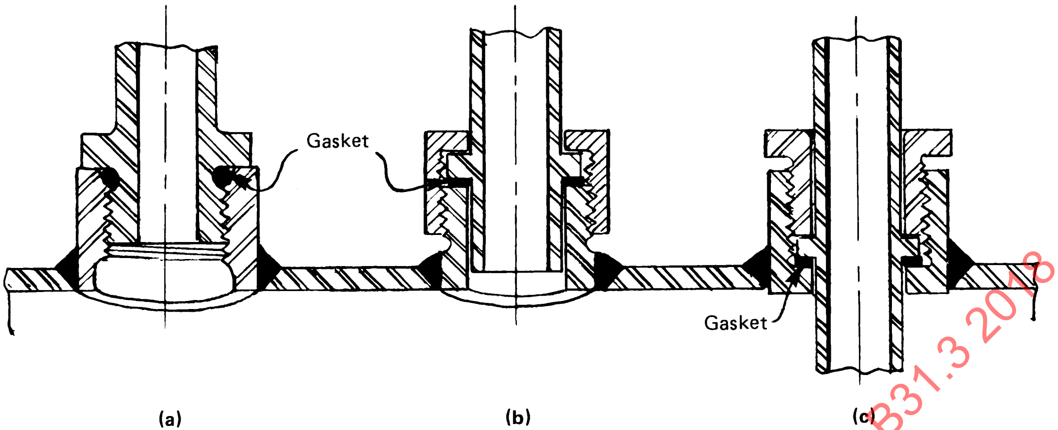
**335.2.1 Preparation for Assembly.** Any damage to the gasket seating surface that would prevent gasket seating shall be repaired, or the flange shall be replaced.

**335.2.2 Bolting Torque**

*(a)* In assembling flanged joints, the gasket shall be uniformly compressed to the proper design loading.

*(b)* Special care shall be used in assembling flanged joints in which the flanges have widely differing mechanical properties. Tightening to a predetermined torque is recommended.

**Figure 335.3.3 Typical Threaded Joints Using Straight Threads**




GENERAL NOTE: Threads are ASME B1.1 straight threads.

**335.2.3 Bolt Length.** Bolts shall extend through their nuts such that there is complete thread engagement for the full depth of the nut.

**335.2.4 Gaskets.** No more than one gasket shall be used between contact faces in assembling a flanged joint.

**335.2.5 Flanged Joint Assembly.** Assembly requirements for bolted flanged joints and flanged joint assembler qualifications shall be considered in the engineering design. For guidance, see ASME PCC-1, Guidelines for Pressure Boundary Bolted Flange Joint Assembly, and ASME BPVC, Section VIII, Division 1, Nonmandatory Appendix S.

### 335.3 Threaded Joints

(18) **335.3.1 Thread Compound or Lubricant.** Any compound or lubricant used on threads shall be suitable for the service temperatures and shall not react unfavorably with either the service fluid or the piping material.

**335.3.2 Joints for Seal Welding.** A threaded joint to be seal welded shall be made up without thread compound. A joint containing thread compound that leaks during leak testing may be seal welded in accordance with para. 328.5.3, provided all compound is removed from exposed threads.

**335.3.3 Straight Threaded Joints.** Typical joints using straight threads, with sealing at a surface other than the threads, are shown in Figure 335.3.3, illustrations (a), (b), and (c). Care shall be taken to avoid distorting the seat when incorporating such joints into piping assemblies by welding, brazing, or bonding.

### 335.4 Tubing Joints

**335.4.1 Flared Tubing Joints.** The sealing surface of the flare shall be examined for imperfections before assembly and any flare having imperfections shall be rejected.

**335.4.2 Flareless and Compression Tubing Joints.** Where the manufacturer's instructions call for a specified number of turns of the nut, these shall be counted from the point at which the nut becomes finger tight.

### 335.5 Caulked Joints

Caulked joints shall be installed and assembled in accordance with the manufacturer's instructions, as modified by the engineering design. Care shall be taken to ensure adequate engagement of joint members.

### 335.6 Expanded Joints and Special Joints

**335.6.1 General.** Expanded joints and special joints (as defined in para. 318) shall be installed and assembled in accordance with the manufacturer's instructions, as modified by the engineering design. Care shall be taken to ensure adequate engagement of joint members.

**335.6.2 Packed Joints.** Where a packed joint is used to absorb thermal expansion, proper clearance shall be provided at the bottom of the socket to permit this movement.

### 335.9 Cleaning of Piping

This Code does not prescribe mandatory procedures for flushing and cleaning. However, for potential hazards that may result from performing such procedures refer to Appendix F, para. F335.9 for precautionary considerations.

### 335.10 Identification of Piping

See Appendix F, para. F335.10.

# Chapter VI
# Inspection, Examination, and Testing

## 340 INSPECTION

### 340.1 General

This Code distinguishes between examination (see para. 341) and inspection. Inspection applies to functions performed for the owner by the owner's Inspector or the Inspector's delegates. References in this Code to the "Inspector" are to the owner's Inspector or the Inspector's delegates.

### 340.2 Responsibility for Inspection

It is the owner's responsibility, exercised through the owner's Inspector, to verify that all required examinations and testing have been completed and to inspect the piping to the extent necessary to be satisfied that it conforms to all applicable examination requirements of the Code and of the engineering design.

### 340.3 Rights of the Owner's Inspector

The owner's Inspector and the Inspector's delegates shall have access to any place where work concerned with the piping installation is being performed. This includes manufacture, fabrication, heat treatment, assembly, erection, examination, and testing of the piping. They shall have the right to audit any examination, to inspect the piping using any examination method specified by the engineering design, and to review all certifications and records necessary to satisfy the owner's responsibility stated in para. 340.2.

### (18) 340.4 Qualifications of the Owner's Inspector

*(a)* The owner's Inspector shall be designated by the owner and shall be the owner, an employee of the owner, an employee of an engineering or scientific organization, or the employee of a recognized insurance or inspection company acting as the owner's agent. The owner's Inspector shall not represent nor be an employee of the piping manufacturer, fabricator, or erector unless the owner is also the manufacturer, fabricator, or erector.

*(b)* The owner's Inspector shall meet one of the following requirements:

*(1)* have at least 10 years of experience in the design, fabrication, or examination of industrial pressure piping. Each 20% of satisfactorily completed work toward an accredited engineering degree shall be considered equivalent to 1 year of experience, up to 5 years total.

*(2)* have a professional engineering registration or nationally recognized equivalent with at least 5 years of experience in the design, fabrication, or examination of industrial pressure piping.

*(3)* be a certified welding inspector or a senior certified welding inspector as defined in AWS QC1, Specification for AWS Certification of Welding Inspectors, or nationally recognized equivalent with at least 5 years of experience in the design, fabrication, or examination of industrial pressure piping.

*(4)* be an authorized piping inspector as defined in API 570, Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems, with at least 5 years of experience in the design, fabrication, or examination of industrial pressure piping.

*(c)* In delegating performance of inspection, the owner's Inspector is responsible for determining that a person to whom an inspection function is delegated is qualified to perform that function.

## 341 EXAMINATION

### 341.1 General

Examination applies to quality control functions performed by the manufacturer (for components only), fabricator, or erector. Reference in this Code to an examiner is to a person who performs quality control examinations.

### 341.2 Responsibility for Examination

Inspection does not relieve the manufacturer, the fabricator, or the erector of the responsibility for

*(a)* providing materials, components, and workmanship in accordance with the requirements of this Code and of the engineering design [see para. 300(b)(3)]

*(b)* performing all required examinations

*(c)* preparing suitable records of examinations and tests for the Inspector's use

### 341.3 Examination Requirements

**341.3.1 General.** Prior to initial operation, each piping installation, including components and workmanship, shall be examined in accordance with the applicable requirements of para. 341. The type and extent of any additional examination required by the engineering design, and the acceptance criteria to be applied, shall be specified. Joints not included in examinations required by para. 341.4 or by the engineering design are accepted if they pass the leak test required by para. 345.

*(a)* For P-Nos. 3, 4, 5A, 5B, 5C, and 15E materials, examinations shall be performed after completion of heat treatment. However, examinations need not be repeated on welds or portions of welds that are subjected to additional heat treatments and have not been repaired by welding.

*(b)* For a welded branch connection, the examination of, and any necessary repairs to, the pressure-containing weld shall be completed before any reinforcing pad or saddle is added.

**341.3.2 Acceptance Criteria.** Acceptance criteria shall be as stated in the engineering design and shall at least meet the applicable requirements stated below.

*(a)* *Welds*. See Figure 341.3.2 for typical weld imperfections.

*(1)* For radiography and visual, see Table 341.3.2.

*(2)* For magnetic particle, see para. 344.3.2.

*(3)* For liquid penetrant, see para. 344.4.2.

*(4)* For ultrasonic, see para. 344.6.2.

*(b)* *Castings.* Acceptance criteria for castings are specified in para. 302.3.3.

**341.3.3 Defective Components and Workmanship.** Defects (imperfections of a type or magnitude not acceptable by the criteria specified in para. 341.3.2) shall be repaired, or the defective item or work shall be replaced. Discontinuities detected outside the area required to be examined during weld joint examinations should be evaluated and resolved in a manner acceptable to the owner and designer.

Examination shall be as follows:

*(a)* When the defective item or work is repaired, the repaired portion of the item or work shall be examined. The examination shall use the same methods and acceptance criteria employed for the original examination. See also para. 341.3.1(a).

*(b)* When the defective item or work is replaced, the new item or work used to replace the defective item or work shall be examined. The examination shall use any method and applicable acceptance criteria that meet the requirements for the original examination. See also para. 341.3.1(a).

**341.3.4 Progressive Sampling for Examination.** When required spot or random examination reveals a defect, then

*(a)* two additional samples of the same kind (if welded or bonded joints, by the same welder, bonder, or operator) from the original designated lot shall be given the same type of examination

*(b)* if the items examined as required by (a) above are acceptable, the defective item shall be repaired or replaced and reexamined as specified in para. 341.3.3, and all items represented by these two additional samples shall be accepted, but

*(c)* if any of the items examined as required by (a) above reveals a defect, two further samples of the same kind shall be examined for each defective item found by that sampling

*(d)* if all the items examined as required by (c) above are acceptable, the defective item(s) shall be repaired or replaced and reexamined as specified in para. 341.3.3, and all items represented by the additional sampling shall be accepted, but

*(e)* if any of the items examined as required by (c) above reveals a defect, all items represented by the progressive sampling shall be either

*(1)* repaired or replaced and reexamined as required, or

*(2)* fully examined and repaired or replaced as necessary, and reexamined as necessary to meet the requirements of this Code

*(f)* If any of the defective items are repaired or replaced, reexamined, and a defect is again detected in the repaired or replaced item, continued progressive sampling in accordance with (a), (c), and (e) is not required based on the new defects found. The defective item(s) shall be repaired or replaced and reexamined until acceptance as specified in para. 341.3.3. Spot or random examination (whichever is applicable) is then performed on the remaining unexamined joints.

## 341.4 Extent of Required Examination

**341.4.1 Examination — Normal Fluid Service.** Piping in Normal Fluid Service shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in para. 341.3.2 and in Table 341.3.2, for Normal Fluid Service unless otherwise specified. (18)

*(a)* *Visual Examination.* At least the following shall be examined in accordance with para. 344.2:

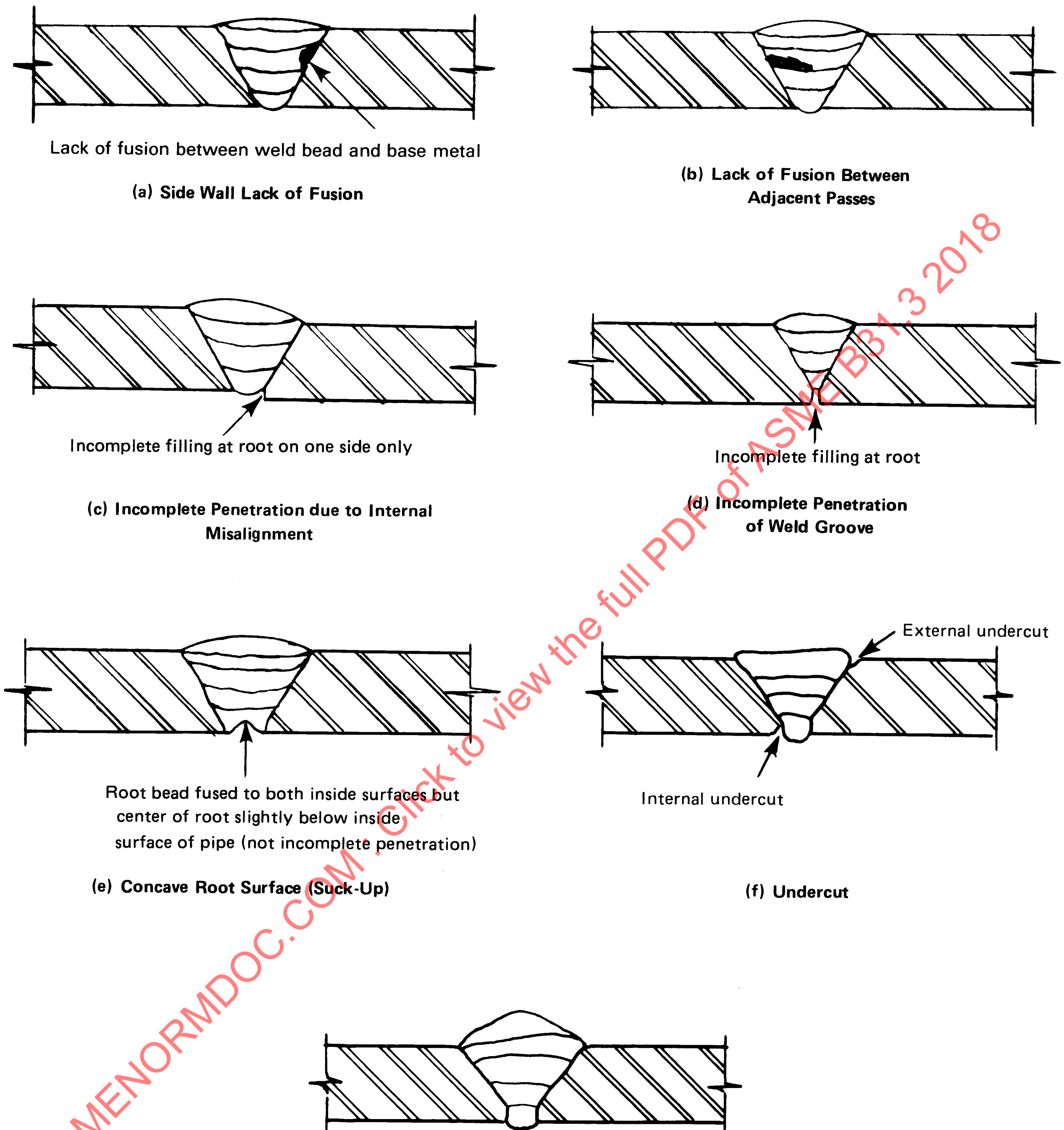
*(1)* sufficient materials and components, selected at random, to satisfy the examiner that they conform to specifications and are free from defects.

*(2)* at least 5% of fabrication, as defined in para. 300.2.

*(3)* 100% of all completed welds, except those in components made in accordance with a listed standard. See para. 341.5.1(a) for examination of longitudinal welds required to have a joint factor, $E_j$, of 0.90.

*(4)* random examination of the assembly of threaded, bolted, and other joints to satisfy the examiner that they conform to the applicable requirements of para. 335. When pneumatic testing is to be performed, all threaded, bolted, and other mechanical joints shall be examined.

**Figure 341.3.2 Typical Weld Imperfections**




(a) Side Wall Lack of Fusion

(b) Lack of Fusion Between Adjacent Passes

(c) Incomplete Penetration due to Internal Misalignment

(d) Incomplete Penetration of Weld Groove

(e) Concave Root Surface (Suck-Up)

(f) Undercut

(g) Excess External Reinforcement

(18)

## Table 341.3.2 Acceptance Criteria for Welds — Visual and Radiographic Examination

| Criteria (A to M) for Types of Welds and for Service Conditions [Note (1)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Normal and Category M Fluid Service | | | Severe Cyclic Conditions | | | Category D Fluid Service | | | | | Examination Methods | |
| Girth, Miter Groove, and Branch Connection Welds [Note (2)] | Longitudinal Groove Weld [Note (3)] | Fillet Weld [Note (4)] | Girth, Miter Groove, and Branch Connection Welds [Note (2)] | Longitudinal Groove Weld [Note (3)] | Fillet Weld [Note (4)] | Girth and Miter Groove Welds | Longitudinal Groove Weld [Note (3)] | Fillet Weld [Note (4)] | Branch Connection Weld [Note (2)] | Weld Imperfection | Visual | Radiography |
| A | A | A | A | A | A | A | A | A | A | Crack | ✓ | ✓ |
| A | A | A | A | A | A | C | A | N/A | A | Lack of fusion | ✓ | ✓ |
| B | A | N/A | A | A | N/A | C | A | N/A | B | Incomplete penetration | ✓ | ✓ |
| E | E | N/A | D | D | N/A | N/A | N/A | N/A | N/A | Rounded Indications | ... | ✓ |
| G | G | N/A | F | F | N/A | N/A | N/A | N/A | N/A | Linear indications | ... | ✓ |
| H | A | H | A | A | A | I | A | H | H | Undercutting | ✓ | ✓ |
| A | A | A | A | A | A | A | A | A | A | Surface porosity or exposed slag inclusion [Note (5)] | ✓ | ... |
| N/A | N/A | N/A | J | J | J | N/A | N/A | N/A | N/A | Surface finish | ✓ | ... |
| K | K | N/A | K | K | N/A | K | K | N/A | K | Concave surface, concave root, or burn-through | ✓ | ✓ |
| L | L | L | L | L | L | M | M | M | M | Weld reinforcement or internal protrusion | ✓ | ... |

GENERAL NOTES:
(a) Weld imperfections are evaluated by one or more of the types of examination methods given, as specified in paras. 341.4.1, 341.4.2, 341.4.3, and M341.4, or by the engineering design.
(b) "N/A" indicates the Code does not establish acceptance criteria or does not require evaluation of this kind of imperfection for this type of weld.
(c) Check (✓) indicates examination method generally used for evaluating this kind of weld imperfection.
(d) Ellipsis (...) indicates examination method not generally used for evaluating this kind of weld imperfection.

NOTES:
(1) Criteria given are for required examination. More-stringent criteria may be specified in the engineering design. See also paras. 341.5 and 341.5.3.
(2) Branch connection weld includes pressure containing welds in branches and fabricated laps.
(3) Longitudinal groove weld includes straight and spiral (helical) seam. Criteria are not intended to apply to welds made in accordance with a standard listed in Table A-1, Table A-1M, or Table 326.1. Alternative Leak Test requires examination of these welds; see para. 345.9.
(4) Fillet weld includes socket and seal welds, and attachment welds for slip-on flanges, branch reinforcement, and supports.
(5) These imperfections are evaluated only for welds ≤5 mm ($^3/_{16}$ in.) in nominal thickness.

(18)

## Criterion Value Notes for Table 341.3.2

| Symbol | Criterion Measure | Acceptable Value Limits [Note (1)] | |
|---|---|---|---|
| A | Extent of imperfection | Zero (no evident imperfection) | |
| B | Cumulative length of incomplete penetration | ≤38 mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less | |
| C | Cumulative length of lack of fusion and incomplete penetration | ≤38 mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less | |
| D | Size and distribution of rounded indications | See ASME BPVC, Section VIII, Division 1, Appendix 4 [Note (2)] | |
| E | Size and distribution of rounded indications | For $\overline{T}_w \leq 6$ mm ($^1/_4$ in.), limit is same as D [Note (2)]<br>For $\overline{T}_w > 6$ mm ($^1/_4$ in.), limit is 1.5 × D [Note (2)] | |
| F | Linear indications | | |
| | Individual length | $\leq\overline{T}_w/3$ | |
| | Individual width | ≤2.5 mm ($^3/_{32}$ in.) and $\leq\overline{T}_w/3$ | |
| | Cumulative length | $\leq\overline{T}_w$ in any 12 $\overline{T}_w$ weld length [Note (2)] | |
| G | Linear indications | | |
| | Individual length | $\leq 2\overline{T}_w$ | |
| | Individual width | ≤3 mm ($^1/_8$ in.) and $\leq\overline{T}_w/2$ | |
| | Cumulative length | $\leq 4\overline{T}_w$ in any 150 mm (6 in.) weld length [Note (2)] | |
| H | Depth of undercut | ≤1 mm ($^1/_{32}$ in.) and $\leq\overline{T}_w/4$ | |
| | Cumulative length of internal and external undercut | ≤38 mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less | |
| I | Depth of undercut | ≤1.5 mm ($^1/_{16}$ in.) and ≤[$\overline{T}_w/4$ or 1 mm ($^1/_{32}$ in.)] | |
| | Cumulative length of internal and external undercut | ≤38 mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less | |
| J | Surface roughness | ≤12.5 μm (500 μin.) $R_a$ in accordance with ASME B46.1 | |
| K | Depth of surface concavity, root concavity, or burn-through | Total joint thickness, including weld reinforcement, $\geq\overline{T}_w$ [Notes (3) and (4)] | |
| L | Height of reinforcement or internal protrusion [Note (5)] in any plane through the weld shall be within limits of the applicable height value in the tabulation at right, except as provided in Note (6). Weld metal shall merge smoothly into the component surfaces. | For $\overline{T}_w$, mm (in.) | Height, mm (in.) |
| | | ≤6 ($^1/_4$) | ≤1.5 ($^1/_{16}$) |
| | | >6 ($^1/_4$), ≤13 ($^1/_2$) | ≤3 ($^1/_8$) |
| | | >13 ($^1/_2$), ≤25 (1) | ≤4 ($^5/_{32}$) |
| | | >25 (1) | ≤5 ($^3/_{16}$) |
| M | Height of reinforcement or internal protrusion [Note (5)] as described in L. Note (6) does not apply. | Limit is twice the value applicable for L above | |

NOTES:

(1) Where two limiting values are separated by "and," the lesser of the values determines acceptance. Where two sets of values are separated by "or," the larger value is acceptable. $\overline{T}_w$ is the nominal wall thickness of the thinner of two components joined by a butt weld.

## Criterion Value Notes for Table 341.3.2 (Cont'd)

NOTES: (Cont'd)

(2) Porosity and inclusions such as slag or tungsten are defined as rounded indications where the maximum length is three times the width or less. These indications may be circular, elliptical, or irregular in shape; may have tails; and may vary in density. Indications where the length is greater than three times the width are defined as linear indications and may also be slag, porosity, or tungsten.

(3) For circumferential groove welded joints in pipe, tube, and headers made entirely without the addition of filler metal, external concavity shall not exceed the lesser of 1 mm ($^1/_{32}$ in.) or 10% of the joint nominal thickness. The contour of the concavity shall blend smoothly with the base metal. The total joint thickness, including any reinforcement, shall not be less than the minimum wall thickness, $t_m$.

(4) For radiography, acceptability may be determined by comparing the density of the image through the affected area to the density through the adjacent base metal ($\overline{T}_w$). If digital radiography is used, brightness comparison may be utilized. A density or brightness darker than the adjacent base metal is cause for rejection.

(5) For groove welds, height is the lesser of the measurements made from the surfaces of the adjacent components; both reinforcement and internal protrusion are permitted in a weld. For fillet welds, height is measured from the theoretical throat, Figure 328.5.2A; internal protrusion does not apply.

(6) For welds in aluminum alloy only, internal protrusion shall not exceed the following values:
(a) 1.5 mm ($^1/_{16}$ in.) for thickness ≤2 mm ($^5/_{64}$ in.)
(b) 2.5 mm ($^3/_{32}$ in.) for thickness >2 mm and ≤6 mm ($^1/_4$ in.)
For external reinforcement and for greater thicknesses, see the tabulation for symbol L.

*(5)* random examination during erection of piping, including checking of alignment, supports, and cold spring.

*(6)* examination of erected piping for evidence of defects that would require repair or replacement, and for other evident deviations from the intent of the design.

*(b) Other Examination*

*(1)* Not less than 5% of circumferential butt and miter groove welds shall be examined fully by random radiography in accordance with para. 344.5 or by random ultrasonic examination in accordance with para. 344.6. The welds to be examined in each designated lot shall include the work product of each welder or welding operator whose welds are part of the lot. The work of welders depositing only tack welds need not be represented as part of the lot. Welds shall also be selected to maximize coverage of intersections with longitudinal joints. When a circumferential weld with an intersecting longitudinal weld(s) is examined, at least the adjacent 38 mm ($1\frac{1}{2}$ in.) of each intersecting weld shall be examined. In-process examination in accordance with para. 344.7 may be substituted for all or part of the radiographic or ultrasonic examination on a weld-for-weld basis if specified in the engineering design or specifically authorized by the Inspector.

*(2)* Not less than 5% of all brazed joints shall be examined by in-process examination in accordance with para. 344.7, the joints to be examined being selected to ensure that the work of each brazer making the production joints is included.

*(c) Certifications and Records.* The examiner shall be assured, by examination of certifications, records, and other evidence, that the materials and components are of the specified grades and that they have received required heat treatment, examination, and testing. The examiner shall provide the Inspector with a certification that all the quality control requirements of the Code and of the engineering design have been carried out.

**341.4.2 Examination — Category D Fluid Service.** Piping and piping elements for Category D Fluid Service as designated in the engineering design shall be visually examined in accordance with para. 344.2 to the extent necessary to satisfy the examiner that components, materials, and workmanship conform to the requirements of this Code and the engineering design. Acceptance criteria are as stated in para. 341.3.2 and in Table 341.3.2, for Category D fluid service, unless otherwise specified.

**341.4.3 Examination — Severe Cyclic Conditions.** Piping to be used under severe cyclic conditions shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in para. 341.3.2 and in Table 341.3.2, for severe cyclic conditions, unless otherwise specified.

*(a) Visual Examination.* The requirements of para. 341.4.1(a) apply with the following exceptions:

*(1)* All fabrication shall be examined.

*(2)* All threaded, bolted, and other joints shall be examined.

*(3)* All piping erection shall be examined to verify dimensions and alignment. Supports, guides, and points of cold spring shall be checked to ensure that movement of the piping under all conditions of startup, operation, and shutdown will be accommodated without undue binding or unanticipated constraint.

*(b) Other Examination.* All circumferential butt and miter groove welds and all fabricated branch connection welds comparable to those shown in Figure 328.5.4E shall be examined by 100% radiography in accordance with para. 344.5, or (if specified in the engineering design) by 100% ultrasonic examination in accordance with para. 344.6. Socket welds and branch connection welds that are not radiographed shall be examined by magnetic particle or liquid penetrant methods in accordance with para. 344.3 or 344.4.

*(c)* In-process examination in accordance with para. 344.7, supplemented by appropriate nondestructive examination, may be substituted for the examination required in (b) above on a weld-for-weld basis if specified in the engineering design or specifically authorized by the Inspector.

*(d) Certification and Records.* The requirements of para. 341.4.1(c) apply.

**341.4.4 Examination — Elevated Temperature Fluid Service.** Piping in Elevated Temperature Fluid Service shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in para. 341.3.2 and in Table 341.3.2, for Normal Fluid Service, unless the requirements for severe cyclic conditions apply or otherwise specified.

*(a) Visual Examination.* The requirements of para. 341.4.1(a) apply with the following exceptions:

*(1)* All fabrication shall be examined.

*(2)* All threaded, bolted, and other joints shall be examined.

*(3)* All piping erection shall be examined to verify dimensions and alignment. Supports, guides, and points of cold spring shall be checked to ensure that movement of the piping under all conditions of startup, operation, and shutdown will be accommodated without undue binding or unanticipated constraint.

*(b) Additional Examination.* The examination requirements of para. 341.4.1(b) apply with the following exceptions:

*(1)* Fabrication for longitudinal and spiral (helical seam) welds in P-No. 4 and P-No. 5 materials, except those in components made in accordance with a listed specification, shall be examined by 100% radiography

in accordance with para. 344.5, or by 100% ultrasonic examination in accordance with para. 344.6.

*(2)* Socket welds and branch connection welds in P-No. 4 and P-No. 5 materials that are not radiographed or ultrasonically examined shall be examined by magnetic particle or liquid penetrant methods in accordance with para. 344.3 or 344.4.

*(c) Additional Examination Required for Autogenous Welds, Without Filler Metal, in Austenitic Stainless Steel and Austenitic High Nickel Alloys.* Autogenously welded pipe shall receive nondestructive examination in accordance with the material specification. Autogenously welded expansion joint bellows shall be examined in accordance with para. X302.2.2(c).

*(d) Certification and Records.* The requirements of para. 341.4.1(c) apply.

### 341.5 Supplementary Examination

Any of the methods of examination described in para. 344 may be specified by the engineering design to supplement the examination required by para. 341.4. The extent of supplementary examination to be performed and any acceptance criteria that differ from those in para. 341.3.2 shall be specified in the engineering design.

#### 341.5.1 Spot Radiography

*(a) Longitudinal Welds.* Spot radiography for longitudinal groove welds required to have a weld joint factor $E_j$ of 0.90 requires examination by radiography in accordance with para. 344.5 of at least 300 mm (1 ft) in each 30 m (100 ft) of weld for each welder or welding operator. Acceptance criteria are those stated in Table 341.3.2 for radiography under Normal Fluid Service.

*(b) Circumferential Butt Welds and Other Welds.* It is recommended that the extent of examination be not less than one shot on one in each 20 welds for each welder or welding operator. Unless otherwise specified, acceptance criteria are as stated in Table 341.3.2 for radiography under Normal Fluid Service for the type of joint examined.

*(c) Progressive Sampling for Examination.* The provisions of para. 341.3.4 are applicable.

*(d) Welds to Be Examined.* The locations of welds and the points at which they are to be examined by spot radiography shall be selected or approved by the Inspector.

**341.5.2 Hardness Tests.** Hardness tests are not required to verify proper heat treatment except as otherwise specified in the engineering design.

**341.5.3 Examinations to Resolve Uncertainty.** Any method may be used to resolve doubtful indications. Acceptance criteria shall be those for the required examination.

## 342 EXAMINATION PERSONNEL

### 342.1 Personnel Qualification and Certification

Personnel performing nondestructive examination to the requirements of this Code shall be qualified and certified for the method to be utilized following a procedure as described in ASME BPVC, Section V, Article 1, T-120(e) or (f).

### 342.2 Specific Requirement

For in-process examination, the examinations shall be performed by personnel other than those performing the production work.

## 343 EXAMINATION PROCEDURES

Any examination shall be performed in accordance with a written procedure that conforms to one of the methods specified in para. 344, including special methods (see para. 344.1.2). Procedures shall be written as required in ASME BPVC, Section V, Article 1, T-150. The employer shall make the examination procedures employed available to the Inspector.

## 344 TYPES OF EXAMINATION

### 344.1 General

**344.1.1 Methods.** Except as provided in para. 344.1.2, any examination required by this Code, by the engineering design, or by the Inspector shall be performed in accordance with one of the methods specified herein.

**344.1.2 Special Methods.** If a method not specified herein is to be used, it and its acceptance criteria shall be specified in the engineering design in enough detail to permit qualification of the necessary procedures and examiners.

**344.1.3 Definitions.** The following terms apply to any type of examination:

*100% examination:* complete examination of all of a specified kind of item in a designated lot of piping[1]

*random examination*[2]*:* complete examination of a percentage of a specified kind of item in a designated lot of piping[1]

[1] A designated lot is that quantity of piping to be considered in applying the requirements for examination in this Code. The quantity or extent of a designated lot should be established by agreement between the contracting parties before the start of work. More than one kind of designated lot may be established for different kinds of piping work. See Pipe Fabrication Institute Standard ES-48, Random Examination, for examples of lot selection.

[2] Random or spot examination will not ensure a fabrication product of a prescribed quality level throughout. Items not examined in a lot of piping represented by such examination may contain defects that further examination could disclose. Specifically, if all radiographically disclosable weld defects must be eliminated from a lot of piping, 100% radiographic examination must be specified.

*spot examination*[2]*:* a specified partial examination of each of a specified kind of item in a designated lot of piping,[1] e.g., of part of the length of all shop-fabricated welds in a lot of jacketed piping

*random spot examination*[2]*:* a specified partial examination of a percentage of a specified kind of item in a designated lot of piping[1]

### 344.2 Visual Examination

(18) **344.2.1 Definition.** Visual examination is the direct observation of the external and internal portions of components, joints, and other piping elements that are readily accessible or can be exposed to view before, during, or after manufacture, fabrication, assembly, erection, examination, or testing. This examination includes verification of Code and engineering design requirements for materials, components, dimensions, joint preparation, alignment, welding, bonding, brazing, bolting, threading, or other joining method, supports, assembly, and erection.

(18) **344.2.2 Method.** Visual examination shall be performed in accordance with ASME BPVC, Section V, Article 9. Examination shall be by the direct visual technique. The use of a remote visual technique and the acceptance criteria beyond the requirements of this Code shall be a matter of agreement between contracting parties prior to the start of fabrication.

Records of individual visual examinations are not required except for those of in-process examinations as specified in para. 344.7.

### 344.3 Magnetic Particle Examination

**344.3.1 Method.** Examination of castings is covered in para. 302.3.3. Magnetic particle examination of welds and of components other than castings shall be performed in accordance with ASME BPVC, Section V, Article 7.

**344.3.2 Acceptance Criteria.** Magnetic particle indications are caused by the attraction of the test media to surface or near-surface discontinuities in the area under test. However, all such indications are not necessarily imperfections, since excessive roughness, magnetic permeability variations, etc., may produce nonrelevant indications. Inadvertent accumulation of particles not related to magnetic attraction is classified as a false indication. Indications shall be verified as being relevant, nonrelevant, or false. Additional surface preparation and/or other test methods may be used as needed to verify the relevance of an indication.

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications that have any dimension greater than 1.5 mm ($\frac{1}{16}$ in.) shall be considered relevant.

*(a) Indications*

*(1)* A linear indication is one having a length greater than three times its width.

*(2)* A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.

*(b) Examination.* All surfaces to be examined shall be free of

*(1)* relevant linear indications

*(2)* relevant rounded indications >5.0 mm ($\frac{3}{16}$ in.)

*(3)* four or more relevant rounded indications in a line separated by 1.5 mm ($\frac{1}{16}$ in.) or less, edge to edge

### 344.4 Liquid Penetrant Examination

**344.4.1 Method.** Examination of castings is covered in para. 302.3.3. Liquid penetrant examination of welds and of components other than castings shall be performed in accordance with ASME BPVC, Section V, Article 6.

**344.4.2 Acceptance Criteria.** Liquid penetrant indications are caused by the bleed-out of a visible or fluorescent dye from a surface discontinuity in the area under test. However, all such indications are not necessarily imperfections, since excessive roughness, poor surface preparation, etc., may produce nonrelevant indications. Inadvertent evidence of penetrant not related to actual bleed-out is classified as a false indication. Indications shall be verified as being relevant, nonrelevant, or false. Additional surface preparation and/or other test methods may be used as needed to verify the relevance of an indication.

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications that have any dimension greater than 1.5 mm ($\frac{1}{16}$ in.) shall be considered relevant.

*(a) Indications*

*(1)* A linear indication is one having a length greater than three times its width.

*(2)* A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.

*(b) Examination.* All surfaces to be examined shall be free of

*(1)* relevant linear indications

*(2)* relevant rounded indications >5.0 mm ($\frac{3}{16}$ in.)

*(3)* four or more relevant rounded indications in a line separated by 1.5 mm ($\frac{1}{16}$ in.) or less, edge to edge

### 344.5 Radiographic Examination

**344.5.1 Method.** Radiography of castings is covered in (18)
para. 302.3.3. Radiography of welds and of components other than castings shall be performed in accordance with ASME BPVC, Section V, Article 2. For the purpose of image quality indicator (IQI) selection, for welds with reinforcement, the thickness used shall be the nominal wall

thickness, $\overline{T}_w$, plus the allowable external reinforcement and internal reinforcement (protrusion) combined.

#### 344.5.2 Extent of Radiography

*(a) 100% Radiography.* This applies only to girth and miter groove welds and to fabricated branch connection welds comparable to Figure 328.5.4E, unless otherwise specified in the engineering design.

*(b) Random Radiography.* This applies only to girth and miter groove welds.

*(c) Spot Radiography.* This requires a single exposure radiograph in accordance with para. 344.5.1 at a point within a specified extent of welding. For girth, miter, and branch groove welds, the minimum requirement is

*(1)* for sizes ≤DN 65 (NPS 2½), a single elliptical exposure encompassing the entire weld circumference

*(2)* for sizes >DN 65, the lesser of 25% of the inside circumference or 152 mm (6 in.)

For longitudinal welds, the minimum requirement is 152 mm (6 in.) of weld length.

### 344.6 Ultrasonic Examination

**344.6.1 Method.** Examination of castings is covered in para. 302.3.3; other product forms are not covered. Ultrasonic examination of welds shall be performed in accordance with ASME BPVC, Section V, Article 4, except that the alternative specified in (a) and (b) below is permitted for basic calibration blocks specified in T-434.2.1 and T-434.3.

*(a)* When the basic calibration blocks have not received heat treatment in accordance with T-434.1.5, transfer methods shall be used to correlate the responses from the basic calibration block and the component. Transfer is accomplished by noting the difference between responses received from the same reference reflector in the basic calibration block and in the component and correcting for the difference.

*(b)* The reference reflector may be a V-notch (which must subsequently be removed), an angle beam search unit acting as a reflector, or any other reflector that will aid in accomplishing the transfer.

*(c)* When the transfer method is chosen as an alternative, it shall be used, at the minimum

*(1)* for sizes ≤DN 50 (NPS 2), once in each ten welded joints examined

*(2)* for sizes >DN 50 and ≤DN 450 (NPS 18), once in each 1.5 m (5 ft) of welding examined

*(3)* for sizes >DN 450, once for each welded joint examined

*(d)* Each type of material and each size and wall thickness shall be considered separately in applying the transfer method. In addition, the transfer method shall be used at least twice on each type of weld joint.

*(e)* The reference level for monitoring discontinuities shall be modified to reflect the transfer correction when the transfer method is used.

**344.6.2 Acceptance Criteria.** Acceptance criteria shall (18)
be as described in (a) or (b).

*(a)* A linear-type discontinuity is unacceptable if the amplitude of the indication exceeds the reference level and its length exceeds

*(1)* 6 mm (¼ in.) for $\overline{T}_w \le 19$ mm (¾ in.)

*(2)* $\overline{T}_w/3$ for 19 mm (¾ in.) $< \overline{T}_w \le 57$ mm (2¼ in.)

*(3)* 19 mm (¾ in.) for $\overline{T}_w > 57$ mm (2¼ in.)

*(b)* The fracture-mechanics-based ultrasonic examination acceptance criteria in Appendix R may be used if all requirements of Appendix R are met.

### 344.7 In-Process Examination

**344.7.1 Definition.** In-process examination comprises examination of the following, as applicable:

*(a)* joint preparation and cleanliness

*(b)* preheating

*(c)* fit-up, joint clearance, and internal alignment prior to joining

*(d)* variables specified by the joining procedure, including filler material

*(1)* (for welding) position and electrode

*(2)* (for brazing) position, flux, brazing temperature, proper wetting, and capillary action

*(e)* (for welding) condition of the root pass after cleaning — external and, where accessible, internal — aided by liquid penetrant or magnetic particle examination when specified in the engineering design

*(f)* (for welding) slag removal and weld condition between passes

*(g)* appearance of the finished joint

**344.7.2 Method.** The examination is visual, in accordance with para. 344.2, unless additional methods are specified in the engineering design.

## 345 TESTING

### 345.1 Required Leak Test

Prior to initial operation, and after completion of the applicable examinations required by para. 341, each piping system shall be tested to ensure tightness. The test shall be a hydrostatic leak test in accordance with para. 345.4 except as provided herein.

*(a)* At the owner's option, a piping system in Category D fluid service may be subjected to an initial service leak test in accordance with para. 345.7, in lieu of the hydrostatic leak test.

*(b)* Where the owner considers a hydrostatic leak test impracticable, either a pneumatic test in accordance with para. 345.5 or a combined hydrostatic–pneumatic test in

accordance with para. 345.6 may be substituted, recognizing the hazard of energy stored in compressed gas.

*(c)* Where the owner considers both hydrostatic and pneumatic leak testing impracticable, the alternative specified in para. 345.9 may be used if both of the following conditions apply:

*(1)* a hydrostatic test would

*(a)* damage linings or internal insulation

*(b)* contaminate a process that would be hazardous, corrosive, or inoperative in the presence of moisture

*(c)* require significant support modifications for the hydrostatic test load or

*(d)* present the danger of brittle fracture due to low metal temperature during the test

*(2)* a pneumatic test would

*(a)* present an undue hazard of possible release of energy stored in the system or

*(b)* present the danger of brittle fracture due to low metal temperature during the test

*(d)* Unless specified in the engineering design, lines open to the atmosphere, such as vents or drains downstream of the last shutoff valve, need not be leak tested.

## 345.2 General Requirements for Leak Tests

Requirements in para. 345.2 apply to more than one type of leak test.

### (18) 345.2.1 Limitations on Pressure

*(a) Reduced Test Pressure.* If the test pressure would produce a circumferential or longitudinal stress (based on minimum pipe wall thickness) in excess of yield strength at test temperature or is greater than 1.5 times the component rating at test temperature, the test pressure may be reduced to the maximum pressure that will not exceed the lesser of the yield strength or 1.5 times a component rating at test temperature. [See para. 302.3.2.] For metallic bellows expansion joints, see Appendix X, para. X302.2.3(a).

*(b) Test Fluid Expansion.* If a pressure test is to be maintained for a period of time and the test fluid in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

*(c) Preliminary Pneumatic Test.* A preliminary test using air at no more than 170 kPa (25 psi) gage pressure may be made prior to hydrostatic testing to locate major leaks.

### 345.2.2 Other Test Requirements

*(a) Examination for Leaks.* The leak test pressure shall be maintained for at least 10 min and then all joints and connections shall be examined for leaks. The test pressure may be reduced to not less than the design pressure while performing this examination.

*(b) Heat Treatment.* Leak tests shall be conducted after any heat treatment has been completed.

*(c) Low Test Temperature.* The possibility of brittle fracture shall be considered when conducting leak tests at metal temperatures near the ductile–brittle transition temperature.

### 345.2.3 Special Provisions for Testing

*(a) Piping Components and Subassemblies.* Piping components and subassemblies may be tested either separately or as assembled piping.

*(b) Flanged Joints.* Flanged joints used to connect piping components and subassemblies that have previously been tested, and flanged joints at which a blank or blind is used to isolate equipment or other piping during a test, need not be leak tested in accordance with para. 345.1.

*(c) Closure Welds.* The final weld connecting piping systems or components that have been successfully tested in accordance with para. 345 need not be leak tested provided the weld is examined in-process in accordance with para. 344.7 and passes with 100% radiographic examination in accordance with para. 344.5 or 100% ultrasonic examination in accordance with para. 344.6.

*(d) Instrument Connections.* Threaded joints, tubing joints, or a combination of these joints used to connect instruments to previously leak tested piping need not be leak tested in accordance with para. 345.1.

*(e)* See also Appendix F, para. F345.2.3.

### 345.2.4 Externally Pressured Piping

*(a)* Except as provided in (b) below, piping systems subject to external pressure shall be tested at an internal gage pressure 1.5 times the external differential pressure, but not less than 105 kPa (15 psi).

*(b)* As an alternative to leak testing under internal pressure, piping systems designed for vacuum service only may be subjected to a vacuum leak test method, technique, and acceptance criteria specified by the owner. The vacuum leak test shall be performed following a written procedure complying with the applicable technical requirements of ASME BPVC, Section V, Article 10. Leak-testing personnel shall be qualified and certified as required by ASME BPVC, Section V, Article 1, T-120(e) or (f).

### 345.2.5 Jacketed Piping (18)

*(a)* The internal line shall be leak tested on the basis of the internal or external design pressure, whichever results in a higher test pressure. This test must be performed before the jacket is completed if it is necessary to provide visual access to joints of the internal line as required by para. 345.3.1.

*(b)* The jacket shall be leak tested in accordance with para. 345.1 based on the jacket design conditions. The test pressure is permitted to be lower when so specified in the engineering design.

**345.2.6 Repairs or Additions After Leak Testing.** If repairs or additions are made following the leak test, the affected piping shall be retested, except that for minor repairs or additions the owner may waive retest requirements when precautionary measures are taken to assure sound construction.

**345.2.7 Test Records.** Records shall be made of each piping system during the testing, including

*(a)* date of test
*(b)* identification of piping system tested
*(c)* test fluid
*(d)* test pressure
*(e)* certification of results by examiner

These records need not be retained after completion of the test if a certification by the Inspector that the piping has satisfactorily passed pressure testing as required by this Code is retained.

## 345.3 Preparation for Leak Test

### 345.3.1 Joints Exposed

*(a)* Except as provided in (b) and (c) below, all joints, welds (including structural attachment welds to pressure-containing components), and bonds shall be left uninsulated and exposed for examination during leak testing.

*(b)* Joints previously tested in accordance with this Code may be insulated or covered.

*(c)* At the owner's option, joints in Category D Fluid Service that are subject to a hydrostatic leak test (para. 345.4) or an initial service leak test (para. 345.7) may be insulated and have protective weather sheathing installed prior to leak testing. Consideration shall be given to increasing the test period to allow time for possible leakage to pass through the insulation and weather sheathing.

*(d)* All joints may be primed and painted prior to leak testing unless a sensitive leak test (para. 345.8) is required.

**345.3.2 Temporary Supports.** Piping designed for vapor or gas shall be provided with additional temporary supports, if necessary, to support the weight of test liquid.

### 345.3.3 Piping With Expansion Joints

*(a)* Unrestrained expansion joints depend on external main anchors to resist pressure thrust forces. Except as limited in para. 345.3.3(c), a piping system containing unrestrained expansion joints shall be leak tested without any temporary restraints in accordance with para. 345 up to 150% of the expansion joint design pressure. If the required test pressure exceeds 150% of the expansion joint design pressure and the main anchors are not designed to resist the pressure thrust forces at the required test pressure, for that portion of the test when the pressure exceeds 150% of the expansion joint design pressure, the expansion joint shall either be temporarily removed or temporary restraints shall be added to resist the pressure thrust forces.

*(b)* Self-restrained metallic bellows expansion joints (i.e., tied, hinged, pressure balanced, etc.) have restraint hardware designed to resist the pressure thrust forces. Except as limited in para. 345.3.3(c), a piping system containing self-restrained expansion joints shall be leak tested in accordance with para. 345. A self-restrained expansion joint previously shop tested by the manufacturer in accordance with Appendix X may be excluded from the system to be leak tested, except when a sensitive leak test in accordance with para. 345.8 is required. Restraint hardware for all types of expansion joints shall be designed for the pressure thrust forces at the test pressure.

*(c)* When a metallic bellows expansion joint is installed in the piping system subject to a leak test and the leak test pressure determined in accordance with para. 345 exceeds the pressure of the test performed by the manufacturer in accordance with Appendix X, the required leak test pressure shall be reduced to the manufacturer's test pressure.

**345.3.4 Limits of Tested Piping.** Equipment that is not to be tested shall be either disconnected from the piping or isolated by blinds or other means during the test. A valve may be used provided the valve (including its closure mechanism) is suitable for the test pressure.

## 345.4 Hydrostatic Leak Test

**345.4.1 Test Fluid.** The fluid shall be water unless there is the possibility of damage due to freezing or to adverse effects of water on the piping or the process (see para. F345.4.1). In that case another suitable nontoxic liquid may be used. If the liquid is flammable, its flash point shall be at least 49°C (120°F), and consideration shall be given to the test environment.

**345.4.2 Test Pressure.** Except as provided in para. 345.4.3, the hydrostatic test pressure at every point in a metallic piping system shall be as follows:

*(a)* not less than 1.5 times the design pressure.

*(b)* when the design temperature is greater than the test temperature, the minimum test pressure, at the point under consideration, shall be calculated using eq. (24).

$$P_T = 1.5\,PS_T/S \tag{24}$$

where

$P$ = internal design gage pressure
$P_T$ = minimum test gage pressure
$S$ = allowable stress at component design temperature for the prevalent pipe material; see Table A-1 or Table A-1M
$S_T$ = allowable stress at test temperature for the prevalent pipe material; see Table A-1 or Table A-1M

*(c)* in those cases where the piping system may not include pipe itself, any other component in the piping system, other than pipe-supporting elements and bolting, may be used to determine the $S_T/S$ ratio based on the applicable allowable stresses obtained from Table A-1 or Table A-1M. In those cases where the piping system may be made up of equivalent lengths of more than one material, the $S_T/S$ ratio shall be based on the minimum calculated ratio of the included materials.

**345.4.3 Hydrostatic Test of Piping With Vessels as a System**[3]

*(a)* Where the test pressure of piping attached to a vessel is the same as or less than the test pressure for the vessel, the piping may be tested with the vessel at the piping test pressure.

*(b)* Where the test pressure of the piping exceeds the vessel test pressure, and it is not considered practicable to isolate the piping from the vessel, the piping and the vessel may be tested together at the vessel test pressure, provided the owner approves and the vessel test pressure is not less than 77% of the piping test pressure calculated in accordance with para. 345.4.2(b).

## 345.5 Pneumatic Leak Test

**345.5.1 Precautions.** Pneumatic testing involves the hazard of released energy stored in compressed gas. Particular care must therefore be taken to minimize the chance of brittle failure during a pneumatic leak test. Test temperature is important in this regard and must be considered when the designer chooses the material of construction. See para. 345.2.2(c) and Appendix F, paras. F323.4 and F345.5.1.

**345.5.2 Pressure Relief Device.** A pressure relief device shall be provided, having a set pressure not higher than the test pressure plus the lesser of 345 kPa (50 psi) or 10% of the test pressure.

**345.5.3 Test Fluid.** The gas used as test fluid, if not air, shall be nonflammable and nontoxic.

**345.5.4 Test Pressure.** The test pressure shall be not less than 1.1 times the design pressure and shall not exceed the lesser of

*(a)* 1.33 times the design pressure

*(b)* the pressure that would exceed 90% of the pressure described in para. 345.2.1(a)

**345.5.5 Procedure.** The pressure shall be gradually increased until a gage pressure that is the lesser of one-half the test pressure or 170 kPa (25 psi) is attained, at which time a preliminary check shall be made, including examination of joints in accordance with para. 341.4.1(a). Thereafter, the pressure shall be gradually increased in steps until the test pressure is reached, holding the pressure at each step long enough to equalize piping strains. The pressure shall then be reduced to the design pressure before examining for leakage in accordance with para. 345.2.2(a).

## 345.6 Hydrostatic–Pneumatic Leak Test

If a combination hydrostatic–pneumatic leak test is used, the requirements of para. 345.5 shall be met, and the pressure in the liquid filled part of the piping shall not exceed the limits stated in para. 345.4.2.

## 345.7 Initial Service Leak Test

This test is applicable only to piping in Category D Fluid Service, at the owner's option. See para. 345.1(a).

**345.7.1 Test Fluid.** The test fluid is the service fluid.

**345.7.2 Procedure.** During or prior to initial operation, the pressure shall be gradually increased in steps until the operating pressure is reached, holding the pressure at each step long enough to equalize piping strains. A preliminary check shall be made as described in para. 345.5.5 if the service fluid is a gas or vapor.

**345.7.3 Examination for Leaks.** The examination for leaks required by para. 345.2.2(a) shall be conducted while the system is at operating pressure. It is permissible to omit examination for leaks of joints and connections previously tested in accordance with this Code.

## 345.8 Sensitive Leak Test (18)

**345.8.1 Precautions.** The precautions described in para. 345.5.1 shall be considered when applicable.

**345.8.2 Method.** The test shall be the Bubble Test — Direct Pressure Technique in accordance with ASME BPVC, Section V, Article 10, Mandatory Appendix I or another leak test method that has a demonstrated sensitivity not less than $10^{-3}$ std mL/s under test conditions.

When the Bubble Test — Direct Pressure Technique is used

*(a)* the test pressure shall be at least the lesser of 105 kPa (15 psi) or 25% of the design pressure.

*(b)* the pressure shall be gradually increased until a gage pressure equal to the lesser of one-half the test pressure or 170 kPa (25 psi) is attained, at which time a preliminary check shall be made. Then the pressure shall be gradually increased in steps until the test pressure is reached, the pressure being held long enough at each step to equalize piping strains.

## 345.9 Alternative Leak Test

The following procedures and leak test method may be used only under the conditions stated in para. 345.1(c).

[3] The provisions of para. 345.4.3 do not affect the pressure test requirements of any applicable vessel code.

**345.9.1 Examination of Welds.** Welds, including those used in the manufacture of welded pipe and fittings, that have not been subjected to hydrostatic or pneumatic leak tests in accordance with this Code, shall be examined as follows:

*(a)* Circumferential, longitudinal, and spiral (helical seam) groove welds shall be 100% radiographed in accordance with para. 344.5 or 100% ultrasonically examined in accordance with para. 344.6.

*(b)* All welds, including structural attachment welds, not covered in (a) above, shall be examined using the liquid penetrant method (para. 344.4) or, for magnetic materials, the magnetic particle method (para. 344.3).

**345.9.2 Flexibility Analysis.** A flexibility analysis of the piping system shall have been made in accordance with the requirements of para. 319.4.2(b), if applicable, or (c) and (d).

**345.9.3 Test Method.** The system shall be subjected to a sensitive leak test in accordance with para. 345.8.

## 346 RECORDS

### 346.2 Responsibility

It is the responsibility of the piping designer, the manufacturer, the fabricator, and the erector, as applicable, to prepare the records required by this Code and by the engineering design.

### 346.3 Retention of Records

Unless otherwise specified by the engineering design, the following records shall be retained for at least 5 years after the record is generated for the project:

*(a)* examination procedures

*(b)* examination personnel qualifications

*(c)* examination reports

# Chapter VII
# Nonmetallic Piping and Piping Lined With Nonmetals

## A300 GENERAL STATEMENTS

*(a)* Chapter VII pertains to nonmetallic piping and to piping lined with nonmetals.

*(b)* The organization, content, and paragraph designations of this Chapter correspond to those of the first six Chapters (the base Code). The prefix A is used.

*(c)* Provisions and requirements of the base Code apply only as stated in this Chapter.

*(d)* Metallic piping that provides the pressure containment for a nonmetallic lining shall conform to the requirements of Chapters I through VI, and to those in Chapter VII not limited to nonmetals.

*(e)* This Chapter makes no provision for piping to be used under severe cyclic conditions.

*(f)* With the exceptions stated above, Chapter I applies in its entirety.

## PART 1
## CONDITIONS AND CRITERIA

## A301 DESIGN CONDITIONS

Paragraph 301 applies in its entirety, with the exception of paras. 301.2 and 301.3. See below.

### A301.2 Design Pressure

Paragraph 301.2 applies in its entirety, except that references to paras. A302.2.4 and A304 replace references to paras. 302.2.4 and 304, respectively.

### A301.3 Design Temperature

Paragraph 301.3 applies with the following exceptions.

**A301.3.1 Design Minimum Temperature.** Paragraph 301.3.1 applies; but see para. A323.2.2, rather than para. 323.2.2.

**A301.3.2 Uninsulated Components.** The component design temperature shall be the fluid temperature, unless a higher temperature will result from solar radiation or other external heat sources.

## A302 DESIGN CRITERIA

Paragraph A302 states pressure–temperature ratings, stress criteria, design allowances, and minimum design values, together with permissible variations of these factors as applied to the design of piping.

### A302.1 General

The designer shall be satisfied as to the adequacy of the nonmetallic material and its manufacture, considering at least the following:

*(a)* tensile, compressive, flexural, and shear strength, and modulus of elasticity, at design temperature (long term and short term)

*(b)* creep rate at design conditions

*(c)* design stress and its basis

*(d)* ductility and plasticity

*(e)* impact and thermal shock properties

*(f)* temperature limits

*(g)* transition temperature — melting and vaporization

*(h)* porosity and permeability

*(i)* testing methods

*(j)* methods of making joints and their efficiency

*(k)* possibility of deterioration in service

### A302.2 Pressure–Temperature Design Criteria

**A302.2.1 Listed Components Having Established Ratings.** Paragraph 302.2.1 applies, except that reference to Table A326.1 replaces reference to Table 326.1.

**A302.2.2 Listed Components Not Having Specific Ratings.** Nonmetallic piping components for which design stresses have been developed in accordance with para. A302.3, but which do not have specific pressure–temperature ratings, shall be rated by rules for pressure design in para. A304, within the range of temperatures for which stresses are shown in Appendix B, modified as applicable by other rules of this Code.

Piping components that do not have allowable stresses or pressure–temperature ratings shall be qualified for pressure design as required by para. A304.7.2.

**A302.2.3 Unlisted Components.** Paragraph 302.2.3 applies, except that references to Table A326.1 and paras. A304 and A323 replace references to Table 326.1 and paras. 304 and 323, respectively. (18)

**A302.2.4 Allowances for Pressure and Temperature Variations**

*(a) Nonmetallic Piping.* Allowances for variations of pressure or temperature, or both, above design conditions are not permitted. The most severe conditions of coincident pressure and temperature shall be used to determine the design conditions for a piping system. See paras. 301.2 and 301.3.

*(b) Metallic Piping With Nonmetallic Lining.* Allowances for pressure and temperature variations provided in para. 302.2.4 are permitted only if the suitability of the lining material for the increased conditions is established through prior successful service experience or tests under comparable conditions.

**A302.2.5 Rating at Junction of Different Services.** When two services that operate at different pressure–temperature conditions are connected, the valve segregating the two services shall be rated for the more severe service condition.

## A302.3 Allowable Stresses and Other Design Limits

**A302.3.1 General**

*(a)* Table B-1 contains hydrostatic design stresses (HDS). Tables B-2 and B-3 provide listings of specifications that meet the criteria of paras. A302.3.2(b) and (c), respectively. Tables B-4 and B-5 contain allowable pressures. These HDS values, allowable stress criteria, and pressures shall be used in accordance with the Notes to Appendix B, and may be used in design calculations (where the allowable stress *S* means the appropriate design stress) except as modified by other provisions of this Code. Use of hydrostatic design stresses for calculations other than pressure design has not been verified. The bases for determining allowable stresses and pressures are outlined in para. A302.3.2.

*(b)* The stresses and allowable pressures are grouped by materials and listed for stated temperatures. Straight-line interpolation between temperatures is permissible.

**A302.3.2 Bases for Allowable Stresses and Pressures**[1] (18)

*(a) Thermoplastics.* The method of determining HDS is described in ASTM D2837. HDS values are given in Table B-1 for those materials and temperatures for which sufficient data have been compiled to substantiate the determination of stress.

*(b) Reinforced Thermosetting Resin (Laminated).* The design stress (DS) values for materials listed in Table B-2 shall be one-tenth of the minimum tensile strengths specified in ASTM C582 and are valid only in the temperature range from −29°C (−20°F) through 82°C (180°F).

*(c) Reinforced Thermosetting Resin and Reinforced Plastic Mortar (Filament Wound and Centrifugally Cast).* The hydrostatic design basis stress (HDBS) values for materials listed in Table B-3 shall be obtained by the procedures in ASTM D2992 and are valid only at 23°C (73°F). HDS shall be obtained by multiplying the HDBS by a service (design) factor[2] selected for the application, in accordance with procedures described in ASTM D2992, within the following limits:

*(1)* When using the cyclic HDBS, the service (design) factor *F* shall not exceed 1.0.

*(2)* When using the static HDBS, the service (design) factor *F* shall not exceed 0.5.

*(d) Other Materials.* Allowable pressures in Tables B-4 and B-5 have been determined conservatively from physical properties of materials conforming to the listed specifications, and have been confirmed by extensive experience. Use of other materials shall be qualified as required by para. A304.7.2.

[1] Titles of ASTM Specifications and AWWA Standards referenced herein are as follows:
ASTM C14, Concrete Sewer, Storm Drain, and Culvert Pipe
ASTM C301, Method of Testing Vitrified Clay Pipe
ASTM C582, Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion Resistant Equipment
ASTM D2321, Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications
ASTM D2837, Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
ASTM D2992, Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-RTR) Pipe and Fittings
ASTM D3839, Underground Installation of Fiberglass Pipe
AWWA C900, Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 60 In. (100 mm Through 1,500 mm)
AWWA C950, Glass-Fiber-Reinforced Thermosetting Resin Pressure Pipe

[2] The service (design) factor, *F*, should be selected by the designer after evaluating fully the service conditions and the engineering properties of the specific material under consideration. Aside from the limits in paras. A302.3.2(c)(1) and (2), it is not the intent of this Code to specify service (design) factors.

#### A302.3.3 Limits of Calculated Stresses Due to Sustained Loads[1]

*(a) Internal Pressure Stresses.* Limits of stress due to internal pressure are covered in para. A304.

*(b) External Pressure Stresses.* Stresses due to uniform external pressure shall be considered safe when the wall thickness of the component and its means of stiffening have been qualified as required by para. A304.7.2.

*(c) External Loading Stresses.* Design of piping under external loading shall be based on the following:

*(1) Thermoplastic Piping.* ASTM D2321 or AWWA C900.

*(2) Reinforced Thermosetting Resin (RTR) and Reinforced Plastic Mortar (RPM) Piping.* ASTM D3839 or Appendix A of AWWA C950.

*(3)* Strain and possible buckling shall be considered when determining the maximum allowable deflection in (1) or (2) above, but in no case shall the allowable diametral deflection exceed 5% of the pipe inside diameter.

*(4)* Nonmetallic piping not covered in (1) or (2) above shall be subjected to a crushing or three-edge bearing test in accordance with ASTM C14 or C301; the allowable load shall be 25% of the minimum value obtained.

(18) **A302.3.4 Limits of Calculated Stresses Due to Occasional Loads**

*(a) Operation*

*(1)* For other than RTR and RPM piping, the sum of stresses in any component in a piping system due to sustained loads, such as pressure and weight, and of the stresses produced by occasional loads, such as wind or earthquake, shall not exceed the limits in the applicable part of para. A302.3.3.

*(2)* For RTR and RPM piping, the sum of stresses due to operating loads plus stresses due to occasional loads may be as much as 1.33 times the limits in the applicable part of para. A302.3.3.

*(3)* Wind and earthquake forces need not be considered as acting concurrently.

*(b) Test.* Stresses due to test conditions are not subject to the limitations in para. A302.3.3. It is not necessary to consider other occasional loads, such as wind and earthquake, as occurring concurrently with test loads.

### A302.4 Allowances

Paragraph 302.4 applies in its entirety.

## PART 2
## PRESSURE DESIGN OF PIPING COMPONENTS

### A303 GENERAL

Paragraph 303 applies, except that references to Table A326.1 and para. A302.2.1 replace references to Table 326.1 and para. 302.2.1. For nonmetallic components, reference to para. A304 replaces reference to para. 304.

### A304 PRESSURE DESIGN OF PIPING COMPONENTS

### A304.1 Straight Pipe

#### A304.1.1 General

*(a)* The required thickness of straight sections of pipe shall be determined by eq. (25).

$$t_m = t + c \tag{25}$$

The minimum thickness $T$ for the pipe selected, considering manufacturer's minus tolerance, shall be not less than $t_m$.

*(b)* The following nomenclature is used in the equations for pressure design of straight pipe:

$c$ = the sum of mechanical allowances (thread or groove depth) plus corrosion and erosion allowance. For threaded components, the nominal thread depth (dimension $h$ of ASME B1.20.1 or equivalent) shall apply. For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.
$D$ = outside diameter of pipe
$F$ = service (design) factor. See para. A302.3.2(c).
$P$ = internal design gage pressure
$S$ = design stress from applicable Table in Appendix B
$T$ = pipe wall thickness (measured or minimum in accordance with the purchase specification)
$t$ = pressure design thickness, as calculated in accordance with para. A304.1.2 for internal pressure or as determined in accordance with para. A304.1.3 for external pressure
$t_m$ = minimum required thickness, including mechanical, corrosion, and erosion allowances

**A304.1.2 Straight Nonmetallic Pipe Under Internal Pressure.** The internal pressure design thickness, $t$, shall be not less than that calculated by one of the following equations, using stress values listed in or derived from the appropriate table in Appendix B:

*(a) Thermoplastic Pipe* [see para. A302.3.2(a)]

$$t = \frac{PD}{2S + P}(\text{Table B-1}) \quad (26a)$$

*(b) RTR (Laminated) Pipe* [see para. A302.3.2(b)][3]

$$t = \frac{PD}{2S + P}(\text{Table B-2}) \quad (26b)$$

*(c) RTR (Filament Wound) and RPM (Centrifugally Cast) Pipe* [see para. A302.3.2(c)][3]

$$t = \frac{PD}{2SF + P}(\text{Table B-3}) \quad (26c)$$

#### A304.1.3 Straight Pipe Under External Pressure

*(a) Nonmetallic Pipe.* The external pressure design thickness, $t$, shall be qualified as required by para. A304.7.2.

*(b) Metallic Pipe Lined With Nonmetals*

*(1)* The external pressure design thickness, $t$, for the base (outer) material shall be determined in accordance with para. 304.1.3.

*(2)* The external pressure design thickness, $t$, for the lining material shall be qualified as required by para. A304.7.2.

### A304.2 Curved and Mitered Segments of Pipe

**A304.2.1 Pipe Bends.** The minimum required thickness, $t_m$, of a bend, after bending, shall be determined as for straight pipe in accordance with para. A304.1.

**A304.2.2 Elbows.** Manufactured elbows not in accordance with para. A303 shall be qualified as required by para. A304.7.2.

**A304.2.3 Miter Bends.** Miter bends shall be qualified as required by para. A304.7.2.

### A304.3 Branch Connections

**A304.3.1 General.** A pipe having a branch connection is weakened by the opening that must be made in it and, unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide added reinforcement. The amount of reinforcement shall be qualified as required by para. A304.7.2 except as provided in para. A304.3.2.

**A304.3.2 Branch Connections Using Fittings.** It may be assumed without calculation that a branch connection has adequate strength to sustain the internal and external pressure that will be applied to it if it utilizes a fitting (a tee, lateral, or cross) in accordance with para. A303.

**A304.3.3 Additional Design Considerations.** The requirements of paras. A304.3.1 and A304.3.2 are intended to assure satisfactory performance of a branch connection subjected only to internal or external pressure. The designer shall also consider paras. 304.3.5(a), (c), and (d).

### A304.4 Closures

Closures not in accordance with para. A303 shall be qualified as required by para. A304.7.2.

### A304.5 Pressure Design of Nonmetallic Flanges

#### A304.5.1 General

*(a)* Flanges not in accordance with para. A303, or A304.5.1(b) or (d) shall be qualified as required by para. A304.7.2.

*(b)* Flanges for use with flat ring gaskets may be designed in accordance with ASME BPVC, Section VIII, Division 1, Appendix 2, except that the allowable stresses and temperature limits of this Code shall govern. Nomenclature shall be as defined in ASME BPVC, except for the following:

$P$ = design gage pressure
$S_a$ = bolt design stress at atmospheric temperature[4]
$S_b$ = bolt design stress at design temperature[4]
$S_f$ = allowable stress for flange material from Table B-1, B-2, or B-3

*(c)* The rules in (b) above are not applicable to a flanged joint having a gasket that extends outside the bolts (usually to the outside diameter of the flange).

*(d)* For flanges that make solid contact outside the bolts, ASME BPVC, Section VIII, Division 1, Appendix Y should be used.

**A304.5.2 Blind Flanges.** Blind flanges not in accordance with para. A303 may be designed in accordance with para. 304.5.2, except that allowable stress, $S$, shall be taken from Tables in Appendix B. Otherwise, they shall be qualified as required by para. A304.7.2.

### A304.6 Reducers

Reducers not in accordance with para. A303 shall be qualified as required by para. A304.7.2.

### A304.7 Pressure Design of Other Components

**A304.7.1 Listed Components.** Other pressure containing components, manufactured in accordance with standards in Table A326.1 but not covered elsewhere in para. A304, may be utilized in accordance with para. A303.

**A304.7.2 Unlisted Components.** Pressure design of unlisted components and joints, to which the rules elsewhere in para. A304 do not apply, shall be based on calculations consistent with the design criteria of this Code. Calculations shall be substantiated by one or both of the means stated in (a) and (b) below, considering

[3] The internal design pressure thickness, $t$, shall not include any thickness of the pipe wall reinforced with less than 20% by weight of reinforcing fibers.

[4] Bolt design stresses shall not exceed those in Table A-2 or Table A-2M.

applicable ambient and dynamic effects in paras. 301.4 through 301.11.

*(a)* extensive, successful service experience under comparable design conditions with similarly proportioned components made of the same or like material

*(b)* performance test under design conditions including applicable dynamic and creep effects, continued for a time period sufficient to determine the acceptability of the component or joint for its design life

For (a) or (b) above, the designer may interpolate between sizes, wall thicknesses, and pressure classes, and may determine analogies among related materials.

**A304.7.3 Nonmetallic Components With Metallic Pressure Parts.** Components not covered by standards in Table A326.1, in which both nonmetallic and metallic parts contain the pressure, shall be evaluated by applicable requirements of para. 304.7.2 as well as those of para. A304.7.2.

# PART 3
# FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

## A305 PIPE

Listed pipe may be used in Normal Fluid Service, subject to the limitations of the pressure-containing material and para. A323.4. Unlisted pipe may be used only in accordance with para. A302.2.3.

## A306 FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

*General.* Fittings, bends, miters, laps, and branch connections may be used in accordance with paras. A306.1 through A306.5. Pipe and other materials used in such components shall be suitable for the manufacturing process and the fluid service.

### A306.1 Pipe Fittings

**A306.1.1 Listed Fittings.** Listed fittings may be used in Normal Fluid Service subject to limitations on materials.

**A306.1.2 Unlisted Fittings.** Unlisted fittings may be used only in accordance with para. A302.2.3.

### A306.2 Pipe Bends

**A306.2.1 General.** A bend made in accordance with para. A332 and verified for pressure design in accordance with para. A304.2.1 shall be suitable for the same service as the pipe from which it is made.

**A306.2.2 Corrugated and Other Bends.** Bends of other designs (such as creased or corrugated) shall be qualified for pressure design as required by para. A304.7.2.

### A306.3 Miter Bends

Except as specified in para. 306.3.2, a miter bend that conforms to para. A304.2.3 may be used in Normal Fluid Service.

### A306.4 Fabricated or Flared Laps

The following requirements do not apply to fittings conforming to para. A306.1.

**A306.4.1 Fabricated Laps**

*(a)* The requirements in paras. 306.4.1(a) and (b) shall be met.

*(b)* Lap material shall be suitable for the service conditions. Pressure design shall be qualified as required by para. A304.7.2.

**A306.4.2 Flared Laps.** Flared laps shall not be used in nonmetallic piping.

### A306.5 Fabricated Branch Connections

The following requirements do not apply to fittings conforming to para. A306.1.

**A306.5.1 General.** A fabricated branch connection made by bonding the branch pipe directly to the header pipe, with or without added reinforcement as stated in para. 328.5.4, and shown in Figure 328.5.4, may be used in Normal Fluid Service, provided that pressure design is qualified as required by para. A304.7.2.

**A306.5.2 Specific Requirements.** Fabricated branch connections shall be made as specified in para. A328.5.

## A307 VALVES AND SPECIALTY COMPONENTS

Paragraph 307 applies in its entirety, except that in para. 307.1.2 references to paras. A302.2.3 and A304.7.2 replace references to paras. 302.2.3 and 304.7.2, respectively.

## A308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

### A308.1 General

Paragraph 308.1 applies, except that in para. 308.1.2 reference to para. A302.2.3 replaces reference to para. 302.2.3.

### A308.2 Nonmetallic Flanges

**A308.2.1 General**

*(a)* Flanges shall be adequate, with suitable facing, gasketing, and bolting, to develop the full rating of the joint and to withstand expected external loadings.

*(b)* The designer should consult the manufacturer for ratings of flanges.

**A308.2.2 Threaded Flanges.** Threaded flanges are subject to the requirements for threaded joints in para. A314.

## A308.3 Flange Facings

Paragraph 308.3 applies in its entirety.

## A308.4 Limitations on Gaskets

See also Appendix F, para. F308.4.

**A308.4.1 Lining Used as Facing or Gasket.** Lining material extended over the flange face and used as a gasket shall conform to para. 308.4.

# A309 BOLTING

Bolting includes bolts, bolt studs, studs, cap screws, nuts, and washers. See Appendix F, para. F309.

## A309.1 General

Paragraph 309.1 applies in its entirety.

## A309.2 Specific Bolting

Any bolting that meets the requirements of para. 309.1 may be used with any combination of flange materials and flange facings. Joint assembly shall conform to the requirements of para. A335.2.

## A309.3 Tapped Holes in Nonmetallic Components

Tapped holes for pressure-retaining bolting in piping components may be used provided pressure design is qualified as required by para. A304.7.2.

# PART 4
# FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS

# A310 GENERAL

Paragraph 310 applies in its entirety.

# A311 BONDED JOINTS IN PLASTICS

## A311.1 General

Bonding shall be in accordance with para. A328 and examination shall be in accordance with para. A341.4.1 for use in Normal Fluid Service, subject to the limitations of the material.

## A311.2 Specific Requirements

**A311.2.1 Fillet Bonds.** A fillet bond may be used only in conjunction with a qualified hot gas welding procedure for bonding (see para. A328.5.2).

**A311.2.2 Seal Bonds.** A seal bond may be used only to prevent leakage of a threaded joint and only if it has been demonstrated that there will be no deleterious effect on the materials bonded.

**A311.2.3 Joints Limited to Category D Fluid Service.** Joints that have been examined in accordance with para. 341.4.2 may be used only for Category D Fluid Service.

# A312 FLANGED JOINTS

The designer should consult the manufacturer for ratings of flanged joints in nonmetallic piping and in piping lined with nonmetals.

# A313 EXPANDED JOINTS

Paragraph 313 applies in its entirety.

# A314 THREADED JOINTS

## A314.1 General

A threaded joint is suitable for use in Normal Fluid Service, subject to the limitations of the material and requirements elsewhere in para. A314. A joint conforming to para. 314.1(d) shall not be used.

## A314.2 Specific Requirements

### A314.2.1 Thermoplastic Piping

*(a)* Polyethylene (PE) pipe and tubing shall not be joined by threaded joints.

*(b)* Threaded joints in other thermoplastic piping shall conform to all of the following:

*(1)* The pipe wall shall be at least as thick as Schedule 80 as defined in ASTM D1785.

*(2)* Threads shall be NPT, and shall conform to ASME B1.20.1 or ASTM F1498.

*(3)* Threads shall conform to applicable standards in Table A326.1.

*(4)* A suitable thread sealant shall be used.

**A314.2.2 Reinforced Thermosetting Resin Piping.** Threaded joints in reinforced thermosetting resin (RTR) piping shall conform to the following:

*(a)* External threads shall be factory cut or molded on special thick-walled pipe ends.

*(b)* Matching internal threads shall be factory cut or molded in the fittings.

*(c)* Threading of plain ends of RTR pipe is not permitted, except where such threads are limited to the function of a mechanical lock to matching internal threads factory cut or molded in the bottom portions of fittings with deep sockets.

(d) Factory cut or molded threaded nipples, couplings, or adapters, bonded to plain-end RTR pipe and fittings, may be used where it is necessary to provide connections to threaded metallic piping.

**A314.2.3 Reinforced Plastic Mortar Piping.** Threaded joints are not permitted in reinforced plastic mortar (RPM) piping.

## A315 TUBING JOINTS

Paragraph 315 applies in its entirety, subject to material limitations, exclusion of 315.2(b) regarding severe cyclic conditions, and replacement of references to Table 326.1 and para. 304.7.2 with references to Table A326.1 and para. A304.7.2, respectively.

## A316 CAULKED JOINTS

Paragraph 316 applies in its entirety.

## A318 SPECIAL JOINTS

Special joints are those not covered elsewhere in Chapter VII, Part 4, such as bell type and packed gland type joints.

### A318.1 General

Paragraph 318.1 applies in its entirety, except that, in para. 318.1.2, reference to para. A304.7.2 replaces reference to para. 304.7.2.

### A318.2 Specific Requirements

Paragraph 318.2 applies with the exception of para. 318.2.3.

### A318.3 Piping Lined With Nonmetals

#### A318.3.1 Welding of Metallic Piping

(a) *General.* Joints made in accordance with the rules in para. A329.1 may be used in Normal Fluid Service, subject to material limitations.

(b) *Specific Requirements.* Welds shall be limited to those that do not affect the serviceability of the lining.

#### A318.3.2 Flared Linings

(a) *General.* Flared ends of linings made in accordance with the rules in para. A329.2 may be used in Normal Fluid Service, subject to material limitations.

(b) *Specific Requirements.* Flaring shall be limited to applications that do not affect the serviceability of the lining.

### A318.4 Flexible Elastomeric Sealed Joints

Flexible elastomeric seals conforming to the following may be used in Normal Fluid Service, subject to material limitations:

(a) Seals for joints in thermoplastic piping shall conform to ASTM D3139.

(b) Seals for joints in RTR and RPM piping shall conform to ASTM D4161.

# PART 5
# FLEXIBILITY AND SUPPORT

## A319 FLEXIBILITY OF NONMETALLIC PIPING

### A319.1 Requirements

**A319.1.1 Basic Requirements.** Piping systems shall be designed to prevent thermal expansion or contraction, pressure expansion, or movement of piping supports and terminals from causing

(a) failure of piping or supports from overstrain or fatigue

(b) leakage at joints

(c) detrimental stresses or distortion in piping or in connected equipment (e.g., pumps), resulting from excessive thrusts and moments in the piping

**A319.1.2 Specific Requirements**

(a) In para. A319, guidance, concepts, and data are given to assist the designer in assuring adequate flexibility in piping systems. No specific stress-limiting criteria or methods of stress analysis are presented, since stress–strain behavior of most nonmetals differs considerably from that of metals covered by para. 319 and is less well defined for mathematical analysis.

(b) Piping systems should be designed and laid out so that flexural stresses resulting from displacement due to expansion, contraction, and other movement are minimized. This concept requires special attention to supports, terminals, and other restraints, as well as to the techniques outlined in para. A319.7. See also para. A319.2.2(b).

(c) Further information on design of thermoplastic piping can be found in PPI Technical Report TR-21.

### A319.2 Concepts

**A319.2.1 Displacement Strains.** The concepts of strain (18)
imposed by restraint of thermal expansion or contraction, and by external movement, described in para. 319.2.1, apply in principle to nonmetals. Nevertheless, the assumption that stresses throughout the piping systems can be predicted from these strains because of fully elastic behavior of the piping materials is not always valid.

(a) In thermoplastics piping, displacement strains are not likely to produce immediate failure but may result in detrimental distortion. Progressive deformation may occur upon repeated thermal cycling or on prolonged exposure to elevated temperature.

*(b)* In brittle piping (e.g., porcelain and glass) and some RTR and RPM piping, the materials show rigid behavior and develop high displacement stresses up to the point of sudden breakage due to overstrain.

*(c)* RTR and RPM piping are assumed to display linear elastic behavior, having displacement stresses proportional to displacement strains.

(18) **A319.2.2 Displacement Stresses**

*(a) Elastic Behavior.* The assumption that displacement strains will produce proportional stress over a sufficiently wide range to justify an elastic stress analysis is not always valid for nonmetals. RTR and RPM piping shall be designed for linear elastic behavior, having displacement stresses proportional to displacement strains. In brittle piping, strains initially will produce relatively large elastic stresses. The total displacement strain must be kept small, however, since overstrain results in failure rather than plastic deformation. In thermoplastic piping, strains generally will produce stresses of the overstrained (plastic) type, even at relatively low values of total displacement strain. If a method of flexibility analysis that assumes elastic behavior is selected for thermoplastic piping, the designer shall demonstrate its validity for the piping system under consideration and shall establish safe limits for computed stresses.

*(b) Overstrained Behavior.* Stresses cannot be considered proportional to displacement strains throughout a piping system in which an excessive amount of strain may occur in localized portions of the piping [an unbalanced system; see para. 319.2.2(b)] or in which elastic behavior of the piping material cannot be assumed. Overstrain shall be minimized by system layout and excessive displacements shall be minimized by special joints or expansion devices (see para. A319.7).

**A319.2.3 Cold Spring.** Cold spring is the intentional deformation of piping during assembly to produce a desired initial displacement or reaction. Cold spring may be beneficial in serving to balance the magnitude of the reaction under initial and extreme displacement conditions. When cold spring is properly applied, there is less likelihood of overstrain during initial operation. There is also less deviation from as-installed dimensions during initial operation, so that hangers will not be displaced as far from their original settings. No credit for cold spring is permitted in stress range calculations, or in calculating thrusts and moments.

### A319.3 Properties for Flexibility Analysis

**A319.3.1 Thermal Expansion Data.** Appendix C lists coefficients of thermal expansion for several nonmetals. More precise values in some instances may be obtainable from manufacturers of components. If these values are to be used in stress analysis, the thermal displacements shall be determined as stated in para. 319.3.1.

**A319.3.2 Modulus of Elasticity.** Appendix C lists representative data on the tensile modulus of elasticity, *E*, for several nonmetals as obtained under typical laboratory rate of strain (loading) conditions. More precise values of the short-term and working estimates of effective moduli of elasticity for given conditions of loading and temperature may be obtainable from the manufacturer. For materials and temperatures not listed, refer to ASTM or PPI documents, or to manufacturer's data.

*(a)* Because of their viscoelasticity, the effective moduli of thermoplastics under actual conditions of use will depend on both the specific course of the strain (or load) with time and the specific characteristics of the thermoplastic.

*(b)* The modulus may also vary with the orientation of the specimen. Because the reinforcement plays a significant role in developing the physical properties for RTR and RPM piping, the modulus may vary with the type and orientation of the reinforcement.

**A319.3.3 Poisson's Ratio.** Poisson's ratio varies widely depending upon material and temperature. For that reason, simplified formulas used in stress analysis for metals may not be valid for nonmetals. For RTR and RPM piping, Poisson's ratio varies with the orientation of the reinforcement.

**A319.3.4 Dimensions.** Nominal thicknesses and outside diameters of pipe and fittings shall be used in flexibility calculations.

### A319.4 Analysis

**A319.4.1 Formal Analysis Not Required.** No formal analysis is required for a piping system that

*(a)* duplicates, or replaces without significant change, a system operating with a successful service record

*(b)* can readily be judged adequate by comparison with previously analyzed systems, or

*(c)* is laid out with a conservative margin of inherent flexibility, or employs joining methods or expansion joint devices, or a combination of these methods, in accordance with manufacturers' instructions

**A319.4.2 Formal Analysis Requirements.** For a piping system that does not meet the above criteria, the designer shall demonstrate adequate flexibility by simplified, approximate, or comprehensive stress analysis, using a method that can be shown to be valid for the specific case. If substantially elastic behavior can be demonstrated for the piping system [see para. A319.2.2(a)], methods outlined in para. 319.4 may be applicable.

### A319.5 Reactions

Paragraph 319.5 may be applicable if a formal stress analysis can be shown to be valid for the specific case.

### A319.6 Movements

Special attention shall be given to movement (displacement or rotation) of piping with respect to supports and points of close clearance. Movements of the run pipe at the junction of a small branch connection shall be considered in determining the need for flexibility in the branch pipe.

### A319.7 Means of Increasing Flexibility

Piping layout often provides adequate inherent flexibility through changes in direction, wherein displacements produce chiefly bending and torsional strains of low magnitude. The amount of tension or compression strain (which can produce larger reactions) usually is small.

Where piping lacks inherent flexibility or is unbalanced, additional flexibility shall be provided by one or more of the following means: bends, loops, or offsets; swivel or flexible joints; corrugated, bellows, or slip-joint expansion joints; or other devices permitting angular, rotational, or axial movement. Suitable anchors, ties, or other devices shall be provided as necessary to resist end forces produced by fluid pressure, frictional resistance to movement, and other causes.

## A321 PIPING SUPPORT

Paragraph 321 applies in its entirety.

### A321.5 Supports for Nonmetallic Piping

**A321.5.1 General.** In addition to other applicable requirements of para. 321, supports, guides, and anchors shall be selected and applied to comply with the principles and requirements of para. A319 and the following:

*(a)* Piping shall be supported, guided, and anchored in such a manner as to prevent damage to the piping. Point loads and narrow areas of contact between piping and supports shall be avoided. Suitable padding shall be placed between piping and supports where damage to piping may occur.

*(b)* Valves and equipment that would transmit excessive loads to the piping shall be independently supported to prevent such loads.

*(c)* Consideration shall be given to mechanical guarding in traffic areas.

*(d)* Manufacturers' recommendations for support shall be considered.

**A321.5.2 Supports for Thermoplastic, RTR, and RPM Piping.** Supports shall be spaced to avoid excessive sag or deformation at the design temperature and within the design life of the piping system. Decreases in the modulus of elasticity with increasing temperature and creep of material with time shall be considered when applicable. The coefficient of thermal expansion shall be considered in the design and location of supports.

**A321.5.3 Supports for Brittle Piping.** Brittle piping, such as glass, shall be well supported but free of hindrance to expansion or other movement. Not more than one anchor shall be provided in any straight run without an expansion joint.

# PART 6
# SYSTEMS

## A322 SPECIFIC PIPING SYSTEMS

### A322.3 Instrument Piping

Paragraph 322.3 applies in its entirety, except that references to paras. A301 and A302.2.4 replace references to paras. 301 and 302.2.4, respectively.

### A322.6 Pressure-Relieving Systems

Paragraph 322.6 applies in its entirety, except for para. 322.6.3. See para. A322.6.3.

**A322.6.3 Overpressure Protection.** Paragraph 322.6.3 applies, except that maximum relieving pressure shall be in accordance with para. A302.2.4.

# PART 7
# MATERIALS

## A323 GENERAL REQUIREMENTS

### A323.1 Materials and Specifications

Paragraph 323.1 applies except for para. 323.1.4. See para. A323.1.4.

**A323.1.4 Reclaimed Materials.** Reclaimed piping components may be used, provided they are properly identified as conforming to a listed or published specification (see para. 323.1.1) and otherwise meet the requirements of this Code. The user shall verify that components are suitable for the intended service. Sufficient cleaning, examination, and testing shall be performed to determine the minimum available wall thickness and freedom from any of the following to an extent that would be unacceptable in the intended service:

*(a)* imperfections

*(b)* reduction of mechanical properties, or

*(c)* absorption of deleterious substances

### A323.2 Temperature Limitations

The designer shall verify that materials that meet other requirements of the Code are suitable for service throughout the operating temperature range. Also see the Notes for Tables B-1 through B-5 in Appendix B.

#### A323.2.1 Upper Temperature Limits, Listed Materials

*(a)* Except as provided in (b) below, a listed material shall not be used at a design temperature higher than the maximum for which a stress value or rating is shown, or higher than the maximum recommended temperature in Table A323.4.2C for RTR materials and in Table A323.4.3 for thermoplastics used as linings.

*(b)* A listed material may be used at a temperature higher than the maximum stated in (a) above if there is no prohibition in Appendix B or elsewhere in the Code, and if the designer verifies the serviceability of the material in accordance with para. 323.2.4.

#### A323.2.2 Lower Temperature Limits, Listed Materials

*(a)* Materials for use at design minimum temperatures below certain limits must usually be tested to determine that they have suitable toughness for use in Code piping. Table A323.2.2 sets forth those requirements.

*(b)* When materials are qualified for use at temperatures below the minimum temperature listed in Appendix B, the allowable stresses or pressures shall not exceed the values for the lowest temperatures shown.

*(c)* See also the recommended limits in Table A323.4.2C for reinforced thermosetting resin pipe and in Table A323.4.3 for thermoplastics used as linings.

**A323.2.3 Temperature Limits, Unlisted Materials.** Paragraph 323.2.3 applies.

**A323.2.4 Verification of Serviceability.** When an unlisted material is to be used, or when a listed material is to be used above or below the limits in Appendix B, Table A323.4.2C, or Table A323.4.3, the designer shall comply with the requirements of para. 323.2.4.

### A323.4 Fluid Service Requirements for Nonmetallic Materials

#### A323.4.1 General

*(a)* Nonmetallic materials shall be safeguarded against excessive temperature, shock, vibration, pulsation, and mechanical abuse in all fluid services.

*(b)* Requirements in para. A323.4 apply to pressure-containing parts. They do not apply to materials used for supports, gaskets, or packing. See also Appendix F, para. FA323.4.

#### A323.4.2 Specific Requirements

*(a) Thermoplastics*

*(1)* They shall not be used in flammable fluid service above ground, unless all of the following are met:

*(a)* The size of the piping does not exceed DN 25 (NPS 1).

*(b)* Owner's approval is obtained.

*(c)* Safeguarding in accordance with Appendix G is provided.

*(d)* The precautions of Appendix F, paras. F323.1(a) through (c) are considered.

*(2)* They shall be safeguarded when used in other than Category D Fluid Service.

*(3)* PVC and CPVC shall not be used in compressed air or other compressed gas service.

*(b) Reinforced Plastic Mortars (RPM) Piping.* This piping shall be safeguarded when used in other than Category D Fluid Service.

*(c) Reinforced Thermosetting Resins (RTR) Piping.* This piping shall be safeguarded when used in toxic or flammable fluid services. Table A323.4.2C gives the recommended temperature limits for reinforced thermosetting resins.

*(d) Borosilicate Glass and Porcelain*

*(1)* They shall be safeguarded when used in toxic or flammable fluid services.

*(2)* They shall be safeguarded against large, rapid temperature changes in fluid services.

#### A323.4.3 Piping Lined With Nonmetals

*(a) Metallic Piping Lined With Nonmetals.* Fluid service requirements for the base (outer) material in para. 323.4 govern except as stated in (d) below.

*(b) Nonmetallic Piping Lined With Nonmetals.* Fluid service requirements for the base (outer) material in para. A323.4.2 govern, except as stated in (d) below.

*(c) Nonmetallic Lining Materials.* The lining may be any material that, in the judgment of the user, is suitable for the intended service and for the method of manufacture and assembly of the piping. Fluid service requirements in para. A323.4.2 do not apply to materials used as linings.

*(d)* Properties of both the base and lining materials, and of any bond between them, shall be considered in establishing temperature limitations. Table A323.4.3 gives recommended temperature limits for thermoplastic materials used as linings.

### A323.5 Deterioration of Materials in Service

Paragraph 323.5 applies in its entirety.

## A325 MATERIALS — MISCELLANEOUS

Paragraph 325 applies in its entirety.

# PART 8
# STANDARDS FOR PIPING COMPONENTS

## A326 DIMENSIONS AND RATINGS OF COMPONENTS

### A326.1 Requirements

Paragraph 326 applies in its entirety except that references to Table A326.1 and Appendix B replace references to Table 326.1 and Appendix A, respectively.

### Table A323.2.2 Requirements for Low Temperature Toughness Tests for Nonmetals

| Type of Material | Column A At or Above Listed Minimum Temperature | Column B Below Listed Minimum Temperature |
|---|---|---|
| Listed nonmetallic materials | No added requirement | The designer shall have test results at or below the lowest expected service temperature which assure that the materials and bonds will have adequate toughness and are suitable at the design minimum temperature. |
| Unlisted materials | An unlisted material shall conform to a published specification. Where composition, properties, and product form are comparable to those of a listed material, requirements for the corresponding listed material shall be met. Other unlisted materials shall be qualified as required in Column B. | |

GENERAL NOTE: These requirements are in addition to the requirements of the material specification.



### Table A323.4.2C Recommended Temperature Limits for Reinforced Thermosetting Resin Pipe

| Materials | | Recommended Temperature Limits | | | |
|---|---|---|---|---|---|
| | | Minimum | | Maximum | |
| Resin | Reinforcing | °C | °F | °C | °F |
| Epoxy | Glass fiber | −29 | −20 | 149 | 300 |
| Phenolic | Glass fiber | −29 | −20 | 149 | 300 |
| Furan | Carbon | −29 | −20 | 93 | 200 |
| Furan | Glass fiber | −29 | −20 | 93 | 200 |
| Polyester | Glass fiber | −29 | −20 | 93 | 200 |
| Vinyl ester | Glass fiber | −29 | −20 | 93 | 200 |

GENERAL NOTE: These temperature limits apply only to materials listed and do not reflect evidence of successful use in specific fluid services at these temperatures. The designer should consult the manufacturer for specific applications, particularly as the temperature limits are approached.

### Table A323.4.3 Recommended Temperature Limits for Thermoplastics Used as Linings

| Materials [Note (1)] | Minimum | | Maximum | |
|---|---|---|---|---|
| | °C | °F | °C | °F |
| PFA | −198 | −325 | 260 | 500 |
| PTFE | −198 | −325 | 260 | 500 |
| FEP | −198 | −325 | 204 | 400 |
| ECTFE | −198 | −325 | 171 | 340 |
| ETFE | −198 | −325 | 149 | 300 |
| PVDF | −18 | 0 | 135 | 275 |
| PP | −18 | 0 | 107 | 225 |
| PVDC | −18 | 0 | 79 | 175 |

GENERAL NOTE: These temperature limits are based on material tests and do not necessarily reflect evidence of successful use as piping component linings in specific fluid services at these temperatures. The designer should consult the manufacturer for specific applications, particularly as temperature limits are approached.

NOTE: (1) See para. A326.4 for definitions of materials.

## A326.4 Abbreviations in Table A326.1 and Appendix B

The abbreviations tabulated below are used in this Chapter to replace lengthy phrases in the text, in the titles of standards in Table A326.1, and in the Specification Index for Appendix B. Those marked with an asterisk (*) are in accordance with ASTM D1600, Standard Terminology for Abbreviated Terms Relating to Plastics. Those items marked with a dagger (†) are in accordance with ASTM F412, Standard Terminology Relating to Plastic Piping Systems.

| Abbreviation | Term |
|---|---|
| ABS*† | Acrylonitrile-butadiene-styrene plastics |
| BPS | Bonding Procedure Specification |
| CPVC*† | Chlorinated poly(vinyl chloride) plastics |
| DR† | Dimension ratio |
| DS | Design stress |
| E-CTFE* | Ethylene-chlorotrifluoroethylene |
| ETFE* | Ethylene-tetrafluoroethylene copolymer |
| FEP* | Perfluoro (ethylene-propylene) copolymer |

Table continued

| Abbreviation | Term |
|---|---|
| HDBS | Hydrostatic Design Basis Stress |
| HDS† | Hydrostatic Design Stress |
| PB*† | Polybutylene-1 |
| PE*† | Polyethylene |
| PEX | Cross-linked polyethylene |
| PFA* | Perfluoro (alkoxyalkane) |
| PP*† | Polypropylene |
| PQR | Procedure Qualification Record |
| PR† | Pressure rating |
| PTFE* | Polytetrafluoroethylene |
| PVC*† | Poly(vinyl chloride) |
| PVDC* | Poly(vinylidene chloride) |
| PVDF* | Poly(vinylidene fluoride) |
| RPM | Reinforced plastic mortar |

Table continued

| Abbreviation | Term |
|---|---|
| RTP | Reinforced thermosetting plastic |
| RTR | Reinforced thermosetting resin |
| SDR† | Standard dimension ratios |
| SIDR† | Standard inside diameter dimension ratio |
| WPS | Welding Procedure Specification |

# PART 9
# FABRICATION, ASSEMBLY, AND ERECTION

## A327 GENERAL

Piping materials and components are prepared for assembly and erection by one or more of the fabrication processes in paras. A328, A329, A332, and A334. When any of these processes is used in assembly and erection, requirements are the same as for fabrication.

## A328 BONDING OF PLASTICS

Paragraph A328 applies only to joints in thermoplastic, RTR, and RPM piping. Bonding shall conform to paras. A328.1 through A328.7 and the applicable requirements of para. A311.

### A328.1 Bonding Responsibility

Each employer is responsible for the bonding done by personnel of his/her organization and, except as provided in paras. A328.2.2 and A328.2.3, shall conduct the required performance qualification tests to qualify bonding procedure specifications (BPS) and bonders or bonding operators.

### A328.2 Bonding Qualifications

#### A328.2.1 Qualification Requirements

*(a)* Qualification of the BPS to be used, and of the performance of bonders and bonding operators, is required. To qualify a BPS, all tests and examinations specified therein and in para. A328.2.5 shall be completed successfully.

*(b)* In addition to the procedure for making the bonds, the BPS shall specify at least the following:

*(1)* all materials and supplies (including storage requirements)

*(2)* tools and fixtures (including proper care and handling)

*(3)* environmental requirements (e.g., temperature, humidity, and methods of measurement)

*(4)* joint preparation

*(5)* dimensional requirements and tolerances

*(6)* cure time

*(7)* protection of work

*(8)* tests and examinations other than those required by para. A328.2.5

*(9)* acceptance criteria for the completed test assembly

**A328.2.2 Procedure Qualification by Others.** Subject to the specific approval of the Inspector, a BPS qualified by others may be used provided that

*(a)* the Inspector satisfies him/herself that the proposed qualified BPS has been prepared and executed by a responsible recognized organization with expertise in the field of bonding

*(b)* by signature, the employer accepts both the BPS and procedure qualification record (PQR) as his/her own

*(c)* the employer has at least one currently employed bonder who, while in his/her employ, has satisfactorily passed a performance qualification test using the proposed qualified BPS

**A328.2.3 Performance Qualification by Others.** Without the Inspector's specific approval, an employer shall not accept a performance qualification test made by a bonder or bonding operator for another employer. If approval is given, it is limited to work on piping using the same or equivalent BPS. An employer accepting such performance qualification tests shall obtain a copy of the performance qualification test record from the previous employer, showing the name of the employer by whom the bonder or bonding operator was qualified, the date of such qualification, and the date the bonder or bonding operator last bonded pressure piping under such performance qualification.

**A328.2.4 Qualification Records.** The employer shall maintain a self-certified record, available to the owner or owner's agent and to the Inspector, of the BPS used and the bonders or bonding operators employed by him/her, and showing the dates and results of BPS qualifications and bonding performance qualifications.

**A328.2.5 Qualification Tests.** Tests, as specified in para. A328.2.1(a), shall be performed to qualify each BPS and the performance of each bonder and bonding operator. Test assemblies shall conform to (a) below and the test method shall be in accordance with either (b) or (c).

*(a)* *Test Assembly.* The assembly shall be fabricated in one pipe size in accordance with the BPS and shall contain at least one of each different type of joint identified in the BPS. More than one test assembly may be prepared if necessary to accommodate all of the joint types or to assure that at least one of each joint type is loaded in both circumferential and longitudinal directions. The size of pipe and fittings in the assembly shall be as follows:

*(1)* When the largest size to be qualified is DN 100 (NPS 4) or smaller, the test assembly shall be the largest size qualified.

(18) **Table A326.1 Component Standards**

| Standard or Specification | Designation |
|---|---|
| **Nonmetallic Fittings, Valves, and Flanges** | |
| Process Glass Pipe and Fittings | ASTM C599 |
| Threaded PVC Plastic Pipe Fittings, Sch 80 | ASTM D2464 |
| PVC Plastic Pipe Fittings, Sch 40 | ASTM D2466 |
| PVC Plastic Pipe Fittings, Sch 80 | ASTM D2467 |
| Socket-Type ABS Plastic Pipe Fittings, Sch 40 | ASTM D2468 |
| Thermoplastic Gas Pressure Pipe, Tubing, and Fittings | ASTM D2513 |
| Reinforced Epoxy Resin Gas Pressure Pipe and Fittings | ASTM D2517 |
| Plastic Insert Fittings for PE Plastic Pipe | ASTM D2609 |
| Socket-Type PE Fittings for Outside Diameter-Controlled PE Pipe and Tubing | ASTM D2683 |
| CPVC Plastic Hot- and Cold-Water Distribution Systems | ASTM D2846/D2846M |
| Butt Heat Fusion PE Plastic Fittings for PE Plastic Pipe and Tubing | ASTM D3261 |
| PB Plastic Hot- and Cold-Water Distribution Systems | ASTM D3309 |
| Fiberglass RTR Pipe Fittings for Nonpressure Applications [Note (1)] | ASTM D3840 |
| Machine Made "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Flanges | ASTM D4024 |
| Contact Molded Fiberglass RTR Flanges [Note (1)] | ASTM D5421 |
| Fiberglass Pressure Pipe Fittings | ASTM D5685 |
| Threaded CPVC Plastic Pipe Fittings, Sch 80 | ASTM F437 |
| Socket-Type CPVC Plastic Pipe Fittings, Sch 40 | ASTM F438 |
| CPVC Plastic Pipe Fittings, Schedule 80 | ASTM F439 |
| Electrofusion Type PE Fittings for Outside Diameter Controlled PE Pipe and Tubing | ASTM F1055 |
| Plastic-Lined Ferrous Metal Pipe, Fittings, and Flanges [Notes (2), (3), and (4)] | ASTM F1545 |
| Pressure-Rated Polypropylene (PP) Piping Systems | ASTM F2389 |
| Plastic Industrial Ball Valves [Notes (2) and (3)] | MSS SP-122 |
| **Nonmetallic Pipes and Tubes** | |
| PE Line Pipe | API 15LE |
| Low Pressure Fiberglass Line Pipe | API 15LR |
| Reinforced Concrete Low-Head Pressure Pipe | ASTM C361 |
| Process Glass Pipe and Fittings | ASTM C599 |
| ABS Plastic Pipe, Sch 40 and 80 | ASTM D1527 |
| PVC Plastic Pipe, Sch 40, 80 and 120 | ASTM D1785 |
| PE Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter | ASTM D2239 |
| PVC Plastic Pressure-Rated Pipe (SDR Series) | ASTM D2241 |
| ABS Plastic Pipe (SDR-PR) | ASTM D2282 |
| Classification for Machine-Made RTR Pipe | ASTM D2310 |
| PE Plastic Pipe, Sch 40 & 80, Based on Outside Diameter | ASTM D2447 |
| Thermoplastic Gas Pressure Pipe, Tubing, and Fittings | ASTM D2513 |
| Reinforced Epoxy Resin Gas Pressure Pipe and Fittings | ASTM D2517 |
| PB Plastic Pipe (SDR-PR) | ASTM D2662 |
| PB Plastic Tubing | ASTM D2666 |
| Joints for IPS PVC Pipe Using Solvent Cement | ASTM D2672 |

**Table A326.1 Component Standards (Cont'd)**

| Standard or Specification | Designation |
|---|---|
| **Nonmetallic Pipes and Tubes (Cont'd)** | |
| PE Plastic Tubing | ASTM D2737 |
| CPVC Plastic Hot- and Cold-Water Distribution System | ASTM D2846/D2846M |
| Filament-Wound Fiberglass RTR Pipe [Note (1)] | ASTM D2996 |
| Centrifugally Cast Fiberglass RTR Pipe | ASTM D2997 |
| PB Plastic Pipe (SDR-PR) Based on Outside Diameter | ASTM D3000 |
| PE Plastic Pipe (DR-PR) Based on Controlled Outside Diameter | ASTM D3035 |
| PB Plastic Hot- and Cold-Water Distribution Systems | ASTM D3309 |
| Fiberglass RTR Pressure Pipe [Note (1)] | ASTM D3517 |
| Fiberglass RTR Sewer and Industrial Pressure Pipe [Note (1)] | ASTM D3754 |
| CPVC Plastic Pipe, Sch 40 and 80 | ASTM F441/F441M |
| CPVC Plastic Pipe (SDR-PR) | ASTM F442/F442M |
| Crosslinked Polyethylene/Aluminum/Crosslinked Polyethylene (PEX-AL-PEX) Pressure Pipe | ASTM F1281 |
| Polyethylene/Aluminum/Polyethylene (PE-AL-PE) Composite Pressure Pipe | ASTM F1282 |
| Polyolefin Pipe and Fittings for Corrosive Waste Drainage Systems [Notes (2) and (3)] | ASTM F1412 |
| Plastic-Lined Ferrous Metal Pipe, Fittings, and Flanges [Notes (2), (3), and (4)] | ASTM F1545 |
| PVDF Corrosive Waste Drainage Systems | ASTM F1673 |
| Pressure-Rated Polypropylene (PP) Piping Systems | ASTM F2389 |
| Metric and Inch-sized Crosslinked Polyethylene (PEX) Pipe | ASTM F2788/F2788M |
| Reinforced Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids | AWWA C300 |
| Prestressed Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids | AWWA C301 |
| Reinforced Concrete Pressure Pipe, Noncylinder Type | AWWA C302 |
| Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 60 In. (100 mm Through 1,500 mm) | AWWA C900 |
| Fiberglass Pressure Pipe | AWWA C950 |
| **Miscellaneous** | |
| Contact-Molded RTP Laminates for Corrosion Resistant Equipment | ASTM C582 |
| Threads for Fiberglass RTR Pipe (60 deg stub) [Note (1)] | ASTM D1694 |
| Solvent Cements for ABS Plastic Pipe and Fittings | ASTM D2235 |
| Solvent Cements for PVC Plastic Piping Systems | ASTM D2564 |
| Joints for Plastic Pressure Pipes Using Flexible Elastomeric Seals | ASTM D3139 |
| Fiberglass RTR Pipe Joints Using Flexible Elastomeric Seals [Note (1)] | ASTM D4161 |
| Design and Construction of Nonmetallic Enveloped Gaskets for Corrosive Service | ASTM F336 |
| Solvent Cements for CPVC Plastic Pipe and Fittings | ASTM F493 |
| Taper Pipe Threads 60° for Thermoplastic Pipe and Fittings | ASTM F1498 |
| Metal Insert Fittings for Polyethylene/Aluminum/Polyethylene and Crosslinked Polyethylene/Aluminum/Crosslinked Polyethylene Composite Pressure Pipe | ASTM F1974 |

GENERAL NOTE: It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in Appendix E.

NOTES:
(1) The term "fiberglass RTR" takes the place of the ASTM designation "fiberglass (glass-fiber-reinforced thermosetting resin)."
(2) This Standard allows the use of unlisted materials; see para. 323.1.2.
(3) This Standard contains no pressure–temperature ratings.
(4) Cautionary Note: A metallic piping component lined with nonmetal requires proper interaction between liner and host metallic piping component. This is demonstrated by qualification testing required in ASTM F1545. The designer should review this documentation for compliance.

*(2)* When the largest size to be qualified is greater than DN 100 (NPS 4), the size of the test assembly shall be between 25% and 100% of the largest piping size qualified, but shall be a minimum of DN 100 (NPS 4).

*(b) Burst Test Method.* The test assembly shall be subjected to a burst test in accordance with the applicable sections of ASTM D1599.[5] The time to burst in this standard may be extended. The test is successful if failure initiates outside of any bonded joint.

*(c) Hydrostatic Test Method.* The test assembly shall be subjected to hydrostatic pressure of at least $P_T$ for not less than 1 hr with no leakage or separation of joints.

*(1)* For thermoplastics, $P_T$ shall be determined in accordance with eq. (27)

$$P_T = 0.80\overline{T}\left(\frac{S_S + S_H}{D - \overline{T}}\right) \tag{27}$$

where

$D$ = outside diameter of pipe

$S_H$ = mean long-term hydrostatic strength (LTHS) in accordance with ASTM D2837. Use twice the 23°C (73°F) HDB design stress from Table B-1 if listed, or use manufacturer's data.

$S_S$ = mean short-term burst stress in accordance with ASTM D1599,[5] from Table B-1 if listed, otherwise from manufacturer's data

$\overline{T}$ = nominal thickness of pipe

*(2)* For RTR (laminated and filament-wound) and RPM, $P_T$ shall be 3 times the manufacturer's allowable pressure for the components being joined.

*(3)* The test shall be conducted so that the joint is loaded in both the circumferential and longitudinal directions.

**A328.2.6 Performance Requalification.** Renewal of a bonding performance qualification is required when

*(a)* a bonder or bonding operator has not used the specific bonding process for a period of 6 months or more, or

*(b)* there is specific reason to question the individual's ability to make bonds that meet the BPS

## A328.3 Bonding Materials and Equipment

**A328.3.1 Materials.** Bonding materials that have deteriorated by exposure to air or prolonged storage, or will not spread smoothly, shall not be used in making joints.

**A328.3.2 Equipment.** Fixtures and tools used in making joints shall be in such condition as to perform their functions satisfactorily.

## A328.4 Preparation for Bonding

Preparation shall be defined in the BPS and shall specify such requirements as

*(a)* cutting

*(b)* cleaning

*(c)* preheat

*(d)* end preparation

*(e)* fit-up

## A328.5 Bonding Requirements

### A328.5.1 General

*(a)* Production joints shall be made only in accordance with a written bonding procedure specification (BPS) that has been qualified in accordance with para. A328.2. Manufacturers of piping materials, bonding materials, and bonding equipment should be consulted in the preparation of the BPS.

*(b)* Production joints shall be made only by qualified bonders or bonding operators who have appropriate training or experience in the use of the applicable BPS and have satisfactorily passed a performance qualification test that was performed in accordance with a qualified BPS.

*(c)* Each qualified bonder and bonding operator shall be assigned an identification symbol. Unless otherwise specified in the engineering design, each pressure-containing bond or adjacent area shall be stenciled or otherwise suitably marked with the identification symbol of the bonder or bonding operator. Identification stamping shall not be used and any marking paint or ink shall not be detrimental to the piping material. In lieu of marking the bond, appropriate records may be filed.

*(d)* Qualification in one BPS does not qualify a bonder or bonding operator for any other bonding procedure.

*(e)* Longitudinal joints are not covered in para. A328.

### A328.5.2 Hot Gas Welded Joints in Thermoplastic Piping[5]

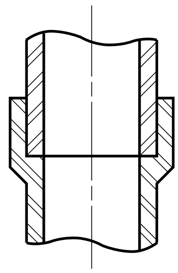
*(a) Preparation.* Surfaces to be hot gas welded together shall be cleaned of any foreign material. For butt welds, the joining edges should be beveled at 20 deg to 40 deg with 1 mm ($^1\!/_{32}$ in.) root face and root gap.

*(b) Procedure.* Joints shall be made in accordance with the qualified BPS.

*(c) Branch Connections.* A fabricated branch connection shall be made by inserting the branch pipe in the hole in the run pipe. Dimensions of the joint shall conform to Figure 328.4.4, illustration (c). The hole in the run pipe shall be beveled at 45 deg. Alternatively, a fabricated branch connection shall be made using a manufactured full reinforcement saddle with integral socket.

[5] Titles of referenced standards and specifications are listed in Table A326.1, except ASTM D1599, Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings; ASTM D2657, Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings; ASTM D2855, Practice for Making Solvent-Cemented Joints with PVC Pipe and Fittings; and ASTM F1290, Practice for Electrofusion Joining Polyolefin Pipe and Fittings.

**Figure A328.5.3 Thermoplastic Solvent Cemented Joint**



Socket Joint

#### A328.5.3 Solvent Cemented Joints in Thermoplastic Piping[5]

*(a) Preparation.* Thermoplastic pipe and fitting surfaces shall be prepared in accordance with ASTM D2855 for PVC, ASTM F493 for CPVC, and ASTM D2235 for ABS. A dry fit test of each joint is required before solvent cementing. The pipe shall enter the fitting socket between one-third and two-thirds of the full socket depth when assembled by hand.

*(b) Procedure.* Joints shall be made in accordance with the qualified BPS. ASTM D2855 provides a suitable basis for development of such a procedure. Solvent cements for PVC, CPVC, and ABS shall conform to ASTM D2564, D2846, and D2235, respectively. Application of cement to both surfaces to be joined and assembly of these surfaces shall produce a continuous bond between them with visual evidence of cement at least flush with the outer end of the fitting bore around the entire joint perimeter. See Figure A328.5.3.

*(c) Branch Connections.* A fabricated branch connection shall be made using a manufactured full reinforcement saddle with integral branch socket. The reinforcement saddle shall be solvent cemented to the run pipe over its entire contact surface.

#### A328.5.4 Heat Fusion Joints in Thermoplastic Piping[5]

*(a) Preparation.* Surfaces to be heat fused together shall be cleaned of all foreign material.

*(b) Procedure.* Joints shall be made in accordance with the qualified BPS. The general procedures in ASTM D2657, Techniques I — Socket Fusion, II — Butt Fusion, and III — Saddle Fusion, provide a suitable basis for development of such a procedure. Uniform heating of both surfaces to be joined and assembly of these surfaces shall produce a continuous homogeneous bond between them and shall produce a small fillet of fused material at the outer limits of the joint. See Figure A328.5.4 for typical heat fusion joints. Fixtures shall be used to align components when joints are made.

*(c) Branch Connections.* A fabricated branch connection is permitted only where molded fittings are unavailable.

#### A328.5.5 Electrofusion Joints in Thermoplastic Piping[5]

*(a) Preparation.* Surfaces to be heat fused together shall be cleaned of all foreign material.

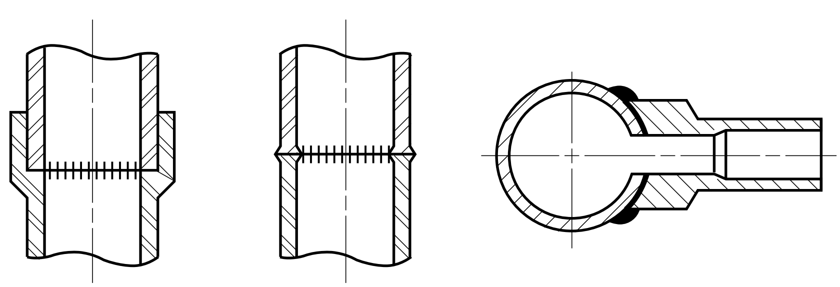
*(b) Procedure.* Joints shall be made in accordance with the qualified BPS. The general procedures in ASTM F1290, Technique I — Coupling Procedure and Technique II — Saddle Procedure, provide a suitable basis for the development of such a procedure. See Figure A328.5.5.

#### A328.5.6 Adhesive Joints in RTR and RPM Piping

*(a) Procedure.* Joints shall be made in accordance with the qualified BPS. Application of adhesive to the surfaces to be joined and assembly of these surfaces shall produce a continuous bond between them and shall seal over all cuts to protect the reinforcement from the service fluid. See Figure A328.5.6.

*(b) Branch Connections.* A fabricated branch connection shall be made using a manufactured full reinforcement saddle having a socket or integral length of branch pipe suitable for a nozzle or coupling. The hole in the run pipe shall be made with a hole saw; the cut

**Figure A328.5.4 Thermoplastic Heat Fusion Joints**



Socket Joint — Butt Joint — Saddle Joint

**Figure A328.5.5 Thermoplastic Electrofusion Joints**

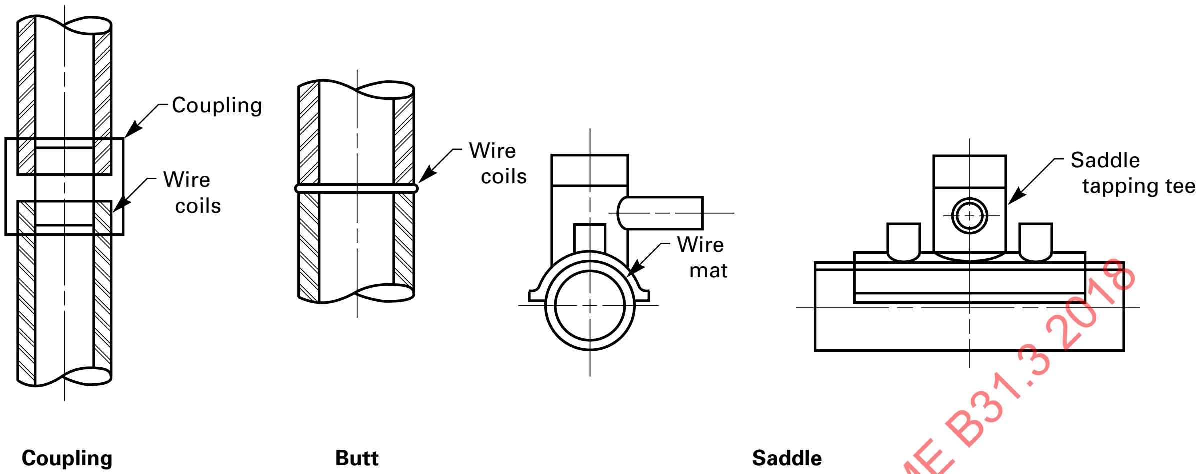



**Figure A328.5.6 Fully Tapered Thermosetting Adhesive Joint**

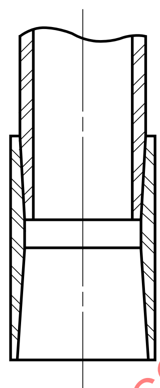
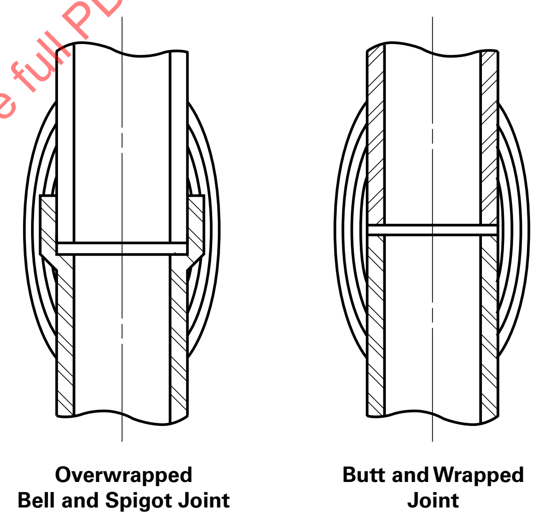


**Figure A328.5.7 Thermosetting Wrapped Joints**




edges of the hole shall be sealed with adhesive at the time the saddle is bonded to the run pipe.

### A328.5.7 Butt-and-Wrapped Joints in RTR and RPM Piping[5]

*(a) Procedure.* Joints shall be made in accordance with the qualified BPS. Application of plies of reinforcement saturated with catalyzed resin to the surfaces to be joined shall produce a continuous structure with them. Cuts shall be sealed to protect the reinforcement from the service fluid. See Figure A328.5.7.

*(b) Branch Connections.* For a fabricated branch connection made by inserting the branch pipe into a hole in the run pipe, the hole shall be made with a hole saw.

## A328.6 Bonding Repair

Defective material, joints, and other workmanship that fails to meet the requirements of this Code and of the engineering design shall be repaired or replaced. See also para. 341.3.3.

## A328.7 Seal Bonds

If threaded joints are to be seal bonded in accordance with para. A311.2.2, the work shall be done by qualified bonders and all exposed threads shall be covered by the seal bond.

## A329 FABRICATION OF PIPING LINED WITH NONMETALS

### A329.1 Welding of Metallic Piping

#### A329.1.1 General

*(a)* Paragraph A329.1 applies only to welding subassemblies of metallic piping that have previously been lined with nonmetals.

*(b)* Welding that conforms to para. A329.1 may be used in accordance with para. A318.3.1.

**A329.1.2 Specific Welding Requirements.** Welding shall conform to the requirements of para. 328 and the following additional requirements:

*(a)* Modifications made in preparation for welding to suit manufacturer's recommendations shall be specified in the engineering design.

*(b)* Welding shall be performed so as to maintain the continuity of the lining and its serviceability.

*(c)* If a lining has been damaged, it shall be repaired or replaced.

*(d)* Qualification to one WPS for a specific lining material does not qualify a welder or welding operator for any other welding procedure involving different lining materials.

### A329.2 Flaring of Nonmetallic Linings

#### A329.2.1 General

*(a)* Paragraph A329.2 applies only to the flaring of linings in pipe that has previously been lined with nonmetals.

*(b)* Flaring that conforms to para. A329.2 may be used in accordance with para. A318.3.2.

*(c)* Flaring shall be performed only in accordance with a written flaring procedure specification, and only by qualified operators who have appropriate training or experience in the use of the applicable flaring procedure specification.

## A332 BENDING AND FORMING

### A332.1 General

Paragraph 332.1 applies in its entirety.

### A332.2 Bending

Paragraph 332.2 applies, except para. 332.2.2.

### A332.3 Forming

Paragraph 332.3 applies, except for heat treatment.

## A334 JOINING NONPLASTIC PIPING

### A334.1 Borosilicate Glass Piping

Short unflanged pieces used to correct for differences between fabrication drawings and field dimensions may be cut to length and finished in the field.

### A334.2 Repair of Defects

Defective material, joints, and other workmanship in nonplastic piping that fail to meet the requirements of para. A334 or of the engineering design shall be repaired or replaced.

Completed repairs and replacements shall be examined, subject to the same limitations on imperfections as the original work.

## A335 ASSEMBLY AND ERECTION

### A335.1 Alignment

Paragraph 335.1 applies in its entirety.

### A335.2 Flanged and Mechanical Joints

Paragraph 335.2 applies in its entirety.

#### A335.2.5 Nonmetallic Bolted Joints

*(a)* Bolted joints in nonmetallic piping may be assembled with any combination of flange material and flange facings, except that the following apply when other than flat face flanges and full face gaskets are used:

*(1)* consideration shall be given to the strength of the flanges, and to sustained loads, displacement strains, and occasional loads described in paras. A302.3.3 and A302.3.4

*(2)* an appropriate bolt-up sequence shall be specified

*(b)* Appropriate limits shall be specified for bolt-up torque, and those limits shall not be exceeded.

*(c)* Flat washers shall be used under bolt heads and nuts.

**A335.2.6 Metallic Piping Lined With Nonmetals.** In assembling mechanical joints in metallic piping lined with nonmetals, consideration shall be given to means for maintaining electrical continuity between pipe sections, where static sparking could cause ignition of flammable vapors. See Appendix F, para. FA323.4(a).

### A335.3 Threaded Joints

Paragraph 335.3 applies except for para. 335.3.2. See para. A335.3.2.

**A335.3.2 Joints for Seal Bonding.** A threaded joint to be seal bonded shall be made up without thread compound. A joint containing thread compound that leaks during leak testing may be seal bonded in accordance with para. A328.6, provided all compound is removed from exposed threads.

**A335.3.4 Tools, Nonmetallic Piping.** Either strap wrenches or other full circumference wrenches shall be used to tighten threaded pipe joints. Tools and other devices used to hold or apply forces to the pipe shall be such that the pipe surface is not scored or deeply scratched.

**A335.3.5 RTR and RPM Piping.** In assembling threaded joints in RTR and RPM piping, where threads may be exposed to fluids that can attack the reinforcing material, threads shall be coated with sufficient resin to cover the threads and completely fill the clearance between the pipe and the fitting.

## A335.4 Tubing Joints

**A335.4.1 Flared Joints in Thermoplastic Tubing.** In addition to preparation in accordance with para. 335.4.1, the end of the tubing shall be cut perpendicular to the tube centerline, preferably with a tubing cutter specially made for thermoplastic tubing. No cuts, scratches, dirt, or surface damage to either inside or outside diameter are permitted on the pipe end to be flared.

**A335.4.2 Flareless and Compression Tubing Joints.** Paragraph 335.4.2 applies.

## A335.5 Caulked Joints

Paragraph 335.5 applies.

## A335.6 Special Joints

Paragraph 335.6 applies, except that expanded joints are not permitted.

**A335.6.3 Flexible Elastomeric Sealed Joints.** Assembly of flexible elastomeric sealed joints shall be in accordance with the manufacturer's recommendations and the following:

*(a)* Seal and bearing surfaces shall be free from injurious imperfections.

*(b)* Any lubricant used to facilitate joint assembly shall be compatible with the joint components and the intended service.

*(c)* Proper joint clearances and piping restraints (if not integral in the joint design) shall be provided to prevent joint separation when expansion can occur due to thermal and/or pressure effects.

## A335.8 Assembly of Brittle Piping

**A335.8.1 General.** Care shall be used to avoid scratching of brittle nonmetallic piping in handling and supporting. Any scratched or chipped components shall be replaced. Care shall be used in handling glass-lined and cement-lined metal pipe because the lining can be injured or broken by blows that do not dent or break the pipe.

**A335.8.2 Borosilicate Glass Piping.** In addition to the precaution in para. A335.8.1, borosilicate glass piping components shall be protected from weld spatter. Any component so damaged shall be replaced. Flanges and cushion inserts shall be carefully fitted and aligned to pipe, fittings, and valve ends. Gaskets shall be of the construction recommended for the joint. Installation and torquing of bolts shall be in accordance with the manufacturer's recommendations.

## A335.9 Cleaning of Piping

See Appendix F, para. F335.9.

# PART 10
# INSPECTION, EXAMINATION, AND TESTING

## A340 INSPECTION

Paragraph 340 applies in its entirety.

## A341 EXAMINATION

## A341.1 General

Paragraph 341.1 applies.

## A341.2 Responsibility for Examination

Paragraph 341.2 applies in its entirety.

## A341.3 Examination Requirements

**A341.3.1 Responsibility for Examination.** Paragraph 341.3.1 applies, except for (a) and (b), which apply only for metals.

**A341.3.2 Acceptance Criteria.** Acceptance criteria shall be as stated in the engineering design, and shall at least meet the applicable requirements for bonds in Table A341.3.2 and requirements elsewhere in the Code.

**A341.3.3 Defective Components and Workmanship.** Paragraph 341.3.3 applies in its entirety.

**A341.3.4 Progressive Sampling for Examination.** Paragraph 341.3.4 applies in its entirety.

## A341.4 Extent of Required Examination

**A341.4.1 Examination Normally Required.** Piping in Normal Fluid Service shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in para. A341.3.2 unless otherwise specified.

*(a)* *Visual Examination.* At least the following shall be examined in accordance with para. 344.2:

(18) **Table A341.3.2 Acceptance Criteria for Bonds**

| Type of Imperfection | Thermoplastic Material — Hot Gas Welded Joint | Thermoplastic Material — Solvent Cemented Joint | Thermoplastic Material — Heat Fusion Joint | RTR and RPM Materials [Note (1)] — Adhesive Cemented Joint |
|---|---|---|---|---|
| Cracks | None permitted | Not applicable | None permitted | None permitted |
| Unfilled areas in joint | None permitted | None permitted | None permitted | None permitted |
| Unbonded areas in joint | None permitted | None permitted | None permitted | None permitted |
| Inclusions of charred material | None permitted | Not applicable | None permitted | None permitted |
| Unfused filler material inclusions | None permitted | Not applicable | Not applicable | None permitted |
| Protrusion of material into pipe bore, % of pipe wall thickness | Not applicable | Cement, 50% | Fused material, 25% | Adhesive, 25% |

NOTE: (1) RTR = reinforced thermosetting resin; RPM = reinforced plastic mortar.

*(1)* materials and components in accordance with para. 341.4.1(a)(1).

*(2)* at least 5% of fabrication. For bonds, each type of bond made by each bonder and bonding operator shall be represented.

*(3)* 100% of fabrication for bonds other than circumferential, except those in components made in accordance with a listed specification.

*(4)* assembly and erection of piping in accordance with paras. 341.4.1(a)(4), (5), and (6).

*(b)* *Other Examination.* Not less than 5% of all bonded joints shall be examined by in-process examination in accordance with para. 344.7, the joints to be examined being selected to ensure that the work of each bonder and bonding operator making the production joints is examined.

*(c)* *Certifications and Records.* Paragraph 341.4.1(c) applies.

**A341.4.2 Examination — Category D Fluid Service.** Piping and piping elements for Category D Fluid Service as designated in the engineering design shall be visually examined to the extent necessary to satisfy the examiner that components, materials, and workmanship conform to the requirements of this Code and the engineering design.

### A341.5 Supplementary Examination

**A341.5.1 General.** Any applicable method of examination described in para. 344 may be specified by the engineering design to supplement the examination required by para. A341.4. The extent of supplementary examination to be performed and any acceptance criteria that differ from those in para. A341.3.2 shall be specified in the engineering design.

**A341.5.2 Examinations to Resolve Uncertainty.** Paragraph 341.5.3 applies.

## A342 EXAMINATION PERSONNEL

Paragraph 342 applies in its entirety.

## A343 EXAMINATION PROCEDURES

Paragraph 343 applies in its entirety.

## A344 TYPES OF EXAMINATION

### A344.1 General

Paragraph 344.1 applies in its entirety.

### A344.2 Visual Examination

Paragraph 344.2 applies in its entirety.

### A344.5 Radiographic Examination

Radiographic examination may be used in accordance with para. 344.1.2.

### A344.6 Ultrasonic Examination

Ultrasonic examination may be used in accordance with para. 344.1.2.

### A344.7 In-Process Examination

Paragraph 344.7 applies in its entirety.

## A345 TESTING

### A345.1 Required Leak Test

*(a)* Prior to initial operation, each piping system shall be tested to ensure tightness. The test shall be a hydrostatic leak test in accordance with para. A345.4, except as provided herein.

*(b)* Paragraphs 345.1(a) and (b) apply.

### A345.2 General Requirements for Leak Test

Requirements in para. A345.2 apply to more than one type of leak test.

**A345.2.1 Limitations on Pressure.** Paragraphs 345.2.1(b) and (c) apply.

#### A345.2.2 Other Test Requirements

*(a)* Paragraph 345.2.2(a) applies.

*(b)* The possibility of brittle fracture shall be considered when conducting leak tests on brittle materials or at low temperature.

*(c)* Paragraphs 345.2.3 through 345.2.7 apply.

### A345.3 Preparation for Leak Test

Paragraph 345.3 applies in its entirety, considering bonds in place of welds, and excluding expansion joints.

### A345.4 Hydrostatic Leak Test

**A345.4.1 Test Fluid.** Paragraph 345.4.1 applies.

#### A345.4.2 Test Pressure

*(a) Nonmetallic Piping.* Except as provided in para. A345.4.3, the hydrostatic test pressure at any point in a nonmetallic piping system shall be not less than 1.5 times the design pressure, but shall not exceed 1.5 times the maximum rated pressure of the lowest-rated component in the system.

*(b) Thermoplastic Piping.* For piping systems in which the design temperature is above the test temperature, para. 345.4.2(b) applies, except that $S$ and $S_T$ shall be from Table B-1 instead of Table A-1 or Table A-1M.

*(c) Metallic Piping With Nonmetallic Lining.* Paragraph 345.4.2 applies.

**A345.4.3 Hydrostatic Test of Piping With Vessels as a System.** Paragraph 345.4.3 applies.

### A345.5 Pneumatic Leak Test

**A345.5.1 Precautions.** In addition to the requirements of para. 345.5.1, a pneumatic test of nonmetallic piping is permitted only with the owner's approval, and precautions in Appendix F, para. FA323.4 should be considered.

#### A345.5.2 Other Requirements

*(a)* Paragraphs 345.5.2 through 345.5.5 apply.

*(b)* PVC and CPVC piping shall not be pneumatically tested.

### A345.6 Hydrostatic–Pneumatic Leak Test

If a combined hydrostatic–pneumatic leak test is used, the requirements of para. A345.5 shall be met, and the pressure in the liquid-filled part of the piping shall not exceed the values calculated in accordance with para. A345.4.2 or 345.4.2, as applicable.

### A345.7 Initial Service Leak Test

Paragraph 345.7 applies in its entirety for Category D Fluid Service only.

### A345.8 Sensitive Leak Test

Paragraph 345.8 applies.

### A346 RECORDS

Paragraph 346 applies in its entirety.

# Chapter VIII
# Piping for Category M Fluid Service

## M300 GENERAL STATEMENTS

*(a)* Chapter VIII pertains to piping designated by the owner as being in Category M Fluid Service. See para. 300(b)(1) and Appendix M.

*(b)* The organization, content, and paragraph designations of this Chapter correspond to those of the base Code (Chapters I through VI) and Chapter VII. The prefix M is used.

*(c)* Provisions and requirements of the base Code and Chapter VII apply only as stated in this Chapter.

*(d)* Consideration shall be given to the possible need for engineered safeguards as described in Appendix G, para. G300.3, in addition to the inherent safeguards described in paras. G300.1 and G300.2.

*(e)* This Chapter makes no provision for piping to be used under severe cyclic conditions. If it is not feasible to eliminate the severe cyclic conditions, the engineering design shall specify any necessary provisions in accordance with para. 300(c)(5).

*(f)* Chapter I applies in its entirety.

## PART 1
## CONDITIONS AND CRITERIA

## M301 DESIGN CONDITIONS

Paragraph 301 applies in its entirety, with the exceptions of paras. 301.3 and 301.5. See paras. M301.3 and M301.5.

### M301.3 Design Temperature, Metallic Piping

Use of any temperature other than the fluid temperature as the design temperature shall be substantiated by heat transfer calculations confirmed by tests or by experimental measurements.

### M301.5 Dynamic Effects

Paragraph 301.5 applies with the exception of paras. 301.5.1 and 301.5.4. See paras. M301.5.1 and M301.5.4.

**M301.5.1 Impact.** Design, layout, and operation of piping shall be conducted so as to minimize impact and shock loads. In the event that such loadings are unavoidable, para. 301.5.1 applies.

**M301.5.4 Vibration.** Suitable dynamic analysis, such as computer simulation, shall be made where necessary to avoid or minimize conditions that lead to detrimental vibration, pulsation, or resonance effects in the piping.

## M302 DESIGN CRITERIA

### M302.1 General

Paragraph M302 pertains to pressure–temperature ratings, stress criteria, design allowances, and minimum design values, together with permissible variations of these factors as applied to piping design. Paragraph 302 applies in its entirety, with the exception of para. 302.2.4. See para. M302.2.4.

**M302.2.4 Allowance for Pressure and Temperature Variations, Metallic Piping.** Use of allowances in para. 302.2.4 is not permitted.

## PART 2
## PRESSURE DESIGN OF METALLIC PIPING COMPONENTS

## M303 GENERAL

Paragraph 303 applies in its entirety.

## M304 PRESSURE DESIGN OF METALLIC COMPONENTS

Paragraph 304 applies in its entirety.

## PART 3
## FLUID SERVICE REQUIREMENTS FOR METALLIC PIPING COMPONENTS

## M305 PIPE

### M305.1 General

Listed pipe may be used in accordance with para. M305.2. Unlisted pipe may be used only as provided in para. 302.2.3.

### M305.2 Specific Requirements for Metallic Pipe

Pipe listed in para. 305.2.2 shall not be used. The provision for severe cyclic conditions in para. 305.2.3 does not apply [see para. M300(e)].

## M306 METALLIC FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

*General*. Fittings, bends, miters, laps, and branch connections may be used in accordance with paras. M306.1 through M306.6. Pipe and other materials used in such components shall be suitable for the manufacturing process and the fluid service.

### M306.1 Pipe Fittings

Paragraph 306.1 applies in its entirety, with the exception of paras. 306.1.3 and 306.1.4. See para. M306.1.3.

#### M306.1.3 Specific Fittings

*(a)* Proprietary welding branch outlet fittings that have been design proof tested successfully as prescribed in ASME B16.9, MSS SP-97, or ASME BPVC, Section VIII, Division 1, UG-101 may be used within their established ratings.

*(b)* Fittings conforming to MSS SP-43 and MSS SP-119 shall not be used.

*(c)* Proprietary "Type C" lap-joint stub-end buttwelding fittings shall not be used.

### M306.2 Pipe Bends

Paragraph 306.2 applies, except that bends designed as creased or corrugated shall not be used.

### M306.3 Miter Bends

A miter bend shall conform to para. 306.3.1 and shall not make a change in direction at a single joint (angle α in Figure 304.2.3) greater than 22.5 deg. Paragraph 306.3.3 does not apply [see para. M300(e)].

### M306.4 Fabricated or Flared Laps

**M306.4.1 General.** The following requirements do not apply to fittings conforming to para. M306.1, nor to laps integrally forged on pipe ends. Paragraph 306.4.1 applies.

**M306.4.2 Flared Laps.** Flared laps shall not be used.

### M306.5 Fabricated Branch Connections

The following requirements do not apply to fittings conforming to para. M306.1. Paragraph 306.5.1 applies, with the following exceptions:

*(a)* Of the methods listed in para. 304.3.1(a), the one in para. 304.3.1(a)(3) may be used only if those in paras. 304.3.1(a)(1) and (2) are unavailable.

*(b)* Of the branch connections described in paras. 304.3.2(b) and (c), those having threaded outlets are permitted only in accordance with para. M314 and those having socket welding outlets are permitted only in accordance with para. M311.2.

### M306.6 Closures

The following requirements do not apply to blind flanges or to fittings conforming to para. M306.1. Of the closures described in para. 304.4, flat closures in accordance with ASME BPVC, Section VIII, Division 1, UG-34 and UW-13, and conical closures without transition knuckles [UG-32(g) and UG-33(f)], may be used only if others are not available. The requirements in M306.5 apply to openings in closures [see also para. 304.4.2(b)].

## M307 METALLIC VALVES AND SPECIALTY COMPONENTS

The following requirements for valves shall also be met as applicable by other pressure-containing piping components, e.g., traps, strainers, and separators. See also Appendix F, paras. F301.4 and F307.

### M307.1 General

Paragraph 307.1 applies, subject to the requirements in para. M307.2.

### M307.2 Specific Requirements

*(a)* Paragraph 307.2.2 applies.

*(b)* Valves having threaded bonnet joints (other than union joints) shall not be used.

*(c)* Only metallic valves conforming to the following requirements may be used:

*(1)* Special consideration shall be given to valve design to prevent stem leakage to the environment.

*(2)* Bonnet or cover plate closures and body joints shall be flanged, secured by at least four bolts with gasketing conforming to para. 308.4; or proprietary, attached by bolts, lugs, or other substantial means, and having a gasket design that increases gasket compression as fluid pressure increases; or secured with a full penetration weld made in accordance with para. M311; or secured by a straight thread sufficient for mechanical strength, a metal-to-metal seat, and a seal weld made in accordance with para. M311, all acting in series.

## M308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

Paragraph 308.1 applies in its entirety.

### M308.2 Specific Requirements for Metallic Flanges

Paragraph 308.2.4 does not apply [see para. M300(e)]. The following shall not be used:

(a) single-welded slip-on flanges
(b) expanded-joint flanges
(c) slip-on flanges used as lapped flanges unless the requirements in para. 308.2.1(c) are met
(d) threaded metallic flanges, except those employing lens rings or similar gaskets and those used in lined pipe where the liner extends over the gasket face

### M308.3 Flange Facings

Paragraph 308.3 applies in its entirety.

### M308.4 Gaskets

Paragraph 308.4 applies in its entirety.

### M308.5 Blanks

All blanks shall be marked with material, rating, and size.

## M309 BOLTING

Paragraph 309 applies, except for para. 309.2.4 [see para. M300(e)].

# PART 4
# FLUID SERVICE REQUIREMENTS FOR METALLIC PIPING JOINTS

## M310 METALLIC PIPING, GENERAL

Paragraph 310 applies in its entirety.

## M311 WELDED JOINTS IN METALLIC PIPING

Welded joints may be made in any metal for which it is possible to qualify welding procedures, welders, and welding operators in accordance with para. M328.

### M311.1 General

Paragraph 311.1 applies with the following exceptions:
(a) Split backing rings shall not be used.
(b) Socket welded joints greater than DN 50 (NPS 2) are not permitted.
(c) Examination shall be in accordance with para. M341.4.

### M311.2 Specific Requirements

Paragraphs 311.2.1(a); 311.2.2(a), (b), and (d); 311.2.3; and 311.2.4 apply.

## M312 FLANGED JOINTS IN METALLIC PIPING

Paragraph 312 applies in its entirety.

## M313 EXPANDED JOINTS IN METALLIC PIPING

Expanded joints shall not be used.

## M314 THREADED JOINTS IN METALLIC PIPING

### M314.1 General

Paragraphs 314.1(a), (b), and (c) apply.

### M314.2 Specific Requirements

**M314.2.1 Taper-Threaded Joints.** Paragraph 314.2.1 applies except that only components suitable for Normal Fluid Service in sizes 8 ≤ DN ≤ 25 ($\frac{1}{4}$ ≤ NPS ≤ 1) are permitted (see Table 314.2.1). Sizes smaller than DN 20 (NPS $\frac{3}{4}$) shall be safeguarded (see Appendix G).

**M314.2.2 Straight-Threaded Joints.** Paragraph 314.2.2 applies. In addition, components shall have adequate mechanical strength and the joint shall have a confined seating surface not subject to relative rotation as or after the joint is tightened. [See Figure 335.3.3, illustrations (b) and (c) for acceptable construction.]

## M315 TUBING JOINTS IN METALLIC PIPING

Paragraph 315 applies, except for para. 315.2(b).

## M316 CAULKED JOINTS

Caulked joints shall not be used.

## M317 SOLDERED AND BRAZED JOINTS

Soldered, brazed, and braze welded joints shall not be used.

## M318 SPECIAL JOINTS IN METALLIC PIPING

Paragraph 318 applies, with the exception that adhesive joints and bell type joints shall not be used.

# PART 5
# FLEXIBILITY AND SUPPORT OF METALLIC PIPING

## M319 FLEXIBILITY OF METALLIC PIPING

Paragraph 319 applies, with the exception that the simplified rules in para. 319.4.1(c) do not apply.

## M320 ANALYSIS OF SUSTAINED LOADS

Paragraph 320 applies.

## M321 PIPING SUPPORT

Paragraph 321 applies, except that supporting elements welded to the piping shall be of listed material.

# PART 6
# SYSTEMS

## M322 SPECIFIC PIPING SYSTEMS

### M322.3 Instrument Piping

Paragraph 322.3 applies, with the exception that for signal tubing in contact with process fluids and process temperature–pressure conditions

*(a)* tubing shall be not larger than 16 mm ($^5\!/_8$ in.) O.D. and shall be suitable for the service

*(b)* an accessible block valve shall be provided to isolate the tubing from the pipeline

*(c)* joining methods shall conform to the requirements of para. M315

### M322.6 Pressure-Relieving Systems

Paragraph 322.6 applies, except for para. 322.6.3. See para. M322.6.3.

#### M322.6.3 Overpressure Protection

*(a)* Paragraph 322.6.3(a) applies.

*(b)* Relief set pressure shall be in accordance with ASME BPVC, Section VIII, Division 1.

*(c)* The maximum relieving pressure shall be in accordance with Section VIII, Division 1.

# PART 7
# METALLIC MATERIALS

## M323 GENERAL REQUIREMENTS

### M323.1 Materials and Specifications

Paragraph 323.1.1 applies. See paras. M323.1.2, M323.1.3, and M323.1.4.

**M323.1.2 Unlisted Materials.** Paragraph 323.1.2 applies, with the additional requirement that the designer shall fully document the determination of allowable stresses as part of the engineering design.

**M323.1.3 Unknown Materials.** Materials of unknown specification shall not be used.

**M323.1.4 Reclaimed Metallic Materials.** Reclaimed materials may be used when the material certification records are available for the specific materials employed, and the designer is assured that the material is sound and free from harmful defects.

(18) ### M323.2 Temperature Limitations

Paragraph 323.2 applies with the exception that, in regard to lower temperature limits, the relaxation of minimum temperature limits stated in Notes (3) and (6) of Table 323.2.2 and in paras. 323.2.2(h) and (i) is not permitted.

### M323.3 Impact Testing Methods and Acceptance Criteria

Paragraph 323.3 applies in its entirety.

### M323.4 Fluid Service Requirements for Metallic Materials

Paragraph 323.4.1 applies.

**M323.4.2 Specific Requirements.** Paragraph 323.4.2 applies, except that cast irons other than ductile iron shall not be used for pressure-containing parts, and lead and tin shall be used only as linings.

**M323.4.3 Metallic Cladding and Lining Materials.** In addition to the requirements of para. 323.4.3, where materials covered in paras. 323.4.2(c)(2) and 323.4.3 are used as cladding or lining in which the cladding or lining also serves as a gasket or as part of the flange facing, consideration shall be given to the design of the flanged joint to prevent leakage to the environment.

### M323.5 Deterioration of Materials in Service

Paragraph 323.5 applies in its entirety.

## M325 MATERIALS — MISCELLANEOUS

### M325.1 Joining and Auxiliary Materials

In applying para. 325, materials such as solvents, brazes, and solders shall not be used. Nonmetallic materials used as gaskets and packing materials shall be suitable for the fluid service.

# PART 8
# STANDARDS FOR PIPING COMPONENTS

## M326 DIMENSIONS AND RATINGS OF COMPONENTS

Paragraph 326.1.3 applies.

### M326.1 Dimensional Requirements

**M326.1.1 Listed Piping Components.** Except for prohibitions and restrictions stated elsewhere in Chapter VIII, components made in accordance with standards and specifications listed in Table 326.1 may be used in Category M service.

**M326.1.2 Unlisted Piping Components.** Paragraph 326.1.2 applies, except that dimensions of unlisted components shall be governed by requirements in paras. 303 and 304.

### M326.2 Ratings of Components

Paragraph 326.2 applies in its entirety.

### M326.3 Reference Documents

Paragraph 326.3 applies in its entirety.

## PART 9
## FABRICATION, ASSEMBLY, AND ERECTION OF METALLIC PIPING

### M327 GENERAL

Metallic piping materials and components are prepared for assembly and erection by one or more of the fabrication processes in paras. M328, M330, M331, and M332. When any of these processes is used in assembly and erection, requirements are the same as for fabrication.

### M328 WELDING OF METALS

Welding shall be in accordance with paras. M311.1 and 328, except see para. M328.3.

### M328.3 Welding Materials

Paragraph 328.3 applies in its entirety, except that split backing rings shall not be used, and removable backing rings and consumable inserts may be used only where their suitability has been demonstrated by procedure qualification.

### M330 PREHEATING OF METALS

Paragraph 330 applies in its entirety.

### M331 HEAT TREATMENT OF METALS

Paragraph 331 applies in its entirety, with the exception that no requirements less stringent than those of Table 331.1.1 shall be specified.

### M332 BENDING AND FORMING OF METALS

Paragraph 332 applies in its entirety, except that bending that conforms to para. 332.2.3 is not permitted.

### M335 ASSEMBLY AND ERECTION OF METALLIC PIPING

### M335.1 General

(18) **M335.1.1 Alignment.** In addition to the requirements of para. 335.1, any bending or forming required for alignment and fit-up shall be heat treated if required by para. 332.4.

### M335.2 Flanged Joints

Paragraph 335.2 applies in its entirety.

### M335.3 Threaded Joints

Paragraphs 335.3.1 and 335.3.2 apply. See paras. M335.3.3 and M335.3.4.

**M335.3.3 Straight-Threaded Joints.** The requirements of para. 335.3.3 are subject to the limitations in para. M322.

**M335.3.4 Condition of Threads.** Taper-threaded components and threaded ends permitted under para. M314.2.1 shall be examined before assembly for cleanliness and continuity of threads and shall be rejected if not in conformance with ASME B1.20.1 or other applicable standards.

### M335.4 Tubing Joints

**M335.4.1 Flared Tubing Joints.** The requirements of para. 335.4.1 apply; however, see para. M322 for limitations associated with specific piping systems.

**M335.4.2 Flareless and Compression Tubing Joints.** The requirements of para. 335.4.2 apply; however, see para. M322 for limitations associated with specific piping systems.

### M335.6 Special Joints

Special joints shall be in accordance with paras. M318 and 335.6.1.

### M335.9 Cleaning of Piping

See Appendix F, para. F335.9.

### M335.10 Identification of Piping

See Appendix F, para. F335.10.

## PART 10
## INSPECTION, EXAMINATION, TESTING, AND RECORDS OF METALLIC PIPING

### M340 INSPECTION

Paragraph 340 applies in its entirety.

### M341 EXAMINATION

Paragraphs 341.1, 341.2, 341.3, and 341.5 apply in their entirety. See para. M341.4.

### M341.4 Extent of Required Examination

Paragraph 341.4.1 applies with the following exceptions:

*(a)* *Visual Examination*

*(1)* All fabrication shall be examined.

*(2)* All threaded, bolted, and other mechanical joints shall be examined.

*(b) Other Examination.* The radiography/ultrasonic examination requirements of para. 341.4.1(b)(1) apply, except that 100% of circumferential butt and miter welds and of fabricated lap and branch connection welds comparable to those shown in Figure 328.5.4E; Figure 328.5.4F; and Figure 328.5.5, illustrations (d) and (e), shall be examined.

## M342 EXAMINATION PERSONNEL

Paragraph 342 applies.

## M343 EXAMINATION PROCEDURES

Paragraph 343 applies.

## M344 TYPES OF EXAMINATION

Paragraph 344 applies in its entirety.

## M345 TESTING

Paragraph 345 applies, except that

*(a)* a sensitive leak test in accordance with para. 345.8 shall be included in the required leak test (para. 345.1)

*(b)* the initial service leak test (para. 345.7) does not apply

## M346 RECORDS

Paragraph 346 applies in its entirety.

# PARTS 11 THROUGH 20, CORRESPONDING TO CHAPTER VII

See para. M300(b).

## MA300 GENERAL STATEMENTS

Paragraphs MA300 through MA346 apply to nonmetallic piping and piping lined with nonmetals, based on Chapter VII. Paragraph A300(d) applies.

# PART 11
# CONDITIONS AND CRITERIA

## MA301 DESIGN CONDITIONS

Paragraph A301 applies in its entirety.

## MA302 DESIGN CRITERIA

Paragraphs A302.1 and A302.4 apply. See paras. MA302.2 and MA302.3.

### MA302.2 Pressure–Temperature Design Criteria

Paragraph A302.2 applies, with the exception of para. A302.2.4. See para. MA302.2.4.

**MA302.2.4 Allowances for Pressure and Temperature Variation.** Paragraph A302.2.4(a) applies to both nonmetallic piping and to metallic piping with nonmetallic lining.

### MA302.3 Allowable Stresses and Other Design Limits

Paragraph A302.3 applies.

### MA302.4 Allowances

Paragraph 302.4 applies in its entirety.

# PART 12
# PRESSURE DESIGN OF NONMETALLIC PIPING COMPONENTS

## MA303 GENERAL

Paragraph A303 applies in its entirety.

## MA304 PRESSURE DESIGN OF NONMETALLIC COMPONENTS

Paragraph A304 applies in its entirety.

# PART 13
# FLUID SERVICE REQUIREMENTS FOR NONMETALLIC PIPING COMPONENTS

## MA305 PIPE

Paragraph A305 applies in its entirety.

## MA306 NONMETALLIC FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

Paragraphs A306.1 and A306.2 apply. See para. MA306.3.

### MA306.3 Miter Bends

Miter bends not designated as fittings conforming to para. A306.1 shall not be used.

### MA306.4 Fabricated Laps

Fabricated laps shall not be used.

### MA306.5 Fabricated Branch Connections

Nonmetallic fabricated branch connections shall not be used.

## MA307 VALVES AND SPECIALTY COMPONENTS

Paragraph A307 applies, except that nonmetallic valves and specialty components shall not be used.

## MA308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

Paragraphs A308.1, 308.3, and A308.4 apply in their entirety. See para. MA308.2.

### MA308.2 Nonmetallic Flanges

Threaded nonmetallic flanges shall not be used.

## MA309 BOLTING

Paragraph A309 applies in its entirety.

# PART 14
# FLUID SERVICE REQUIREMENTS FOR NONMETALLIC PIPING JOINTS

## MA310 GENERAL

Paragraph 310 applies in its entirety.

## MA311 BONDED JOINTS

### MA311.1 General

Paragraph A311.1 applies in its entirety.

### MA311.2 Specific Requirements

Hot gas welded, heat fusion, solvent cemented, and adhesive bonded joints are not permitted except in linings.

## MA312 FLANGED JOINTS

Paragraph 312 applies in its entirety.

## MA313 EXPANDED JOINTS

Expanded joints shall not be used.

## MA314 THREADED JOINTS

### MA314.1 General

Threaded joints shall not be used.

## MA315 TUBING JOINTS IN NONMETALLIC PIPING

Paragraph A315 applies in its entirety.

## MA316 CAULKED JOINTS

Caulked joints shall not be used.

## MA318 SPECIAL JOINTS

Paragraph A318 applies in its entirety.

# PART 15
# FLEXIBILITY AND SUPPORT OF NONMETALLIC PIPING

## MA319 PIPING FLEXIBILITY

Paragraph A319 applies in its entirety.

## MA321 PIPING SUPPORT

Paragraph A321 applies in its entirety.

# PART 16
# NONMETALLIC AND NONMETALLIC-LINED SYSTEMS

## MA322 SPECIFIC PIPING SYSTEMS

Paragraph A322 applies in its entirety.

# PART 17
# NONMETALLIC MATERIALS

## MA323 GENERAL REQUIREMENTS

Paragraph A323.1 applies with the additional requirement described in para. MA323.1.2. Paragraph A323.2 applies in its entirety. See para. MA323.4.

**MA323.1.2 Unlisted Materials.** Paragraph 323.1.2 applies with the additional requirement that the designer shall fully document the determination of allowable stresses as part of the engineering design.

### MA323.4 Fluid Service Requirements for Nonmetallic Materials

Paragraph A323.4.1 applies. See paras. MA323.4.2 and MA323.4.3.

**MA323.4.2 Specific Requirements.** Paragraph A323.4.2 applies, except that materials listed under paras. A323.4.2(a), (b), and (d) may be used only as linings. Thermoplastics may be used as gaskets in accordance with paras. M325.1 and MA323.4.3.

**MA323.4.3 Nonmetallic Lining Materials.** Paragraph A323.4.3 applies with the additional requirement that where a material in para. A323.4.2 is used as a lining that also serves as a gasket or as part of the flange facing, consideration shall be given to design of the flanged joint to prevent leakage to the environment.

## PART 18
## STANDARDS FOR NONMETALLIC AND NONMETALLIC-LINED PIPING COMPONENTS

### MA326 DIMENSIONS AND RATINGS OF COMPONENTS

Paragraph A326 applies in its entirety. Table A326.1 applies, except for components and systems prohibited or restricted elsewhere in this Chapter.

## PART 19
## FABRICATION, ASSEMBLY, AND ERECTION OF NONMETALLIC AND NONMETALLIC-LINED PIPING

### MA327 GENERAL

Paragraph A327 applies in its entirety.

### MA328 BONDING OF PLASTICS

Paragraph A328 applies in its entirety.

### MA329 FABRICATION OF PIPING LINED WITH NONMETALS

Paragraph A329 applies in its entirety.

### MA332 BENDING AND FORMING

Paragraph A332 applies in its entirety.

### MA334 JOINING NONPLASTIC PIPING

Paragraph A334 applies in its entirety.

### MA335 ASSEMBLY AND ERECTION

Paragraph A335 applies in its entirety.



## PART 20
## INSPECTION, EXAMINATION, TESTING, AND RECORDS OF NONMETALLIC AND NONMETALLIC-LINED PIPING

### MA340 INSPECTION

Paragraph 340 applies in its entirety.

### MA341 EXAMINATION

Paragraph A341 applies in its entirety.

#### MA341.1 General

Paragraphs 341.1, 341.2, A341.3, and A341.5 apply in their entirety. See para. MA341.4.

#### MA341.4 Extent of Required Examination

Paragraph A341.4.1 applies, except as follows:

*(a) Visual Examination*

*(1)* All fabrication shall be visually examined.

*(2)* All bolted and other mechanical joints shall be examined.

### MA342 EXAMINATION PERSONNEL

Paragraph 342 applies in its entirety.

### MA343 EXAMINATION PROCEDURES

Paragraph 343 applies in its entirety.

### MA344 TYPES OF EXAMINATION

Paragraph A344 applies in its entirety.

### MA345 TESTING

Paragraph A345 applies except that

*(a)* a sensitive leak test in accordance with para. 345.8 shall be included in the required leak test (para. A345.1)

*(b)* the initial service leak test (para. A345.7) does not apply

### MA346 RECORDS

Paragraph 346 applies in its entirety.

# Chapter IX High Pressure Piping

## (18) K300 GENERAL STATEMENTS

*(a) Applicability.* This Chapter pertains to piping designated by the owner as being in High Pressure Fluid Service. See (e).

*(b) Responsibilities.* In addition to the responsibilities stated in para. 300(b),

*(1)* for piping designated as being in High Pressure Fluid Service, the owner shall provide all system operations information necessary for the designer to perform the analyses and testing required by this Chapter

*(2)* the designer shall make a written report to the owner summarizing the design calculations and certifying that the design has been performed in accordance with this Chapter

*(c)* The identification, intent, and Code requirements in paras. 300(a), (c), (d), (e), and (f) apply.

*(d)* The organization, content, and, wherever possible, paragraph designations of this Chapter correspond to those of the first six Chapters (the base Code). The prefix K is used.

*(e) High Pressure Piping.* This Chapter provides alternative rules for design and construction of piping designated by the owner as being in High Pressure Fluid Service.

*(1)* Provisions and requirements of the base Code apply only as stated in this Chapter.

*(2)* Use of this Chapter is permitted only at the option of the owner, and when the owner chooses to designate piping as being in High Pressure Fluid Service, its requirements apply in their entirety.

*(3)* There are no pressure limitations for the application of these rules. See Appendix F, para. FK300.

### (18) K300.1 Scope

The text introducing para. 300.1 applies.

**K300.1.1 Content and Coverage.** Paragraph 300.1.1 applies.

**K300.1.2 Packaged Equipment Piping.** Interconnecting piping as described in para. 300.1.2 shall conform to the requirements of this Chapter.

**K300.1.3 Exclusions.** In addition to the exclusions stated in para. 300.1.3, this Chapter excludes nonmetallic and nonmetallic-lined piping.

**K300.1.4 Rounding.** Paragraph 300.1.4 applies.

**K300.1.5 Category M Fluid Service.** This Chapter makes no provision for piping in Category M Fluid Service. If such piping is required by the owner, the engineering design shall be developed as provided in para. 300(c)(5).

### K300.2 Definitions

Paragraph 300.2 applies except for terms relating only to nonmetals and severe cyclic conditions.

The term "allowable stress" is used in lieu of basic allowable stress.

The term "safeguarding" and other terms characterizing hazardous fluid services are not used in this Chapter but should be taken into account in design.

### K300.3 Nomenclature

Paragraph 300.3 applies.

### K300.4 Status of Appendices (18)

Paragraph 300.4 and Table 300.4 apply, except for Appendices A, B, H, L, R, S, V, and X.

# PART 1 CONDITIONS AND CRITERIA

## K301 DESIGN CONDITIONS (18)

Paragraph 301 applies with the exceptions of paras. 301.2, 301.3, 301.4.2, 301.5, and 301.7.3.

### K301.2 Design Pressure

**K301.2.1 General.** Paragraph 301.2.1 applies, except that references to para. 302.2.4 are not applicable and refer to para. K304 instead of para. 304.

**K301.2.2 Required Pressure Containment or Relief.** Paragraphs 301.2.2(a) and (b) apply, but refer to para. K322.6.3 instead of para. 322.6.3. Paragraph 301.2.2(c) is not applicable.

### K301.3 Design Temperature

Paragraph 301.3 applies with the exceptions of paras. 301.3.1 and 301.3.2 and the following exceptions in the text:

*(a)* Refer to para. K301.2 instead of para. 301.2.

*(b)* Refer to para. K301.3.2 instead of para. 301.3.2.

**K301.3.1 Design Minimum Temperature.** Paragraph 301.3.1 applies, but refer to para. K323.2.2 instead of para. 323.2.2.

**K301.3.2 Uninsulated Components.** The fluid temperature shall be used as the component temperature.

### K301.4 Ambient Effects

**K301.4.2 Fluid Expansion Effects.** Paragraph 301.4.2 applies, except that reference to para. 322.6.3(b)(2) is not applicable.

### K301.5 Dynamic Effects

Paragraph 301.5 applies with the exception of para. 301.5.4.

**K301.5.4 Vibration.** Suitable dynamic analysis shall be made where necessary, to avoid or minimize conditions that lead to detrimental vibration, pulsation, or resonance effects in the piping.

### K301.7 Thermal Expansion and Contraction Effects

**K301.7.3 Loads Due to Differences in Expansion Characteristics.** Paragraph 301.7.3 applies, except that reference to metallic–nonmetallic piping is not applicable.

## K302 DESIGN CRITERIA

### K302.1 General

In para. K302, pressure–temperature ratings, stress criteria, design allowances, and minimum design values are stated, and permissible variations of these factors as applied to design of high pressure piping systems are formulated.

The designer shall be satisfied as to the adequacy of the design, and of materials and their manufacture, considering at least the following:

*(a)* tensile, compressive, flexural, and shear strength at design temperature
*(b)* fatigue strength
*(c)* design stress and its basis
*(d)* ductility and toughness
*(e)* possible deterioration of mechanical properties in service
*(f)* thermal properties
*(g)* temperature limits
*(h)* resistance to corrosion and erosion
*(i)* fabrication methods
*(j)* examination and testing methods
*(k)* hydrostatic test conditions
*(l)* bore imperfections

### K302.2 Pressure–Temperature Design Criteria

**K302.2.1 Listed Components Having Established Ratings.** Pressure–temperature ratings for certain piping components have been established and are contained in some of the standards in Table K326.1. Unless limited elsewhere in this Chapter, those ratings are acceptable for design pressures and temperatures under this Chapter. With the owner's approval, the rules and limits of this Chapter may be used to extend the pressure–temperature ratings of a component beyond the ratings of the listed standard, but not beyond the limits stated in para. K323.2.

**K302.2.2 Listed Components Not Having Specific Ratings**

*(a)* Piping components for which design stresses have been developed in accordance with para. K302.3, but that do not have specific pressure–temperature ratings, shall be rated by rules for pressure design in para. K304, within the range of temperatures for which stresses are shown in Table K-1, modified as applicable by other rules of this Chapter.

*(b)* Piping components that do not have allowable stresses or pressure–temperature ratings shall be qualified for pressure design as required by para. K304.7.2.

**K302.2.3 Unlisted Components.** Piping components not listed in Table K326.1 may be used subject to all of the following requirements: (18)

*(a)* The material shall comply with para. K323.
*(b)* The designer shall be satisfied that the design is suitable for the intended service.
*(c)* Pressure–temperature ratings shall be established in accordance with the rules in para. K304.
*(d)* Fatigue analysis shall be performed as required by para. K304.8.

**K302.2.4 Allowance for Pressure and Temperature Variations.** Variations in pressure, temperature, or both above the design conditions, except during pressure-relieving events (see para. K322.6.3), are not permitted for any piping system. The design pressure and design temperature resulting in the most severe coincident pressure and temperature shall determine the design conditions. See paras. K301.2 and K301.3. (18)

**K302.2.5 Ratings at Junction of Different Services.** Paragraph 302.2.5 applies.

### K302.3 Allowable Stresses and Other Design Limits

**K302.3.1 General.** The allowable stresses defined below shall be used in design calculations unless modified by other provisions of this Chapter.

*(a) Tension.* Allowable stresses in tension for use in design in accordance with this Chapter are listed in Table K-1, except that maximum allowable stress values and design stress intensity values for bolting, respectively, are listed in ASME BPVC, Section II, Part D, Tables 3 and 4.

The tabulated stress values in Table K-1 are grouped by materials and product form and are for stated temperatures up to the limit provided for the materials in para. K323.2.1. Straight line interpolation between temperatures to determine the allowable stress for a specific design temperature is permissible. Extrapolation is not permitted.

*(b) Shear and Bearing.* Allowable stress in shear shall be 0.80 times the allowable stress in tension tabulated in Table K-1. Allowable stress in bearing shall be 1.60 times the allowable stress in tension.

*(c) Compression.* Allowable stress in compression shall be no greater than the allowable stress in tension tabulated in Table K-1. Consideration shall be given to structural stability.

*(d) Fatigue.* Allowable values of stress amplitude, which are provided as a function of design life in ASME BPVC, Section VIII, Division 2, Part 3, para. 3.15, or Section VIII, Division 3, Article KD-3, as applicable, may be used in fatigue analysis in accordance with para. K304.8.

**K302.3.2 Bases for Allowable Stresses.** The bases for establishing allowable stress values for materials in this Chapter are as follows:

*(a) Bolting Materials.* The criteria of ASME BPVC, Section II, Part D, Appendix 2, para. 2-120 or 2-130, or Section VIII, Division 3, Article KD-6, para. KD-620, as applicable, apply.

*(b) Other Materials.* For materials other than bolting materials, the following rules apply:

*(1)* Except as provided in (b)(2) below, allowable stress values at design temperature for materials shall not exceed the lower of two-thirds of $S_Y$ and two-thirds of $S_{yt}$. $S_{yt}$ is determined in accordance with eq. (31)

$$S_{yt} = S_Y R_Y \tag{31}$$

where

$R_Y$ = ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength

$S_Y$ = specified minimum yield strength at room temperature

$S_{yt}$ = yield strength at temperature

*(2)* For solution heat treated austenitic stainless steels and certain nickel alloys with similar stress–strain behavior, allowable stress values shall not exceed the lower of two-thirds of $S_Y$ and 90% of $S_{yt}$.

Application of stress values so determined is not recommended for flanged joints and other components in which slight deformation can cause leakage or malfunction. [These values are shown in *italics* or **boldface** in Table K-1, as explained in Table K-1, Note (12).] Instead, either 75% of the stress value in Table K-1 or two-thirds of the yield strength at temperature listed in ASME BPVC, Section II, Part D, Table Y-1, as applicable, should be used.

*(c) Unlisted Materials.* For a material that conforms to para. K323.1.2, allowable stress values at design temperature shall not exceed the lower of two-thirds of $S_Y$ and two-thirds of $S_{yt}$.

*(1)* Except as provided in (c)(2) below, $S_{yt}$ shall be determined in accordance with eq. (31).

*(2)* If the yield strength at temperature for an unlisted material is contained in ASME BPVC, Section II, Part D, Table Y-1, that yield strength at temperature value may be used directly in the determination of allowable stress.

*(d) Cyclic Stresses.* Allowable values of alternating stress or equipment alternating stress, as applicable, shall be in accordance with ASME BPVC, Section VIII, Division 2, Part 3, para. 3.15 and Part 5; or Division 3, Article KD-3; respectively.

**K302.3.3 Castings.**[1] Cast piping components shall conform to all of the following requirements: (18)

*(a)* All surfaces shall have a roughness average, $R_a$, not greater than 6.3 μm $R_a$ (250 μin. $R_a$); see ASME B46.1 for a definition of $R_a$.

*(b)* All nonferromagnetic surfaces shall be examined using the liquid penetrant method in accordance with ASTM E165, with acceptability judged in accordance with MSS SP-93, Table 1. All ferromagnetic surfaces shall be examined using either the liquid penetrant method or the magnetic particle method, in accordance with ASTM E165 or ASTM E709, respectively. Acceptability of imperfections, including those in weld repairs, shall be judged in accordance with MSS SP-93, Table 1 or MSS SP-53, Table 1, respectively.

*(c)* Each casting shall be fully examined either ultrasonically in accordance with ASTM E114 or radiographically in accordance with ASTM E94. Cracks and hot tears (Category D and E discontinuities in accordance with the standards listed in Table K302.3.3D) and imperfections whose depths exceed 3% of nominal wall thickness are not permitted. Acceptable severity levels for radiographic examination of castings shall be in accordance with Table K302.3.3D.

**K302.3.4 Weld Joint Quality Factor.** Piping components containing welds shall have a weld joint quality factor $E_j$ = 1.00 (see Table 302.3.4), except that the acceptance criteria for these welds shall be in accordance with

[1] See Notes to Tables 302.3.3C and 302.3.3D for titles of standards referenced herein.

**Table K302.3.3D Acceptable Severity Levels for Steel Castings**

| Thickness Examined, mm (in.) | Applicable Standards | Acceptable Severity Level | Acceptable Discontinuity Categories |
|---|---|---|---|
| $\overline{T} \leq 51$ (2) | ASTM E446 | 1 | A, B, C |
| $51 < \overline{T} \leq 114$ (4.5) | ASTM E186 | 1 | A, B, C |
| $114 < \overline{T} \leq 305$ (12) | ASTM E280 | 1 | A, B, C |

para. K341.3.2. Spiral (helical seam) welds are not permitted.

(18) **K302.3.5 Limits of Calculated Stresses Due to Sustained Loads and Displacement Strains**

*(a) Internal Pressure Stresses.* Stresses due to internal pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of para. K304.

*(b) External Pressure Stresses.* Stresses due to external pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of para. K304.

*(c) Stresses Due to Sustained Loads, $S_L$.* The stresses due to sustained loads, $S_L$, in any component in a piping system (see para. K320) shall not exceed $S_h$, where $S_h$ is the allowable stress provided in Table K-1 at the metal temperature for the operating condition being considered. The thickness of pipe used in calculating $S_L$ shall be the nominal thickness minus the mechanical, corrosion, and erosion allowance, $c$.

*(d) Allowable Displacement Stress Range, $S_A$.* The computed displacement stress range, $S_E$, in a piping system (see para. 319.4.4) shall not exceed the allowable displacement stress range, $S_A$ (see para. 319.2.3), calculated by

$$S_A = 1.25S_c + 0.25S_h \tag{32}$$

where

$S_c$ = allowable stress from Table K-1 at minimum metal temperature expected during the displacement cycle under analysis

$S_h$ = allowable stress from Table K-1 at maximum metal temperature expected during the displacement cycle under analysis

(18) **K302.3.6 Limits of Calculated Stresses Due to Occasional Loads**

*(a) Operation.* Stresses due to occasional loads may be calculated using the equations for stress due to sustained loads in para. K320.2. The sum of the stresses due to sustained loads, such as pressure and weight, $S_L$, and of the stresses produced by occasional loads, such as wind and earthquake, may be as much as 1.2 times the allowable stress provided in Table K-1 at the metal temperature for the occasional condition being considered. Where the allowable stress value in Table K-1 exceeds two-thirds of $S_{yt}$, $S_L$ shall not exceed 90% of $S_{yt}$ listed in ASME BPVC, Section II, Part D, Table Y-1. Wind and earthquake forces need not be considered as acting concurrently.

*(b) Test.* Stresses due to test conditions are not subject to the limitations in para. K302.3. It is not necessary to consider other occasional loads, such as wind and earthquake, as occurring concurrently with test loads.

### K302.4 Allowances

In determining the minimum required thickness of a piping component, allowances shall be included for corrosion, erosion, and thread or groove depth. See the definition of $c$ in para. K304.1.1(b).

### K302.5 Mechanical Strength

Paragraph 302.5 applies.

## PART 2
## PRESSURE DESIGN OF PIPING COMPONENTS

### K303 GENERAL

Components manufactured in accordance with standards listed in Table K326.1 shall be considered suitable for use at pressure–temperature ratings in accordance with para. K302.2.

### K304 PRESSURE DESIGN OF HIGH PRESSURE COMPONENTS

### K304.1 Straight Pipe

#### K304.1.1 General

*(a)* The required wall thickness of straight sections of pipe shall be determined in accordance with eq. (33).

$$t_m = t + c \tag{33}$$

The minimum wall thickness, $T$, for the pipe selected, considering manufacturer's minus tolerance, shall be not less than $t_m$.

*(b)* The following nomenclature is used in the equation for pressure design of straight pipe:

$c$ = $c_i + c_o$
= the sum of mechanical allowances[2] (thread or groove depth) plus corrosion and erosion allowances (where $c_i$ = the sum of *internal* allowances and $c_o$ = the sum of *external* allowances). For threaded components, the nominal thread depth (dimension $h$ of ASME B1.20.1 or

[2] For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.

equivalent) shall apply, except that for straight threaded connections, the external thread groove depth need not be considered provided

(a) it does not exceed 20% of the wall thickness;

(b) the ratio of outside to inside diameter, $D/d$, is greater than 1.1;

(c) the internally threaded attachment provides adequate reinforcement; and

(d) the thread plus the undercut area, if any, does not extend beyond the reinforcement for a distance more than the nominal wall thickness of the pipe.

$t$ = pressure design wall thickness, as calculated in para. K304.1.2 for internal pressure, or in accordance with the procedure listed in para. K304.1.3 for external pressure

$t_m$ = minimum required wall thickness, including mechanical, corrosion, and erosion allowances

Adequate reinforcement by the attachment is defined as that necessary to ensure that the static burst pressure of the connection will equal or exceed that of the unthreaded portion of the pipe. The adequacy of the reinforcement shall be substantiated as required by para. K304.7.2.

(18) **K304.1.2 Straight Pipe Under Internal Pressure**

(a) Except as provided in (b) below for solution heat treated austenitic stainless steels and certain nickel alloys with similar stress–strain behavior, the internal pressure design wall thickness, $t$, shall be not less than that calculated in accordance with eq. (34a) for pipe with a specified outside diameter and minimum wall thickness, or eq. (34b) for pipe with a specified inside diameter and minimum wall thickness[3,4]

$$t = \frac{D - 2c_o}{2}\left(1 - e^{-P/S}\right) \tag{34a}$$

or

$$t = \frac{d + 2c_i}{2}\left(e^{P/S} - 1\right) \tag{34b}$$

Alternatively, the internal design gage pressure, $P$, may be calculated by eq. (35a) or (35b)[3,4]

$$P = S \times \ln\left[\frac{D - 2c_o}{D - 2(T - c_i)}\right] \tag{35a}$$

or

$$P = S \times \ln\left[\frac{d + 2(T - c_o)}{d + 2c_i}\right] \tag{35b}$$

where

$D$ = outside diameter of pipe. For design calculations in accordance with this Chapter, the outside diameter of the pipe is the maximum value allowable under the specifications.

$d$ = inside diameter of pipe. For design calculations in accordance with this Chapter, the inside diameter of the pipe is the maximum value allowable under the specifications.

$P$ = internal design gage pressure

$S$ = allowable stress from Table K-1

$T$ = pipe wall thickness (measured or minimum in accordance with the purchase specification)

(b) At design temperatures where allowable stress, $S$, values in Table K-1 are in **boldface** (solution heat treated austenitic stainless steels and certain nickel alloys with similar stress–strain behavior only), the internal pressure design wall thickness, $t$, shall be not less than that calculated in accordance with eq. (34c) for pipe with a specified outside diameter and minimum wall thickness, or eq. (34d) for pipe with a specified inside diameter and minimum wall thickness[3,4]

$$t = \frac{D - 2c_o}{2}\left(1 - e^{-1.155P/S}\right) \tag{34c}$$

or

$$t = \frac{d + 2c_i}{2}\left(e^{1.155P/S} - 1\right) \tag{34d}$$

Alternatively, the internal design gage pressure, $P$, may be calculated by eq. (35c) or (35d)[3,4]

$$P = \frac{S}{1.155}\ln\left[\frac{D - 2c_o}{D - 2(T - c_i)}\right] \tag{35c}$$

or

$$P = \frac{S}{1.155}\ln\left[\frac{d + 2(T - c_o)}{d + 2c_i}\right] \tag{35d}$$

**K304.1.3 Straight Pipe Under External Pressure.** The pressure design thickness for straight pipe under external pressure shall be determined in accordance with para. K304.1.2 for pipe where $D/t < 3.33$, if at least one end of the pipe is exposed to full external pressure, producing a compressive axial stress. For $D/t \geq 3.33$, and for $D/t < 3.33$ where external pressure is not applied to at least one end of the pipe, the pressure design wall thickness shall be determined in accordance with para. 304.1.3 except that the stress values shall be taken from Table K-1.

[3] The intent of these equations is to provide a factor of not less than 1.732 (or $\sqrt{3}$) on the pressure required, according to the von Mises theory, to initiate yielding on the outside surface of a cylinder made from an elastic-perfectly plastic material. For solution heat treated austenitic stainless steels and certain nickel alloys with similar stress–strain behavior, this factor is as low as approximately 1.5 at elevated temperatures.

[4] Any mechanical, corrosion, or erosion allowance, $c$, not specified as internal, $c_i$, or external, $c_o$, shall be assumed to be internal, i.e., $c = c_i$ and $c_o = 0$.

## K304.2 Curved and Mitered Segments of Pipe

**K304.2.1 Pipe Bends.** The minimum required wall thickness, $t_m$, of a bend, after bending, may be determined as for straight pipe in accordance with para. K304.1, provided that the bend radius of the pipe centerline is equal to or greater than ten times the nominal pipe outside diameter and the tolerances and strain limits of para. K332 are met. Otherwise the design shall be qualified as required by para. K304.7.2.

**K304.2.2 Elbows.** Manufactured elbows not in accordance with para. K303 and pipe bends not in accordance with para. K304.2.1 shall be qualified as required by para. K304.7.2.

**K304.2.3 Miter Bends.** Miter bends are not permitted.

**K304.2.4 Curved Segments of Pipe Under External Pressure.** The wall thickness of curved segments of pipe subjected to external pressure may be determined as specified for straight pipe in para. K304.1.3, provided the design length, $L$, is the running centerline length between any two sections that are stiffened in accordance with para. 304.1.3.

## K304.3 Branch Connections

**K304.3.1 General.** Acceptable branch connections include a fitting in accordance with para. K303, an extruded outlet in accordance with para. 304.3.4, or a branch connection fitting (see para. 300.2) similar to that shown in Figure K328.5.4.

**K304.3.2 Strength of Branch Connections**

*(a)* The opening made for a branch connection reduces both static and fatigue strength of the run pipe. There shall be sufficient material in the branch connection to contain pressure and meet reinforcement requirements.

*(b)* Static pressure design of a branch connection not in accordance with para. K303 shall conform to para. 304.3.4 for an extruded outlet or shall be qualified as required by para. K304.7.2.

**K304.3.3 Reinforcement of Welded Branch Connections.** Branch connections made as provided in para. 304.3.3 are not permitted.

## K304.4 Closures

*(a)* Closures not in accordance with para. K303 or (b) below shall be qualified as required by para. K304.7.2.

*(b)* Closures may be designed in accordance with the methods, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 2 or Division 3, and ASME BPVC, Section II, Part D.

## K304.5 Pressure Design of Flanges and Blanks

**K304.5.1 Flanges — General**

*(a)* Flanges not in accordance with para. K303 or (b) below shall be qualified as required by para. K304.7.2.

*(b)* A flange may be designed in accordance with the methods, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 2, Part 4, para. 4.16, or Part 5, or Division 3, Article KD-6, and ASME BPVC, Section II, Part D.

**K304.5.2 Blind Flanges**

*(a)* Blind flanges not in accordance with para. K303 or (b) or (c) below shall be qualified as required by para. K304.7.2.

*(b)* A blind flange may be designed in accordance with eq. (36). The thickness of the flange selected shall be not less than $t_m$ (see para. K304.1.1 for nomenclature), considering manufacturing tolerance

$$t_m = t + c \tag{36}$$

The methods, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 2, Part 4, para. 4.6 may be used, with the following changes in nomenclature, to calculate $t_m$:

$c$ = sum of mechanical allowances, defined in para. K304.1.1

$t$ = pressure design thickness as calculated for the given style of blind flange using the appropriate equation of ASME BPVC, Section VIII, Division 2, Part 4, para. 4.6

*(c)* A blind flange may be designed in accordance with the rules, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 3, Article KD-6 and ASME BPVC, Section II, Part D.

**K304.5.3 Blanks.** Design of blanks shall be in accordance with para. 304.5.3(b), except that $E$ shall be 1.00 and the definitions of $S$ and $c$ shall be in accordance with para. K304.1.1.

## K304.6 Reducers

Reducers not in accordance with para. K303 shall be qualified as required by para. K304.7.2.

## K304.7 Pressure Design of Other Components

**K304.7.1 Listed Components.** Other pressure-containing components manufactured in accordance with standards in Table K326.1 may be utilized in accordance with para. K303.

**K304.7.2 Unlisted Components.** Pressure design of unlisted components to which the rules elsewhere in para. K304 do not apply shall be based on the pressure design criteria of this Chapter. The designer shall ensure that the pressure design has been substantiated through one or more of the means stated in (a), (b), and (c) below. Note that designs are also required to be checked for adequacy of mechanical strength as described in para. K302.5.

*(a)* extensive, successful service experience under comparable design conditions with similarly proportioned components made of the same or like material.

*(b)* performance testing sufficient to substantiate both the static pressure design and fatigue life at the intended operating conditions. Static pressure design may be substantiated by demonstrating that failure or excessive plastic deformation does not occur at a pressure equivalent to two times the internal design pressure, $P$. The test pressure shall be two times the design pressure multiplied by the ratio of allowable stress at test temperature to the allowable stress at design temperature, and by the ratio of actual yield strength to the specified minimum yield strength at room temperature from Table K-1.

*(c)* detailed stress analysis (e.g., finite element method) with results evaluated as described in ASME BPVC, Section VIII, Division 3, Article KD-2, except that for linear elastic analyses

*(1)* $S_y/1.5$ in Division 3 shall be replaced by $S$ from Table K-1, and

*(2)* the Division 3 stress intensity limits due to sustained loads may be increased by the same factor applied in para. K302.3.6(a) when wind or earthquake loads are included. However, this limit shall not exceed 90% of $S_{yt}$ listed in ASME BPVC, Section II, Part D, Table Y-1.

*(d)* for (a), (b), and (c) above, interpolations supported by analysis are permitted between sizes, wall thicknesses, and pressure classes, as well as analogies among related materials with supporting material property data. Extrapolation is not permitted.

**K304.7.3 Components With Nonmetallic Parts.** Except for gaskets and packing, nonmetallic parts are not permitted.

(18) **K304.7.4 Expansion Joints.** Expansion joints are not permitted.

## K304.8 Fatigue Analysis

**K304.8.1 General.** A fatigue analysis shall be performed on each piping system, including all components[5] and joints therein, and considering the stresses resulting from attachments, to determine its suitability for the cyclic operating conditions[6] specified in the engineering design. Except as permitted in (a) and (b) below, or in paras. K304.8.4 and K304.8.5, this analysis shall be in accordance with ASME BPVC, Section VIII, Division 2 or Division 3.[7] The cyclic conditions shall include pressure variations as well as thermal variations or displacement stresses. The requirements of para. K304.8 are in addition to the requirements for a flexibility analysis stated in para. K319. No formal fatigue analysis is required in systems that

*(a)* are duplicates of successfully operating installations or replacements without significant change of systems with a satisfactory service record or

*(b)* can readily be judged adequate by comparison with previously analyzed systems

### K304.8.2 Amplitude of Alternating Stress

*(a) Fatigue Analysis Based Upon ASME BPVC, Section VIII, Division 2.* The value of the alternating stress amplitude for comparison with design fatigue curves shall be determined in accordance with Part 5. The allowable amplitude of alternating stress shall be determined from the applicable design fatigue curve in Part 3, para. 3.15.

*(b) Fatigue Analysis Based Upon ASME BPVC, Section VIII, Division 3*

*(1)* The values of the alternating stress intensity, the associated mean stress, and the equivalent alternating stress intensity shall be determined in accordance with Articles KD-2 and KD-3. The allowable amplitude of the equivalent alternating stress shall be determined from the applicable design fatigue curve in Article KD-3.

*(2)* If it can be shown that the piping component will fail in a leak-before-burst mode, the number of design cycles (design fatigue life) may be calculated in accordance with either Article KD-3 or Article KD-4. If a leak-before-burst mode of failure cannot be shown, the fracture mechanics evaluation outlined in Article KD-4 shall be used to determine the number of design cycles of the component.

*(c) Additional Considerations.* The designer is cautioned that the considerations listed in para. K302.1 may reduce the fatigue life of the component below the value predicted by para. (a) or (b) above.

### K304.8.3 Pressure Stress Evaluation for Fatigue Analysis

*(a)* For fatigue analysis of straight pipe, eq. (37) may be used to calculate the stress intensity[8] at the inside surface due only to internal pressure

$$S = \frac{PD^2}{2(T-c)[D-(T-c)]} \tag{37}$$

[5] Bore imperfections may reduce fatigue life.

[6] If the range of temperature change varies, equivalent full temperature cycles $N$ may be computed using eq. (1d) in para. 302.3.5.

[7] Fatigue analysis in accordance with ASME BPVC, Section VIII, Division 2 or Division 3, requires that stress concentration factors be used in computing the cyclic stresses.

[8] The term "stress intensity" is defined in ASME BPVC, Section VIII, Division 3.

**Table K305.1.2 Required Ultrasonic or Eddy Current Examination of Pipe and Tubing for Longitudinal Defects**

| Diameter, mm (in.) | Examination Required | Paragraph Reference |
|---|---|---|
| $d < 3.2$ ($\frac{1}{8}$) or $D < 6.4$ ($\frac{1}{4}$) | None | ... |
| $3.2$ ($\frac{1}{8}$) $\le d \le 17.5$ ($\frac{11}{16}$) and $6.4$ ($\frac{1}{4}$) $\le D \le 25.4$ (1) | Eddy current (ET) [Note (1)] or ultrasonic (UT) | K344.8 or K344.6 |
| $d > 17.5$ ($\frac{11}{16}$) or $D > 25.4$ (1) | Ultrasonic (UT) | K344.6 |

NOTE: (1) This examination is limited to cold drawn austenitic stainless steel pipe and tubing.

(b) For fatigue analysis of curved pipe, eq. (37) may be used, with the dimensions of the straight pipe from which it was formed, to calculate the maximum stress intensity at the inside surface due only to internal pressure, provided that the centerline bend radius is not less than ten times the nominal outside diameter of the pipe, and that the tolerance and strain limits of para. K332 are met. Bends of smaller radius shall be qualified as required by para. K304.7.2.

(c) If the value of $S$ calculated by eq. (37) exceeds three times the allowable stress from Table K-1 at the average temperature during the loading cycle, an inelastic analysis is required.

**K304.8.4 Fatigue Evaluation by Test.** With the owner's approval, the design fatigue life of a component may be established by destructive testing in accordance with para. K304.7.2 in lieu of the above analysis requirements.

**K304.8.5 Extended Fatigue Life.** The design fatigue life of piping components may be extended beyond that determined by ASME BPVC, Section VIII, Division 2, Part 3, para. 3.15 and Part 5; or Division 3, Article KD-3; as applicable, by the use of one of the following methods, provided that the component is qualified in accordance with para. K304.7.2:

(a) surface treatments, such as improved surface finish

(b) prestressing methods, such as autofrettage, shot peening, or shrink fit

The designer is cautioned that the benefits of prestress may be reduced due to thermal, strain softening, or other effects.

# PART 3
# FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

## K305 PIPE

Pipe includes components designated as "tube" or "tubing" in the material specification, when intended for pressure service.

### K305.1 Requirements

**K305.1.1 General.** Pipe and tubing shall be either seamless or longitudinally welded with straight seam and a joint quality factor $E_j$ = 1.00, examined in accordance with Note (2) of Table K341.3.2. Spiral (helical seam) welds are not permitted.

**K305.1.2 Additional Examination.** Pipe and tubing shall have passed a 100% examination for longitudinal defects in accordance with Table K305.1.2. This examination is in addition to acceptance tests required by the material specification.

**K305.1.3 Heat Treatment.** Heat treatment, if required, shall be in accordance with para. K331.

**K305.1.4 Unlisted Pipe and Tubing.** Unlisted pipe and tubing may be used only in accordance with para. K302.2.3.

## K306 FITTINGS, BENDS, AND BRANCH CONNECTIONS

Pipe and other materials used in fittings, bends, and branch connections shall be suitable for the manufacturing or fabrication process and otherwise suitable for the service.

### K306.1 Pipe Fittings

**K306.1.1 General.** All castings shall have examination (18)
and acceptance criteria in accordance with para. K302.3.3. All welds shall have a weld quality factor $E_j$ = 1.00, with examination and acceptance criteria in accordance with paras. K341 through K344. Spiral (helical seam) welds are not permitted. Listed fittings may be used in accordance with para. K303. Unlisted fittings may be used only in accordance with para. K302.2.3.

**K306.1.2 Specific Fittings**

(a) Socket welding fittings are not permitted.

(b) Threaded fittings are permitted only in accordance with para. K314.

(c) Branch connection fittings (see para. 300.2) whose design has been performance tested successfully as required by para. K304.7.2(b) may be used within their established ratings.

### K306.2 Pipe Bends

**K306.2.1 General.** A bend made in accordance with para. K332.2 and verified for pressure design in accordance with para. K304.2.1 shall be suitable for the same service as the pipe from which it is made.

**K306.2.2 Corrugated and Other Bends.** Bends of other design (such as creased or corrugated) are not permitted.

### K306.3 Miter Bends

Miter bends are not permitted.

### K306.4 Fabricated or Flared Laps

Only forged laps are permitted.

### K306.5 Fabricated Branch Connections

Fabricated branch connections constructed by welding shall be fabricated in accordance with para. K328.5.4 and examined in accordance with para. K341.4.

## K307 VALVES AND SPECIALTY COMPONENTS

The following requirements for valves shall also be met, as applicable, by other pressure-containing piping components, e.g., traps, strainers, and separators.

### K307.1 General

Pressure design of unlisted valves shall be qualified as required by para. K304.7.2.

## K308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

### K308.1 General

Pressure design of unlisted flanges shall be verified in accordance with para. K304.5.1 or qualified as required by para. K304.7.2.

### K308.2 Specific Flanges

**K308.2.1 Threaded Flanges.** Threaded flanges may be used only within the limitations on threaded joints in para. K314.

**K308.2.2 Other Flange Types.** Slip-on, socket welding, and expanded joint flanges, and flanges for flared laps, are not permitted.

### K308.3 Flange Facings

The flange facing shall be suitable for the service and for the gasket and bolting employed.

### K308.4 Gaskets

Gaskets shall be selected so that the required seating load is compatible with the flange rating and facing, the strength of the flange, and its bolting. Materials shall be suitable for the service conditions. Mode of gasket failure shall be considered in gasket selection and joint design.

### K308.5 Blanks

Blanks shall have a marking, identifying material, pressure–temperature rating, and size, that is visible after installation.

## K309 BOLTING

Bolting, including bolts, bolt studs, studs, cap screws, nuts, and washers, shall meet the requirements of ASME BPVC, Section VIII, Division 2, Part 3, para. 3.7; Part 4, para. 4.16; and Part 5, para. 5.7. See also Appendix F, para. F309, of this Code.

# PART 4
# FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS

## K310 GENERAL

Joints shall be suitable for the fluid handled, and for the pressure–temperature and other mechanical loadings expected in service.

Factors such as assembly and disassembly (if applicable), cyclic loading, vibration, shock, bending, and thermal expansion and contraction of joints shall be considered in the engineering design.

## K311 WELDED JOINTS

### K311.1 General

Welds shall conform to the following:

*(a)* Welding shall be in accordance with para. K328.

*(b)* Preheating and heat treatment shall be in accordance with paras. K330 and K331, respectively.

*(c)* Examination shall be in accordance with para. K341.4, with acceptance criteria as shown in Table K341.3.2.

### K311.2 Specific Requirements

**K311.2.1 Backing Rings and Consumable Inserts.** Backing rings shall not be used. Consumable inserts shall not be used in butt welded joints except when specified by the engineering design.

**K311.2.2 Fillet Welds.** Fillet welds may be used only for structural attachments in accordance with the requirements of paras. K321 and K328.5.2.

**K311.2.3 Other Weld Types.** Socket welds and seal welds are not permitted.

## K312 FLANGED JOINTS

Flanged joints shall be selected for leak tightness, considering the requirements of para. K308, flange facing finish, and method of attachment. See also para. F312.

### K312.1 Joints Using Flanges of Different Ratings

Paragraph 312.1 applies.

## K313 EXPANDED JOINTS

Expanded joints are not permitted.

(18) ## K314 THREADED PIPE JOINTS

For the purposes of this paragraph, "pipe" does not include "tube" or "tubing."

### K314.1 General

Except as provided in paras. K314.2 and K314.3, threaded pipe joints are not permitted.

*(a)* Layout of piping shall be such as to minimize strain on threaded joints that could adversely affect sealing.

*(b)* Supports shall be designed to control or minimize strain and vibration on threaded joints and seals.

### K314.2 Taper-Threaded Pipe Joints

*(a)* Taper-threaded pipe joints shall be used only for instrumentation, vents, drains, and similar purposes, and shall be not larger than DN 15 (NPS ½).

*(b)* Externally threaded piping components shall be at least Schedule 160 in nominal wall thickness. The nominal thickness of Schedule 160 piping is listed in ASME B36.10M for DN 15 (NPS ½) and in ASME B16.11 for sizes smaller than DN 15 (NPS ½).

### K314.3 Straight-Threaded Pipe Joints

**K314.3.1 Joints With Seal Formed by Projecting Pipe.** Threaded joints where the threads are used to attach flanges or fittings, and in which the pipe end projects through the flange or fitting and is machined to form the sealing surface with a lens ring, cone ring, the mating pipe end, or other similar sealing device, may be used. Such joints shall be qualified in accordance with para. K304.7.2.

#### K314.3.2 Other Straight-Threaded Joints

*(a) Other Joints Using Components Conforming to Listed Standards.* Pipe joints may incorporate straight-threaded fittings conforming to listed standards in Table K326.1, provided the fittings

*(1)* are compatible with the pipe with which they are used, considering tolerances and other characteristics

*(2)* comply with para. K302.2.1 or para. K302.2.2

*(b) Other Joints Using Components Not Conforming to Listed Standards.* Other straight-threaded pipe joints (e.g., a union comprising external and internal ends joined with a threaded union nut, or other constructions shown typically in Figure 335.3.3) may be used. Such joints shall be qualified by performance testing in accordance with para. K304.7.2(b). Testing shall be conducted for each material type/grade and heat treatment condition, component configuration (e.g., elbow), size (e.g., NPS), and pressure rating. Performance testing of joints in which the process of making up the joint involves significant uncontrolled loads (e.g., hammer unions) shall include testing designed to simulate actual loads.

## K315 TUBING JOINTS (18)

### K315.1 Flared End Tubing Joints

Flared end tubing joints, whether the flare provides the seal, carries the load, or both, may be used, provided the type of fitting selected is adequate for the design pressure, other loadings, and the design temperature. The design shall also be qualified in accordance with para. K304.7.2.

### K315.2 Flareless Tubing Joints Using Components Conforming to Listed Standards

Tubing joints may incorporate flareless type fittings conforming to listed standards in Table K326.1, provided the fittings

*(a)* are compatible with the tubing with which they are used, considering tolerances and other characteristics

*(b)* comply with para. K302.2.1 or para. K302.2.2

### K315.3 Flareless Tubing Joints Using Components Not Conforming to Listed Standards

Tubing joints may incorporate flareless type fittings not conforming to listed standards in Table K326.1, provided the type of fitting selected is adequate for the design pressure, other loadings, and the design temperature, and meets the requirements of para. K302.2.3.

## K316 CAULKED JOINTS

Caulked joints are not permitted.

## K317 SOLDERED AND BRAZED JOINTS

### K317.1 Soldered Joints

Soldered joints are not permitted.

### K317.2 Brazed Joints

*(a)* Braze welded joints and fillet joints made with brazing filler metal are not permitted.

*(b)* Brazed joints shall be made in accordance with para. K333 and shall be qualified as required by para. K304.7.2. Such application is the owner's responsibility. The melting point of brazing alloys shall be considered when exposure to fire is possible.

## (18) K318 SPECIAL JOINTS

Special joints are those not covered elsewhere in this Part.

### K318.1 General

Joints may be used in accordance with para. 318.2 and the requirements for materials and components in this Chapter.

### K318.2 Specific Requirements

**K318.2.1 Prototype Tests.** A prototype joint shall have been subjected to performance tests in accordance with para. K304.7.2(b) to determine the safety of the joint under test conditions simulating all expected service conditions. Testing shall include cyclic simulation.

**K318.2.2 Prohibited Joints.** Bell type and adhesive joints are not permitted.

# PART 5
# FLEXIBILITY AND SUPPORT

## (18) K319 FLEXIBILITY

Flexibility analysis shall be performed for each piping system. Paragraphs 319.1 through 319.6 apply, except for para. 319.4.1(c). The computed displacement stress range shall be within the allowable displacement stress range in para. K302.3.5 and shall also be included in the fatigue analysis in accordance with para. K304.8.

## (18) K320 ANALYSIS OF SUSTAINED LOADS

### K320.1 Basic Assumptions and Requirements

Paragraph 320.1 applies, but refer to para. K302.3.5(c) instead of para. 302.3.5(c).

### K320.2 Stress Due to Sustained Loads

Paragraph 320.2 applies, except that references to expansion joints are not applicable.

## K321 PIPING SUPPORT

Piping supports and methods of attachment shall be in accordance with para. 321 except as modified below, and shall be detailed in the engineering design.

### K321.1 General

**K321.1.1 Objectives.** Paragraph 321.1.1 applies, but substitute "Chapter" for "Code" in (a).

**K321.1.4 Materials.** Paragraph 321.1.4 applies, but replace (e) with the following:

*(e)* Attachments welded to the piping shall be of a material compatible with the piping and the service. Other requirements are specified in paras. K321.3.2 and K323.4.2(b).

### K321.3 Structural Attachments

**K321.3.2 Integral Attachments.** Paragraph 321.3.2 applies, but substitute "K321.1.4(e)" for "321.1.4(e)" and "Chapter IX" for "Chapter V."

# PART 6
# SYSTEMS

## K322 SPECIFIC PIPING SYSTEMS

### K322.3 Instrument Piping

**K322.3.1 Definition.** Instrument piping within the scope of this Chapter includes all piping and piping components used to connect instruments to high pressure piping or equipment. Instruments, permanently sealed fluid-filled tubing systems furnished with instruments as temperature- or pressure-responsive devices, and control piping for air or hydraulically operated control apparatus (not connected directly to the high pressure piping or equipment) are not within the scope of this Chapter.

**K322.3.2 Requirements.** Instrument piping within the scope of this Chapter shall be in accordance with para. 322.3.2 except that the design pressure and temperature shall be determined in accordance with para. K301, and the requirements of para. K310 shall apply. Instruments, and control piping not within the scope of this Chapter, shall be designed in accordance with para. 322.3.

### K322.6 Pressure-Relieving Systems

Paragraph 322.6 applies, except for para. 322.6.3.

**K322.6.3 Overpressure Protection.** Overpressure protection for high pressure piping systems shall conform to the following:

*(a)* The cumulative capacity of the pressure-relieving devices shall be sufficient to prevent the pressure from rising more than 10% above the piping design pressure at the operating temperature during the relieving condition for a single relieving device or more than 16% above the design pressure when more than one device is provided, except as provided in (c) below.

*(b)* System protection must include one relief device set at or below the design pressure at the operating temperature for the relieving condition, with no device set to operate at a pressure greater than 105% of the design pressure, except as provided in (c) below.

*(c)* Supplementary pressure-relieving devices provided for protection against overpressure due to fire or other unexpected sources of external heat shall be set to operate at a pressure not greater than 110% of the design pressure of the piping system and shall be capable of limiting the maximum pressure during relief to no more than 121% of the design pressure.

## PART 7
## MATERIALS

### K323 GENERAL REQUIREMENTS

*(a)* Paragraph K323 states limitations and required qualifications for materials based on their inherent properties. Their use is also subject to requirements elsewhere in Chapter IX and in Table K-1.

*(b)* Specific attention should be given to the manufacturing process to ensure uniformity of properties throughout each piping component.

*(c)* See para. K321.1.4 for support materials.

### K323.1 Materials and Specifications

#### K323.1.1 Listed Materials

*(a)* Any material used in a pressure-containing piping component shall conform to a listed specification, except as provided in (b) below or in para. K323.1.2.

*(b)* Materials manufactured to specification editions different from those listed in Appendix E may be used, provided

*(1)* the requirements for chemical composition and heat-treatment condition in the edition of the specification to which the material was manufactured meet the requirements of the listed edition

*(2)* the specified minimum tensile and yield strengths, and, if applicable, the specified maximum tensile and yield strengths, required by the two editions of the specification are the same, and

*(3)* the material has been tested and examined in accordance with the requirements of the listed edition of the specification

A material that does not meet the requirements of paras. K323.1.1(b)(1), (2), and (3) may be evaluated as an unlisted material in accordance with para. K323.1.2.

**K323.1.2 Unlisted Materials.** An unlisted material may be used, provided it conforms to a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control, and otherwise meets the requirements of this Chapter. Allowable stresses shall be determined in accordance with the applicable allowable stress basis of this Chapter or a more conservative basis.

**K323.1.3 Unknown Materials.** Materials of unknown specification, type, or grade are not permitted.

**K323.1.4 Reclaimed Materials.** Reclaimed pipe and other piping components may be used provided they are properly identified as conforming to a listed specification, have documented service history for the material and fatigue life evaluation, and otherwise meet the requirements of this Chapter. Sufficient cleaning and inspection shall be made to determine minimum wall thickness and freedom from defects that would be unacceptable in the intended service.

**K323.1.5 Product Analysis.** Conformance of materials to the product analysis chemical requirements of the applicable specification shall be verified, and certification shall be supplied. Requirements for product analysis are defined in the applicable materials specification.

**K323.1.6 Repair of Materials by Welding.** A material defect may be repaired by welding, provided that all of the following criteria are met:

*(a)* The material specification provides for weld repair.

*(b)* The welding procedure and welders or welding operators are qualified as required by para. K328.2.

*(c)* The repair and its examination are performed in accordance with the material specification and with the owner's approval.

### K323.2 Temperature Limitations (18)

The designer shall verify that materials that meet other requirements of this Chapter are suitable for service throughout the operating temperature range.

**K323.2.1 Upper Temperature Limits, Listed Materials.** (18) A listed material shall not be used at a temperature above the maximum for which a stress value is shown in Appendix K, Table K-1.

#### K323.2.2 Lower Temperature Limits, Listed Materials

*(a)* The lowest permitted service temperature for a component or weld shall be the impact test temperature determined in accordance with para. K323.3.4(a), except as provided in (b) or (c) below.

*(b)* For a component or weld subjected to a longitudinal or circumferential stress ≤ 41 MPa (6 ksi), the lowest service temperature shall be the lower of −46°C (−50°F) or the impact test temperature determined in para. K323.3.4(a).

*(c)* For materials exempted from Charpy testing by Note (2) of Table K323.3.1, the service temperature shall not be lower than −46°C (−50°F).

**K323.2.3 Temperature Limits, Unlisted Materials.** An unlisted material acceptable under para. K323.1.2 shall be qualified for service at all temperatures within a stated range from design minimum temperature to design (maximum) temperature, in accordance with para. K323.2.4. However, the upper temperature limit shall be less than the temperature for which an allowable stress, determined in accordance with para. 302.3.2, is governed by the creep or stress rupture provisions of that paragraph.

(18) **K323.2.4 Verification of Serviceability**

*(a)* When an unlisted material is used, the designer is responsible for demonstrating the validity of the allowable stresses and other design limits, and of the approach taken in using the material, including the derivation of stress data and the establishment of temperature limits.

*(b)* Paragraph 323.2.4(b) applies except that allowable stress values shall be determined in accordance with para. K302.3.

## K323.3 Impact Testing Methods and Acceptance Criteria

**K323.3.1 General.** Except as provided in Table K323.3.1, Note (2), piping components used in High Pressure Fluid Service shall be subjected to Charpy V-notch impact testing. The testing shall be performed in accordance with Table K323.3.1 on representative samples using the testing methods described in paras. K323.3.2, K323.3.3, and K323.3.4. Acceptance criteria are described in para. K323.3.5.

**K323.3.2 Procedure.** Paragraph 323.3.2 applies.

**K323.3.3 Test Specimens**

*(a)* Each set of impact test specimens shall consist of three specimen bars. Impact tests shall be made using standard 10 mm (0.394 in.) square cross section Charpy V-notch specimen bars oriented in the transverse direction.

*(b)* Where component size and/or shape does not permit specimens as specified in (a) above, standard 10 mm square cross-section longitudinal Charpy specimens may be prepared.

*(c)* Where component size and/or shape does not permit specimens as specified in (a) or (b) above, subsize longitudinal Charpy specimens may be prepared. Test temperature shall be reduced in accordance with Table 323.3.4. See also Table K323.3.1, Note (2).

*(d)* If necessary in (a), (b), or (c) above, corners of specimens parallel to and on the side opposite the notch may be as shown in Figure K323.3.3.

**K323.3.4 Test Temperatures.** For all Charpy impact tests, the test temperature criteria in (a) or (b) below shall be observed.

*(a)* Charpy impact tests shall be conducted at a temperature no higher than the lower of the following:

*(1)* 20°C (70°F)

*(2)* the lowest metal temperature at which a piping component or weld will be subjected to a stress greater than 41 MPa (6 ksi). In specifying the lowest metal temperature, the following shall be considered:

*(-a)* range of operating conditions

*(-b)* upset conditions

*(-c)* ambient temperature extremes

*(-d)* required leak test temperature

*(b)* Where the largest possible test specimen has a width along the notch less than the lesser of 80% of the material thickness or 8 mm (0.315 in.), the test shall be conducted at a reduced temperature in accordance with Table 323.3.4, considering the temperature as reduced below the test temperature required by (a) above.

**K323.3.5 Acceptance Criteria**

*(a) Minimum Energy Requirements for Materials Other Than Bolting.* The applicable minimum impact energy requirements for materials shall be those shown in Table K323.3.5. Lateral expansion shall be measured in accordance with ASTM A370 (for title see para. 323.3.2). The results shall be included in the impact test report.

*(b) Minimum Energy Requirements for Bolting Materials.* The applicable minimum energy requirements shall be those shown in Table K323.3.5 except as provided in Table K323.3.1.

*(c) Weld Impact Test Requirements.* Where two base metals having different required impact energy values are joined by welding, the impact test energy requirements shall equal or exceed the requirements of the base material having the lower required impact energy.

*(d) Retests*

*(1) Retest for Absorbed Energy Criteria.* When the average value of the three specimens equals or exceeds the minimum value permitted for a single specimen, and the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, a retest of three additional specimens shall be made. The value for each of these retest specimens shall equal or exceed the required average value.

*(2) Retest for Erratic Test Results.* When an erratic result is caused by a defective specimen or uncertainty in the test, a retest will be allowed. The report giving test results shall specifically state why the original specimen was considered defective or which step of the test procedure was carried out incorrectly.

## K323.4 Requirements for Materials

**K323.4.1 General.** Requirements in para. K323.4 apply to pressure-containing parts, not to materials used as supports, gaskets, packing, or bolting. See also Appendix F, para. F323.4.

## Table K323.3.1 Impact Testing Requirements

<table>
<tr><th colspan="2">Test Characteristics</th><th>Column A<br>Pipe, Tubes, and Components Made From Pipe or Tubes</th><th>Column B<br>Other Components, Fittings, Etc.</th><th>Column C<br>Bolts</th></tr>
<tr><td rowspan="2">Tests on Materials</td><td>Number of tests</td><td colspan="3">As required by the material specification, or one test set per lot [see Note (1)], whichever is greater, except as permitted by Note (2).</td></tr>
<tr><td>Location and orientation of specimens [see Note (3)]</td><td>(a) Transverse to the longitudinal axis, with notch parallel to axis. [See Note (4).]<br>(b) Where component size and/or shape does not permit specimens as specified in (a) above, paras. K323.3.3(b), (c), and (d) apply as needed.</td><td>(a) Transverse to the direction of maximum elongation during rolling or to direction of major working during forging. Notch shall be oriented parallel to direction of maximum elongation or major working.<br>(b) If there is no single identifiable axis, e.g., for castings or triaxial forgings, specimens shall either meet the longitudinal values of Table K323.3.5, or three sets of orthogonal specimens shall be prepared, and the lowest impact values obtained from any set shall meet the transverse values of Table K323.3.5.<br>(c) Where component size and/or shape does not permit specimens as specified in (a) or (b) above, paras. K323.3.3(c) and (d) apply as needed.</td><td>(a) Bolts ≤52 mm (2 in.) nominal size made in accordance with ASTM A320 shall meet the impact requirements of that specification.<br>(b) For all other bolts, longitudinal specimens shall be taken. The impact values obtained shall meet the transverse values of Table K323.3.5.</td></tr>
<tr><td rowspan="3">Tests on Welds in Fabrication or Assembly</td><td>Test pieces [see Note (5)]</td><td colspan="3">Test pieces for preparation of impact specimens shall be made for each welding procedure, type of electrode, or filler metal (i.e., AWS E-XXXX classification) and each flux to be used. All test pieces shall be subject to heat treatment, including cooling rates and aggregate time at temperature or temperatures, essentially the same as the heat treatment which the finished component will have received.</td></tr>
<tr><td>Number of test pieces [see Note (6)]</td><td colspan="3">(1) One test piece with a thickness $T$ for each range of material thicknesses which can vary from $\frac{1}{2}T$ to $T$ + 6 mm ($\frac{1}{4}$ in.).<br>(2) Unless otherwise specified in this Chapter [see Note (4)] or the engineering design, test pieces need not be made from individual material lots, or from material for each job, provided welds in other certified material of the same thickness ranges and to the same specification (type and grade, not heat or lot) have been tested as required and the records of those tests are made available.</td></tr>
<tr><td>Location and orientation of specimens</td><td colspan="3">(1) Weld metal impact specimens shall be taken across the weld with the notch in the weld metal. Each specimen shall be oriented so that the notch axis is normal to the surface of the material and one face of the specimen shall be within 1.5 mm ($\frac{1}{16}$ in.) of the surface of the material.<br>(2) Heat affected zone impact specimens shall be taken across the weld and have sufficient length to locate the notch in the heat affected zone, after etching. The notch shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone material as possible in the resulting fracture.<br>(3) The impact values obtained from both the weld metal and heat affected zone specimens shall be compared to the transverse values in Table K323.3.5 for the determination of acceptance criteria.</td></tr>
</table>

NOTES:

(1) A lot shall consist of pipe or components of the same nominal size, made from the same heat of material, and heat treated together. If a continuous type furnace is used, pipe or components may be considered to have been heat treated together if they are processed during a single continuous time period at the same furnace conditions.

(2) Impact tests are not required when the maximum obtainable longitudinal Charpy specimen has a width along the notch less than 2.5 mm (0.098 in.). See para. K323.2.2(c).

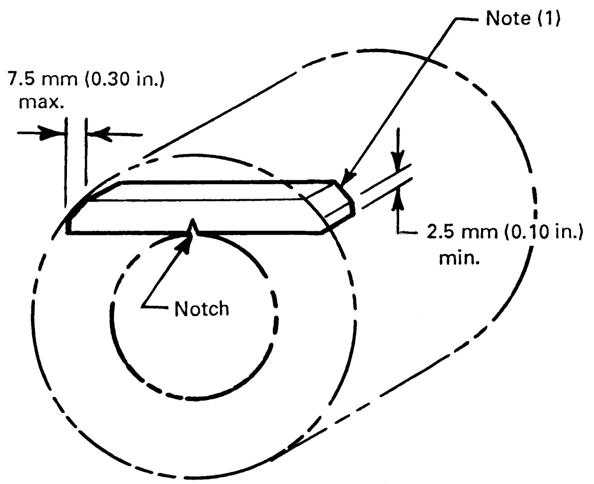
(3) Impact tests shall be performed on a representative sample of material after completion of all heat treatment and forming operations involving plastic deformation, except that cold bends made in accordance with para. K304.2.1 need not be tested after bending.

(4) For longitudinally welded pipe, specimens shall be taken from the base metal, weld metal, and the heat affected zone.

(5) For welds in the fabrication or assembly of piping or components, including repair welds.

(6) The test piece shall be large enough to permit preparing the number of specimens required by para. K323.3. If this is not possible, additional test pieces shall be prepared.

**Figure K323.3.3 Example of an Acceptable Impact Test Specimen**




GENERAL NOTE: This Figure illustrates how an acceptable transverse Charpy specimen can be obtained from a tubing or component shape too small for a full length standard specimen in accordance with ASTM A370. The corners of a longitudinal specimen parallel to and on the side opposite the notch may be as shown.

NOTE: (1) Corners of the Charpy specimen [see para. K323.3.3(d)] may follow the contour of the component within the dimension limits shown.

#### K323.4.2 Specific Requirements

*(a)* Ductile iron and other cast irons are not permitted.

*(b)* Zinc-coated materials are not permitted for pressure containing components and may not be attached to pressure-containing components by welding.

**K323.4.3 Metallic Clad and Lined Materials.** Materials with metallic cladding or lining may be used in accordance with the following provisions:

*(a)* For metallic clad or lined piping components, the base metal shall be an acceptable material as defined in para. K323, and the thickness used in pressure design in accordance with para. K304 shall not include the thickness of the cladding or lining. The allowable stress used shall be that for the base metal at the design temperature. For such components, the cladding or lining may be any material that, in the judgment of the user, is suitable for the intended service and for the method of manufacture and assembly of the piping component.

*(b)* Fabrication by welding of clad or lined piping components and the inspection and testing of such components shall be done in accordance with applicable provisions of ASME BPVC, Section VIII, Division 1, UCL-30 through UCL-52, and the provisions of this Chapter.

*(c)* If a metallic liner also serves as a gasket or as part of the flange facing, the requirements and limitations in para. K308.4 apply.

### K323.5 Deterioration of Materials in Service

Paragraph 323.5 applies.

## K325 MISCELLANEOUS MATERIALS

Paragraph 325 applies.

# PART 8
# STANDARDS FOR PIPING COMPONENTS

## K326 REQUIREMENTS FOR COMPONENTS

### K326.1 Dimensional Requirements

**K326.1.1 Listed Piping Components.** Dimensional standards for piping components are listed in Table K326.1. Dimensional requirements contained in specifications listed in Appendix K shall also be considered requirements of this Code.

**K326.1.2 Unlisted Piping Components.** Piping components not listed in Table K326.1 or Appendix K shall meet the pressure design requirements described in para. K302.2.3 and the mechanical strength requirements described in para. K302.5.

**K326.1.3 Threads.** The dimensions of piping connection threads not otherwise covered by a governing component standard or specification shall conform to the requirements of applicable standards listed in Table K326.1 or Appendix K.

### K326.2 Ratings of Components

**K326.2.1 Listed Components.** The pressure–temperature ratings of components listed in Table K326.1 are accepted for pressure design in accordance with para. K303.

**K326.2.2 Unlisted Components.** The pressure–temperature ratings of unlisted piping components shall conform to the applicable provisions of para. K304.

### K326.3 Reference Documents

The documents listed in Table K326.1 contain references to codes, standards, and specifications not listed in Table K326.1. Such unlisted codes, standards, and specifications shall be used only in the context of the listed documents in which they appear.

The design, materials, fabrication, assembly, examination, inspection, and testing requirements of this Chapter are not applicable to components manufactured in accordance with the documents listed in Table K326.1, unless specifically stated in this Chapter or in the listed document.

**Table K323.3.5 Minimum Required Charpy V-Notch Impact Values**

| Specimen Orientation | Pipe Wall or Component Thickness, mm (in.) | Number of Specimens [Note (1)] | Energy, J (ft-lbf) [Note (2)] for Specified Minimum Yield Strength, MPa (ksi) ≤932 (≤135) | >932 (>135) |
|---|---|---|---|---|
| Transverse | ≤25 (≤1) | Average for 3 | 27 (20) | 34 (25) |
| | | Minimum for 1 | 20 (15) | 27 (20) |
| | >25 and ≤51 (>1 and ≤2) | Average for 3 | 34 (25) | 41 (30) |
| | | Minimum for 1 | 27 (20) | 33 (24) |
| | >51 (>2) | Average for 3 | 41 (30) | 47 (35) |
| | | Minimum for 1 | 33 (24) | 38 (28) |
| Longitudinal | ≤25 (≤1) | Average for 3 | 54 (40) | 68 (50) |
| | | Minimum for 1 | 41 (30) | 54 (40) |
| | >25 and ≤51 (>1 and ≤2) | Average for 3 | 68 (50) | 81 (60) |
| | | Minimum for 1 | 54 (40) | 65 (48) |
| | >51 (>2) | Average for 3 | 81 (60) | 95 (70) |
| | | Minimum for 1 | 65 (48) | 76 (56) |

NOTES:
(1) See para. K323.3.5(c) for permissible retests.
(2) Energy values in this Table are for standard size specimens. For subsize specimens, these values shall be multiplied by the ratio of the actual specimen width to that of a full-size specimen, 10 mm (0.394 in.).



(18) ### K326.4 Repair of Piping Components by Welding

A defect in a piping component may be repaired by welding subject to all of the following requirements:

*(a)* The piping component specification provides for weld repair or, if not covered by a specification, the manufacturer allows for weld repair.

*(b)* The welding procedure and welders or welding operators are qualified as required by para. K328.2.

*(c)* The repair and its examination are performed in accordance with the piping component specification or, if not covered by a specification, the manufacturer's requirements.

*(d)* The owner approves the weld repair.

# PART 9
# FABRICATION, ASSEMBLY, AND ERECTION

## K327 GENERAL

Piping materials and components are prepared for assembly and erection by one or more of the fabrication processes covered in paras. K328, K330, K331, K332, and K333. When any of these processes is used in assembly or erection, requirements are the same as for fabrication.

## K328 WELDING

Welding that conforms to the requirements of para. K328 may be used in accordance with para. K311.

### K328.1 Welding Responsibility

Each employer is responsible for the welding done by the personnel of his/her organization and shall conduct the tests required to qualify welding procedures, and to qualify and as necessary requalify welders and welding operators.

### K328.2 Welding Qualifications

**K328.2.1 Qualification Requirements.** Qualification of the welding procedures to be used and of the performance of welders and welding operators shall comply with the requirements of ASME BPVC, Section IX, except as modified herein.

*(a)* Impact tests shall be performed for all procedure qualifications in accordance with para. K323.3.

*(b)* Test weldments shall be made using the same specification and type or grade of base metal(s), and the same specification and classification of filler metal(s) as will be used in production welding.

*(c)* Test weldments shall be subjected to essentially the same heat treatment, including cooling rate and cumulative time at temperature, as the production welds.

**Table K326.1 Component Standards**

| Standard or Specification | Designation |
|---|---|
| **Bolting** | |
| Square and Hex Bolts and Screws, Inch Series; Including Hex Cap Screws and Lag Screws | ASME B18.2.1 |
| Square and Hex Nuts (Inch Series) | ASME B18.2.2 |
| **Metallic Fittings, Valves, and Flanges** | |
| Pipe Flanges and Flanged Fittings [Note (1)] | ASME B16.5 |
| Factory-Made Wrought Buttwelding Fittings [Note (1)] | ASME B16.9 |
| Forged Fittings, Socket Welding and Threaded [Note (1)] | ASME B16.11 |
| Valves — Flanged, Threaded, and Welding End [Note (1)] | ASME B16.34 |
| Line Blanks [Note (1)] | ASME B16.48 |
| Standard Marking System for Valves, Fittings, Flanges, and Unions | MSS SP-25 |
| High Pressure Chemical Industry Flanges and Threaded Stubs for Use with Lens Gaskets [Note (1)] | MSS SP-65 |
| **Metallic Pipe and Tubes** | |
| Welded and Seamless Wrought Steel Pipe [Note (1)] | ASME B36.10M |
| Stainless Steel Pipe [Note (1)] | ASME B36.19M |
| **Miscellaneous** | |
| Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads | API 5B |
| Unified Inch Screw Threads (UN and UNR Thread Form) | ASME B1.1 |
| Pipe Threads, General Purpose (Inch) | ASME B1.20.1 |
| Metallic Gaskets for Pipe Flanges | ASME B16.20 |
| Buttwelding Ends | ASME B16.25 |
| Surface Texture (Surface Roughness, Waviness, and Lay) | ASME B46.1 |

GENERAL NOTE: The approved edition dates of these standards and specifications, along with the names and addresses of the sponsoring organizations, are shown in Appendix E.

NOTE: (1) The use of components made in accordance with these standards is permissible, provided they are
*(a)* examined and leak tested in accordance with the requirements of paras. K341 and K345, respectively.
*(b)* impact tested in accordance with the methods described in paras. K323.3.1 through K323.3.4, and meet the acceptance criteria specified in para. K323.3.5. Note that such impact testing may require the destruction of one component from the same lot as the component to be used in service [see Table K323.3.1, Note (1)].



*(d)* When tensile specimens are required by ASME BPVC, Section IX, the yield strength shall also be determined, using the method required for the base metal. The yield strength of each test specimen shall be not less than the specified minimum yield strength at room temperature ($S_Y$) for the base metals joined. Where two base metals having different $S_Y$ values are joined by welding, the yield strength of each test specimen shall be not less than the lower of the two $S_Y$ values.

*(e)* Mechanical testing is required for all performance qualification tests.

*(f)* Qualification on pipe or tubing shall also qualify for plate, but qualification on plate does not qualify for pipe or tubing.

*(g)* For thickness greater than 51 mm (2 in.), the procedure test coupon shall be at least 75% as thick as the thickest joint to be welded in production.

**K328.2.2 Procedure Qualification by Others.** Qualification of welding procedures by others is not permitted.

**K328.2.3 Performance Qualification by Others.** Welding performance qualification by others is not permitted.

**K328.2.4 Qualification Records.** Paragraph 328.2.4 applies.

## K328.3 Materials

**K328.3.1 Filler Metal.** Filler metal shall be specified in the engineering design and shall conform to the requirements of ASME BPVC, Section IX. A filler metal not yet incorporated in ASME BPVC, Section IX may be used with the owner's approval if a procedure qualification test, including an all-weld-metal test, is first successfully made.

**K328.3.2 Weld Backing Material.** Backing rings shall not be used.

**K328.3.3 Consumable Inserts.** Paragraph 328.3.3 applies, except that procedures shall be qualified as required by para. K328.2.

## K328.4 Preparation for Welding

**K328.4.1 Cleaning.** Paragraph 328.4.1 applies.

### K328.4.2 End Preparation

*(a) General*

*(1)* Butt weld end preparation is acceptable only if the surface is machined or ground to bright metal.

*(2)* Butt welding end preparation contained in ASME B16.25 or any other end preparation that meets the procedure qualification is acceptable. [For convenience, the basic bevel angles taken from ASME B16.25, with some additional J-bevel angles, are shown in Figure 328.4.2, illustrations (a) and (b).]

*(b) Circumferential Welds*

*(1)* If components' ends are trimmed as shown in Figure 328.4.2, illustration (a) or (b) to accommodate consumable inserts, or as shown in Figure K328.4.3 to correct internal misalignment, such trimming shall not result in a finished wall thickness before welding less than the required minimum wall thickness, $t_m$.

*(2)* It is permissible to size pipe ends of the same nominal size to improve alignment, if wall thickness requirements are maintained.

*(3)* Where necessary, weld metal may be deposited on the inside or outside of the component to permit alignment or provide for machining to ensure satisfactory seating of inserts.

*(4)* When a butt weld joins sections of unequal wall thickness and the thicker wall is more than $1\frac{1}{2}$ times the thickness of the other, end preparation and geometry shall be in accordance with acceptable designs for unequal wall thickness in ASME B16.5.

### K328.4.3 Alignment

*(a) Girth Butt Welds*

*(1)* Inside diameters of components at the ends to be joined shall be aligned within the dimensional limits in the welding procedure and the engineering design, except that no more than 1.5 mm ($^1/_{16}$ in.) misalignment is permitted as shown in Figure K328.4.3.

*(2)* If the external surfaces of the two components are not aligned, the weld shall be tapered between the two surfaces with a slope not steeper than 1:4.

*(b) Longitudinal Butt Joints.* Preparation for longitudinal butt welds (not made in accordance with a standard listed in Table K-1 or Table K326.1) shall conform to the requirements of para. K328.4.3(a).

*(c) Branch Connection Welds*

*(1)* The dimension *m* in Figure K328.5.4 shall not exceed ±1.5 mm ($^1/_{16}$ in.).

*(2)* The dimension *g* in Figure K328.5.4 shall be specified in the engineering design and the welding procedure.

## K328.5 Welding Requirements

**K328.5.1 General.** The requirements of paras. 328.5.1(b), (d), (e), and (f) apply in addition to the requirements specified below.

*(a)* All welds, including tack welds, repair welds, and the addition of weld metal for alignment [paras. K328.4.2(b)(3) and K328.4.3(c)(1)], shall be made by qualified welders or welding operators, in accordance with a qualified procedure.

*(b)* Tack welds at the root of the joint shall be made with filler metal equivalent to that used for the root pass. Tack welds shall be fused with the root pass weld, except that those that have cracked shall be removed. Bridge tacks (above the root) shall be removed.

**K328.5.2 Fillet Welds.** Fillet welds, where permitted (see para. K311.2.2), shall be fused with and shall merge smoothly into the component surfaces.

**K328.5.3 Seal Welds.** Seal welds are not permitted.

**K328.5.4 Welded Branch Connections.** Branch connection fittings (see para. 300.2), attached by smoothly contoured full penetration groove welds of a design that permits 100% interpretable radiographic examination, are the only types acceptable.

Figure K328.5.4 shows acceptable details of welded branch connections. The illustrations are typical and are not intended to exclude acceptable types of construction not shown.

**K328.5.5 Fabricated Laps.** Fabricated laps are not permitted.

## K328.6 Weld Repair

Paragraph 328.6 applies, except that procedures and performance shall be qualified as required by para. K328.2.1. See also para. K341.3.3.

**Figure K328.4.3 Pipe Bored for Alignment: Trimming and Permitted Misalignment**

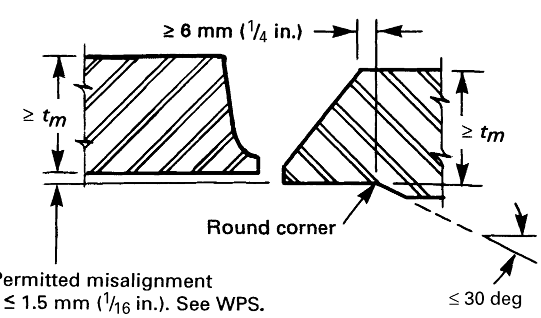
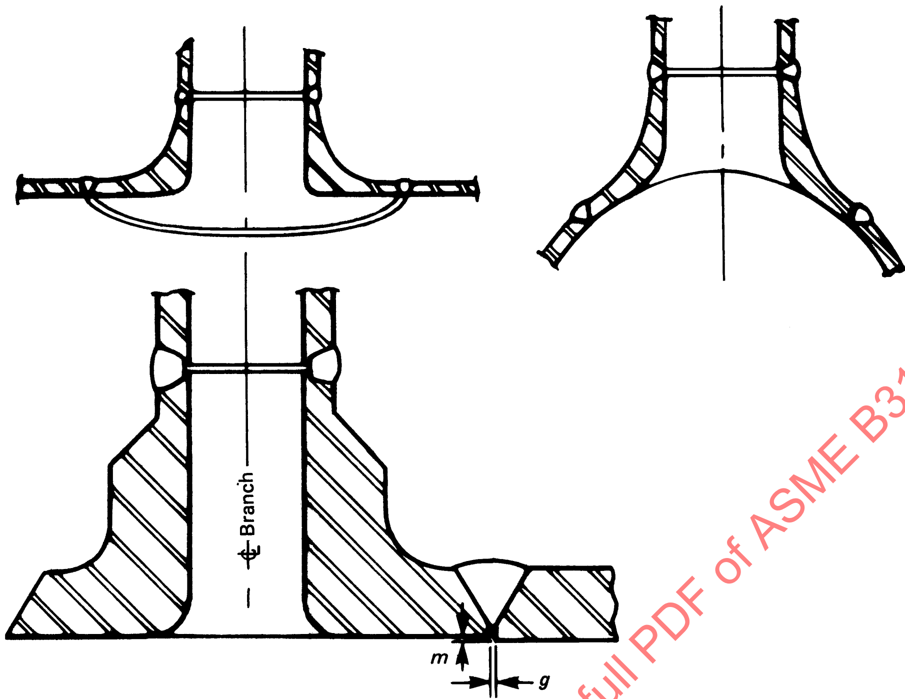


**Figure K328.5.4 Some Acceptable Welded Branch Connections Suitable for 100% Radiography**




## K330 PREHEATING

### K330.1 General

Paragraph 330.1 applies, except that seal welds are not permitted in this Chapter.

**K330.1.1 Requirements.** Paragraph 330.1.1 applies.

**K330.1.2 Unlisted Materials.** Paragraph 330.1.2 applies.

**K330.1.3 Temperature Verification.** Paragraph 330.1.3(a) applies. Temperature-indicating materials and techniques shall not be detrimental to the base metals.

**K330.1.4 Preheat Zone.** Paragraph 330.1.4 applies.

### K330.2 Specific Requirements

Paragraph 330.2 applies in its entirety.

## K331 HEAT TREATMENT

The text introducing para. 331 applies.

### K331.1 General

**K331.1.1 Heat Treatment Requirements.** The provisions of para. 331 and Table 331.1.1 apply, except as specified below.

*(a)* Heat treatment is required for all thicknesses of P-Nos. 4 and 5 materials.

*(b)* For welds other than longitudinal in quenched and tempered materials, when heat treatment is required by the engineering design, the temperature shall not be higher than 28°C (50°F) below the tempering temperature of the material.

*(c)* Longitudinal welds in quenched and tempered material shall be heat treated in accordance with the applicable material specification.

**K331.1.3 Governing Thickness.** When components are joined by welding, the thickness to be used in applying the heat treatment provisions of Table 331.1.1 shall be that of the thicker component measured at the joint, except as follows:

In the case of fillet welds used for attachment of external nonpressure parts, such as lugs or other pipe-supporting elements, heat treatment is required when the thickness through the weld and base metal in any plane is more than twice the minimum material thickness requiring heat treatment (even though the thickness of the components at the joint is less than that minimum thickness) except as follows:

*(a)* not required for P-No. 1 materials when weld throat thickness is 16 mm ($^5/_8$ in.) or less, regardless of base metal thickness.

*(b)* not required for P-Nos. 3, 4, 5, 10A, and 10B materials when weld throat thickness is 6 mm ($^1/_4$ in.) or less, regardless of base metal thickness, provided that not less than the recommended minimum preheat is applied and

the specified minimum tensile strength of the base metal is less than 490 MPa (71 ksi).

*(c)* not required for ferritic materials when welds are made with filler metal that does not air harden. Austenitic welding materials may be used for welds to ferritic materials when the effects of service conditions, such as differential thermal expansion due to elevated temperature, or corrosion, will not adversely affect the weldment.

**K331.1.4 Heating and Cooling.** Paragraph 331.1.4 applies.

**K331.1.6 Temperature Verification.** Heat treatment temperature shall be checked by thermocouple pyrometers or other suitable methods to ensure that the WPS requirements are met. Temperature-indicating materials and techniques shall not be detrimental to the base metals.

### K331.2 Specific Requirements

Paragraph 331.2 applies in its entirety.

## K332 BENDING AND FORMING

### K332.1 General

Pipe shall be hot or cold bent in accordance with a written procedure to any radius that will result in surfaces free of cracks and free of buckles. The procedure shall address at least the following, as applicable:

*(a)* material specification and range of size and thickness

*(b)* range of bend radii and fiber elongation

*(c)* minimum and maximum metal temperature during bending

*(d)* method of heating and maximum hold time

*(e)* description of bending apparatus and procedure to be used

*(f)* mandrels or material and procedure used to fill the bore

*(g)* method for protection of thread and machined surfaces

*(h)* examination to be performed

*(i)* required heat treatment

*(j)* postheat treatment dimensional adjustment technique

### K332.2 Bending

**K332.2.1 Bend Flattening.** The difference between the maximum and the minimum diameters at any cross section of a bend shall not exceed 8% of nominal outside diameter for internal pressure and 3% for external pressure.

**K332.2.2 Bending Temperature.** Paragraph 332.2.2 applies, except that in cold bending of quenched and tempered ferritic materials, the temperature shall be at least 28°C (50°F) below the tempering temperature.

### K332.3 Forming

Piping components shall be formed in accordance with a written procedure. The temperature range shall be consistent with material characteristics, end use, and specified heat treatment. The thickness after forming shall be not less than required by design. The procedure shall address at least the following, as applicable:

*(a)* material specification and range of size and thickness

*(b)* maximum fiber elongation expected during forming

*(c)* minimum and maximum metal temperature during bending

*(d)* method of heating and maximum hold time

*(e)* description of forming apparatus and procedure to be used

*(f)* materials and procedures used to provide internal support during forming

*(g)* examination to be performed

*(h)* required heat treatment

### K332.4 Required Heat Treatment

**K332.4.1 Hot Bending and Forming.** After hot bending and forming, heat treatment is required for all thicknesses of P-Nos. 3, 4, 5, 6, 10A, and 10B materials that are not quenched and tempered. Times and temperatures shall be in accordance with para. 331. Quenched and tempered materials shall be reheat treated to the original material specification.

**K332.4.2 Cold Bending and Forming**

*(a)* After cold bending and forming, heat treatment in accordance with (b) below is required, regardless of thickness, when specified in the engineering design or when the maximum calculated fiber elongation exceeds 5% strain or 50% of the basic minimum specified longitudinal elongation for the applicable specification, grade, and thickness for P-Nos. 1 through 6 materials (unless it has been demonstrated that the selection of the pipe and the procedure for making the components provide assurance that the most severely formed portion of the material has retained an elongation of not less than 10%).

*(b)* Heat treatment is required regardless of thickness and shall conform to the temperatures and durations given in Table 331.1.1, except that for quenched and tempered materials, the stress relieving temperature shall not exceed a temperature 28°C (50°F) below the tempering temperature of the material.

## K333 BRAZING AND SOLDERING

Brazing shall be in accordance with para. 333. The owner shall specify examination requirements for brazed joints.

## K335 ASSEMBLY AND ERECTION

### K335.1 General

Paragraph 335.1 applies.

### K335.2 Flanged Joints

Paragraph 335.2 applies, except that bolts shall extend completely through their nuts.

### K335.3 Threaded Joints

Paragraph 335.3 applies, except that threaded joints shall not be seal welded.

### K335.4 Special Joints

Special joints (as defined in para. K318) shall be installed and assembled in accordance with the manufacturer's instructions, as modified by the engineering design. Care shall be taken to ensure full engagement of joint members.

### K335.5 Cleaning of Piping

See Appendix F, para. F335.9.

# PART 10
# INSPECTION, EXAMINATION, AND TESTING

## K340 INSPECTION

Paragraphs 340.1 through 340.4 apply.

## K341 EXAMINATION

Paragraphs 341.1 and 341.2 apply.

### K341.3 Examination Requirements

**K341.3.1 General.** Prior to initial operation, each piping installation, including components and workmanship, shall be examined in accordance with para. K341.4 and the engineering design. If heat treatment is performed, examination shall be conducted after its completion.

**K341.3.2 Acceptance Criteria.** Acceptance criteria shall be as stated in the engineering design and shall at least meet the applicable requirements stated in (a) and (b) below, and elsewhere in this Chapter.

*(a)* Table K341.3.2 states acceptance criteria (limits on imperfections) for welds. See Figure 341.3.2 for typical weld imperfections.

(18) **Table K341.3.2 Acceptance Criteria for Welds**

| Type of Imperfection | Criteria (A–F) for Types of Welds, and for Required Examination Methods [Note (1)] | | | | | |
|---|---|---|---|---|---|---|
| | Methods | | Type of Weld | | | |
| | Visual | Ultrasonics or Radiography | Girth Groove | Longitudinal Groove [Note (2)] | Fillet [Note (3)] | Branch Connection [Note (4)] |
| Crack | ✓ | ✓ | A | A | A | A |
| Lack of fusion | ✓ | ✓ | A | A | A | A |
| Incomplete penetration | ✓ | ✓ | A | A | A | A |
| Internal porosity | ... | ✓ | B | B | N/A | B |
| Linear indication | ... | ✓ | C | C | N/A | C |
| Undercutting | ✓ | ✓ | A | A | A | A |
| Surface porosity or exposed slag inclusion | ✓ | ... | A | A | A | A |
| Concave root surface (suck-up) | ✓ | ✓ | D | D | N/A | D |
| Surface finish | ✓ | ... | E | E | E | E |
| Reinforcement or internal protrusion | ✓ | ... | F | F | F | F |

GENERAL NOTES:
(a) Weld imperfections are evaluated by one or more of the types of examination methods given, as specified in paras. K341.4.1 and K341.4.2.
(b) "N/A" indicates this Chapter does not establish acceptance criteria or does not require evaluation of this kind of imperfection for this type of weld.
(c) Check (✓) indicates examination method generally used for evaluating this kind of weld imperfection.
(d) Ellipsis (...) indicates examination method not generally used for evaluating this kind of weld imperfection.
(e) Symbols A through F are explained in the table on the next page.

NOTES:
(1) Criteria given are for required examination. More-stringent criteria may be specified in the engineering design.
(2) Longitudinal welds include only those permitted in paras. K302.3.4 and K305. The criteria shall be met by all welds, including those made in accordance with a standard listed in Table K326.1 or in Appendix K.
(3) Fillet welds include only those permitted in para. K311.2.2.
(4) Branch connection welds include only those permitted in para. K328.5.4.

(18) **Criterion Value Notes for Table K341.3.2**

| Criterion | | Acceptable Value Limits [Note (1)] | |
|---|---|---|---|
| **Symbol** | **Measure** | | |
| A | Extent of imperfection | Zero (no evident imperfection) | |
| B | Size and distribution of internal porosity | See ASME BPVC, Section VIII, Division 1, Appendix 4 | |
| C | Internal slag inclusion, tungsten inclusion, or linear indication. Indications are unacceptable if the amplitude exceeds the reference level, or indications have lengths that exceed | | |
| | Individual length [Note (2)] | 6 mm ($\frac{1}{4}$ in.) for $\overline{T}_w \leq 19$ mm ($\frac{3}{4}$ in.) | |
| | | $\overline{T}_w/3$ for 19 mm ($\frac{3}{4}$ in.) $< \overline{T}_w \leq 57$ mm ($2\frac{1}{4}$ in.) | |
| | | 19 mm ($\frac{3}{4}$ in.) for $\overline{T}_w >$ 57 mm ($2\frac{1}{4}$ in.) | |
| | Cumulative length | $\leq \overline{T}_w$ in any 12 $\overline{T}_w$ weld length | |
| D | Depth of root surface concavity | Wall Thickness, $\overline{T}_w$, mm (in.) | Depth of Surface Concavity, mm (in.) |
| | | ≤13 ($\frac{1}{2}$) | ≤1.5 ($\frac{1}{16}$) |
| | | >13 ($\frac{1}{2}$) and ≤51 (2) | ≤3 ($\frac{1}{8}$) |
| | | >51 (2) | ≤4 ($\frac{5}{32}$) |
| | | and total joint thickness including weld reinforcement $\geq \overline{T}_w$ | |
| E | Surface roughness | ≤12.5 μm (500 μin.) $R_a$ (see ASME B46.1 for definition of roughness average, $R_a$) | |
| F | Height of reinforcement or internal protrusion [Note (3)] in any plane through the weld shall be within the limits of the applicable height value in the tabulation at the right. Weld metal shall be fused with and merge smoothly into the component surfaces. | Wall Thickness, $\overline{T}_w$, mm (in.) | External Weld Reinforcement or Internal Weld Protrusion, mm (in.) |
| | | ≤13 ($\frac{1}{2}$) | ≤1.5 ($\frac{1}{16}$) |
| | | >13 ($\frac{1}{2}$) and ≤51 (2) | ≤3 ($\frac{1}{8}$) |
| | | >51 (2) | ≤4 ($\frac{5}{32}$) |

NOTES:

(1) Where two limiting values are given, the lesser measured value governs acceptance. $\overline{T}_w$ is the nominal wall thickness of the thinner of two components joined by a butt weld.

(2) For ultrasonic examination, refer to para. K344.6.3 for acceptable value limits.

(3) For groove welds, height is the lesser of the measurements made from the surfaces of the adjacent components. For fillet welds, height is measured from the theoretical throat; internal protrusion does not apply. Required thickness $t_m$ shall not include reinforcement or internal protrusion.

*(b)* Acceptance criteria for castings are specified in para. K302.3.3.

**K341.3.3 Defective Components and Workmanship.** Defects (imperfections of a type or magnitude not acceptable by the criteria specified in para. K341.3.2) shall be repaired, or the defective item or work shall be replaced.

Examination shall be as follows:

*(a)* When the defective item or work is repaired, the repaired portion of the item or work shall be examined. The examination shall use the same methods and acceptance criteria employed for the original examination. See also para. K341.3.1(a).

*(b)* When the defective item or work is replaced, the new item or work used to replace the defective item or work shall be examined. The examination shall use any method and applicable acceptance criteria that meet the requirements for the original examination. See also para. K341.3.1(a).

## K341.4 Extent of Required Examination

Piping shall be examined to the extent specified herein or to any greater extent specified in the engineering design.

### K341.4.1 Visual Examination

*(a)* The requirements of para. 341.4.1(a) apply with the following exceptions in regard to extent of examination:

*(1) Materials and Components.* 100%.

*(2) Fabrication.* 100%.

*(3) Threaded, Bolted, and Other Joints.* 100%.

*(4) Piping Erection.* All piping erection shall be examined to verify dimensions and alignment. Supports, guides, and points of cold spring shall be checked to ensure that movement of the piping under all conditions of startup, operation, and shutdown will be accommodated without undue binding or unanticipated constraint.

*(b) Pressure-Containing Threads.* 100% examination for finish and fit is required. Items with visible imperfections in thread finish and/or the following defects shall be rejected:

*(1) Tapered Threads.* Failure to meet gaging requirements in API Spec 5B or ASME B1.20.1, as applicable.

*(2) Straight Threads.* Excessively loose or tight fit when gaged for light interference fit.

#### K341.4.2 Radiographic and Ultrasonic Examination

*(a)* All girth, longitudinal, and branch connection welds shall be 100% radiographically examined, except as permitted in (b) below.

*(b)* When specified in the engineering design and with the owner's approval, ultrasonic examination of welds may be substituted for radiographic examination where $\overline{T}_w \geq 13$ mm ($\frac{1}{2}$ in.).

*(c)* In-process examination (see para. 344.7) shall not be substituted for radiographic or ultrasonic examination of welds.

**K341.4.3 Certifications and Records.** Paragraph 341.4.1(c) applies.

### K341.5 Supplementary Examination

Any of the examination methods described in para. K344 may be specified by the engineering design to supplement the examination required by para. K341.4. The extent of supplementary examination to be performed and any acceptance criteria that differ from those specified in para. K341.3.2 shall be specified in the engineering design.

**K341.5.1 Hardness Tests.** Paragraph 341.5.2 applies.

**K341.5.2 Examinations to Resolve Uncertainty.** Paragraph 341.5.3 applies.

## K342 EXAMINATION PERSONNEL

Paragraph 342 applies in its entirety.

## K343 EXAMINATION PROCEDURES

Paragraph 343 applies, except that the examination methods shall comply with para. K344.

## K344 TYPES OF EXAMINATION

### K344.1 General

Paragraphs 344.1.1 and 344.1.2 apply. In para. 344.1.3, terms other than "100% examination" apply only to supplementary examinations.

### K344.2 Visual Examination

Paragraph 344.2 applies in its entirety.

### K344.3 Magnetic Particle Examination

The method for magnetic particle examination shall be as specified in

*(a)* paragraph K302.3.3(b) for castings

*(b)* ASME BPVC, Section V, Article 7 for welds and other components

### K344.4 Liquid Penetrant Examination

The method for liquid penetrant examination shall be as specified in

*(a)* paragraph K302.3.3(b) for castings

*(b)* ASME BPVC, Section V, Article 6 for welds and other components

### K344.5 Radiographic Examination

The method for radiographic examination shall be as specified in

*(a)* paragraph K302.3.3(c) for castings

*(b)* ASME BPVC, Section V, Article 2 for welds and other components

### K344.6 Ultrasonic Examination

**K344.6.1 Castings.** The method for ultrasonic examination of castings shall be as specified in para. K302.3.3(c).

#### K344.6.2 Pipe and Tubing

*(a) Method.* Pipe and tubing, required or selected in accordance with Table K305.1.2 to undergo ultrasonic examination, shall pass a 100% examination for longitudinal defects in accordance with ASTM E213, Ultrasonic Testing of Metal Pipe and Tubing. Longitudinal (axial) reference notches shall be introduced on the outer and inner surfaces of the calibration (reference) standard in accordance with Fig. 3(c) of ASTM E213 to a depth not greater than the larger of 0.1 mm (0.004 in.) or 4% of specimen thickness and a length not more than 10 times the notch depth.

*(b) Acceptance Criteria.* Any indication greater than that produced by the calibration notch represents a defect; defective pipe and tubing shall be rejected.

*(c) Records.* For pipe and tubing that passes this examination, a report shall be prepared that contains at least the information specified in 15.2.1 through 15.2.6 of ASTM E213.

#### K344.6.3 Welds (18)

*(a) Method.* The method for ultrasonic examination of welds shall be as specified in ASME BPVC, Section V, Article 4 for nominal thickness, $\overline{T}_w$, greater than or equal to 13 mm ($\frac{1}{2}$ in.) but less than 25 mm (1 in.), and ASME BPVC, Section VIII, Division 3, KE-301 and KE-302 for nominal wall thickness, $\overline{T}_w$, greater than or equal to 25 mm (1 in.).

*(b) Acceptance Criteria.* Cracks, lack of fusion, incomplete penetration, or undercutting are unacceptable regardless of size or length (see Table K341.3.2). In addition, for an internal slag inclusion, tungsten inclusion, or linear indication

*(1)* for nominal wall thickness, $\overline{T}_w$, greater than or equal to 13 mm ($^1\!/_2$ in.) but less than 25 mm (1 in.), the acceptance criterion for the thickness to be examined specified in para. 344.6.2 applies.

*(2)* for nominal wall thickness, $\overline{T}_w$, greater than or equal to 25 mm (1 in.), the acceptance criteria specified in ASME BPVC, Section VIII, Division 3, KE-333 for the thickness to be examined apply.

### K344.7 In-Process Examination

Paragraph 344.7 applies in its entirety.

### K344.8 Eddy Current Examination

**K344.8.1 Method.** The method for eddy current examination of pipe and tubing shall follow the general guidelines of ASME BPVC, Section V, Article 8, subject to the following specific requirements:

*(a)* Cold drawn austenitic stainless steel pipe and tubing, selected in accordance with Table K305.1.2 for eddy current examination, shall pass a 100% examination for longitudinal defects.

*(b)* A calibration (reference) standard shall be prepared from a representative sample. A longitudinal (axial) reference notch shall be introduced on the inner surface of the standard to a depth not greater than the larger of 0.1 mm (0.004 in.) or 5% of specimen thickness and a length not more than 6.4 mm (0.25 in.).

**K344.8.2 Acceptance Criteria.** Any indication greater than that produced by the calibration notch represents a defect; defective pipe or tubing shall be rejected.

**K344.8.3 Records.** For pipe and tubing that passes this examination, a report shall be prepared that includes at least the following information:

*(a)* material identification by type, size, lot, heat, etc.
*(b)* listing of examination equipment and accessories
*(c)* details of examination technique (including examination speed and frequency) and end effects, if any
*(d)* description of the calibration standard, including dimensions of the notch, as measured
*(e)* examination results

## K345 LEAK TESTING

### K345.1 Required Leak Test

Prior to initial operation, each piping system shall be leak tested.

*(a)* Each weld and each piping component, except bolting and individual gaskets to be used during final system assembly and pressure-relieving devices to be used during operation, shall be hydrostatically or pneumatically leak tested in accordance with para. K345.4 or K345.5, respectively. The organization conducting the test shall ensure that during the required leak testing of components and welds, adequate protection is provided to prevent injury to people and damage to property from missile fragments, shock waves, or other consequences of any failure that might occur in the pressurized system.

*(b)* In addition to the requirements of (a) above, a leak test of the installed piping system, excluding pressure-relieving devices to be used during operation, shall be conducted at a pressure not less than 110% of the design pressure to ensure tightness, except as provided in (c) or (d) below.

*(c)* If the leak test required in (a) above is conducted on the installed piping system, the additional test in (b) above is not required.

*(d)* With the owner's approval, pressure-relieving devices to be used during operation may be included in the leak test required in (b) above. The leak test pressure may be reduced to prevent the operation of, or damage to, the pressure-relieving devices, but shall not be less than 90% of the lowest set pressure of the pressure-relieving devices in the system.

*(e)* For closure welds, examination in accordance with para. K345.2.3(c) may be substituted for the leak test required in (a) above.

*(f)* None of the following leak tests may be used in lieu of the leak tests required in para. K345.1:

*(1)* initial service leak test (para. 345.7)
*(2)* sensitive leak test (para. 345.8)
*(3)* alternative leak test (para. 345.9)

### K345.2 General Requirements for Leak Tests

Paragraphs 345.2.4 through 345.2.7 apply. See below for paras. K345.2.1, K345.2.2, and K345.2.3.

#### K345.2.1 Limitations on Pressure

*(a) Through-Thickness Yielding.* If the test pressure would produce stress (exclusive of stress intensification) in excess of $S_{yt}$ at the outside surface of a component[10] at test temperature, as determined by calculation or by testing in accordance with para. K304.7.2(b), the test pressure may be reduced to the maximum pressure that will result in a stress (exclusive of stress intensification) at the outside surface that will not exceed $S_{yt}$.

*(b)* The provisions of paras. 345.2.1(b) and (c) apply.

**K345.2.2 Other Test Requirements.** Paragraph 345.2.2 applies. In addition, the minimum metal temperature during testing shall be not less than the impact test temperature (see para. K323.3.4).

[10] See para. K304.1.2, footnote 4.

**K345.2.3 Special Provisions for Leak Testing.** Paragraphs K345.2.3(a), (b), and (c) below apply only to the leak test specified in para. K345.1(a). They are not applicable to the installed piping system leak test specified in para. K345.1(b).

*(a) Piping Components and Subassemblies.* Piping components and subassemblies may be leak tested either separately or as assembled piping.

*(b) Flanged Joints.* Flanged joints used to connect piping components that have previously been leak tested, and flanged joints at which a blank or blind flange is used to isolate equipment or other piping during the leak test, need not be leak tested.

*(c) Closure Welds.* Leak testing of the final weld connecting piping systems or components that have been successfully leak tested is not required, provided the weld is examined in-process in accordance with para. 344.7 and passes the required 100% radiographic examination in accordance with para. K341.4.2.

## K345.3 Preparation for Leak Test

Paragraph 345.3 applies in its entirety.

## K345.4 Hydrostatic Leak Test

Paragraph 345.4.1 applies. See paras. K345.4.2 and K345.4.3 below.

**K345.4.2 Test Pressure for Components and Welds.** Except as provided in para. K345.4.3, the hydrostatic test pressure at every point in a metallic piping system shall be as follows:

*(a)* not less than 1.25 times the design pressure.

*(b)* when the design temperature is greater than the test temperature, the minimum test pressure, at the point under consideration, shall be calculated by eq. (38)

$$P_T = 1.25 P S_T / S \tag{38}$$

where

$P$ = internal design gage pressure

$P_T$ = minimum test gage pressure

$S$ = allowable stress at component design temperature for the prevalent pipe material; see Appendix K, Table K-1

$S_T$ = allowable stress at test temperature for the prevalent pipe material; see Table K-1

*(c)* in those cases where the piping system may not include pipe itself, any other component in the piping system, other than pipe-supporting elements and bolting, may be used to determine the $S_T/S$ ratio based on the applicable allowable stresses obtained from Table K-1. In those cases where the piping system may be made up of equivalent lengths of more than one material, the $S_T/S$ ratio shall be based on the minimum calculated ratio of the included materials.

**K345.4.3 Hydrostatic Test of Piping With Vessels as a System.** Paragraph 345.4.3(a) applies.

## K345.5 Pneumatic Leak Test

Paragraph 345.5 applies, except for para. 345.5.4. See para. K345.5.4 below.

**K345.5.4 Test Pressure.** The pneumatic test pressure for components and welds shall be identical to that required for the hydrostatic test in accordance with para. K345.4.2.

## K345.6 Hydrostatic–Pneumatic Leak Test for Components and Welds

If a combination hydrostatic–pneumatic leak test is used, the requirements of para. K345.5 shall be met, and the pressure in the liquid-filled part of the piping shall not exceed the limits stated in para. K345.4.2.

# K346 RECORDS

## K346.1 Responsibility

It is the responsibility of the piping designer, the manufacturer, the fabricator, and the erector, as applicable, to prepare the records required by this Chapter and by the engineering design.

## K346.2 Required Records (18)

At least the following records, as applicable, shall be provided to the owner or the Inspector by the person responsible for their preparation:

*(a)* the engineering design

*(b)* material certifications

*(c)* procedures used for fabrication, welding, heat treatment, examination, and testing

*(d)* repair records of materials and piping components, including the welding procedure used for each, and location of repairs

*(e)* performance qualifications for welders and welding operators

*(f)* qualifications of examination personnel

*(g)* records of examination of pipe and tubing for longitudinal defects as specified in paras. K344.6.2(c) and K344.8.3, as applicable

## K346.3 Retention of Records

The owner shall retain one set of the required records for at least 5 years after they are received.

# Chapter X
# High Purity Piping

## U300 GENERAL STATEMENTS

*(a)* Chapter X pertains to piping designated by the owner as being in High Purity Fluid Service. See also Appendix M.

*(b)* The organization, content, and paragraph designations of this Chapter correspond to those of the base Code (Chapters I through VI), Chapter VII, and Chapter VIII. The prefix U is used to designate Chapter X requirements.

*(c)* Provisions and requirements of the base Code, Chapter VII, and Chapter VIII apply only as stated in this Chapter.

*(d)* For piping not in High Purity Fluid Service, Code requirements are found in Chapters I through IX.

*(e)* *High Purity Piping.* Chapter X provides alternative rules for design and construction of piping designated by the owner as being High Purity Fluid Service.

*(1)* These rules apply only when specified by the owner, and only as a whole, not in part.

*(2)* Chapter X rules do not provide for High Pressure Fluid Service.

*(3)* Chapter VII applies to nonmetallic piping and piping lined with nonmetals in High Purity Fluid Service.

*(f)* Chapter I applies.

## PART 1
## CONDITIONS AND CRITERIA

Chapter II, Part 1 applies. See para. U301.3.2(b)(5).

## U301 DESIGN CONDITIONS

### U301.3 Design Temperature

#### U301.3.2 Uninsulated Components

*(b)*

*(5)* compression, face seal, and hygienic clamped fittings and joints — 100% of the fluid temperature

## PART 2
## PRESSURE DESIGN OF PIPING COMPONENTS

Chapter II, Part 2 applies. See Figure U304.5.3 for representative configuration for metal face seal blanks.

## PART 3
## FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

Chapter II, Part 3 applies. See paras. U306.6, U307.3, and U308.

## U306 FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

### U306.6 Tube Fittings

*(a)* Tube fittings not listed in Table 326.1 or Appendix A shall meet the pressure design requirements described in para. 302.2.3 and the mechanical strength requirements described in para. 303.

*(b)* Compression-type tube fittings may be used in accordance with para. U315.2 provided that the type of fitting selected complies with the following:

*(1)* The gripping action of the fitting shall provide vibration resistance as demonstrated by exhibiting a stress intensity factor equal to or less than 1.5.

*(2)* Intermixing of components from different manufacturers is permitted only when specified in the engineering design.

*(c)* Face seal or hygienic clamp-type fittings in which the tightness of the joint is provided by a seating surface other than the threads (e.g., a metal face-seal fitting comprising internal and external threaded components, glands, and gasket or other constructions shown typically in Figure U335.7.1) may be used.

## U307 VALVES AND SPECIALTY COMPONENTS

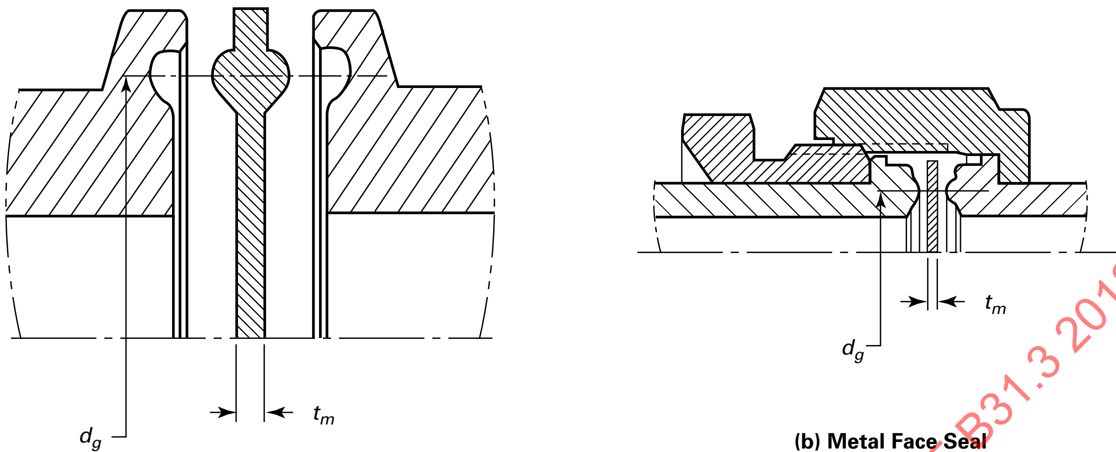
### U307.3 High Purity Fluid Service Valves

Valves such as ball, bellows, and diaphragm valves designed for High Purity Fluid Service that are not listed in Table 326.1 shall meet the pressure design requirements described in para. 302.2.2 and the mechanical strength requirements described in para. 303.

## U308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

Flanges should be avoided whenever possible. When flanges are utilized, para. 308 applies, except expanded joint flanges described in para. 308.2.2 are not permitted.

**Figure U304.5.3 Blanks**




(a) Hygienic Clamp-Type Fitting

(b) Metal Face Seal

## PART 4
## FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS

Chapter II, Part 4 applies, except expanded joints, flared tube fittings, and caulked joints, described in paras. 313, 315, and 316, respectively, are not permitted. See paras. U311, U311.1(c), U314, and U315.

### U311 WELDED JOINTS

Paragraph 311 applies, except for para. 311.1(c). See para. U311.1(c).

### U311.1 General

*(c)* Examination shall be in accordance with para. U341.4.1.

### U314 THREADED JOINTS

Threaded joints should be avoided whenever possible. When threaded joints are utilized, para. 314 applies.

### U315 TUBING JOINTS

Paragraph 315 applies. See paras. U315.1, U315.2(c), and U315.3.

### U315.1 General

In selecting and applying compression, face seal, and hygienic clamp-type tube fittings, the designer shall consider the possible adverse effects on the joints of such factors as assembly and disassembly, cyclic loading, vibration, shock, and thermal expansion and contraction. See para. FU315.

### U315.2 Joints Conforming to Listed Standards

*(c)* Joints using compression, face seal, hygienic clamp, and automatic welding tube fittings covered by listed standards may be used.

### U315.3 Joints Not Conforming to Listed Standards

*(a)* Compression-type tube fitting joints shall be fully gageable on initial installation to ensure sufficient tightening.

*(b)* Safeguarding is required for face seal or hygienic clamp-type joints used under severe cyclic conditions.

## PART 5
## FLEXIBILITY AND SUPPORT

Chapter II, Part 5 applies. See para. U319.3.6.

### U319 PIPING FLEXIBILITY

### U319.3 Properties for Flexibility Analysis

**U319.3.6 Flexibility and Stress Intensification Factors.** Paragraph 319.3.6 applies; however, piping components used in high-purity applications, e.g., multiport block valves, hygienic unions, crosses, and point-of-use and adaptor fittings, often do not have geometries similar to those in Table D300.

## PART 6
## SYSTEMS

Chapter II, Part 6 applies.

## PART 7
## METALLIC MATERIALS

The provisions and requirements in Chapter III for materials apply. Materials commonly used in high purity process piping systems include austenitic, ferritic, and duplex stainless steels, and nickel and nickel alloys.

## PART 8
## STANDARDS FOR PIPING COMPONENTS

Chapter IV applies.

## PART 9
## FABRICATION, ASSEMBLY, AND ERECTION

### U327 GENERAL

Metallic piping materials and components are prepared for assembly and erection by one or more of the fabrication processes covered in paras. U328, U330, U331, and U332. When any of these processes is used in assembly or erection, requirements are the same as for fabrication.

### U328 WELDING

Paragraph 328 applies, except for paras. 328.3.2, 328.5.4, and 328.5.5. See paras. U328.2.1(g) and (h), U328.4, U328.4.4, and U328.5.1(g) for additional requirements.

#### U328.2 Welding and Brazing Qualification

**U328.2.1 Qualification Requirements**

*(g)* A change in the type or nominal composition of the backing (purge) gas shall require requalification.

*(h)* The welding process shall be orbital GTAW, except for tack welds. Tack welds made prior to orbital welding may be manual GTAW.

#### (18) U328.4 Preparation for Welding

Paragraph 328.4.1 applies. Additionally, when weld coupon examination is specified in the engineering design or in the referencing code or standard (e.g., ASME BPE or SEMI), primary weld coupons shall be made in accordance with para. U328.4.4(b)(1) and examined in accordance with para. U344.8 prior to the start of production welding. This will demonstrate that the orbital welding equipment is set up properly and the weld program is sufficient to make repeatable production welds in accordance with the qualified welding procedure specification (WPS).

**U328.4.4 Preparation of Weld Coupons**

*(a)* Weld coupons shall be made by qualified welding operators using the same qualified WPS and the same variables used for production welds.

*(b)* *Methods*

*(1)* Primary weld coupons shall be made from two short sections of tubing selected from the same diameter, wall thickness, and alloy as the material used for production. Sections shall be of sufficient length for fit up in the weld head allowing for attachment of inside diameter purge apparatus outside of the weld head. The sections shall be welded together in a square groove weld on a butt joint.

*(2)* Production weld coupons may be made in accordance with para. U328.4.4(b)(1) or, at the owner's discretion, may be cut from actual production welds. The weld coupons shall be selected to ensure that the work product of each welding operator doing the production welding is represented.

#### U328.5 Welding Requirements

**U328.5.1 General**

*(g)* Tack welds shall be fully consumed after completion of the weld. Tack welds shall be made by a qualified welder or welding operator.

### U330 PREHEATING

Paragraph 330 applies.

### U331 HEAT TREATMENT

Paragraph 331 applies.

### U332 BENDING AND FORMING

Paragraph 332 applies in its entirety.

### U333 BRAZING AND SOLDERING

Brazing and soldering are not permitted.

### U335 ASSEMBLY AND ERECTION

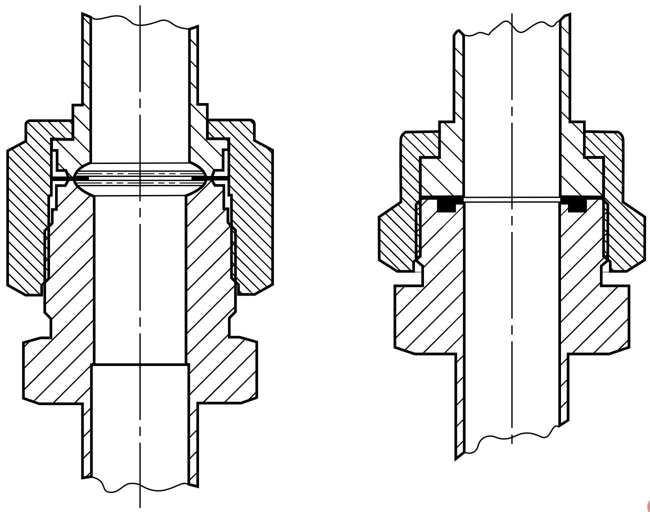
Paragraph 335 applies, except for paras. 335.4.1, 335.5, and 335.6. See paras. U335.7 and U335.8.

#### U335.7 Face Seal Joints

**U335.7.1 Metal Face Seal.** Metal face seal joints shall be installed and assembled in accordance with manufacturer's instructions. See Figure U335.7.1, illustration (a).

**U335.7.2 Nonmetallic Face Seal.** Nonmetallic face seal joints shall be installed and assembled in accordance with manufacturer's instructions. Care shall be taken to avoid distorting the seal when incorporating such joints into

**Figure U335.7.1 Face Seal Joints**



(a) Metal Face Seal

(b) Nonmetallic Face Seal

piping assemblies by welding. See Figure U335.7.1, illustration (b).

### U335.8 Hygienic Clamp Joint Assembly

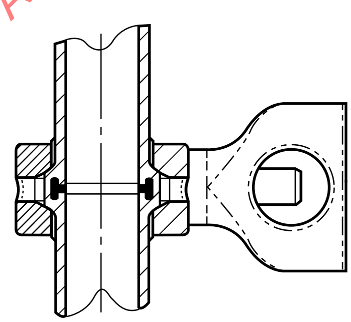
Hygienic clamp joint assembly components, e.g., those shown in Figures U335.8A, U335.8B, and U335.8C, shall be installed and assembled in accordance with the manufacturer's instructions. Care shall be taken to avoid distorting the seal when incorporating such joints into piping assemblies by welding.

## PART 10
## INSPECTION, EXAMINATION, AND TESTING

### U340 INSPECTION

Paragraph 340 applies in its entirety.

**Figure U335.8A Hygienic Clamp Joint Assembly**



### U341 EXAMINATION

Paragraph 341 applies. See paras. U341.3.2 and U341.4.1.

### U341.3 Examination Requirements

**U341.3.2 Acceptance Criteria.** Acceptance criteria for all coupon and production welds shall be as stated in the engineering design or in the referencing code or standard (e.g., ASME BPE or SEMI) and shall at least meet the applicable requirements in para. 341.3.2. (18)

### U341.4 Extent of Required Examination

**U341.4.1 Examination.** A weld coupon examination in accordance with para. U344.8 may be used in lieu of the 5% random radiography/ultrasonic examination required in para. 341.4.1(b)(1) when the following are employed in fabrication:

*(a)* autogenous automatic orbital welding

*(b)* automatic orbital welding with the use of consumable insert rings

**U341.4.5 Weld Coupon Examination.** Weld coupons shall be made and examined in accordance with para. U344.8 when any of the following conditions exist:

*(a)* beginning of shift

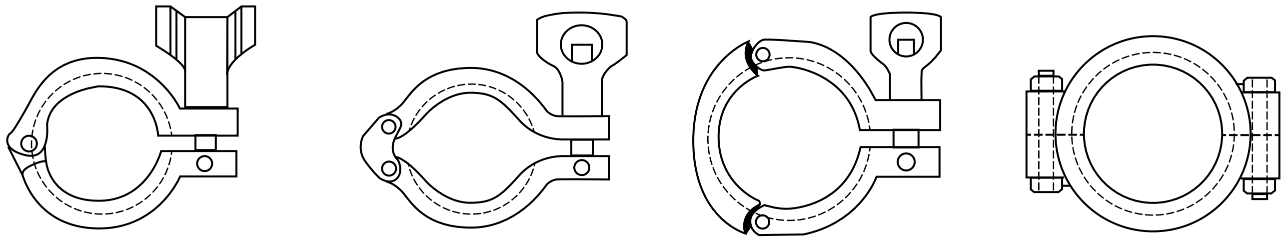
*(b)* change of purge source

*(c)* change of power supply

*(d)* change of equipment, e.g., weld head, weld-head extensions, tungsten

*(e)* any time there is a weld defect

**Figure U335.8B Hygienic Clamp Types**



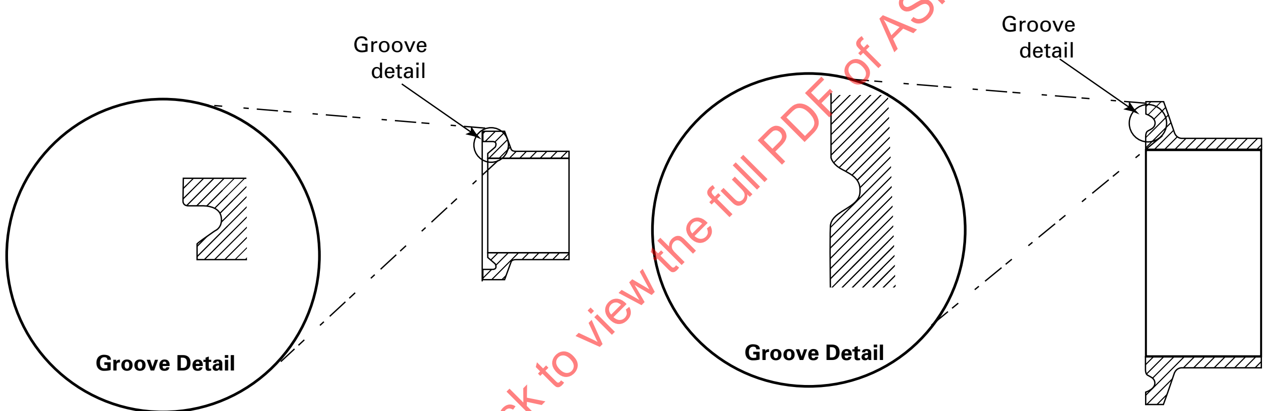
(1) Two-Piece Single Pin With Wing Nut

(2) Two-Piece Double Pin With Wing Nut

(3) Three-Piece Double Pin With Wing Nut

(4) Two-Bolt Heavy Duty

**Figure U335.8C Hygienic Ferrules**




(1) Type A:
O.D. Tube Sizes 1/4 in. Through 1 in.

(2) Type B:
O.D. Tube Sizes 1 in. and Above



## U342 EXAMINATION PERSONNEL

Paragraph 342 applies in its entirety. See para. U342.2(a).

### U342.2 Specific Requirement

*(a)* For weld coupon examination

*(1)* the examinations shall be performed by personnel other than those performing the production work or

*(2)* with the owner's approval, the personnel performing the production work shall be permitted to perform the examination, provided the personnel meet the personnel qualification and certification requirements in para. 342.1

## U343 EXAMINATION PROCEDURES

Paragraph 343 applies.

## U344 TYPES OF EXAMINATION

Paragraph 344 applies. See paras. U344.2 and U344.8.

### U344.2 Visual Examination

Paragraph 344.2 applies, except that in addition to the method described in para. 344.2.2, borescopic examination shall be acceptable.

### U344.8 Weld Coupon Examination

**U344.8.1 Requirements.** Weld coupon examination comprises examination of weld coupons for the following, as applicable:

*(a)* prior to welding of coupons made in accordance with para. U328.4.4(b)(1)

*(1)* joint preparation and cleanliness

*(2)* fit-up, collet or clamp grip, and alignment in the weld head

*(3)* variables in the orbital welding machine specified in the WPS

*(b)* after welding of coupons made in accordance with para. U328.4.4(b)(1), and for weld coupons made in accordance with para. U328.4.4(b)(2), for compliance with para. U341.3.2

*(1)* alignment

*(2)* weld penetration

*(3)* weld bead width variation

*(4)* weld bead meander

*(5)* discoloration

*(6)* weld defects, e.g., cracks, porosity, or sulfur stringers

To allow direct visual examination of the inside surfaces, the weld coupon may be cut or a suitable indirect visual examination method (e.g., borescopic examination) may be used.

**U344.8.2 Method.** A weld coupon shall be made to allow visual examination in accordance with para. U344.2, unless otherwise specified in the engineering design.

## U345 TESTING

Paragraph 345 applies except for paras. 345.1, 345.8, and 345.9. See paras. U345.1, U345.8, and U345.9.

### U345.1 Required Leak Test

Paragraph 345.1 applies, except that, at the owner's option, a helium mass spectrometer test in accordance with para. U345.8.1 may be substituted for the hydrostatic leak test.

### U345.8 Sensitive Leak Test

Paragraph 345.8 applies, except that the helium mass spectrometer test described in para. U345.8.1 is also an acceptable method.

**U345.8.1 Helium Mass Spectrometer Test.** The test shall be one of the following methods and performed in accordance with the following:

*(a)* For pressurized systems, the test shall be in accordance with ASME BPVC, Section V, Article 10, Appendix IV (Helium Mass Spectrometer — Detector Probe Technique).

*(1)* The test pressure shall be the lesser of 105 kPa (15 psig) gage or 25% of the design pressure.

*(2)* Prior to testing, the test pressure shall be held a minimum of 30 min.

*(3)* Unless otherwise specified in the engineering design, the system tested is acceptable when no leakage is detected that exceeds the allowable leakage rate of $1 \times 10^{-4}$ std cc/s.

*(b)* For evacuated systems, the test shall be in accordance with ASME BPVC, Section V, Article 10, Appendix V (Helium Mass Spectrometer Test — Tracer Probe Technique).

*(1)* The piping system shall be evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system.

*(2)* Unless otherwise specified in the engineering design, the system tested is acceptable when no leakage is detected that exceeds the allowable leakage rate of $1 \times 10^{-5}$ std cc/s.

### U345.9 Alternative Leak Test

Paragraph 345.9 applies, except that welds may be examined by weld coupon examination method in accordance with para. U341.4.5 and the test method may be helium mass spectrometer test in accordance with para. U345.8.1.

## U346 RECORDS

### U346.2 Responsibility

It is the responsibility of the piping designer, the manufacturer, the fabricator, and the erector, as applicable, to prepare the records required by this Code, ASME BPE, SEMI, or other industry standard as specified in the engineering design.

### U346.3 Retention of Records

Paragraph 346.3 applies.



# PART 11
# HIGH PURITY PIPING IN CATEGORY M FLUID SERVICE

## UM300 GENERAL STATEMENTS

*(a)* Chapter X, Part 11 pertains to piping designated by the owner as being high purity piping in Category M Fluid Service. See also Appendix M.

*(b)* The organization, content, and paragraph designations of these Parts correspond to those of Chapter VIII. The prefix UM is used.

*(c)* Paragraphs M300(d), (e), and (f) apply.

*(d)* Provisions and requirements of Chapter VIII apply with the additional requirements in paras. UM307, UM307.2, UM322, UM322.3, UM328, UM335, UM335.3.3, UM341, UM341.4(b)(1) and (2), and UM345(b).

## UM307 METALLIC VALVES AND SPECIALTY COMPONENTS

Paragraph M307 applies in its entirety. See also para. UM307.2(a).

### UM307.2 Specific Requirements

*(a)* For bellows or diaphragm sealed type valves, the bonnet or cover plate closure shall be secured by a straight thread sufficient for mechanical strength, have a metal-to-metal seat, and include a secondary stem seal.

## UM322 SPECIFIC PIPING SYSTEMS

Paragraph M322 applies, except for para. M322.3(c). See para. UM322.3(c).

### UM322.3 Instrument Piping

*(c)* joining methods shall conform to the requirements of para. U315

## UM328 WELDING OF MATERIALS

Welding shall be in accordance with paras. M311.1 and U328, except examination shall be in accordance with para. UM341.

## UM335 ASSEMBLY AND ERECTION OF METALLIC PIPING

Paragraph M335 applies, except for para. M335.3.3. See para. UM335.3.3.

**UM335.3.3 Straight-Threaded Joints.** The requirements of para. M335.3.3 are subject to the limitations in para. UM322.

## UM341 EXAMINATION

Paragraph M341 applies. See UM341.4(b)(1) and (2).

### UM341.4 Extent of Required Examination

*(b) Other Examination*

*(1)* The 100% radiography/ultrasonic examination required in para. M341.4(b) applies.

*(2)* The in-process examination alternative permitted in para. 341.4.1(b)(1) applies, except a weld coupon examination in accordance with para. U344.8 is also an acceptable substitute when specified in the engineering design or by the Inspector.

## UM345 TESTING

Paragraph M345(a) applies. See para. UM345(b).

*(b)* A sensitive leak test in accordance with para. U345.8 shall be included in the required leak test (para. U345.1).

# APPENDIX A
# ALLOWABLE STRESSES AND QUALITY FACTORS FOR METALLIC PIPING AND BOLTING MATERIALS

Begins on the next page.

(18)

## Specification Index for Appendix A

| Spec. No. | Title |
|---|---|
| **ASTM** | |
| A36 | Carbon Structural Steel |
| A47 | Ferritic Malleable Iron Castings |
| A48 | Gray Iron Castings |
| A53 | Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless |
| A105 | Carbon Steel Forgings for Piping Applications |
| A106 | Seamless Carbon Steel Pipe for High-Temperature Service |
| A126 | Gray Iron Castings for Valves, Flanges, and Pipe Fittings |
| A134 | Pipe, Steel, Electric-Fusion (Arc)-Welded (Sizes NPS 16 and Over) |
| A135 | Electric-Resistance-Welded Steel Pipe |
| A139 | Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over) |
| A179 | Seamless Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes |
| A181 | Carbon Steel Forgings, for General-Purpose Piping |
| A182 | Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service |
| A193 | Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications |
| A194 | Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both |
| A197 | Cupola Malleable Iron |
| A203 | Pressure Vessel Plates, Alloy Steel, Nickel |
| A204 | Pressure Vessel Plates, Alloy Steel, Molybdenum |
| A213 | Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes |
| A216 | Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service |
| A217 | Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service |
| A234 | Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service |
| A240 | Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications |
| A268 | Seamless and Welded Ferritic and Martensitic Stainless Steel Tubing for General Service |
| A269 | Seamless and Welded Austenitic Stainless Steel Tubing for General Service |
| A270 | Seamless and Welded Austenitic and Ferritic/Austenitic Stainless Steel Sanitary Tubing |
| A276 | Stainless Steel Bars and Shapes |
| A278 | Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 650°F (350°C) |
| A283 | Low and Intermediate Tensile Strength Carbon Steel Plates |
| **ASTM (Cont'd)** | |
| A285 | Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength |
| A299 | Pressure Vessel Plates, Carbon Steel, Manganese-Silicon |
| A302 | Pressure Vessel Plates, Alloy Steel, Manganese-Molybdenum and Manganese-Molybdenum-Nickel |
| A307 | Carbon Steel Bolts and Studs, 60 000 PSI Tensile Strength |
| A312 | Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes |
| A320 | Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service |
| A333 | Seamless and Welded Steel Pipe for Low-Temperature Service and Other Applications with Required Notch Toughness |
| A334 | Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service |
| A335 | Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service |
| A350 | Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components |
| A351 | Castings, Austenitic, for Pressure-Containing Parts |
| A352 | Steel Castings, Ferritic and Martensitic, for Pressure-Containing Parts, Suitable for Low-Temperature Service |
| A353 | Pressure Vessel Plates, Alloy Steel, Double-Normalized and Tempered 9% Nickel |
| A354 | Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners |
| A358 | Electric-Fusion-Welded Austenitic Chromium-Nickel Stainless Steel Pipe for High-Temperature Service and General Applications |
| A369 | Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service |
| A376 | Seamless Austenitic Steel Pipe for High-Temperature Service |
| A381 | Metal-Arc-Welded Steel Pipe for Use With High-Pressure Transmission Systems |
| A387 | Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum |
| A395 | Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures |
| A403 | Wrought Austenitic Stainless Steel Piping Fittings |
| A409 | Welded Large Diameter Austenitic Steel Pipe for Corrosive or High-Temperature Service |
| A420 | Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service |
| A426 | Centrifugally Cast Ferritic Alloy Steel Pipe for High-Temperature Service |
| A437 | Stainless and Alloy-Steel Turbine-Type Bolting Material Specially Heat Treated for High-Temperature Service |

## Specification Index for Appendix A (Cont'd)

| Spec. No. | Title |
|---|---|
| **ASTM (Cont'd)** | |
| A451 | Centrifugally Cast Austenitic Steel Pipe for High-Temperature Service |
| A453 | High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels |
| A479 | Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels |
| A487 | Steel Castings Suitable for Pressure Service |
| A494 | Castings, Nickel and Nickel Alloy |
| A515 | Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service |
| A516 | Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service |
| A524 | Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures |
| A536 | Ductile Iron Castings |
| A537 | Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel |
| A553 | Pressure Vessel Plates, Alloy Steel, Quenched and Tempered 7, 8, and 9 % Nickel |
| A563 | Carbon and Alloy Steel Nuts |
| A571 | Austenitic Ductile Iron Castings for Pressure-Containing Parts Suitable for Low-Temperature Service |
| A587 | Electric-Resistance-Welded Low-Carbon Steel Pipe for the Chemical Industry |
| A645 | Pressure Vessel Plates, 5 % and 5 $^1/_2$ % Nickel Alloy Steels, Specially Heat Treated |
| A671 | Electric-Fusion-Welded Steel Pipe for Atmospheric and Lower Temperatures |
| A672 | Electric-Fusion-Welded Steel Pipe for High-Pressure Service at Moderate Temperatures |
| A675 | Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties |
| A691 | Carbon and Alloy Steel Pipe, Electric-Fusion-Welded for High-Pressure Service at High Temperatures |
| A694 | Carbon and Alloy Steel Forgings for Pipe Flanges, Fittings, Valves, and Parts for High-Pressure Transmission Service |
| A696 | Steel Bars, Carbon, Hot-Wrought or Cold-Finished, Special Quality, for Pressure Piping Components |
| A707 | Forged Carbon and Alloy Steel Flanges for Low-Temperature Service |
| A789 | Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service |
| A790 | Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe |
| A813 | Single- or Double-Welded Austenitic Stainless Steel Pipe |
| A814 | Cold-Worked Welded Austenitic Stainless Steel Pipe |
| A815 | Wrought Ferritic, Ferritic/Austenitic, and Martensitic Stainless Steel Piping Fittings |
| A860 | Wrought High-Strength Ferritic Steel Butt-Welding Fittings |
| A928 | Ferritic/Austenitic (Duplex) Stainless Steel Pipe Electric Fusion Welded with Addition of Filler Metal |
| A992 | Structural Steel Shapes |
| A995 | Castings, Austenitic-Ferritic (Duplex) Stainless Steel, for Pressure-Containing Parts |
| A1010 | Higher-Strength Martensitic Stainless Steel Plate, Sheet, and Strip |
| A1011 | Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, and Ultra-High Strength |
| A1053 | Welded Ferritic-Martensitic Stainless Steel Pipe |
| B21 | Naval Brass Rod, Bar, and Shapes |
| B26 | Aluminum-Alloy Sand Castings |
| B42 | Seamless Copper Pipe, Standard Sizes |
| B43 | Seamless Red Brass Pipe, Standard Sizes |
| B61 | Steam or Valve Bronze Castings |
| B62 | Composition Bronze or Ounce Metal Castings |
| B68 | Seamless Copper Tube, Bright Annealed |
| B75 | Seamless Copper Tube |
| B88 | Seamless Copper Water Tube |
| B96 | Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes and Pressure Vessels |
| B98 | Copper-Silicon Alloy Rod, Bar and Shapes |
| B127 | Nickel-Copper Alloy (UNS N04400) Plate, Sheet, and Strip |
| B148 | Aluminum-Bronze Sand Castings |
| B150 | Aluminum Bronze Rod, Bar and Shapes |
| B152 | Copper Sheet, Strip, Plate and Rolled Bar |
| B160 | Nickel Rod and Bar |
| B161 | Nickel Seamless Pipe and Tube |
| B162 | Nickel Plate, Sheet and Strip |
| B163 | Seamless Nickel and Nickel Alloy Condenser and Heat Exchanger Tubes |
| B164 | Nickel-Copper Alloy Rod, Bar, and Wire |
| B165 | Nickel-Copper Alloy (UNS N04400) Seamless Pipe and Tube |
| B166 | Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Rod, Bar, and Wire |

## Specification Index for Appendix A (Cont'd)

| Spec. No. | Title |
|---|---|
| **ASTM (Cont'd)** | |
| B167 | Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Seamless Pipe and Tube |
| B168 | Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Plate, Sheet and Strip |
| B169 | Aluminum Bronze Sheet, Strip, and Rolled Bar |
| B171 | Copper-Alloy Plate and Sheet for Pressure Vessels, Condensers, and Heat Exchangers |
| B187 | Copper, Bus Bar, Rod, and Shapes and General Purpose Rod, Bar, and Shapes |
| B209 | Aluminum and Aluminum-Alloy Sheet and Plate |
| B210 | Aluminum and Aluminum-Alloy Drawn Seamless Tubes |
| B211 | Aluminum and Aluminum-Alloy Rolled or Cold Finished Bar, Rod, and Wire |
| B221 | Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes |
| B241 | Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube |
| B247 | Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings |
| B265 | Titanium and Titanium Alloy Strip, Sheet, and Plate |
| B280 | Seamless Copper Tube for Air Conditioning and Refrigeration Field Service |
| B283 | Copper and Copper-Alloy Die Forgings (Hot-Pressed) |
| B333 | Nickel-Molybdenum Alloy Plate, Sheet, and Strip |
| B335 | Nickel-Molybdenum Alloy Rod |
| B345 | Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube for Gas and Oil Transmission and Distribution Piping Systems |
| B348 | Titanium and Titanium Alloy Bars and Billets |
| B361 | Factory-Made Wrought Aluminum and Aluminum-Alloy Welding Fittings |
| B363 | Seamless and Welded Unalloyed Titanium and Titanium Alloy Welding Fittings |
| B366 | Factory-Made Wrought Nickel and Nickel Alloy Fittings |
| B367 | Titanium and Titanium Alloy Castings |
| B371 | Copper-Zinc-Silicon Alloy Rod |
| B381 | Titanium and Titanium Alloy Forgings |
| B407 | Nickel-Iron-Chromium Alloy Seamless Pipe and Tube |
| B408 | Nickel-Iron-Chromium Alloy Rod and Bar |

| Spec. No. | Title |
|---|---|
| **ASTM (Cont'd)** | |
| B409 | Nickel-Iron-Chromium Alloy Plate, Sheet, and Strip |
| B423 | Nickel-Iron-Chromium-Molybdenum-Copper Alloy (UNS N08825, N08221, and N06845) Seamless Pipe and Tube |
| B424 | Ni-Fe-Cr-Mo-Cu Alloy (UNS N08825, UNS N08221, and UNS N06845) Plate, Sheet, and Strip |
| B425 | Ni-Fe-Cr-Mo-Cu Alloy (UNS N08825, UNS N08221, and UNS N06845) Rod and Bar |
| B435 | UNS N06002, UNS N06230, UNS N12160, and UNS R30556 Plate, Sheet, and Strip |
| B443 | Nickel-Chromium-Molybdenum-Columbium Alloy (UNS N06625) and Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219) Plate, Sheet, and Strip |
| B444 | Nickel-Chromium-Molybdenum-Columbium Alloys (UNS N06625 and UNS N06852) and Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219) Pipe and Tube |
| B446 | Nickel-Chromium-Molybdenum-Columbium Alloy (UNS N06625), Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219), and Nickel-Chromium-Molybdenum-Tungsten Alloy (UNS N06650) Rod and Bar |
| B462 | Forged or Rolled UNS N06030, UNS N06022, UNS N06035, UNS N06200, UNS N06059, UNS N10362, UNS N06686, UNS N08020, UNS N08024. UNS N08026, UNS N08367, UNS N10276, UNS N10665, UNS N10675, UNS N10629, UNS N08031, UNS N06045, UNS N06025, UNS R20033 Alloy Pipe Flanges, Forged Fittings, and Valves and Parts for Corrosive High-Temperature Service |
| B463 | UNS N08020 Alloy Plate, Sheet, and Strip |
| B464 | Welded UNS N08020 Alloy Pipe |
| B466 | Seamless Copper-Nickel Pipe and Tube |
| B467 | Welded Copper-Nickel Pipe |
| B474 | Electric Fusion Welded Nickel and Nickel Alloy Pipe |
| B491 | Aluminum and Aluminum-Alloy Extruded Round Tubes for General-Purpose Applications |
| B493 | Zirconium and Zirconium Alloy Forgings |
| B514 | Welded Nickel-Iron-Chromium Alloy Pipe |
| B515 | Welded UNS N08120, UNS N08800, UNS N08810, and UNS N08811 Alloy Tubes |
| B517 | Welded Nickel-Chromium-Iron-Alloy (UNS N06600, UNS N06603, UNS N06025, and UNS N06045) Pipe |
| B523 | Seamless and Welded Zirconium and Zirconium Alloy Tubes |
| B547 | Aluminum and Aluminum-Alloy Formed and Arc-Welded Round Tube |
| B550 | Zirconium and Zirconium Alloy Bar and Wire |
| B551 | Zirconium and Zirconium Alloy Strip, Sheet, and Plate |
| B564 | Nickel Alloy Forgings |
| B572 | UNS N06002, UNS N06230, UNS N12160, and UNS R30556 Rod |

## Specification Index for Appendix A (Cont'd)

| Spec. No. | Title |
|---|---|
| **ASTM (Cont'd)** | |
| B574 | Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Molybdenum-Chromium, Low-Carbon Nickel-Molybdenum-Chromium-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Rod |
| B575 | Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, Low-Carbon Nickel-Chromium-Molybdenum-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Tungsten, and Low-Carbon Nickel-Molybdenum-Chromium Alloy Plate, Sheet and Strip |
| B581 | Nickel-Chromium-Iron-Molybdenum-Copper Alloy Rod |
| B582 | Nickel-Chromium-Iron-Molybdenum-Copper Alloy Plate, Sheet, and Strip |
| B584 | Copper Alloy Sand Castings for General Applications |
| B619 | Welded Nickel and Nickel-Cobalt Alloy Pipe |
| B620 | Nickel-Iron-Chromium-Molybdenum Alloy (UNS N08320) Plate, Sheet, and Strip |
| B621 | Nickel-Iron-Chromium-Molybdenum Alloy (UNS N08320) Rod |
| B622 | Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube |
| B625 | UNS N08925, UNS N08031, UNS N08932, UNS N08926, UNS N08354, UNS N08830, and UNS R20033 Plate, Sheet, and Strip |
| B626 | Welded Nickel and Nickel-Cobalt Alloy Tube |
| B649 | Ni-Fe-Cr-Mo-Cu-N Low-Carbon Alloys (UNS N08925, UNS N08031, UNS N08354, and UNS N08926), and Cr-Ni-Fe-N Low-Carbon Alloy (UNS R20033) Bar and Wire, and Ni-Cr-Fe-Mo-N Alloy (UNS N08936) Wire |
| B658 | Seamless and Welded Zirconium and Zirconium Alloy Pipe |
| B668 | UNS N08028 Seamless Pipe and Tube |
| B675 | UNS N08367 Welded Pipe |
| B688 | Chromium-Nickel-Molybdenum-Iron (UNS N08366 and UNS N08367) Plate, Sheet, and Strip |
| B690 | Iron-Nickel-Chromium-Molybdenum Alloys (UNS N08366 and UNS N08367) Seamless Pipe and Tube |
| B704 | Welded UNS N06625, UNS N06219 and UNS N08825 Alloy Tubes |
| B705 | Nickel-Alloy (UNS N06625, N06219 and N08825) Welded Pipe |
| B709 | Iron-Nickel-Chromium-Molybdenum Alloy (UNS N08028) Plate, Sheet, and Strip |
| B725 | Welded Nickel (UNS N02200/UNS N02201) and Nickel Copper Alloy (UNS N04400) Pipe |
| B729 | Seamless UNS N08020, UNS N08026, and UNS N08024 Nickel-Alloy Pipe and Tube |
| B804 | UNS N08367 and UNS N08926 Welded Pipe |
| B861 | Titanium and Titanium Alloy Seamless Pipe |
| B862 | Titanium and Titanium Alloy Welded Pipe |
| E112 | Standard Test Methods for Determining Average Grain Size |
| F3125 | High Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 MPa) Minimum Tensile Strength |
| **API** | |
| 5L | Line Pipe |
| **CSA** | |
| Z245.1 | Steel Pipe |

GENERAL NOTE: It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in Appendix E.

# NOTES FOR TABLES A-1, A-1M, A-1A, A-1B, A-2, AND A-2M (18)

GENERAL NOTES:

(a) The allowable stress values, P-Number assignments, weld joint and casting quality factors, and minimum temperatures in Tables A-1, A-1A, A-1B, A-2, and A-2M, together with the referenced Notes in the stress tables, are requirements of this Code.

(b) Notes (1) through (7) are referenced in column headings and in body headings for material type and product form; Notes (8) and following are referenced in the Notes column for specific materials. Notes marked with an asterisk (*) restate requirements found in the text of the Code.

(c) The stress values given in ksi as shown in Tables A-1 and A-2, and given in MPa as shown in Tables A-1M and A-2M, may be used. The values stated in ksi are not exact equivalents to the values stated in MPa. Therefore, for any given material, the user of the Code should use only the ksi or the MPa values.

(d) For copper and copper alloys, the following symbols are used in the Temper column: H = drawn; H01 = quarter hard; H02 = half hard; H06 = extra hard; H55 = light drawn; H58 = drawn, general purpose; H80 = hard drawn; HR50 = drawn, stress relieved; M20 = hot rolled; O25 = hot rolled, annealed; O50 = light annealed; O60 = soft annealed; O61 = annealed; WO50 = welded, annealed; and WO61 = welded, fully finished, annealed.

(e) For nickel and nickel alloys, the following abbreviations are used in the Class column: ann., annealed; C.D., cold worked; forg., forged; H.F., hot finished; H.R., hot rolled; H.W., hot worked; plt., plate; R., rolled; rel., relieved; sol., solution; str., stress; and tr., treated.

(f) In Table A-1M, the following abbreviations are used in the Product Form column: forg., forgings; ftg., fittings; pl., plate; shps., shapes; sht., sheet; smls., seamless; and wld., welded.

NOTES:

(1) *The stress values in Tables A-1 and A-1M, and the design stress values in Tables A-2 and A-2M, are basic allowable stresses in tension in accordance with para. 302.3.1(a). For pressure design, the stress values from Tables A-1 and A-1M are multiplied by the appropriate quality factor $E$ ($E_c$ from Table A-1A or $E_j$ from Table A-1B). Stress values in shear and bearing are stated in para. 302.3.1(b); those in compression in para. 302.3.1(c).

(2) *The quality factors for castings $E_c$ in Table A-1A are basic factors in accordance with para. 302.3.3(b). The quality factors for longitudinal weld joints $E_j$ in Table A-1B are basic factors in accordance with para. 302.3.4(a). See paras. 302.3.3(c) and 302.3.4(b) for enhancement of quality factors. See also para. 302.3.1(a), footnote 1.

(3) The stress values for austenitic stainless steels in these Tables may not be applicable if the material has been given a final heat treatment other than that required by the material specification or by reference to Note (30) or (31).

(4a) *In Table A-1, stress values printed in *italics* exceed two-thirds of the expected yield strength at temperature. Stress values in **boldface** are equal to 90% of expected yield strength at temperature. See paras. 302.3.2(d)(3) and (e).

(4b) *In Table A-1M, stress values printed in *italics* are tensile-controlled values. Yield-controlled stress values are in normal font and time-dependent stress values are in **boldface.**

(5) *See ASME BPVC, Section IX, QW-200.3 for a description of P-Number groupings. P-Numbers are indicated by number or by a number followed by a letter (e.g., 8, 5B, or 11A).

(6) *The minimum temperature shown is that design minimum temperature for which the material is normally suitable without impact testing other than that required by the material specification. However, the use of a material at a design minimum temperature colder than −29°C (−20°F) is established by rules elsewhere in this Code, including para. 323.2.2 and other impact test requirements. For carbon steels with a letter designation in the Min. Temp. column, see para. 323.2.2(e) and the applicable curve and Notes in Figure 323.2.2A.

(7) The letter "a" indicates alloys that are not recommended for welding and that, if welded, must be individually qualified. The letter "b" indicates copper base alloys that must be individually qualified.

(8) *There are restrictions on the use of this material in the text of the Code as follows:

*(a)* See para. 305.2.1; temperature limits are −29°C to 186°C (−20°F to 366°F).

*(b)* See para. 305.2.2; pipe shall be safeguarded when used outside the temperature limits in Note (8a).

*(c)* See Table 323.2.2, box B-2.

*(d)* See para. 323.4.2(a).

*(e)* See para. 323.4.2(b).

*(f)* See para. 309.2.1.

*(g)* See para. 309.2.2.

(9) *For pressure–temperature ratings of components made in accordance with standards listed in Table 326.1, see para. 326.2.1. Stress values in Tables A-1 and A-1M may be used to calculate ratings for unlisted components, and special ratings for listed components, as permitted by para. 303.

(9a) Component standards listed in Table 326.1 impose the following restrictions on this material when used as a forging: composition, properties, heat treatment, and grain size shall conform to this specification; manufacturing procedures, tolerances, tests, certification, and markings shall be in accordance with ASTM B564.

(10) *This casting quality factor is applicable only when proper supplementary examination has been performed (see para. 302.3.3).
(11) *For use under this Code, radiography shall be performed after heat treatment.
(12) *Certain forms of this material, as stated in Table 323.2.2, must be impact tested to qualify for service below −29°C (−20°F). Alternatively, if provisions for impact testing are included in the material specification as supplementary requirements and are invoked, the material may be used down to the temperature at which the test was conducted in accordance with the specification.
(13) Properties of this material vary with thickness or size. Stress values are based on minimum properties for the thickness listed.
(14) For use in Code piping at the stated stress values, the required minimum tensile and yield properties must be verified by tensile test. If such tests are not required by the material specification, they shall be specified in the purchase order.
(15) These stress values are established from a consideration of strength only and will be satisfactory for average service. For bolted joints where freedom from leakage over a long period of time without retightening is required, lower stress values may be necessary as determined from the flexibility of the flange and bolts and corresponding relaxation properties.
(16) DELETED.
(17) DELETED.
(18) DELETED.
(19) *This specification includes requirements for random radiographic inspection for mill quality control. If the 0.90 joint factor is to be used, the welds shall meet the requirements of Table 341.3.2 for longitudinal butt welds with spot radiography in accordance with Table 302.3.4. This shall be a matter of special agreement between purchaser and manufacturer.
(20) For pipe sizes ≥DN 200 (NPS 8) with wall thicknesses ≥Sch 140, the specified minimum tensile strength is 483 MPa (70 ksi).
(21) For material thickness >127 mm (5 in.), the specified minimum tensile strength is 483 MPa (70 ksi).
(21a) For material thickness >127 mm (5 in.), the specified minimum tensile strength is 448 MPa (65 ksi).
(22) The minimum tensile strength for weld (qualification) and stress values shown shall be multiplied by 0.90 for pipe having an outside diameter less than 51 mm (2 in.) and a $D/t$ value less than 15. This requirement may be waived if it can be shown that the welding procedure to be used will consistently produce welds that meet the listed minimum tensile strength of 165 MPa (24 ksi).
(23) DELETED.
(24) Yield strength is not stated in the material specification. The value shown is based on yield strengths of materials with similar characteristics.
(25) This steel may develop embrittlement after service at approximately 316°C (600°F) and higher temperature.
(26) This unstabilized grade of stainless steel increasingly tends to precipitate intergranular carbides as the carbon content increases above 0.03%. See also para. F323.4(c)(2).
(27) For temperatures above 427°C (800°F), these stress values apply only when the carbon content is 0.04% or higher.
(28) For temperatures above 538°C (1,000°F), these stress values apply only when the carbon content is 0.04% or higher.
(29) The stress values above 538°C (1,000°F) listed here shall be used only when the steel's austenitic micrograin size, as defined in ASTM E112, is No. 6 or less (coarser grain). Otherwise, the lower stress values listed for the same material, specification, and grade shall be used.
(30) For temperatures above 538°C (1,000°F), these stress values may be used only if the material has been heat treated by heating to a minimum temperature of 1 093°C (2,000°F) and quenching in water or rapidly cooling by other means.
(31) For temperatures above 538°C (1,000°F), these stress values may be used only if the material has been heat treated by heating to a minimum temperature of 1 038°C (1,900°F) and quenching in water or rapidly cooling by other means.
(32) Stress values shown are for the lowest strength base material permitted by the specification to be used in the manufacture of this grade of fitting. If a higher strength base material is used, the higher stress values for that material may be used in design.
(33) For welded construction with work hardened grades, use the stress values for annealed material; for welded construction with precipitation hardened grades, use the special stress values for welded construction given in the Tables.
(34) If material is welded, brazed, or soldered, the allowable stress values for the annealed condition shall be used.
(35) This steel is intended for use at high temperatures; it may have low ductility and/or low impact properties at room temperature after being used above the temperature indicated by para. F323.4(c)(4).
(36) The specification permits this material to be furnished without solution heat treatment or with other than a solution heat treatment. When the material has not been solution heat treated, the minimum temperature shall be −29°C (−20°F) unless the material is impact tested in accordance with para. 323.3.
(37) Impact requirements for seamless fittings shall be governed by those listed in this Table for the particular base material specification in the grades permitted (A312, A240, and A182). When A276 materials are used in the manufacture of these fittings, the Notes, minimum temperatures, and allowable stresses for comparable grades of A240 materials shall apply.
(38) DELETED.
(39) This material when used below −29°C (−20°F) shall be impact tested if the carbon content is above 0.10%.
(40) *This casting quality factor can be enhanced by supplementary examination in accordance with para. 302.3.3(c) and Table 302.3.3C. The higher factor from Table 302.3.3C may be substituted for this factor in pressure design equations.
(41) Design stresses for the cold drawn temper are based on hot rolled properties until required data on cold drawn are submitted.
(42) This is a product specification. No design stresses are necessary. Limitations on metal temperature for materials covered by this specification are as follows:

| Grade(s) | Metal Temperature, °C (°F) |
|---|---|
| 1 | −29 to 482 (−20 to 900) |
| 2, 2H, and 2HM | −48 to 593 (−55 to 1,100) |
| 3 | −29 to 593 (−20 to 1,100) |
| 4 | −48 to 593 (−55 to 1,100) |
| 4L | −101 to 593 (−150 to 1,100) |
| 6 | −29 to 427 (−20 to 800) |
| 7 | −48 to 593 (−55 to 1,100) |
| 7L | −101 to 593 (−150 to 1,100) |
| 7M | −48 to 593 (−55 to 1,100) |
| 7ML | −73 to 593 (−100 to 1,100) |
| 8FA [see Note (39)] | −29 to 427 (−20 to 800) |
| 8MA and 8TA | −198 to 816 (−325 to 1,500) |
| 8, 8A, and 8CA | −254 to 816 (−425 to 1,500) |

(42a) DELETED.

(42b) This is a product specification. No design stresses are necessary. For limitations on usage, see paras. 309.2.1 and 309.2.2.

(43) *The stress values given for this material are not applicable when either welding or thermal cutting is employed [see para. 323.4.2(c)].

(44) This material shall not be welded.

(45) Stress values shown are applicable for "die" forgings only.

(46) Lines of allowable stresses in Tables A-1 and A-1M for all materials in A312 include heavily cold worked (HCW) material as defined in A312, para. 6.1.4.

(47) If no welding is employed in fabrication of piping from these materials, the stress values may be increased to 230 MPa (33.3 ksi).

(48) The stress value to be used for this gray iron material at its upper temperature limit of 232°C (450°F) is the same as that shown in the 204°C (400°F) column.

(49) If the chemical composition of this Grade is such as to render it hardenable, qualification under P-No. 6 is required.

(50) This material is grouped in P-No. 7 because its hardenability is low.

(51) This material may require special consideration for welding qualification. See ASME BPVC, Section IX, QW/QB-422. For use in this Code, a qualified WPS is required for each strength level of material.

(52) Copper-silicon alloys are not always suitable when exposed to certain media and high temperature, particularly above 100°C (212°F). The user should satisfy himself/herself that the alloy selected is satisfactory for the service for which it is to be used.

(53) Stress relief heat treatment is required for service above 232°C (450°F).

(54) The maximum operating temperature is arbitrarily set at 260°C (500°F) because hard temper adversely affects design stress in the creep rupture temperature ranges.

(55) Pipe produced to this specification is not intended for high temperature service. The stress values apply to either nonexpanded or cold expanded material in the as-rolled, normalized, or normalized and tempered condition.

(56) Because of thermal instability, this material is not recommended for service above 427°C (800°F).

(57) Conversion of carbides to graphite may occur after prolonged exposure to temperatures over 427°C (800°F). See para. F323.4(b)(2).

(58) Conversion of carbides to graphite may occur after prolonged exposure to temperatures over 468°C (875°F). See para. F323.4(b)(3).

(59) For temperatures above 482°C (900°F), consider the advantages of killed steel. See para. F323.4(b)(4).

(60) For all design temperatures, the maximum hardness shall be Rockwell C35 immediately under the thread roots. The hardness shall be taken on a flat area at least 3 mm ($\frac{1}{8}$ in.) across, prepared by removing threads. No more material than necessary shall be removed to prepare the area. Hardness determination shall be made at the same frequency as tensile tests.

(61) Annealed at approximately 982°C (1,800°F).

(62) Annealed at approximately 1 121°C (2,050°F).

(63) For stress relieved tempers (T351, T3510, T3511, T451, T4510, T4511, T651, T6510, T6511), stress values for material in the listed temper shall be used.

(64) The minimum tensile strength of the reduced section tensile specimen in accordance with ASME BPVC, Section IX, QW-462.1, shall not be less than 758 MPa (110.0 ksi).

(65) The minimum temperature shown in Tables A-1 and A-1M is for the heaviest wall meeting the specified mechanical property requirements in the specification. The minimum temperature for lighter walls shall be as shown in the following tabulation:

**Impact Test Temperature (°C) for Plate Thicknesses Shown**

| Spec. No. and Grade | Max. 51 mm | Over 51 mm to 76 mm |
|---|---|---|
| A203 A | −68 | −59 |
| A203 B | −68 | −59 |
| A203 D | −101 | −87 |
| A203 E | −101 | −87 |

**Impact Test Temperature (°F) for Plate Thicknesses Shown**

| Spec. No. and Grade | Max. 2 in. | Over 2 in. to 3 in. |
|---|---|---|
| A203 A | −90 | −75 |
| A203 B | −90 | −75 |
| A203 D | −150 | −125 |
| A203 E | −150 | −125 |

(66) Stress values shown are 90% of those for the corresponding core material.

(67) For use under this Code, the heat treatment requirements for pipe manufactured to A671, A672, and A691 shall be as required by para. 331 for the particular material being used.

(68) The tension test specimen from plate 12.7 mm ($\frac{1}{2}$ in.) and thicker is machined from the core and does not include the cladding alloy; therefore, the stress values listed are those for materials less than 12.7 mm.

(69) This material may be used only in nonpressure applications.

(70) Alloy 625 (UNS N06625) in the annealed condition is subject to severe loss of impact strength at room temperature after exposure in the range of 538°C to 760°C (1,000°F to 1,400°F).

(71) These materials are normally microalloyed with Cb, V, and/or Ti. Supplemental specifications agreed to by manufacturer and purchaser commonly establish chemistry more restrictive than the base specification, as well as plate rolling specifications and requirements for weldability (i.e., C-equivalent) and toughness.

(72) For service temperature >454°C (850°F), weld metal shall have a carbon content >0.05%.

(73) Heat treatment is required after welding for all products of zirconium Grade R60705. See Table 331.1.1.

(74) Mechanical properties of fittings made from forging stock shall meet the minimum tensile requirements of one of the bar, forging, or rod specifications listed in Table 2 of B366 for which tensile testing is required.

(75) Stress values shown are for materials in the normalized and tempered condition, or when the heat treatment is unknown. If material is annealed, use the following values above 510°C (950°F):

| **Temp., °C** | **538** | **566** | **593** | **621** | **649** |
|---|---|---|---|---|---|
| *S*, MPa | 55.1 | 39.3 | 26.2 | 16.5 | 9.6 |

| **Temp., °F** | **1,000** | **1,050** | **1,100** | **1,150** | **1,200** |
|---|---|---|---|---|---|
| *S*, ksi | 8.0 | 5.7 | 3.8 | 2.4 | 1.4 |

(76) DELETED.

(77) The pipe grades listed below, produced in accordance with CSA (Canadian Standards Association) Z245.1, shall be considered as equivalents to API 5L and treated as listed materials.

**Grade Equivalents**

| **API 5L** | **CSA Z245.1** |
|---|---|
| B | 241 |
| X42 | 290 |
| X46 | 317 |
| X52 | 359 |
| X56 | 386 |
| X60 | 414 |
| X65 | 448 |
| X70 | 483 |
| X80 | 550 |

(78) Not permitted for the P4 and P5 materials in Table 302.3.5 for Elevated Temperature Fluid Service.

(79) For use under this Code, impact testing shall be performed in accordance with para. 323.3 at the design minimum temperature but not warmer than −29°C (−20°F).

## Table A-1 Basic Allowable Stresses in Tension for Metals (18)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | | | | | | | Specified Min. Strength, ksi | | Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Material | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Notes | Min. Temp., °F (6) | Tensile | Yield | Min. Temp. to 100 | 200 | 300 | 400 | 500 | 600 | 650 |
| **Iron — Castings** | | | | | | | | | | | | | | | |
| Gray | A48 | 20 | F11401 | ... | (8e)(48) | −20 | 20 | ... | 2.0 | 2.0 | 2.0 | 2.0 | ... | ... | ... |
| Gray | A278 | 20 | F11401 | ... | (8e)(48) | −20 | 20 | ... | 2.0 | 2.0 | 2.0 | 2.0 | ... | ... | ... |
| Gray | A126 | A | F11501 | ... | (8e)(9)(48) | −20 | 21 | ... | 2.0 | 2.0 | 2.0 | 2.0 | ... | ... | ... |
| Gray | A48 | 25 | F11701 | ... | (8e)(48) | −20 | 25 | ... | 2.5 | 2.5 | 2.5 | 2.5 | ... | ... | ... |
| Gray | A278 | 25 | F11701 | ... | (8e)(48) | −20 | 25 | ... | 2.5 | 2.5 | 2.5 | 2.5 | ... | ... | ... |
| Gray | A48 | 30 | F12101 | ... | (8e)(48) | −20 | 30 | ... | 3.0 | 3.0 | 3.0 | 3.0 | ... | ... | ... |
| Gray | A278 | 30 | F12101 | ... | (8e)(48) | −20 | 30 | ... | 3.0 | 3.0 | 3.0 | 3.0 | ... | ... | ... |
| Gray | A126 | B | F12102 | ... | (8e)(9)(48) | −20 | 31 | ... | 3.0 | 3.0 | 3.0 | 3.0 | ... | ... | ... |
| Gray | A48 | 35 | F12401 | ... | (8e)(48) | −20 | 35 | ... | 3.5 | 3.5 | 3.5 | 3.5 | ... | ... | ... |
| Gray | A278 | 35 | F12401 | ... | (8e)(48) | −20 | 35 | ... | 3.5 | 3.5 | 3.5 | 3.5 | ... | ... | ... |
| Gray | A48 | 40 | F12801 | ... | (8e)(9)(48) | −20 | 40 | ... | 4.0 | 4.0 | 4.0 | 4.0 | ... | ... | ... |
| Gray | A126 | C | F12802 | ... | (8e)(9)(48) | −20 | 41 | ... | 4.0 | 4.0 | 4.0 | 4.0 | ... | ... | ... |
| Gray | A278 | 40 | F12803 | ... | (8e)(9)(53) | −20 | 40 | ... | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| Gray | A48 | 45 | F13101 | ... | (8e)(48) | −20 | 45 | ... | 4.5 | 4.5 | 4.5 | 4.5 | ... | ... | ... |
| Gray | A48 | 50 | F13501 | ... | (8e)(48) | −20 | 50 | ... | 5.0 | 5.0 | 5.0 | 5.0 | ... | ... | ... |
| Gray | A278 | 50 | F13502 | ... | (8e)(53) | −20 | 50 | ... | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Gray | A48 | 55 | F13801 | ... | (8e)(48) | −20 | 55 | ... | 5.5 | 5.5 | 5.5 | 5.5 | ... | ... | ... |
| Gray | A48 | 60 | F14101 | ... | (8e)(48) | −20 | 60 | ... | 6.0 | 6.0 | 6.0 | 6.0 | ... | ... | ... |
| Gray | A278 | 60 | F14102 | ... | (8e)(53) | −20 | 60 | ... | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| Cupola malleable | A197 | ... | F22000 | ... | (8e)(9) | −20 | 40 | 30 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| Malleable | A47 | 32510 | F22200 | ... | (8e)(9) | −20 | 50 | 32.5 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Ferritic ductile | A395 | 60-40-18 | F32800 | ... | (8d)(9) | −20 | 60 | 40 | 20.0 | 19.0 | 17.9 | 16.9 | 15.9 | 14.9 | 14.1 |
| Austenitic ductile | A571 | D-2M | F43010 | 1 | (8d) | −20 | 65 | 30 | 20.0 | ... | ... | ... | ... | ... | ... |
| Ductile | A536 | 65-45-12 | F33100 | ... | (8d)(9) | −20 | 65 | 45 | 21.7 | 21.7 | 21.7 | 21.7 | 21.6 | ... | ... |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Material | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi Tensile | Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)] Min. Temp. to 100 | 200 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Carbon Steel — Pipes and Tubes** | | | | | | | | | | | | | |
| A285 Gr. A | A134 | ... | ... | ... | ... | 1 | (8b)(57) | B | 45 | 24 | 15.0 | 14.7 | 14.2 |
| A285 Gr. A | A672 | A45 | K01700 | ... | ... | 1 | (57)(59)(67) | B | 45 | 24 | 15.0 | 14.7 | 14.2 |
| Butt weld | API 5L | A25 | ... | ... | ... | 1 | (8a)(77) | −20 | 45 | 25 | 15.0 | 15.0 | 14.7 |
| Smls & ERW | API 5L | A25 | ... | ... | ... | 1 | (57)(59)(77) | B | 45 | 25 | 15.0 | 15.0 | 14.7 |
| ... | A179 | ... | K01200 | ... | ... | 1 | (57)(59) | −20 | 47 | 26 | 15.7 | 15.7 | 15.3 |
| Type F | A53 | A | K02504 | ... | ... | 1 | (8a) | 20 | 48 | 30 | 16.0 | 16.0 | 16.0 |
| ... | A139 | A | ... | ... | ... | 1 | (8b) | A | 48 | 30 | 16.0 | 16.0 | 16.0 |
| ... | A587 | ... | K11500 | ... | ... | 1 | (57)(59) | −20 | 48 | 30 | 16.0 | 16.0 | 16.0 |
| ... | A53 | A | K02504 | ... | ... | 1 | (57)(59) | B | 48 | 30 | 16.0 | 16.0 | 16.0 |
| ... | A106 | A | K02501 | ... | ... | 1 | (57) | B | 48 | 30 | 16.0 | 16.0 | 16.0 |
| ... | A135 | A | ... | ... | ... | 1 | (57)(59) | B | 48 | 30 | 16.0 | 16.0 | 16.0 |
| ... | A369 | FPA | K02501 | ... | ... | 1 | (57) | B | 48 | 30 | 16.0 | 16.0 | 16.0 |
| ... | API 5L | A | ... | ... | ... | 1 | (57)(59) | B | 48 | 30 | 16.0 | 16.0 | 16.0 |
| A285 Gr. B | A134 | ... | ... | ... | ... | 1 | (8b)(57) | B | 50 | 27 | 16.7 | 16.5 | 15.9 |
| A285 Gr. B | A672 | A50 | K02200 | ... | ... | 1 | (57)(59)(67) | B | 50 | 27 | 16.7 | 16.5 | 15.9 |
| A285 Gr. C | A134 | ... | ... | ... | ... | 1 | (8b)(57) | A | 55 | 30 | 18.3 | 18.3 | 17.7 |
| ... | A524 | II | K02104 | ... | ... | 1 | (57) | −20 | 55 | 30 | 18.3 | 18.3 | 17.7 |
| ... | A333 | 1 | K03008 | ... | ... | 1 | (57)(59) | −50 | 55 | 30 | 18.3 | 18.3 | 17.7 |
| ... | A334 | 1 | K03008 | ... | ... | 1 | (57)(59) | −50 | 55 | 30 | 18.3 | 18.3 | 17.7 |
| A285 Gr. C | A671 | CA55 | K02801 | ... | ... | 1 | (59)(67) | A | 55 | 30 | 18.3 | 18.3 | 17.7 |
| A285 Gr. C | A672 | A55 | K02801 | ... | ... | 1 | (57)(59)(67) | A | 55 | 30 | 18.3 | 18.3 | 17.7 |
| A516 Gr. 55 | A672 | C55 | K01800 | ... | ... | 1 | (57)(67) | C | 55 | 30 | 18.3 | 18.3 | 17.7 |
| A516 Gr. 60 | A671 | CC60 | K02100 | ... | ... | 1 | (57)(67) | C | 60 | 32 | 20.0 | 19.5 | 18.9 |
| A515 Gr. 60 | A671 | CB60 | K02401 | ... | ... | 1 | (57)(67) | B | 60 | 32 | 20.0 | 19.5 | 18.9 |
| A515 Gr. 60 | A672 | B60 | K02401 | ... | ... | 1 | (57)(67) | B | 60 | 32 | 20.0 | 19.5 | 18.9 |
| A516 Gr. 60 | A672 | C60 | K02100 | ... | ... | 1 | (57)(67) | C | 60 | 32 | 20.0 | 19.5 | 18.9 |
| ... | A139 | B | K03003 | ... | ... | 1 | (8b) | A | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | A135 | B | K03018 | ... | ... | 1 | (57)(59) | B | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | A524 | I | K02104 | ... | ... | 1 | (57) | −20 | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | A53 | B | K03005 | ... | ... | 1 | (57)(59) | B | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | A106 | B | K03006 | ... | ... | 1 | (57) | B | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | A333 | 6 | K03006 | ... | ... | 1 | (57) | −50 | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | A334 | 6 | K03006 | ... | ... | 1 | (57) | −50 | 60 | 35 | 20.0 | 20.0 | 20.0 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | | **Carbon Steel — Pipes and Tubes** | |
| 13.7 | 13.0 | 12.3 | 11.9 | 11.5 | 10.7 | 9.2 | 7.9 | 5.9 | ... | ... | ... | ... | ... | A134 |
| 13.7 | 13.0 | 12.3 | 11.9 | 11.5 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | A45 | A672 |
| 14.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A25 | API 5L |
| 14.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A25 | API 5L |
| 14.8 | 14.1 | 13.3 | 12.8 | 12.4 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | ... | A179 |
| 16.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A | A53 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A | A139 |
| 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2 | 7.9 | ... | ... | ... | ... | ... | ... | A587 |
| 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | A | A53 |
| 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | A | A106 |
| 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | A | A135 |
| 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | FPA | A369 |
| 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | A | API 5L |
| 15.4 | 14.7 | 13.8 | 13.3 | 12.5 | 10.7 | 9.2 | 7.9 | 5.9 | ... | ... | ... | ... | ... | A134 |
| 15.4 | 14.7 | 13.8 | 13.3 | 12.5 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | A50 | A672 |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | ... | ... | ... | ... | ... | A134 |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5 | ... | ... | II | A524 |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | 1 | A333 |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | 1 | A334 |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | CA55 | A671 |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | A55 | A672 |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | C55 | A672 |
| 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | ... | ... | CC60 | A671 |
| 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | CB60 | A671 |
| 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | B60 | A672 |
| 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | C60 | A672 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | B | A139 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | ... | ... | B | A135 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | ... | ... | I | A524 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | B | A53 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | B | A106 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | 6 | A333 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | 6 | A334 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Material | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Carbon Steel — Pipes and Tubes** | | | | | | | | | | | | | |
| ... | A369 | FPB | K03006 | ... | ... | 1 | (57) | −20 | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | A381 | Y35 | ... | ... | ... | 1 | ... | A | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | API 5L | B | ... | ... | ... | 1 | (57)(59)(77) | B | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | A139 | C | K03004 | ... | ... | 1 | (8b) | A | 60 | 42 | 20.0 | 20.0 | 20.0 |
| ... | A139 | D | K03010 | ... | ... | 1 | (8b) | A | 60 | 46 | 20.0 | 20.0 | 20.0 |
| ... | API 5L | X42 | ... | ... | ... | 1 | (55)(77) | A | 60 | 42 | 20.0 | 20.0 | 20.0 |
| ... | A381 | Y42 | ... | ... | ... | 1 | ... | A | 60 | 42 | 20.0 | 20.0 | 20.0 |
| ... | A381 | Y48 | ... | ... | ... | 1 | ... | A | 62 | 48 | 20.7 | 20.7 | 20.7 |
| ... | API 5L | X46 | ... | ... | ... | 1 | (55)(77) | A | 63 | 46 | 21.0 | 21.0 | 21.0 |
| ... | A381 | Y46 | ... | ... | ... | 1 | ... | A | 63 | 46 | 21.0 | 21.0 | 21.0 |
| ... | A381 | Y50 | ... | ... | ... | 1 | ... | A | 64 | 50 | 21.3 | 21.3 | 21.3 |
| A516 Gr. 65 | A671 | CC65 | K02403 | ... | ... | 1 | (57)(67) | B | 65 | 35 | 21.7 | 21.4 | 20.6 |
| A515 Gr. 65 | A671 | CB65 | K02800 | ... | ... | 1 | (57)(67) | A | 65 | 35 | 21.7 | 21.4 | 20.6 |
| A515 Gr. 65 | A672 | B65 | K02800 | ... | ... | 1 | (57)(67) | A | 65 | 35 | 21.7 | 21.4 | 20.6 |
| A516 Gr. 65 | A672 | C65 | K02403 | ... | ... | 1 | (57)(67) | B | 65 | 35 | 21.7 | 21.4 | 20.6 |
| ... | A139 | E | K03012 | ... | ... | 1 | (8b) | A | 66 | 52 | 22.0 | 22.0 | 22.0 |
| ... | API 5L | X52 | ... | ... | ... | 1 | (55)(77) | A | 66 | 52 | 22.0 | 22.0 | 22.0 |
| ... | A381 | Y52 | ... | ... | ... | 1 | ... | A | 66 | 52 | 22.0 | 22.0 | 22.0 |
| A516 Gr. 70 | A671 | CC70 | K02700 | ... | ... | 1 | (57)(67) | B | 70 | 38 | 23.3 | 23.2 | 22.4 |
| A515 Gr. 70 | A671 | CB70 | K03101 | ... | ... | 1 | (57)(67) | A | 70 | 38 | 23.3 | 23.2 | 22.4 |
| A515 Gr. 70 | A672 | B70 | K03101 | ... | ... | 1 | (57)(67) | A | 70 | 38 | 23.3 | 23.2 | 22.4 |
| A516 Gr. 70 | A672 | C70 | K02700 | ... | ... | 1 | (57)(67) | B | 70 | 38 | 23.3 | 23.2 | 22.4 |
| ... | A106 | C | K03501 | ... | ... | 1 | (57) | B | 70 | 40 | 23.3 | 23.3 | 23.3 |
| A537 Cl. 1 | A671 | CD70 | K12437 | ... | ≤2½ thk. | 1 | (67) | D | 70 | 50 | 23.3 | 23.3 | 22.8 |
| A537 Cl. 1 | A672 | D70 | K12437 | ... | ≤2½ thk. | 1 | (67) | D | 70 | 50 | 23.3 | 23.3 | 22.8 |
| A537 Cl. 1 | A691 | CMSH-70 | K12437 | ... | ≤2½ thk. | 1 | (67) | D | 70 | 50 | 23.3 | 23.3 | 22.8 |
| ... | API 5L | X56 | ... | ... | ... | 1 | (51)(55)(71)(77) | A | 71 | 56 | 23.7 | 23.7 | 23.7 |
| ... | A381 | Y56 | ... | ... | ... | 1 | (51)(55)(71) | A | 71 | 56 | 23.7 | 23.7 | 23.7 |
| A299 Gr. A | A671 | CK75 | K02803 | ... | >1 thk. | 1 | (57)(67) | A | 75 | 40 | 25.0 | 24.4 | 23.6 |
| A299 Gr. A | A672 | N75 | K02803 | ... | >1 thk. | 1 | (57)(67) | A | 75 | 40 | 25.0 | 24.4 | 23.6 |
| A299 Gr. A | A691 | CMS-75 | K02803 | ... | >1 thk. | 1 | (57)(67) | A | 75 | 40 | 25.0 | 24.4 | 23.6 |
| A299 Gr. A | A671 | CK75 | K02803 | ... | ≤1 thk. | 1 | (57)(67) | A | 75 | 42 | 25.0 | 25.0 | 24.8 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | Type/ Grade | Spec. No. |
| | | | | | | | | | | **Carbon Steel — Pipes and Tubes (Cont'd)** | | | | |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | FPB | A369 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | Y35 | A381 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | B | API 5L |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C | A139 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | D | A139 |
| 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | X42 | API 5L |
| 20.0 | ... | ... | ... | ... | ... | ... | ... | ...... | ... | ... | ... | ... | Y42 | A381 |
| 20.7 | 20.7 | 20.7 | 18.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | Y48 | A381 |
| 21.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | X46 | API 5L |
| 21.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | Y46 | A381 |
| 21.3 | 21.3 | 21.3 | 18.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | Y50 | A381 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 9.0 | 6.3 | 4.0 | 2.5 | ... | ... | CC65 | A671 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 9.0 | 6.3 | 4.0 | 2.5 | 1.6 | 1.0 | CB65 | A671 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 9.0 | 6.3 | 4.0 | 2.5 | 1.6 | 1.0 | B65 | A672 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 9.0 | 6.3 | 4.0 | 2.5 | 1.6 | 1.0 | C65 | A672 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | E | A139 |
| 22.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | X52 | API 5L |
| 22.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | Y52 | A381 |
| 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5 | ... | ... | CC70 | A671 |
| 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5 | 1.6 | 1.0 | CB70 | A671 |
| 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5 | 1.6 | 1.0 | B70 | A672 |
| 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5 | 1.6 | 1.0 | C70 | A672 |
| 22.8 | 21.7 | 20.4 | 19.8 | 18.3 | 14.8 | 12.0 | ... | ... | ... | ... | ... | ... | C | A106 |
| 22.7 | 22.7 | 22.4 | 21.9 | 18.3 | ... | ... | ... | ... | ... | ... | ... | ... | CD70 | A671 |
| 22.7 | 22.7 | 22.4 | 21.9 | 18.3 | ... | ... | ... | ... | ... | ... | ... | ... | D70 | A672 |
| 22.7 | 22.7 | 22.4 | 21.9 | 18.3 | ... | ... | ... | ... | ... | ... | ... | ... | CMSH-70 | A691 |
| 23.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | X56 | API 5L |
| 23.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | Y56 | A381 |
| 22.8 | 21.7 | 20.4 | 19.8 | 19.1 | 15.7 | 12.6 | 9.3 | 6.7 | 4.0 | 2.5 | 1.6 | 1.0 | CK75 | A671 |
| 22.8 | 21.7 | 20.4 | 19.8 | 19.1 | 15.7 | 12.6 | 9.3 | 6.7 | 4.0 | 2.5 | 1.6 | 1.0 | N75 | A672 |
| 22.8 | 21.7 | 20.4 | 19.8 | 19.1 | 15.7 | 12.6 | 9.3 | 6.7 | 4.0 | 2.5 | 1.6 | 1.0 | CMS-75 | A691 |
| 23.9 | 22.8 | 21.5 | 20.8 | 19.6 | ... | ... | ... | ... | ... | ... | ... | ... | CK75 | A671 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Material | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Carbon Steel — Pipes and Tubes** | | | | | | | | | | | | | |
| A299 Gr. A | A672 | N75 | K02803 | ... | ≤1 thk. | 1 | (57)(67) | A | 75 | 42 | 25.0 | 25.0 | 24.8 |
| A299 Gr. A | A691 | CMS-75 | K02803 | ... | ≤1 thk. | 1 | (57)(67) | A | 75 | 42 | 25.0 | 25.0 | 24.8 |
| ... | API 5L | X60 | ... | ... | ... | 1 | (51)(55)(71)(77) | A | 75 | 60 | 25.0 | 25.0 | 25.0 |
| ... | API 5L | X65 | ... | ... | ... | 1 | (51)(55)(71)(77) | A | 77 | 65 | 25.7 | 25.7 | 25.7 |
| ... | API 5L | X70 | ... | ... | ... | 1 | (51)(55)(71)(77) | A | 82 | 70 | 27.3 | 27.3 | 27.3 |
| ... | API 5L | X80 | ... | ... | ... | 1 | (51)(55)(71)(77) | A | 90 | 80 | 30.0 | 30.0 | 30.0 |
| ... | A381 | Y60 | ... | ... | ... | 1 | (51)(71) | A | 75 | 60 | 25.0 | 25.0 | 25.0 |
| **Carbon Steel — Pipes (Structural Grade)** | | | | | | | | | | | | | |
| A283 Gr. A | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −20 | 45 | 24 | 15.0 | 14.7 | 14.2 |
| A1011 Gr. 30 | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −20 | 49 | 30 | 16.3 | 16.3 | 16.3 |
| A283 Gr. B | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −20 | 50 | 27 | 16.7 | 16.5 | 15.9 |
| A1011 Gr. 33 | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −20 | 52 | 33 | 17.3 | 17.3 | 17.3 |
| A1011 Gr. 36 | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −20 | 53 | 36 | 17.7 | 17.7 | 17.7 |
| A1011 Gr. 40 | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −20 | 55 | 40 | 18.3 | 18.3 | 18.3 |
| A36 | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −20 | 58 | 36 | 19.3 | 19.3 | 19.3 |
| A283 Gr. D | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −20 | 60 | 33 | 20.0 | 20.0 | 19.5 |
| A1011 Gr. 45 | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −20 | 60 | 45 | 20.0 | 20.0 | 20.0 |
| A1011 Gr. 50 | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −20 | 65 | 50 | 21.7 | 21.7 | 21.7 |
| **Carbon Steel — Plates, Bars, Shapes, and Sheets** | | | | | | | | | | | | | |
| ... | A285 | A | K01700 | ... | ... | 1 | (57)(59) | B | 45 | 24 | 15.0 | 14.7 | 14.2 |
| ... | A285 | B | K02200 | ... | ... | 1 | (57)(59) | B | 50 | 27 | 16.7 | 16.5 | 15.9 |
| ... | A516 | 55 | K01800 | ... | ... | 1 | (57) | C | 55 | 30 | 18.3 | 18.3 | 17.7 |
| ... | A285 | C | K02801 | ... | ... | 1 | (57)(59) | A | 55 | 30 | 18.3 | 18.3 | 17.7 |
| ... | A516 | 60 | K02100 | ... | ... | 1 | (57) | C | 60 | 32 | 20.0 | 19.5 | 18.9 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | Type/ Grade | Spec. No. |
| **Carbon Steel — Pipes and Tubes (Cont'd)** | | | | | | | | | | | | | | |
| 23.9 | 22.8 | 21.5 | 20.8 | 19.6 | ... | ... | ... | ... | ... | ... | ... | ... | N75 | A672 |
| 23.9 | 22.8 | 21.5 | 20.8 | 19.6 | ... | ... | ... | ... | ... | ... | ... | ... | CMS-75 | A691 |
| 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | X60 | API 5L |
| 25.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | X65 | API 5L |
| 27.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | X70 | API 5L |
| 30.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | X80 | API 5L |
| 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | Y60 | A381 |
| **Carbon Steel — Pipes (Structural Grade)** | | | | | | | | | | | | | | |
| 13.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A134 |
| 16.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A134 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A134 |
| 17.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A134 |
| 17.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A134 |
| 18.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A134 |
| 19.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A134 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A134 |
| 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A134 |
| 21.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A134 |
| **Carbon Steel — Plates, Bars, Shapes, and Sheets** | | | | | | | | | | | | | | |
| 13.7 | 13.0 | 12.3 | 11.9 | 11.5 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | A | A285 |
| 15.4 | 14.7 | 13.8 | 13.3 | 12.5 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | B | A285 |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | ... | ... | ... | ... | ... | 55 | A516 |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | C | A285 |
| 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.9 | 11.4 | 8.7 | ... | ... | ... | ... | ... | 60 | A516 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Material | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Carbon Steel — Plates, Bars, Shapes, and Sheets** | | | | | | | | | | | | | |
| ... | A515 | 60 | K02401 | ... | ... | 1 | (57) | B | 60 | 32 | 20.0 | 19.5 | 18.9 |
| ... | A696 | B | K03200 | ... | ... | 1 | (57) | A | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | A516 | 65 | K02403 | ... | ... | 1 | (57) | B | 65 | 35 | 21.7 | 21.4 | 20.6 |
| ... | A515 | 65 | K02800 | ... | ... | 1 | (57) | A | 65 | 35 | 21.7 | 21.4 | 20.6 |
| ... | A516 | 70 | K02700 | ... | ... | 1 | (57) | B | 70 | 38 | 23.3 | 23.2 | 22.4 |
| ... | A515 | 70 | K03101 | ... | ... | 1 | (57) | A | 70 | 38 | 23.3 | 23.2 | 22.4 |
| ... | A696 | C | K03200 | ... | ... | 1 | (57) | A | 70 | 40 | 23.3 | 23.3 | 23.3 |
| ... | A537 | ... | K12437 | 1 | ≤2½ thk. | 1 | ... | D | 70 | 50 | 23.3 | 23.3 | 22.8 |
| ... | A299 | A | K02803 | ... | >1 thk. | 1 | (57) | A | 75 | 40 | 25.0 | 24.4 | 23.6 |
| ... | A299 | A | K02803 | ... | ≤1 thk. | 1 | (57) | A | 75 | 42 | 25.0 | 25.0 | 24.8 |
| **Carbon Steel — Plates, Bars, Shapes, and Sheets (Structural)** | | | | | | | | | | | | | |
| ... | A283 | A | K01400 | ... | ... | 1 | (8c)(57) | A | 45 | 24 | 15.0 | 14.7 | 14.2 |
| ... | A1011 | 30 | K02502 | ... | ... | 1 | (8c)(57) | A | 49 | 30 | 16.3 | 16.3 | 16.3 |
| ... | A283 | B | K01702 | ... | ... | 1 | (8c)(57) | A | 50 | 27 | 16.7 | 16.5 | 15.9 |
| ... | A1011 | 33 | K02502 | ... | ... | 1 | (8c)(57) | A | 52 | 33 | 17.3 | 17.3 | 17.3 |
| ... | A1011 | 36 | K02502 | ... | ... | 1 | (8c)(57) | A | 53 | 36 | 17.7 | 17.7 | 17.7 |
| ... | A283 | C | K02401 | ... | ... | 1 | (8c)(57) | A | 55 | 30 | 18.3 | 18.3 | 17.7 |
| ... | A1011 | 40 | K02502 | ... | ... | 1 | (8c)(57) | A | 55 | 40 | 18.3 | 18.3 | 18.3 |
| ... | A36 | ... | K02600 | ... | ... | 1 | (8c) | A | 58 | 36 | 19.3 | 19.3 | 19.3 |
| ... | A283 | D | K02702 | ... | ... | 1 | (8c)(57) | A | 60 | 33 | 20.0 | 20.0 | 19.5 |
| ... | A1011 | 45 | K02507 | ... | ... | 1 | (8c)(57) | A | 60 | 45 | 20.0 | 20.0 | 20.0 |
| ... | A1011 | 50 | K02507 | ... | ... | 1 | (8c)(57) | A | 65 | 50 | 21.7 | 21.7 | 21.7 |
| ... | A992 | ... | ... | ... | ... | 1 | (8c)(57) | A | 65 | 50 | 19.9 | 19.9 | 19.9 |
| **Carbon Steel — Forgings and Fittings** | | | | | | | | | | | | | |
| ... | A350 | LF1 | K03009 | ... | ... | 1 | (9)(57)(59) | −20 | 60 | 30 | 20.0 | 18.3 | 17.7 |
| ... | A181 | ... | K03502 | 60 | ... | 1 | (9)(57)(59) | A | 60 | 30 | 20.0 | 18.3 | 17.7 |
| ... | A420 | WPL6 | K03006 | ... | ... | 1 | (57) | −50 | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | A234 | WPB | K03006 | ... | ... | 1 | (57)(59) | B | 60 | 35 | 20.0 | 20.0 | 20.0 |
| ... | A694 | F42 | K03014 | ... | ... | 1 | (9) | −20 | 60 | 42 | 20.0 | 20.0 | 20.0 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | Type/ Grade | Spec. No. |
| | | | | | | | | **Carbon Steel — Plates, Bars, Shapes, and Sheets (Cont'd)** | | | | | | |
| 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | ... | ... | 60 | A515 |
| 19.9 | 19.0 | 17.9 | 17.3 | 15.6 | ... | ... | ... | ... | ... | ... | ... | ... | B | A696 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 9.0 | ... | ... | ... | ... | ... | 65 | A516 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 9.0 | 6.3 | 4.0 | 2.5 | ... | ... | 65 | A515 |
| 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | ... | ... | ... | ... | ... | 70 | A516 |
| 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5 | ... | ... | 70 | A515 |
| 22.8 | 21.7 | 20.5 | 19.7 | 18.3 | ... | ... | ... | ... | ... | ... | ... | ... | C | A696 |
| 22.7 | 22.7 | 22.4 | 21.9 | 18.3 | ... | ... | ... | ... | ... | ... | ... | ... | Cl. 1 | A537 |
| 22.8 | 21.7 | 20.4 | 19.8 | 19.1 | 15.7 | 12.6 | 9.3 | 6.7 | 4.0 | 2.5 | 1.6 | 1.0 | A | A299 |
| 23.9 | 22.8 | 21.5 | 20.8 | 19.6 | 15.7 | 12.6 | 9.3 | 6.7 | 4.0 | 2.5 | 1.6 | 1.0 | A | A299 |
| | | | | | | | | **Carbon Steel — Plates, Bars, Shapes, and Sheets (Structural)** | | | | | | |
| 13.7 | 13.0 | 12.3 | 11.9 | 11.5 | 10.7 | ... | ... | ... | ... | ... | ... | ... | A | A283 |
| 16.3 | 16.3 | 15.3 | 14.6 | 12.5 | 10.7 | ... | ... | ... | ... | ... | ... | ... | 30 | A1011 |
| 15.4 | 14.7 | 13.8 | 13.3 | 12.5 | 10.7 | ... | ... | ... | ... | ... | ... | ... | B | A283 |
| 17.3 | 17.3 | 16.9 | 14.6 | 12.5 | 10.7 | ... | ... | ... | ... | ... | ... | ... | 33 | A1011 |
| 17.7 | 17.7 | 17.7 | 14.6 | 12.5 | 10.7 | ... | ... | ... | ... | ... | ... | ... | 36 | A1011 |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | ... | ... | ... | ... | ... | ... | ... | C | A283 |
| 18.3 | 18.3 | 18.3 | 18.3 | 15.6 | 13.0 | ... | ... | ... | ... | ... | ... | ... | 40 | A1011 |
| 19.3 | 19.3 | 18.4 | 17.8 | 15.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | A36 |
| 18.8 | 17.9 | 16.9 | 16.3 | 15.8 | 13.9 | ... | ... | ... | ... | ... | ... | ... | D | A283 |
| 20.0 | 20.0 | 20.0 | 20.0 | 16.9 | 13.9 | ... | ... | ... | ... | ... | ... | ... | 45 | A1011 |
| 21.7 | 21.7 | 21.7 | 20.5 | 16.9 | 13.9 | ... | ... | ... | ... | ... | ... | ... | 50 | A1011 |
| 19.9 | 19.9 | 19.9 | 18.9 | 15.5 | 12.8 | 10.5 | ... | ... | ... | ... | ... | ... | ... | A992 |
| | | | | | | | | | | **Carbon Steel — Forgings and Fittings** | | | | |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.8 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | ... | ... | LF1 | A350 |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.8 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | Cl. 60 | A181 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | ... | ... | WPL6 | A420 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | WPB | A234 |
| 20.0 | 19.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F42 | A694 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Material | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Carbon Steel — Forgings and Fittings** | | | | | | | | | | | | | |
| ... | A707 | L1 | K02302 | 1 | ... | 1 | (9) | −20 | 60 | 42 | 20.0 | 20.0 | 20.0 |
| ... | A707 | L2 | K03301 | 1 | ... | 1 | (9) | −50 | 60 | 42 | 20.0 | 20.0 | 20.0 |
| ... | A707 | L3 | K12510 | 1 | ... | 1 | (9) | −50 | 60 | 42 | 20.0 | 20.0 | 20.0 |
| ... | A860 | WPHY 42 | ... | ... | ... | 1 | ... | −50 | 60 | 42 | 20.0 | 20.0 | 20.0 |
| ... | A694 | F46 | K03014 | ... | ... | 1 | (9) | −20 | 63 | 46 | 21.0 | 21.0 | 21.0 |
| ... | A860 | WPHY 46 | ... | ... | ... | 1 | ... | −50 | 63 | 46 | 21.0 | 21.0 | 21.0 |
| ... | A694 | F52 | K03014 | ... | ... | 1 | (9) | −20 | 66 | 52 | 22.0 | 22.0 | 22.0 |
| ... | A707 | L1 | K02302 | 2 | ... | 1 | (9) | −20 | 66 | 52 | 22.0 | 22.0 | 22.0 |
| ... | A707 | L2 | K03301 | 2 | ... | 1 | (9) | −50 | 66 | 52 | 22.0 | 22.0 | 22.0 |
| ... | A707 | L3 | K12510 | 2 | ... | 1 | (9) | −50 | 66 | 52 | 22.0 | 22.0 | 22.0 |
| ... | A860 | WPHY 52 | ... | ... | ... | 1 | ... | −50 | 66 | 52 | 22.0 | 22.0 | 22.0 |
| ... | A350 | LF2 | K03011 | 1 | ... | 1 | (9)(57) | −50 | 70 | 36 | 23.3 | 22.0 | 21.2 |
| ... | A350 | LF2 | K03011 | 2 | ... | 1 | (9)(57) | 0 | 70 | 36 | 23.3 | 22.0 | 21.2 |
| ... | A105 | ... | K03504 | ... | ... | 1 | (9)(57)(59) | −20 | 70 | 36 | 23.3 | 22.0 | 21.2 |
| ... | A181 | ... | K03502 | 70 | ... | 1 | (9)(57)(59) | A | 70 | 36 | 23.3 | 22.0 | 21.2 |
| ... | A234 | WPC | K03501 | ... | ... | 1 | (57)(59) | B | 70 | 40 | 23.3 | 23.3 | 23.3 |
| ... | A694 | F56 | K03014 | ... | ... | 1 | (9) | −20 | 71 | 56 | 23.7 | 23.7 | 23.7 |
| ... | A694 | F60 | K03014 | ... | ... | 1 | (9) | −20 | 75 | 60 | 25.0 | 25.0 | 25.0 |
| ... | A707 | L2 | K03301 | 3 | ... | 1 | (9) | −50 | 75 | 60 | 25.0 | 25.0 | 25.0 |
| ... | A707 | L3 | K12510 | 3 | ... | 1 | (9) | −50 | 75 | 60 | 25.0 | 25.0 | 25.0 |
| ... | A860 | WPHY 60 | ... | ... | ... | 1 | ... | −50 | 75 | 60 | 25.0 | 25.0 | 25.0 |
| ... | A694 | F65 | K03014 | ... | ... | 1 | (9) | −20 | 77 | 65 | 25.7 | 25.7 | 25.7 |
| ... | A860 | WPHY 65 | ... | ... | ... | 1 | ... | −50 | 77 | 65 | 25.7 | 25.7 | 25.7 |
| ... | A694 | F70 | K03014 | ... | ... | 1 | (9)(79) | ... | 82 | 70 | 27.3 | 27.3 | 27.3 |
| ... | A860 | WPHY 70 | ... | ... | ... | 1 | ... | −50 | 82 | 70 | 27.3 | 27.3 | 27.3 |
| **Carbon Steel — Castings** | | | | | | | | | | | | | |
| ... | A216 | WCA | J02502 | ... | ... | 1 | (57) | −20 | 60 | 30 | 20.0 | 18.3 | 17.7 |
| ... | A352 | LCB | J03003 | ... | ... | 1 | (9)(57) | −50 | 65 | 35 | 21.7 | 21.4 | 20.6 |
| ... | A352 | LCC | J02505 | ... | ... | 1 | (9) | −50 | 70 | 40 | 23.3 | 23.3 | 23.3 |
| ... | A216 | WCB | J03002 | ... | ... | 1 | (9)(57) | −20 | 70 | 36 | 23.3 | 22.0 | 21.2 |
| ... | A216 | WCC | J02503 | ... | ... | 1 | (9)(57) | −20 | 70 | 40 | 23.3 | 23.3 | 23.3 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **400** | **500** | **600** | **650** | **700** | **750** | **800** | **850** | **900** | **950** | **1,000** | **1,050** | **1,100** | **Type/ Grade** | **Spec. No.** |
| | | | | | | | | | | | **Carbon Steel — Forgings and Fittings (Cont'd)** | | | |
| 20.0 | 19.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L1 | A707 |
| 20.0 | 19.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L2 | A707 |
| 20.0 | 19.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L3 | A707 |
| 20.0 | 19.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WPHY 42 | A860 |
| 21.0 | 21.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F46 | A694 |
| 21.0 | 21.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WPHY 46 | A860 |
| 22.0 | 22.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F52 | A694 |
| 22.0 | 22.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L1 | A707 |
| 22.0 | 22.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L2 | A707 |
| 22.0 | 22.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L3 | A707 |
| 22.0 | 22.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WPHY 52 | A860 |
| 20.5 | 19.6 | 18.4 | 17.8 | 17.2 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5 | ... | ... | LF2 Cl. 1 | A350 |
| 20.5 | 19.6 | 18.4 | 17.8 | 17.2 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5 | ... | ... | LF2 Cl. 2 | A350 |
| 20.5 | 19.6 | 18.4 | 17.8 | 17.2 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5 | 1.6 | 1.0 | ... | A105 |
| 20.5 | 19.6 | 18.4 | 17.8 | 17.2 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5 | 1.6 | 1.0 | Cl. 70 | A181 |
| 22.8 | 21.7 | 20.4 | 19.8 | 18.3 | 14.8 | 12.0 | ... | ... | ... | ... | ... | ... | WPC | A234 |
| 23.7 | 23.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F56 | A694 |
| 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F60 | A694 |
| 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L2 | A707 |
| 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L3 | A707 |
| 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WPHY 60 | A860 |
| 25.7 | 25.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F65 | A694 |
| 25.7 | 25.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WPHY 65 | A860 |
| 27.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F70 | A694 |
| 27.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WPHY 70 | A860 |
| | | | | | | | | | | | | | **Carbon Steel — Castings** | |
| 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.8 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5 | 1.6 | 1.0 | WCA | A216 |
| 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 9.0 | 6.3 | 4.0 | 2.5 | 1.6 | 1.0 | LCB | A352 |
| 22.8 | 21.7 | 20.4 | 19.8 | 19.2 | ... | ... | ... | ... | ... | ... | ... | ... | LCC | A352 |
| 20.5 | 19.6 | 18.4 | 17.8 | 17.2 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5 | 1.6 | 1.0 | WCB | A216 |
| 22.8 | 21.7 | 20.4 | 19.8 | 18.3 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5 | ... | ... | WCC | A216 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Low and Intermediate Alloy Steel — Pipes** | | | | | | | | | | | | |
| ½Cr–½Mo | A335 | P2 | K11547 | ... | ... | 3 | ... | −20 | 55 | 30 | 18.3 | 18.3 |
| ½Cr–½Mo<br>A387 Gr. 2 Cl. 1 | A691 | ½CR | K12143 | ... | ... | 3 | (11)(67) | −20 | 55 | 33 | 18.3 | 18.3 |
| C–½Mo | A335 | P1 | K11522 | ... | ... | 3 | (58) | −20 | 55 | 30 | 18.3 | 18.3 |
| C–½Mo | A369 | FP1 | K11522 | ... | ... | 3 | (58) | −20 | 55 | 30 | 18.3 | 18.3 |
| ½Cr–½Mo | A369 | FP2 | K11547 | ... | ... | 3 | ... | −20 | 55 | 30 | 18.3 | 18.3 |
| 1Cr–½Mo<br>A387 Gr. 12 Cl. 1 | A691 | 1CR | K11757 | ... | ... | 4 | (11)(67) | −20 | 55 | 33 | 18.3 | 18.3 |
| ½Cr–½Mo | A426 | CP2 | J11547 | ... | ... | 3 | (10) | −20 | 60 | 30 | 20.0 | 18.8 |
| 1½Si–½Mo | A335 | P15 | K11578 | ... | ... | 3 | ... | −20 | 60 | 30 | 20.0 | 18.8 |
| C–½Mo–Si | A426 | CP15 | J11522 | ... | ... | 3 | (10) | −20 | 60 | 30 | 20.0 | 18.8 |
| 1Cr–½Mo | A426 | CP12 | J11562 | ... | ... | 4 | (10) | −20 | 60 | 30 | 20.0 | 18.1 |
| 5Cr–1½Si–½Mo | A426 | CP5b | J51545 | ... | ... | 5B | (10) | −20 | 60 | 30 | 20.0 | 18.1 |
| 3Cr–Mo | A426 | CP21 | J31545 | ... | ... | 5A | (10) | −20 | 60 | 30 | 20.0 | 18.7 |
| ¾Cr–¾Ni–Cu–Al | A333 | 4 | K11267 | ... | ... | 4 | ... | −150 | 60 | 35 | 20.0 | 19.1 |
| 2Cr–½Mo | A369 | FP3b | K21509 | ... | ... | 4 | ... | −20 | 60 | 30 | 20.0 | 18.7 |
| 1Cr–½Mo | A335 | P12 | K11562 | ... | ... | 4 | ... | −20 | 60 | 32 | 20.0 | 19.3 |
| 1Cr–½Mo | A369 | FP12 | K11562 | ... | ... | 4 | ... | −20 | 60 | 32 | 20.0 | 19.3 |
| 1¼Cr–½Mo–Si | A335 | P11 | K11597 | ... | ... | 4 | ... | −20 | 60 | 30 | 20.0 | 18.5 |
| 1¼Cr–½Mo–Si | A369 | FP11 | K11597 | ... | ... | 4 | ... | −20 | 60 | 30 | 20.0 | 18.5 |
| 1¼Cr–½Mo–Si<br>A387 Gr. 11 Cl. 1 | A691 | 1¼CR | K11789 | ... | ... | 4 | (11)(67) | −20 | 60 | 35 | 20.0 | 20.0 |
| 5Cr–½Mo<br>A387 Gr. 5 Cl. 1 | A691 | 5CR | K41545 | ... | ... | 5B | (11)(67) | −20 | 60 | 30 | 20.0 | 18.1 |
| 5Cr–½Mo | A335 | P5 | K41545 | ... | ... | 5B | ... | −20 | 60 | 30 | 20.0 | 18.1 |
| 5Cr–½Mo–Si | A335 | P5b | K51545 | ... | ... | 5B | ... | −20 | 60 | 30 | 20.0 | 18.1 |
| 5Cr–½Mo–Ti | A335 | P5c | K41245 | ... | ... | 5B | ... | −20 | 60 | 30 | 20.0 | 18.1 |
| 5Cr–½Mo | A369 | FP5 | K41545 | ... | ... | 5B | ... | −20 | 60 | 30 | 20.0 | 18.1 |
| 9Cr–1Mo | A335 | P9 | K90941 | ... | ... | 5B | ... | −20 | 60 | 30 | 20.0 | 18.1 |
| 9Cr–1Mo | A369 | FP9 | K90941 | ... | ... | 5B | ... | −20 | 60 | 30 | 20.0 | 18.1 |
| 9Cr–1Mo<br>A387 Gr. 9 Cl. 1 | A691 | 9CR | K90941 | ... | ... | 5B | (11)(67) | −20 | 60 | 30 | 20.0 | 18.1 |
| 3Cr–1Mo | A335 | P21 | K31545 | ... | ... | 5A | ... | −20 | 60 | 30 | 20.0 | 18.7 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 300 | 400 | 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | **Low and Intermediate Alloy Steel — Pipes** | | | | | |
| 18.0 | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.9 | 9.2 | 5.9 | ... | ... | ... | ... | P2 | A335 |
| 18.3 | 18.3 | 18.3 | 18.0 | 17.7 | 17.3 | 16.9 | 16.4 | 15.9 | 14.3 | 9.2 | 5.9 | ... | ... | ... | ... | ½CR | A691 |
| 18.0 | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | P1 | A335 |
| 18.0 | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | FP1 | A369 |
| 18.0 | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.9 | 9.2 | 5.9 | 4.1 | 2.5 | ... | ... | FP2 | A369 |
| 17.6 | 17.6 | 17.2 | 16.8 | 16.5 | 16.3 | 16.0 | 15.7 | 15.4 | 15.0 | 11.3 | 7.2 | 4.5 | 2.8 | 1.8 | 1.1 | 1CR | A691 |
| 18.0 | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.9 | 9.2 | 5.9 | 4.0 | 2.4 | ... | ... | CP2 | A426 |
| 18.2 | 17.7 | 17.3 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 13.8 | 12.5 | 10.0 | 6.3 | 4.0 | 2.4 | ... | ... | P15 | A335 |
| 18.2 | 17.7 | 17.3 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 13.8 | 12.5 | 10.0 | 6.3 | 4.0 | 2.4 | ... | ... | CP15 | A426 |
| 17.0 | 16.2 | 15.7 | 15.2 | 15.0 | 14.8 | 14.6 | 14.3 | 14.0 | 13.6 | 11.3 | 7.2 | 4.5 | 2.8 | 1.8 | 1.1 | CP12 | A426 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | CP5b | A426 |
| 18.2 | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 16.0 | 12.0 | 9.0 | 7.0 | 5.5 | 4.0 | 2.7 | 1.5 | CP21 | A426 |
| 18.2 | 17.3 | 16.4 | 15.5 | 15.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 4 | A333 |
| 18.2 | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.5 | 12.5 | 10.0 | 6.2 | 4.2 | 2.6 | 1.4 | 1.0 | FP3b | A369 |
| 18.1 | 17.3 | 16.7 | 16.3 | 16.0 | 15.8 | 15.5 | 15.3 | 14.9 | 14.5 | 11.3 | 7.2 | 4.5 | 2.8 | 1.8 | 1.1 | P12 | A335 |
| 18.1 | 17.3 | 16.7 | 16.3 | 16.0 | 15.8 | 15.5 | 15.3 | 14.9 | 14.5 | 11.3 | 7.2 | 4.5 | 2.8 | 1.8 | 1.1 | FP12 | A369 |
| 17.6 | 16.8 | 16.2 | 15.7 | 15.4 | 15.1 | 14.8 | 14.4 | 14.0 | 13.6 | 9.3 | 6.3 | 4.2 | 2.8 | 1.9 | 1.2 | P11 | A335 |
| 17.6 | 16.8 | 16.2 | 15.7 | 15.4 | 15.1 | 14.8 | 14.4 | 14.0 | 13.6 | 9.3 | 6.3 | 4.2 | 2.8 | 1.9 | 1.2 | FP11 | A369 |
| 20.0 | 19.6 | 18.9 | 18.3 | 18.0 | 17.6 | 17.2 | 16.8 | 16.4 | 13.7 | 9.3 | 6.3 | 4.2 | 2.8 | 1.9 | 1.2 | 1¼CR | A691 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | 5CR | A691 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | P5 | A335 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | P5b | A335 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | P5c | A335 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | FP5 | A369 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.8 | 14.1 | 10.6 | 7.4 | 5.0 | 3.3 | 2.2 | 1.5 | P9 | A335 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.8 | 14.1 | 10.6 | 7.4 | 5.0 | 3.3 | 2.2 | 1.5 | FP9 | A369 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.8 | 14.1 | 10.6 | 7.4 | 5.0 | 3.3 | 2.2 | 1.5 | 9CR | A691 |
| 18.2 | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 16.0 | 12.0 | 9.0 | 7.0 | 5.5 | 4.0 | 2.7 | 1.5 | P21 | A335 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Low and Intermediate Alloy Steel — Pipes** | | | | | | | | | | | | |
| 3Cr–1Mo | A369 | FP21 | K31545 | ... | ... | 5A | ... | −20 | 60 | 30 | 20.0 | 18.7 |
| 3Cr–1Mo A387 Gr. 21 Cl. 1 | A691 | 3CR | K31545 | ... | ... | 5A | (11)(67) | −20 | 60 | 30 | 20.0 | 18.5 |
| 2¼Cr–1Mo A387 Gr. 22 Cl. 1 | A691 | 2¼CR | K21590 | ... | ... | 5A | (11)(67)(72)(75) | −20 | 60 | 30 | 20.0 | 18.7 |
| 2¼Cr–1Mo | A369 | FP22 | K21590 | ... | ... | 5A | (72)(75) | −20 | 60 | 30 | 20.0 | 18.7 |
| 2¼Cr–1Mo | A335 | P22 | K21590 | ... | ... | 5A | (72)(75) | −20 | 60 | 30 | 20.0 | 18.7 |
| 2Ni–1Cu | A333 | 9 | K22035 | ... | ... | 9A | ... | −100 | 63 | 46 | 21.0 | ... |
| 2Ni–1Cu | A334 | 9 | K22035 | ... | ... | 9A | ... | −100 | 63 | 46 | 21.0 | ... |
| 2¼Ni | A333 | 7 | K21903 | ... | ... | 9A | ... | −100 | 65 | 35 | 21.7 | 21.4 |
| 2¼Ni | A334 | 7 | K21903 | ... | ... | 9A | ... | −100 | 65 | 35 | 21.7 | 21.4 |
| 3½Ni | A333 | 3 | K31918 | ... | ... | 9B | ... | −150 | 65 | 35 | 21.7 | 21.4 |
| 3½Ni | A334 | 3 | K31918 | ... | ... | 9B | ... | −150 | 65 | 35 | 21.7 | 21.4 |
| C–½Mo | A426 | CP1 | J12521 | ... | ... | 3 | (10)(58) | −20 | 65 | 35 | 21.7 | 21.7 |
| C–½Mo A204 Gr. A | A672 | L65 | K11820 | ... | ... | 3 | (11)(58)(67) | −20 | 65 | 37 | 21.7 | 21.7 |
| C–½Mo A204 Gr. A | A691 | CM-65 | K11820 | ... | ... | 3 | (11)(58)(67) | −20 | 65 | 37 | 21.7 | 21.7 |
| 2¼Ni A203 Gr. B | A671 | CFB70 | K22103 | ... | ... | 9A | (11)(65)(67) | −20 | 70 | 40 | 23.3 | ... |
| 3½Ni A203 Gr. E | A671 | CFE70 | K32018 | ... | ... | 9B | (11)(65)(67) | −20 | 70 | 40 | 23.3 | ... |
| C–½Mo A204 Gr. B | A672 | L70 | K12020 | ... | ... | 3 | (11)(58)(67) | −20 | 70 | 40 | 23.3 | 23.3 |
| C–½Mo A204 Gr. B | A691 | CM-70 | K12020 | ... | ... | 3 | (11)(58)(67) | −20 | 70 | 40 | 23.3 | 23.3 |
| 1¼Cr–½Mo | A426 | CP11 | J12072 | ... | ... | 4 | (10) | −20 | 70 | 40 | 23.3 | 23.3 |
| 2¼Cr–1Mo | A426 | CP22 | J21890 | ... | ... | 5A | (10)(72) | −20 | 70 | 40 | 23.3 | 23.3 |
| C–½Mo A204 Gr. C | A672 | L75 | K12320 | ... | ... | 3 | (11)(58)(67) | −20 | 75 | 43 | 25.0 | 25.0 |
| C–½Mo A204 Gr. C | A691 | CM-75 | K12320 | ... | ... | 3 | (11)(58)(67) | −20 | 75 | 43 | 25.0 | 25.0 |
| 9Cr–1Mo–V | A335 | P91 | K90901 | ... | ≤3 thk. | 15E | ... | −20 | 85 | 60 | 28.3 | 28.3 |
| 9Cr–1Mo–V | A691 | 91 | K90901 | ... | ≤3 thk. | 15E | (11)(67) | −20 | 85 | 60 | 28.3 | 28.3 |
| 5Cr–½Mo | A426 | CP5 | J42045 | ... | ... | 5B | (10) | −20 | 90 | 60 | 30.0 | 29.9 |
| 9Cr–1Mo | A426 | CP9 | J82090 | ... | ... | 5B | (10) | −20 | 90 | 60 | 30.0 | 29.9 |
| 9Ni | A333 | 8 | K81340 | ... | ... | 11A | (47) | −320 | 100 | 75 | 33.3 | 33.3 |
| 9Ni | A334 | 8 | K81340 | ... | ... | 11A | ... | −320 | 100 | 75 | 33.3 | 33.3 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 300 | 400 | 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | Type/ Grade | Spec. No. |
| **Low and Intermediate Alloy Steel — Pipes (Cont'd)** | | | | | | | | | | | | | | | | | |
| 18.2 | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 16.0 | 12.0 | 9.0 | 7.0 | 5.5 | 4.0 | 2.7 | 1.5 | FP21 | A369 |
| 18.2 | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 16.0 | 12.0 | 9.0 | 7.0 | 5.5 | 4.0 | 2.7 | 1.5 | 3CR | A691 |
| 18.2 | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0 | 5.7 | 3.8 | 2.4 | 1.4 | $2\frac{1}{4}$CR | A691 |
| 18.2 | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0 | 5.7 | 3.8 | 2.4 | 1.4 | FP22 | A369 |
| 18.2 | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0 | 5.7 | 3.8 | 2.4 | 1.4 | P22 | A335 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 9 | A333 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 9 | A334 |
| 20.6 | 19.9 | 18.9 | 17.5 | 16.7 | 15.7 | 13.9 | 11.4 | 9.0 | 6.5 | 4.5 | 2.5 | 1.6 | 1.0 | ... | ... | 7 | A333 |
| 20.6 | 19.9 | 18.9 | 17.5 | 16.7 | 15.7 | 13.9 | 11.4 | 9.0 | 6.5 | 4.5 | 2.5 | 1.6 | 1.0 | ... | ... | 7 | A334 |
| 20.6 | 19.9 | 18.9 | 17.5 | 16.7 | 15.7 | 13.9 | 11.4 | 9.0 | 6.5 | 4.5 | 2.5 | 1.6 | 1.0 | ... | ... | 3 | A333 |
| 20.6 | 19.9 | 18.9 | 17.5 | 16.7 | 15.7 | 13.9 | 11.4 | 9.0 | 6.5 | 4.5 | 2.5 | 1.6 | 1.0 | ... | ... | 3 | A334 |
| 21.0 | 20.3 | 19.7 | 19.1 | 18.7 | 18.4 | 17.9 | 17.4 | 16.9 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | CP1 | A426 |
| 21.7 | 21.5 | 20.8 | 20.2 | 19.8 | 19.4 | 19.0 | 18.4 | 17.9 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | L65 | A672 |
| 21.7 | 21.5 | 20.8 | 20.2 | 19.8 | 19.4 | 19.0 | 18.4 | 17.9 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | CM-65 | A691 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CFB70 | A671 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CFE70 | A671 |
| 23.3 | 23.2 | 22.5 | 21.8 | 21.4 | 21.0 | 20.5 | 19.9 | 19.3 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | L70 | A672 |
| 23.3 | 23.2 | 22.5 | 21.8 | 21.4 | 21.0 | 20.5 | 19.9 | 19.3 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | CM-70 | A691 |
| 23.3 | 22.5 | 21.7 | 20.9 | 20.5 | 20.1 | 19.7 | 19.2 | 18.7 | 13.7 | 9.3 | 6.3 | 4.2 | 2.8 | 1.9 | 1.2 | CP11 | A426 |
| 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 21.9 | 15.8 | 11.4 | 7.8 | 5.1 | 3.2 | 2.0 | 1.2 | CP22 | A426 |
| 25.0 | 25.0 | 24.2 | 23.4 | 23.0 | 22.6 | 22.0 | 21.4 | 20.7 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | L75 | A672 |
| 25.0 | 25.0 | 24.2 | 23.4 | 23.0 | 22.6 | 22.0 | 21.4 | 20.7 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | CM-75 | A691 |
| 28.3 | 28.2 | 28.1 | 27.7 | 27.3 | 26.7 | 25.9 | 24.9 | 23.7 | 22.3 | 20.7 | 18.0 | 14.0 | 10.3 | 7.0 | 4.3 | P91 | A335 |
| 28.3 | 28.2 | 28.1 | 27.7 | 27.3 | 26.7 | 25.9 | 24.9 | 23.7 | 22.3 | 20.7 | 18.0 | 14.0 | 10.3 | 7.0 | 4.3 | 91 | A691 |
| 29.1 | 28.8 | 28.7 | 28.3 | 27.9 | 27.3 | 26.5 | 25.5 | 24.2 | 16.4 | 11.0 | 7.4 | 5.0 | 3.3 | 2.2 | 1.5 | CP5 | A426 |
| 29.1 | 28.8 | 28.7 | 28.3 | 27.9 | 27.3 | 26.5 | 25.5 | 24.2 | 16.4 | 11.0 | 7.4 | 5.0 | 3.8 | 2.2 | 1.5 | CP9 | A426 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8 | A333 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8 | A334 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Low and Intermediate Alloy Steel — Plates** | | | | | | | | | | | | |
| ½Cr–½Mo | A387 | 2 | K12143 | 1 | ... | 3 | ... | −20 | 55 | 33 | 18.3 | 18.3 |
| 1Cr–½Mo | A387 | 12 | K11757 | 1 | ... | 4 | ... | −20 | 55 | 33 | 18.3 | 18.0 |
| 9Cr–1Mo | A387 | 9 | K90941 | 1 | ... | 5B | ... | −20 | 60 | 30 | 20.0 | 18.1 |
| 1¼Cr–½Mo–Si | A387 | 11 | K11789 | 1 | ... | 4 | ... | −20 | 60 | 35 | 20.0 | 20.0 |
| 5Cr–½Mo | A387 | 5 | K41545 | 1 | ... | 5B | ... | −20 | 60 | 30 | 20.0 | 18.1 |
| 3Cr–1Mo | A387 | 21 | K31545 | 1 | ... | 5A | ... | −20 | 60 | 30 | 20.0 | 18.3 |
| 2¼Cr–1Mo | A387 | 22 | K21590 | 1 | ... | 5A | (72) | −20 | 60 | 30 | 20.0 | 18.7 |
| 2¼Ni | A203 | A | K21703 | ... | ... | 9A | (12)(65) | −20 | 65 | 37 | 21.7 | 21.7 |
| 3½Ni | A203 | D | K31718 | ... | ... | 9B | (12)(65) | −20 | 65 | 37 | 21.7 | 21.7 |
| C–½Mo | A204 | A | K11820 | ... | ... | 3 | (58) | −20 | 65 | 37 | 21.7 | 21.7 |
| 1Cr–½Mo | A387 | 12 | K11757 | 2 | ... | 4 | ... | −20 | 65 | 40 | 21.7 | 21.3 |
| 2¼Ni | A203 | B | K22103 | ... | ... | 9A | (12)(65) | −20 | 70 | 40 | 23.3 | 23.3 |
| 3½Ni | A203 | E | K32018 | ... | ... | 9B | (12)(65) | −20 | 70 | 40 | 23.3 | 23.3 |
| ½Cr–½Mo | A387 | 2 | K12143 | 2 | ... | 3 | ... | −20 | 70 | 45 | 23.3 | 23.3 |
| C–½Mo | A204 | B | K12020 | ... | ... | 3 | (58) | −20 | 70 | 40 | 23.3 | 23.3 |
| Mn–½Mo | A302 | A | K12021 | ... | ... | 3 | ... | −20 | 75 | 45 | 25.0 | 25.0 |
| C–½Mo | A204 | C | K12320 | ... | ... | 3 | (58) | −20 | 75 | 43 | 25.0 | 25.0 |
| 1¼Cr–½Mo–Si | A387 | 11 | K11789 | 2 | ... | 4 | ... | −20 | 75 | 45 | 25.0 | 25.0 |
| 5Cr–½Mo | A387 | 5 | K41545 | 2 | ... | 5B | ... | −20 | 75 | 45 | 25.0 | 24.9 |
| 3Cr–1Mo | A387 | 21 | K31545 | 2 | ... | 5A | ... | −20 | 75 | 45 | 25.0 | 25.0 |
| 2¼Cr–1Mo | A387 | 22 | K21590 | 2 | ... | 5A | (72) | −20 | 75 | 45 | 25.0 | 25.0 |
| Mn–½Mo | A302 | B | K12022 | ... | ... | 3 | ... | −20 | 80 | 50 | 26.7 | 26.7 |
| Mn–½Mo–½Ni | A302 | C | K12039 | ... | ... | 3 | ... | −20 | 80 | 50 | 26.7 | 26.7 |
| Mn–½Mo–¾Ni | A302 | D | K12054 | ... | ... | 3 | ... | −20 | 80 | 50 | 26.7 | 26.7 |
| 9Cr–1Mo–V | A387 | 91 | K90901 | 2 | ≤3 thk. | 15E | ... | −20 | 85 | 60 | 28.3 | 28.3 |
| 8Ni | A553 | II | K71340 | ... | ... | 11A | (47) | −275 | 100 | 85 | 33.3 | ... |
| 5Ni–¼Mo | A645 | A | K41583 | ... | ... | 11A | ... | −275 | 95 | 65 | 31.7 | 31.7 |
| 9Ni | A553 | I | K81340 | ... | ... | 11A | (47) | −320 | 100 | 85 | 33.3 | 33.3 |
| 9Ni | A353 | ... | K81340 | ... | ... | 11A | (47) | −320 | 100 | 75 | 33.3 | 33.3 |
| **Low and Intermediate Alloy Steel — Forgings and Fittings** | | | | | | | | | | | | |
| C–½Mo | A234 | WP1 | K12821 | ... | ... | 3 | (58) | −20 | 55 | 30 | 18.3 | 18.3 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

**Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)]**

| 300 | 400 | 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | Type/ Grade | Spec. No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | **Low and Intermediate Alloy Steel — Plates** | | | | |
| 18.3 | 18.3 | 18.3 | 18.0 | 17.7 | 17.3 | 16.9 | 16.4 | 15.9 | 14.3 | 9.2 | 5.9 | ... | ... | ... | ... | 2 Cl. 1 | A387 |
| 17.6 | 17.6 | 17.2 | 16.8 | 16.5 | 16.3 | 16.0 | 15.7 | 15.4 | 15.0 | 11.3 | 7.2 | 4.5 | 2.8 | 1.8 | 1.1 | 12 Cl. 1 | A387 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.8 | 14.1 | 10.6 | 7.4 | 5.0 | 3.3 | 2.2 | 1.5 | 9 Cl. 1 | A387 |
| 20.0 | 19.6 | 18.9 | 18.3 | 18.0 | 17.6 | 17.2 | 16.8 | 16.4 | 13.7 | 9.3 | 6.3 | 4.2 | 2.8 | 1.9 | 1.2 | 11 Cl. 1 | A387 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | 5 Cl. 1 | A387 |
| 17.5 | 17.0 | 16.6 | 16.2 | 16.0 | 15.8 | 15.5 | 15.2 | 14.9 | 12.0 | 9.0 | 7.0 | 5.5 | 4.0 | 2.7 | 1.5 | 21 Cl. 1 | A387 |
| 18.2 | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0 | 5.7 | 3.8 | 2.4 | 1.4 | 22 Cl. 1 | A387 |
| 21.7 | 21.1 | 20.0 | 18.5 | 17.6 | 16.6 | 13.9 | 11.4 | 9.0 | 6.5 | 4.5 | 2.5 | ... | ... | ... | ... | A | A203 |
| 21.7 | 21.1 | 20.0 | 18.5 | 17.6 | 16.6 | 13.9 | 11.4 | 9.0 | 6.5 | 4.5 | 2.5 | ... | ... | ... | ... | D | A203 |
| 21.7 | 21.5 | 20.8 | 20.2 | 19.8 | 19.4 | 19.0 | 18.4 | 17.9 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | A | A204 |
| 20.8 | 20.8 | 20.8 | 20.3 | 20.0 | 19.7 | 19.4 | 19.1 | 18.6 | 18.0 | 11.3 | 7.2 | 4.5 | 2.8 | 1.8 | 1.1 | 12 Cl. 2 | A387 |
| 23.3 | 22.8 | 21.6 | 20.0 | 19.0 | 16.9 | 13.9 | 11.4 | 9.0 | 6.5 | 4.5 | 2.5 | ... | ... | ... | ... | B | A203 |
| 23.3 | 22.8 | 21.6 | 20.0 | 19.0 | 18.0 | 14.8 | 12.0 | 9.3 | 6.5 | 4.5 | 2.5 | ... | ... | ... | ... | E | A203 |
| 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.1 | 22.4 | 21.7 | 20.9 | 9.2 | 5.9 | ... | ... | ... | ... | 2 Cl. 2 | A387 |
| 23.3 | 23.2 | 22.5 | 21.8 | 21.4 | 21.0 | 20.5 | 19.9 | 19.3 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | B | A204 |
| 25.0 | 25.0 | 25.0 | 25.0 | 24.9 | 24.4 | 23.9 | 23.2 | 20.0 | 13.7 | 8.2 | 4.8 | ... | ... | ... | ... | A | A302 |
| 25.0 | 25.0 | 24.2 | 23.4 | 23.0 | 22.6 | 22.0 | 21.4 | 20.7 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | C | A204 |
| 25.0 | 25.0 | 24.4 | 23.5 | 23.1 | 22.6 | 22.2 | 21.6 | 20.2 | 13.7 | 9.3 | 6.3 | 4.2 | 2.8 | 1.9 | 1.2 | 11 Cl. 2 | A387 |
| 24.2 | 24.0 | 24.0 | 23.6 | 23.2 | 22.7 | 16.5 | 16.0 | 15.1 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | 5 Cl. 2 | A387 |
| 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 18.1 | 13.1 | 9.5 | 6.8 | 4.9 | 3.2 | 2.4 | 1.3 | 21 Cl. 2 | A387 |
| 24.3 | 24.1 | 24.0 | 23.8 | 23.6 | 23.4 | 23.0 | 22.5 | 21.9 | 15.8 | 11.4 | 7.8 | 5.1 | 3.2 | 2.0 | 1.2 | 22 Cl. 2 | A387 |
| 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.5 | 25.7 | 20.0 | 13.7 | 8.2 | 4.8 | ... | ... | ... | ... | B | A302 |
| 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.5 | 25.7 | 20.0 | 13.7 | 8.2 | 4.8 | ... | ... | ... | ... | C | A302 |
| 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.5 | 25.7 | 20.0 | 13.7 | 8.2 | 4.8 | ... | ... | ... | ... | D | A302 |
| 28.3 | 28.2 | 28.1 | 27.7 | 27.3 | 26.7 | 25.9 | 24.9 | 23.7 | 22.3 | 20.7 | 18.0 | 14.0 | 10.3 | 7.0 | 4.3 | 91 Cl. 2 | A387 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | II | A553 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A | A645 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | I | A553 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A353 |
| | | | | | | | | | | | | | **Low and Intermediate Alloy Steel — Forgings and Fittings** | | | | |
| 18.0 | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | WP1 | A234 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Low and Intermediate Alloy Steel — Forgings and Fittings** | | | | | | | | | | | | |
| 1Cr–½Mo | A182 | F12 | K11562 | 1 | ... | 4 | (9) | −20 | 60 | 32 | 20.0 | 19.3 |
| 1Cr–½Mo | A234 | WP12 | K12062 | 1 | ... | 4 | ... | −20 | 60 | 32 | 20.0 | 19.3 |
| 1¼Cr–½Mo–Si | A182 | F11 | K11597 | 1 | ... | 4 | (9) | −20 | 60 | 30 | 20.0 | 18.5 |
| 1¼Cr–½Mo–Si | A234 | WP11 | K11597 | 1 | ... | 4 | ... | −20 | 60 | 30 | 20.0 | 18.5 |
| 2¼Cr–1Mo | A182 | F22 | K21590 | 1 | ... | 5A | (9)(72)(75) | −20 | 60 | 30 | 20.0 | 18.7 |
| 2¼Cr–1Mo | A234 | WP22 | K21590 | 1 | ... | 5A | (72) | −20 | 60 | 30 | 20.0 | 18.7 |
| 5Cr–½Mo | A234 | WP5 | K41545 | ... | ... | 5B | ... | −20 | 60 | 30 | 20.0 | 18.1 |
| 9Cr–1Mo | A234 | WP9 | K90941 | ... | ... | 5B | ... | −20 | 60 | 30 | 20.0 | 18.1 |
| 3½Ni | A420 | WPL3 | K31918 | ... | ... | 9B | ... | −150 | 65 | 35 | 21.7 | 21.4 |
| 3½Ni | A350 | LF3 | K32025 | ... | ... | 9B | (9) | −150 | 70 | 37.5 | 23.3 | 22.9 |
| ½Cr–½Mo | A182 | F2 | K12122 | ... | ... | 3 | (9) | −20 | 70 | 40 | 23.3 | 23.3 |
| C–½Mo | A182 | F1 | K12822 | ... | ... | 3 | (9)(58) | −20 | 70 | 40 | 23.3 | 23.3 |
| 1Cr–½Mo | A182 | F12 | K11564 | 2 | ... | 4 | (9) | −20 | 70 | 40 | 23.3 | 22.9 |
| 1Cr–½Mo | A234 | WP12 | K12062 | 2 | ... | 4 | ... | −20 | 70 | 40 | 23.3 | 22.9 |
| 1¼Cr–½Mo–Si | A182 | F11 | K11572 | 2 | ... | 4 | (9) | −20 | 70 | 40 | 23.3 | 23.3 |
| 1¼Cr–½Mo–Si | A234 | WP11 | K11572 | 2 | ... | 4 | ... | −20 | 70 | 40 | 23.3 | 23.3 |
| 5Cr–½Mo | A182 | F5 | K41545 | ... | ... | 5B | (9) | −20 | 70 | 40 | 23.3 | 23.3 |
| 3Cr–1Mo | A182 | F21 | K31545 | ... | ... | 5A | (9) | −20 | 75 | 45 | 25.0 | 25.0 |
| 2¼Cr–1Mo | A182 | F22 | K21590 | 3 | ... | 5A | (9)(72) | −20 | 75 | 45 | 25.0 | 25.0 |
| 2¼Cr–1Mo | A234 | WP22 | K21590 | 3 | ... | 5A | (72) | −20 | 75 | 45 | 25.0 | 25.0 |
| 9Cr–1Mo | A182 | F9 | K90941 | ... | ... | 5B | (9) | −20 | 85 | 55 | 28.3 | 28.3 |
| 9Cr–1Mo–V | A182 | F91 | K90901 | ... | ≤3 thk. | 15E | ... | −20 | 85 | 60 | 28.3 | 28.3 |
| 9Cr–1Mo–V | A234 | WP91 | K90901 | ... | ≤3 thk. | 15E | ... | −20 | 85 | 60 | 28.3 | 28.3 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 300 | 400 | 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | Type/ Grade | Spec. No. |
| | | | | | | | | Low and Intermediate Alloy Steel — Forgings and Fittings (Cont'd) | | | | | | | | | |
| 18.1 | 17.3 | 16.7 | 16.3 | 16.0 | 15.8 | 15.5 | 15.3 | 14.9 | 14.5 | 11.3 | 7.2 | 4.5 | 2.8 | 1.8 | 1.1 | F12 Cl. 1 | A182 |
| 18.1 | 17.3 | 16.7 | 16.3 | 16.0 | 15.8 | 15.5 | 15.3 | 14.9 | 14.5 | 11.3 | 7.2 | 4.5 | 2.8 | 1.8 | 1.1 | WP12 Cl. 1 | A234 |
| 17.6 | 16.8 | 16.2 | 15.7 | 15.4 | 15.1 | 14.8 | 14.4 | 14.0 | 13.6 | 9.3 | 6.3 | 4.2 | 2.8 | 1.9 | 1.2 | F11 Cl. 1 | A182 |
| 17.6 | 16.8 | 16.2 | 15.7 | 15.4 | 15.1 | 14.8 | 14.4 | 14.0 | 13.6 | 9.3 | 6.3 | 4.2 | 2.8 | 1.9 | 1.2 | WP11 Cl. 1 | A234 |
| 18.2 | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0 | 5.7 | 3.8 | 2.4 | 1.4 | F22 Cl. 1 | A182 |
| 18.2 | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0 | 5.7 | 3.8 | 2.4 | 1.4 | WP22 Cl. 1 | A234 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | WP5 | A234 |
| 17.4 | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.8 | 14.1 | 11.0 | 7.4 | 5.0 | 3.3 | 2.2 | 1.5 | WP9 | A234 |
| 20.6 | 19.9 | 18.9 | 17.5 | 16.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WPL3 | A420 |
| 22.1 | 21.4 | 20.3 | 18.8 | 17.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | LF3 | A350 |
| 23.3 | 23.2 | 22.5 | 21.8 | 21.4 | 21.0 | 20.5 | 19.9 | 19.3 | 18.6 | 9.2 | 5.9 | ... | ... | ... | ... | F2 | A182 |
| 23.3 | 23.2 | 22.5 | 21.8 | 21.4 | 21.0 | 20.5 | 19.9 | 19.3 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | F1 | A182 |
| 22.4 | 21.7 | 20.9 | 20.3 | 20.0 | 19.7 | 19.4 | 19.1 | 18.6 | 18.0 | 11.3 | 7.2 | 4.5 | 2.8 | 1.8 | 1.1 | F12 Cl. 2 | A182 |
| 22.4 | 21.7 | 20.9 | 20.3 | 20.0 | 19.7 | 19.4 | 19.1 | 18.6 | 18.0 | 11.3 | 7.2 | 4.5 | 2.8 | 1.8 | 1.1 | WP12 Cl. 2 | A234 |
| 23.3 | 22.5 | 21.7 | 20.9 | 20.5 | 20.1 | 19.7 | 19.2 | 18.7 | 13.7 | 9.3 | 6.3 | 4.2 | 2.8 | 1.9 | 1.2 | F11 Cl. 2 | A182 |
| 23.3 | 22.5 | 21.7 | 20.9 | 20.5 | 20.1 | 19.7 | 19.2 | 18.7 | 13.7 | 9.3 | 6.3 | 4.2 | 2.8 | 1.9 | 1.2 | WP11 Cl. 2 | A234 |
| 22.6 | 22.4 | 22.4 | 22.0 | 21.7 | 21.2 | 20.6 | 19.8 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | F5 | A182 |
| 24.3 | 24.1 | 24.0 | 23.8 | 23.6 | 23.4 | 23.0 | 22.5 | 18.1 | 13.1 | 9.5 | 6.8 | 4.9 | 3.2 | 2.4 | 1.3 | F21 | A182 |
| 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 21.9 | 15.8 | 11.4 | 7.8 | 5.1 | 3.2 | 2.0 | 1.2 | F22 Cl. 3 | A182 |
| 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 21.9 | 15.8 | 11.4 | 7.8 | 5.1 | 3.2 | 2.0 | 1.2 | WP22 Cl. 3 | A234 |
| 27.4 | 27.2 | 27.1 | 26.8 | 26.3 | 25.8 | 25.0 | 24.0 | 22.9 | 15.2 | 10.6 | 7.4 | 5.0 | 3.3 | 2.2 | 1.5 | F9 | A182 |
| 28.3 | 28.2 | 28.1 | 27.7 | 27.3 | 26.7 | 25.9 | 24.9 | 23.7 | 22.3 | 20.7 | 18.0 | 14.0 | 10.3 | 7.0 | 4.3 | F91 | A182 |
| 28.3 | 28.2 | 28.1 | 27.7 | 27.3 | 26.7 | 25.9 | 24.9 | 23.7 | 22.3 | 20.7 | 18.0 | 14.0 | 10.3 | 7.0 | 4.3 | WP91 | A234 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Low and Intermediate Alloy Steel — Forgings and Fittings** | | | | | | | | | | | | |
| 5Cr–½Mo | A182 | F5a | K42544 | ... | ... | 5B | (9) | −20 | 90 | 65 | 30.0 | 29.9 |
| 9Ni | A420 | WPL8 | K81340 | ... | ... | 11A | (47) | −320 | 100 | 75 | 33.3 | 33.3 |
| **Low and Intermediate Alloy Steel — Castings** | | | | | | | | | | | | |
| C–½Mo | A352 | LC1 | J12522 | ... | ... | 3 | (9)(58) | −75 | 65 | 35 | 21.7 | 21.7 |
| C–½Mo | A217 | WC1 | J12524 | ... | ... | 3 | (9)(58) | −20 | 65 | 35 | 21.7 | 21.7 |
| 2½Ni | A352 | LC2 | J22500 | ... | ... | 9A | (9) | −100 | 70 | 40 | 23.3 | 23.3 |
| 3½Ni | A352 | LC3 | J31550 | ... | ... | 9B | (9) | −150 | 70 | 40 | 23.3 | 23.3 |
| 1Ni–½Cr–½Mo | A217 | WC4 | J12082 | ... | ... | 4 | (9) | −20 | 70 | 40 | 23.3 | 23.3 |
| ¾Ni–1Mo–¾Cr | A217 | WC5 | J22000 | ... | ... | 4 | (9) | −20 | 70 | 40 | 23.3 | 23.3 |
| 1¼Cr–½Mo | A217 | WC6 | J12072 | ... | ... | 4 | (9) | −20 | 70 | 40 | 23.3 | 23.3 |
| 2¼Cr–1Mo | A217 | WC9 | J21890 | ... | ... | 5A | (9) | −20 | 70 | 40 | 23.3 | 23.3 |
| 5Cr–½Mo | A217 | C5 | J42045 | ... | ... | 5B | (9) | −20 | 90 | 60 | 30.0 | 29.9 |
| 9Cr–1Mo | A217 | C12 | J82090 | ... | ... | 5B | (9) | −20 | 90 | 60 | 30.0 | 29.9 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)]

| 300 | 400 | 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | Type/ Grade | Spec. No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Low and Intermediate Alloy Steel — Forgings and Fittings (Cont'd)** | | | | | | | | | | | | | | | | | |
| 29.1 | 28.8 | 28.7 | 28.3 | 27.9 | 27.3 | 26.5 | 25.5 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | F5a | A182 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WPL8 | A420 |
| **Low and Intermediate Alloy Steel — Castings** | | | | | | | | | | | | | | | | | |
| 21.0 | 20.3 | 19.7 | 19.1 | 18.7 | 18.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | LC1 | A352 |
| 21.0 | 20.3 | 19.7 | 19.1 | 18.7 | 18.4 | 17.9 | 17.4 | 16.9 | 13.7 | 8.2 | 4.8 | 4.0 | 2.4 | ... | ... | WC1 | A217 |
| 23.3 | 22.8 | 21.6 | 20.0 | 19.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | LC2 | A352 |
| 23.3 | 22.8 | 21.6 | 20.0 | 19.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | LC3 | A352 |
| 23.3 | 23.3 | 23.0 | 22.4 | 22.1 | 21.7 | 21.2 | 20.6 | 19.8 | 14.3 | 9.2 | 5.9 | ... | ... | ... | ... | WC4 | A217 |
| 23.3 | 23.3 | 23.0 | 22.4 | 22.1 | 21.7 | 21.2 | 20.6 | 19.8 | 14.3 | 9.2 | 5.9 | 4.0 | 2.4 | ... | ... | WC5 | A217 |
| 23.3 | 22.5 | 21.7 | 20.9 | 20.5 | 20.1 | 19.7 | 19.2 | 18.7 | 13.7 | 9.3 | 6.3 | 4.2 | 2.8 | 1.9 | 1.2 | WC6 | A217 |
| 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 21.9 | 15.8 | 11.4 | 7.8 | 5.1 | 3.2 | 2.0 | 1.2 | WC9 | A217 |
| 29.1 | 28.8 | 28.7 | 28.3 | 27.9 | 27.3 | 26.5 | 25.5 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | C5 | A217 |
| 29.1 | 28.8 | 28.7 | 28.3 | 27.9 | 27.3 | 26.5 | 25.5 | 24.2 | 15.2 | 10.6 | 7.4 | 5.0 | 3.3 | 2.2 | 1.5 | C12 | A217 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi | | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Tensile | Yield | Min. Temp. to 100 | 200 | 300 | 400 |
| **Stainless Steel — Pipes and Tubes (3)(4a)** | | | | | | | | | | | | | | | |
| 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321 | S32100 | ... | $>\frac{3}{8}$ thk. | 8 | (28) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | *16.7* |
| 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321 | S32100 | ... | $>\frac{3}{8}$ thk. | 8 | (28)(36) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | *16.7* |
| 18Cr–8Ni | Tube | A213 | TP304L | S30403 | ... | ... | 8 | (14)(36) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.8** |
| 18Cr–8Ni | Tube | A269 | TP304L | S30403 | ... | ... | 8 | (14)(36) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.8** |
| 18Cr–8Ni | Tube | A270 | TP304L | S30403 | ... | ... | 8 | (14) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.8** |
| 18Cr–8Ni | Pipe | A312 | TP304L | S30403 | ... | ... | 8 | ... | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.8** |
| 18Cr–8Ni | Pipe | A358 | 304L | S30403 | ... | ... | 8 | (36) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.8** |
| 16Cr–12Ni–2Mo | Tube | A213 | TP316L | S31603 | ... | ... | 8 | (14)(36) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.7** |
| 16Cr–12Ni–2Mo | Tube | A269 | TP316L | S31603 | ... | ... | 8 | (14)(36) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.7** |
| 16Cr–12Ni–2Mo | Tube | A270 | TP316L | S31603 | ... | ... | 8 | (14) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.7** |
| 16Cr–12Ni–2Mo | Pipe | A312 | TP316L | S31603 | ... | ... | 8 | ... | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.7** |
| 16Cr–12Ni–2Mo | Pipe | A358 | 316L | S31603 | ... | ... | 8 | (36) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.7** |
| 16Cr–12Ni–2Mo–Ti | Tube | A213 | TP316Ti | S31635 | ... | ... | 8 | (30) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321 | S32100 | ... | $>\frac{3}{8}$ thk. | 8 | (28)(30) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | *16.7* |
| 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321 | S32100 | ... | $>\frac{3}{8}$ thk. | 8 | (28)(30)(36) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | *16.7* |
| 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321H | S32109 | ... | $>\frac{3}{8}$ thk. | 8 | (30) | −325 | 70 | 25 | 16.7 | *16.7* | *16.7* | *16.7* |
| 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321H | S32109 | ... | $>\frac{3}{8}$ thk. | 8 | (30)(36) | −325 | 70 | 25 | 16.7 | *16.7* | *16.7* | *16.7* |
| 25Cr–12Ni | ... | A451 | CPH8 | J93400 | ... | ... | 8 | (26)(28)(35) | −325 | 65 | 28 | 18.7 | *18.7* | *18.5* | *18.0* |
| 25Cr–20Ni | ... | A451 | CPK20 | J94202 | ... | ... | 8 | (12)(28)(35)(39) | −325 | 65 | 28 | 18.7 | *18.7* | *18.5* | *18.0* |
| 11Cr–Ti | Tube | A268 | TP409 | S40900 | ... | ... | 7 | (35) | −20 | 60 | 30 | 20.0 | ... | ... | ... |
| 18Cr–Ti | Tube | A268 | TP430Ti | S43036 | ... | ... | 7 | (35)(49) | −20 | 60 | 40 | 20.0 | ... | ... | ... |
| 16Cr–14Ni–2Mo | ... | A451 | CPF10MC | J92971 | ... | ... | 8 | (28) | −325 | 70 | 30 | 20.0 | ... | ... | ... |
| 16Cr–8Ni–2Mo | Pipe | A376 | 16-8-2H | S16800 | ... | ... | 8 | (26)(31)(35) | −325 | 75 | 30 | 20.0 | ... | ... | ... |
| 12Cr–Al | Tube | A268 | TP405 | S40500 | ... | ... | 7 | (35) | −20 | 60 | 30 | 20.0 | 20.0 | 19.6 | 19.3 |
| 13Cr | Tube | A268 | TP410 | S41000 | ... | ... | 6 | (35) | −20 | 60 | 30 | 20.0 | 20.0 | 19.6 | 19.3 |
| 17Cr | Tube | A268 | TP430 | S43000 | ... | ... | 7 | (35)(49) | −20 | 60 | 35 | 20.0 | 20.0 | 19.6 | 19.3 |
| 18Cr–13Ni–3Mo | Pipe | A312 | TP317L | S31703 | ... | ... | 8 | ... | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.9** |
| 25Cr–20Ni | Pipe | A312 | TP310 | S31009 | ... | ... | 8 | (35)(39) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 25Cr–20Ni | ... | A358 | 310S | S31008 | ... | ... | 8 | (28)(35)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 25Cr–20Ni | Pipe | A409 | TP310S | S31008 | ... | ... | 8 | (28)(31)(35)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321 | S32100 | ... | $\le\frac{3}{8}$ thk. | 8 | (28) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Wld. pipe | A312 | TP321 | S32100 | ... | ... | 8 | (28) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Wld. pipe | A358 | 321 | S32100 | ... | ... | 8 | (28)(36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321 | S32100 | ... | $\le\frac{3}{8}$ thk. | 8 | (28)(36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Wld. pipe | A409 | TP321 | S32100 | ... | ... | 8 | (28)(36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)]

| 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | Stainless Steel — Pipes and Tubes (3)(4a) | | | | |
| 16.1 | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321 | A312 |
| 16.1 | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321 | A376 |
| 14.7 | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | *12.6* | *12.3* | 12.0 | 6.3 | 5.1 | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | TP304L | A213 |
| 14.7 | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | *12.6* | *12.3* | 12.0 | 6.3 | 5.1 | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | TP304L | A269 |
| 14.7 | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | *12.6* | *12.3* | 12.0 | 6.3 | 5.1 | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | TP304L | A270 |
| 14.7 | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | *12.6* | *12.3* | 12.0 | 6.3 | 5.1 | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | TP304L | A312 |
| 14.7 | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | *12.6* | *12.3* | 12.0 | 6.3 | 5.1 | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | 304L | A358 |
| 14.8 | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8 | 11.6 | *11.4* | *8.8* | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | TP316L | A213 |
| 14.8 | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8 | 11.6 | *11.4* | *8.8* | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | TP316L | A269 |
| 14.8 | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8 | 11.6 | *11.4* | *8.8* | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | TP316L | A270 |
| 14.8 | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8 | 11.6 | *11.4* | *8.8* | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | TP316L | A312 |
| 14.8 | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8 | 11.6 | *11.4* | *8.8* | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | 316L | A358 |
| 17.8 | 16.8 | 16.5 | 16.2 | 16.1 | 15.9 | 15.8 | 15.7 | 15.5 | 15.3 | 15.1 | 12.3 | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP316Ti | A213 |
| 16.1 | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321 | A312 |
| 16.1 | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321 | A376 |
| 16.1 | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321H | A312 |
| 16.1 | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321H | A376 |
| *17.7* | 17.1 | 16.7 | 16.3 | 15.9 | 15.4 | *14.9* | *14.4* | *13.9* | 11.1 | 8.5 | 6.5 | 5.0 | 3.8 | 2.9 | 2.3 | 1.8 | 1.3 | 0.9 | 0.8 | CPH8 | A451 |
| *17.7* | 17.1 | 16.7 | 16.3 | 15.9 | 15.4 | *14.9* | *14.4* | *13.9* | 11.3 | 9.8 | 8.5 | 7.3 | 6.0 | 4.8 | 3.5 | 2.4 | 1.6 | 1.1 | 0.8 | CPK20 | A451 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | TP409 | A268 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | TP430Ti | A268 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CPF10MC | A451 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 16-8-2H | A376 |
| 19.0 | 18.5 | 18.1 | 17.7 | 17.1 | 16.4 | 15.6 | 14.3 | 8.4 | 4.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | TP405 | A268 |
| 19.0 | 18.5 | 18.1 | 17.7 | 17.1 | 16.4 | 15.6 | 12.3 | 8.8 | 6.4 | 4.4 | 2.9 | 1.8 | 1.0 | ... | ... | ... | ... | ... | ... | TP410 | A268 |
| 19.0 | 18.5 | 18.1 | 17.7 | 17.1 | 16.4 | 15.6 | 12.0 | 9.2 | 6.5 | 4.5 | 3.2 | 2.4 | 1.8 | ... | ... | ... | ... | ... | ... | TP430 | A268 |
| 17.7 | 16.9 | 16.5 | 16.2 | 15.8 | 15.5 | 15.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | TP317L | A312 |
| 19.3 | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | *17.2* | *16.9* | *15.9* | 9.9 | 7.1 | 5.0 | 3.6 | 2.5 | 1.5 | 0.8 | 0.5 | 0.4 | 0.3 | 0.2 | TP310 | A312 |
| 19.3 | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | *17.2* | *16.9* | *15.9* | 9.9 | 7.1 | 5.0 | 3.6 | 2.5 | 1.5 | 0.8 | 0.5 | 0.4 | 0.3 | 0.2 | 310S | A358 |
| 19.3 | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | *17.2* | *16.9* | *15.9* | 9.9 | 7.1 | 5.0 | 3.6 | 2.5 | 1.5 | 0.8 | 0.5 | 0.4 | 0.3 | 0.2 | TP310S | A409 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321 | A312 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321 | A312 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | 321 | A358 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321 | A376 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321 | A409 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel — Pipes and Tubes (3)(4a)** | | | | | | | | | | | | | | | |
| 23Cr–12Ni | Pipe | A312 | TP309 | ... | ... | ... | 8 | (28)(35)(39) | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 23Cr–12Ni | ... | A358 | 309S | S30908 | ... | ... | 8 | (28)(31)(35)(36) | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–8Ni | ... | A451 | CPF8 | J92600 | ... | ... | 8 | (26)(28) | −425 | 70 | 30 | 20.0 | 20.0 | 20.0 | **18.6** |
| 18Cr–10Ni–Cb | Pipe | A312 | TP347 | S34700 | ... | ... | 8 | ... | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | Pipe | A358 | 347 | S34700 | ... | ... | 8 | (30)(36) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | Pipe | A376 | TP347 | S34700 | ... | ... | 8 | (30)(36) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | Pipe | A409 | TP347 | S34700 | ... | ... | 8 | (30)(36) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | Pipe | A312 | TP348 | S34800 | ... | ... | 8 | ... | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | Pipe | A358 | 348 | S34800 | ... | ... | 8 | (30)(36) | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | Pipe | A376 | TP348 | S34800 | ... | ... | 8 | (30)(36) | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | Pipe | A409 | TP348 | S34800 | ... | ... | 8 | (30)(36) | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 25Cr–12Ni | ... | A451 | CPH10 | J93402 | ... | ... | 8 | (12)(14)(28)(35)(39) | −325 | 70 | 30 | 20.0 | 20.0 | 19.9 | 19.4 |
| 25Cr–12Ni | ... | A451 | CPH20 | J93402 | ... | ... | 8 | (12)(14)(28)(35)(39) | −325 | 70 | 30 | 20.0 | 20.0 | 19.9 | 19.4 |
| 25Cr–20Ni | Pipe | A312 | TP310H | S31009 | ... | ... | 8 | (29)(35)(39) | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 25Cr–20Ni | Pipe | A358 | 310S | S31008 | ... | ... | 8 | (28)(29)(35)(36) | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | ... | A451 | CPF8C | J92710 | ... | ... | 8 | (28) | −325 | 70 | 30 | 20.0 | 20.0 | 20.0 | 18.6 |
| 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321 | S32100 | ... | $\le\frac{3}{8}$ thk. | 8 | (28)(30) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti | Wld. pipe | A312 | TP321 | S32100 | ... | ... | 8 | (28)(30) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti | Wld. pipe | A358 | 321 | S32100 | ... | ... | 8 | (28)(30)(36) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321 | S32100 | ... | $\le\frac{3}{8}$ thk. | 8 | (28)(30)(36) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti | Wld. pipe | A409 | TP321 | S32100 | ... | ... | 8 | (28)(30)(36) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321H | S32109 | ... | $\le\frac{3}{8}$ thk. | 8 | (30) | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti | Wld. pipe | A312 | TP321H | S32109 | ... | ... | 8 | (30) | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti | Wld. pipe | A358 | 321H | S32109 | ... | ... | 8 | (30)(36) | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321H | S32109 | ... | $\le\frac{3}{8}$ thk. | 8 | (30)(36) | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 16Cr–12Ni–2Mo | Tube | A213 | TP316 | S31600 | ... | ... | 8 | (14)(26)(28)(31)(36) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | **19.3** |
| 16Cr–12Ni–2Mo | Tube | A269 | TP316 | S31600 | ... | ... | 8 | (14)(26)(28)(31)(36) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | **19.3** |
| 16Cr–12Ni–2Mo | Tube | A270 | TP316 | S31600 | ... | ... | 8 | (14)(26)(28) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | **19.3** |
| 16Cr–12Ni–2Mo | Pipe | A312 | TP316 | S31600 | ... | ... | 8 | (26)(28) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | **19.3** |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | | | | Stainless Steel — Pipes and Tubes (3)(4a) (Cont'd) | | | | | | |
| *19.4* | **18.8** | **18.5** | **18.2** | **18.0** | **17.7** | *17.5* | *17.2* | *16.9* | 13.8 | 10.3 | 7.6 | 5.5 | 4.0 | 3.0 | 2.2 | 1.7 | 1.3 | 1.0 | 0.8 | TP309 | A312 |
| *19.4* | **18.8** | **18.5** | **18.2** | **18.0** | **17.7** | *17.5* | *17.2* | *16.9* | 13.8 | 10.3 | 7.6 | 5.5 | 4.0 | 3.0 | 2.2 | 1.7 | 1.3 | 1.0 | 0.8 | 309S | A358 |
| **17.5** | **16.6** | **16.2** | **15.8** | **15.5** | **15.2** | *14.9* | *14.6* | *14.3* | *12.2* | 9.5 | 7.5 | 6.0 | 4.8 | 3.9 | 3.3 | 2.7 | 2.3 | 2.0 | 1.7 | CPF8 | A451 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | *18.2* | *18.1* | *18.1* | *16.0* | *12.1* | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | TP347 | A312 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | *18.2* | *18.1* | *18.1* | *16.0* | *12.1* | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | 347 | A358 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | *18.2* | *18.1* | *18.1* | *16.0* | *12.1* | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | TP347 | A376 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | *18.2* | *18.1* | *18.1* | *16.0* | *12.1* | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | TP347 | A409 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | *18.2* | *18.1* | *18.1* | *16.0* | *12.1* | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | TP348 | A312 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | *18.2* | *18.1* | *18.1* | *16.0* | *12.1* | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | 348 | A358 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | *18.2* | *18.1* | *18.1* | *16.0* | *12.1* | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | TP348 | A376 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | *18.2* | *18.1* | *18.1* | *16.0* | *12.1* | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | TP348 | A409 |
| *18.9* | **18.3** | **17.9** | **17.5** | **17.0** | **16.5** | *16.0* | *15.4* | *14.9* | 11.1 | 8.5 | 6.5 | 5.0 | 3.8 | 2.9 | 2.3 | 1.8 | 1.3 | 0.9 | 0.8 | CPH10 | A451 |
| *18.9* | **18.3** | **17.9** | **17.5** | **17.0** | **16.5** | *16.0* | *15.4* | *14.9* | 11.1 | 8.5 | 6.5 | 5.0 | 3.8 | 2.9 | 2.3 | 1.8 | 1.3 | 0.9 | 0.8 | CPH20 | A451 |
| *19.3* | **18.5** | **18.2** | **17.9** | **17.7** | **17.4** | *17.2* | *16.9* | *16.7* | 13.8 | 10.3 | 7.6 | 5.5 | 4.0 | 3.0 | 2.2 | 1.7 | 1.3 | 1.0 | 0.8 | TP310H | A312 |
| *19.3* | **18.5** | **18.2** | **17.9** | **17.7** | **17.4** | *17.2* | *16.9* | *16.7* | 13.8 | 10.3 | 7.6 | 5.5 | 4.0 | 3.0 | 2.2 | 1.7 | 1.3 | 1.0 | 0.8 | 310S | A358 |
| **17.5** | **16.6** | **16.2** | **15.8** | **15.5** | **15.2** | *14.9* | *14.6* | *14.3* | *14.0* | *12.1* | *9.1* | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | CPF8C | A451 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321 | A312 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321 | A312 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | 321 | A358 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321 | A376 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321 | A409 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321H | A312 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321H | A312 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | 321H | A358 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321H | A376 |
| **18.0** | **17.0** | **16.6** | **16.3** | **16.1** | **15.9** | **15.7** | **15.6** | **15.4** | **15.3** | *15.1* | *12.4* | *9.8* | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP316 | A213 |
| **18.0** | **17.0** | **16.6** | **16.3** | **16.1** | **15.9** | **15.7** | **15.6** | **15.4** | **15.3** | *15.1* | *12.4* | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP316 | A269 |
| **18.0** | **17.0** | **16.6** | **16.3** | **16.1** | **15.9** | **15.7** | **15.6** | **15.4** | **15.3** | *15.1* | *12.4* | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP316 | A270 |
| **18.0** | **17.0** | **16.6** | **16.3** | **16.1** | **15.9** | **15.7** | **15.6** | **15.4** | **15.3** | *15.1* | *12.4* | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP316 | A312 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi Tensile | Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)] Min. Temp. to 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel — Pipes and Tubes (3)(4a)** | | | | | | | | | | | | | | | |
| 16Cr–12Ni–2Mo | Pipe | A358 | 316 | S31600 | ... | ... | 8 | (26)(28) (31)(36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 16Cr–12Ni–2Mo | Pipe | A376 | TP316 | S31600 | ... | ... | 8 | (26)(28) (31)(36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 16Cr–12Ni–2Mo | Pipe | A409 | TP316 | S31600 | ... | ... | 8 | (26)(28) (31)(36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 18Cr–13Ni–3Mo | Pipe | A312 | TP317 | S31700 | ... | ... | 8 | (26)(28) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 18Cr–13Ni–3Mo | Pipe | A409 | TP317 | S31700 | ... | ... | 8 | (26)(28) (31)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 16Cr–12Ni–2Mo | Pipe | A376 | TP316H | S31609 | ... | ... | 8 | (26)(31) (36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 16Cr–12Ni–2Mo | Pipe | A312 | TP316H | S31609 | ... | ... | 8 | (26) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 18Cr–10Ni–Cb | Pipe | A376 | TP347H | S34709 | ... | ... | 8 | (30)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | Pipe | A312 | TP347 | S34700 | ... | ... | 8 | (28) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | Pipe | A358 | 347 | S34700 | ... | ... | 8 | (28)(30) (36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | Pipe | A376 | TP347 | S34700 | ... | ... | 8 | (28)(30) (36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | Pipe | A409 | TP347 | S34700 | ... | ... | 8 | (28)(30) (36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | Pipe | A312 | TP348 | S34800 | ... | ... | 8 | (28) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | Pipe | A358 | 348 | S34800 | ... | ... | 8 | (28)(30) (36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | Pipe | A376 | TP348 | S34800 | ... | ... | 8 | (28)(30) (36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | Pipe | A409 | TP348 | S34800 | ... | ... | 8 | (28)(30) (36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | Pipe | A312 | TP347H | S34709 | ... | ... | 8 | ... | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | Pipe | A312 | TP348H | S34809 | ... | ... | 8 | ... | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–8Ni | Tube | A213 | TP304 | S30400 | ... | ... | 8 | (14)(26) (28)(31) (36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–8Ni | Tube | A269 | TP304 | S30400 | ... | ... | 8 | (14)(26) (28)(31) (36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–8Ni | Tube | A270 | TP304 | S30400 | ... | ... | 8 | (14)(26) (28) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–8Ni | Pipe | A312 | TP304 | S30400 | ... | ... | 8 | (26)(28) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–8Ni | Pipe | A358 | 304 | S30400 | ... | ... | 8 | (26)(28) (31)(36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–8Ni | Pipe | A376 | TP304 | S30400 | ... | ... | 8 | (20)(26) (28)(31) (36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–8Ni | Pipe | A376 | TP304H | S30409 | ... | ... | 8 | (26)(31) (36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–8Ni | Pipe | A409 | TP304 | S30400 | ... | ... | 8 | (26)(28) (31)(36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–8Ni | Pipe | A312 | TP304H | S30409 | ... | ... | 8 | (26) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–12Ni–2Mo | ... | A451 | CPF8M | J92900 | ... | ... | 8 | (26)(28) | −425 | 70 | 30 | 20.0 | *20.0* | *18.9* | **17.0** |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | | | | Stainless Steel — Pipes and Tubes (3)(4a) | | | | | | (Cont'd) |
| 18.0 | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3 | 15.1 | 12.4 | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | 316 | A358 |
| 18.0 | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3 | 15.1 | 12.4 | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP316 | A376 |
| 18.0 | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3 | 15.1 | 12.4 | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP316 | A409 |
| 18.0 | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3 | 15.1 | 12.4 | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP317 | A312 |
| 18.0 | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3 | 15.1 | 12.4 | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP317 | A409 |
| 18.0 | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3 | 15.1 | 12.4 | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP316H | A376 |
| 18.0 | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3 | 15.1 | 12.4 | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP316H | A312 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | TP347H | A376 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | TP347 | A312 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | 347 | A358 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | TP347 | A376 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | TP347 | A409 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | TP348 | A312 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | 348 | A358 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | TP348 | A376 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | TP348 | A409 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | TP347H | A312 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | TP348H | A312 |
| 17.5 | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | TP304 | A213 |
| 17.5 | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | TP304 | A269 |
| 17.5 | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | TP304 | A270 |
| 17.5 | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | TP304 | A312 |
| 17.5 | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | 304 | A358 |
| 17.5 | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | TP304 | A376 |
| 17.5 | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | TP304H | A376 |
| 17.5 | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | TP304 | A409 |
| 17.5 | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | TP304H | A312 |
| 15.8 | 15.0 | 14.7 | 14.4 | 14.2 | 14.1 | 13.9 | 13.7 | 13.4 | 13.1 | 11.5 | 8.9 | 6.9 | 5.4 | 4.3 | 3.4 | 2.8 | 2.3 | 1.9 | 1.6 | CPF8M | A451 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel — Pipes and Tubes (3)(4a)** | | | | | | | | | | | | | | | |
| 44Fe–25Ni–21Cr–Mo | Tube | A249 | ... | N08904 | ... | ... | 45 | ... | −325 | 71 | 31 | 20.7 | *20.7* | **20.4** | **18.7** |
| 44Fe–25Ni–21Cr–Mo | Pipe | A312 | ... | N08904 | ... | ... | 45 | ... | −325 | 71 | 31 | 20.7 | *20.7* | **20.4** | **18.7** |
| 20Cr–Cu | Tube | A268 | TP443 | S44300 | ... | ... | a | (7)(35) | −20 | 70 | 40 | 23.3 | 23.3 | 23.3 | 23.3 |
| 27Cr | Tube | A268 | TP446-1 | S44600 | ... | ... | 10I | (35) | −20 | 70 | 40 | 23.3 | 23.3 | 22.5 | 21.9 |
| 12Cr | Wld. pipe | A1053 | 50 | S41003 | ... | ... | 7 | ... | −20 | 70 | 50 | 23.3 | 23.3 | 23.3 | 22.8 |
| 25Cr–8Ni–N | ... | A451 | CPE20N | J92802 | ... | ... | 8 | (35)(39) | −325 | 80 | 40 | 26.7 | 26.7 | 26.7 | 26.7 |
| 23Cr–4Ni–Mo–Cu–N | ... | A789 | ... | S32304 | ... | ... | 10H | (25) | −60 | 87 | 58 | 29.0 | 27.9 | 26.1 | 24.7 |
| 23Cr–4Ni–Mo–Cu–N | ... | A790 | ... | S32304 | ... | ... | 10H | (25) | −60 | 87 | 58 | 29.0 | 27.9 | 26.1 | 24.7 |
| 23Cr–4Ni–Mo–Cu–N | Wld. pipe | A928 | 2304 | S32304 | ... | ... | 10H | (25) | −60 | 87 | 58 | 29.0 | 27.9 | 26.1 | 24.7 |
| 20Cr–18Ni–6Mo | Pipe | A813 | ... | S31254 | ... | ... | 8 | (8) | −325 | 94 | 44 | 29.3 | *29.3* | *28.9* | *26.7* |
| 20Cr–18Ni–6Mo | Pipe | A814 | ... | S31254 | ... | ... | 8 | (8) | −325 | 94 | 44 | 29.3 | *29.3* | *28.9* | *26.7* |
| 13Cr | ... | A426 | CPCA15 | J91150 | ... | ... | 6 | (10)(35) | −20 | 90 | 65 | 30.0 | ... | ... | ... |
| 20Cr–18Ni–6Mo | Wld. pipe | A358 | ... | S31254 | ... | $>\frac{3}{16}$ | 8 | ... | −325 | 95 | 45 | 30.0 | *30.0* | **30.0** | **27.4** |
| 20Cr–18Ni–6Mo | Wld pipe | A358 | ... | S31254 | ... | $\leq\frac{3}{16}$ | 8 | ... | −325 | 100 | 45 | 30.0 | *30.0* | **30.0** | **27.4** |
| 22Cr–5Ni–3Mo–N | ... | A789 | ... | S31803 | ... | ... | 10H | (25) | −60 | 90 | 65 | 30.0 | 30.0 | 28.9 | 27.8 |
| 22Cr–5Ni–3Mo–N | ... | A790 | ... | S31803 | ... | ... | 10H | (25) | −60 | 90 | 65 | 30.0 | 30.0 | 28.9 | 27.8 |
| 22Cr–5Ni–3Mo–N | Wld pipe | A928 | ... | S31803 | ... | ... | 10H | (25) | −60 | 90 | 65 | 30.0 | 30.0 | 28.9 | 27.8 |
| 20Cr–18Ni–6Mo | Tube | A249 | ... | S31254 | ... | $>\frac{3}{16}$ thk. | 8 | (8) | −325 | 95 | 45 | 30.0 | *30.0* | *29.5* | *27.3* |
| 20Cr–18Ni–6Mo | Tube | A249 | ... | S31254 | ... | $\leq\frac{3}{16}$ thk. | 8 | (8) | −325 | 98 | 45 | 30.0 | *30.0* | *29.5* | *27.3* |
| 20Cr–18Ni–6Mo | Pipe | A312 | ... | S31254 | ... | $>\frac{3}{16}$ thk. | 8 | (8) | −325 | 95 | 45 | 30.0 | *30.0* | *29.5* | *27.3* |
| 20Cr–18Ni–6Mo | Pipe | A312 | ... | S31254 | ... | $\leq\frac{3}{16}$ thk. | 8 | (8) | −325 | 98 | 45 | 30.0 | *30.0* | *29.5* | *27.3* |
| 26Cr–4Ni–Mo | ... | A789 | ... | S32900 | ... | ... | 10H | (25) | −20 | 90 | 70 | 30.0 | ... | ... | ... |
| 26Cr–4Ni–Mo | ... | A790 | ... | S32900 | ... | ... | 10H | (25) | −20 | 90 | 70 | 30.0 | ... | ... | ... |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Smls. & wld. pipe | A312 | ... | N08367 | ... | $>\frac{3}{16}$ | 45 | (26) | −325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A358 | ... | N08367 | ... | $>\frac{3}{16}$ | 45 | (26) | −325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A813 | ... | N08367 | ... | $>\frac{3}{16}$ | 45 | (26) | −325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A814 | ... | N08367 | ... | $>\frac{3}{16}$ | 45 | (26) | −325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Smls. & wld. pipe | A312 | ... | N08367 | ... | $\leq\frac{3}{16}$ | 45 | (26) | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | **29.6** |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A358 | ... | N08367 | ... | $\leq\frac{3}{16}$ | 45 | (26) | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | **29.6** |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A813 | ... | N08367 | ... | $\leq\frac{3}{16}$ | 45 | (26) | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | **29.6** |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A814 | ... | N08367 | ... | $\leq\frac{3}{16}$ | 45 | (26) | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | **29.6** |
| 21Cr–5Mn–$1\frac{1}{2}$Ni–Cu–N | Tube | A789 | ... | S32101 | ... | $>\frac{3}{16}$ | 10H | (25) | −20 | 94 | 65 | 31.3 | 31.3 | 29.8 | 28.5 |
| 21Cr–5Mn–$1\frac{1}{2}$Ni–Cu–N | Pipe | A790 | ... | S32101 | ... | $>\frac{3}{16}$ | 10H | (25) | −20 | 94 | 65 | 31.3 | 31.3 | 29.8 | 28.5 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)]

| 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | **Stainless Steel — Pipes and Tubes (3)(4a)** | **(Cont'd)** |
| **17.1** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A249 |
| **17.1** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A312 |
| 23.3 | 23.3 | 14.6 | 12.5 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | 2.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | TP443 | A268 |
| 21.5 | 20.9 | 20.6 | 20.2 | 19.7 | 19.1 | 18.4 | 17.5 | 16.4 | 15.1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | TP446-1 | A268 |
| 22.1 | 21.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 50 | A1053 |
| 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CPE20N | A451 |
| 22.9 | 19.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 22.9 | 19.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |
| 22.9 | 19.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2304 | A928 |
| *25.2* | *24.1* | *23.8* | *23.6* | *23.4* | *23.2* | *23.0* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A813 |
| *25.2* | *24.1* | *23.8* | *23.6* | *23.4* | *23.2* | *23.0* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A814 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CPCA15 | A426 |
| **25.8** | **24.7** | **24.3** | **24.1** | **23.9** | **23.7** | **22.8** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A358 |
| **25.8** | **24.7** | **24.3** | **24.1** | **23.9** | **23.7** | **22.8** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A358 |
| 27.2 | 26.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 27.2 | 26.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |
| 27.2 | 26.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A928 |
| *25.8* | *24.7* | *24.3* | *24.1* | *23.9* | *23.7* | *23.6* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A249 |
| *25.8* | *24.7* | *24.3* | *24.1* | *23.9* | *23.7* | *23.6* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A249 |
| *25.8* | *24.7* | *24.3* | *24.1* | *23.9* | *23.7* | *23.6* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A312 |
| *25.8* | *24.7* | *24.3* | *24.1* | *23.9* | *23.7* | *23.6* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A312 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A312 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A358 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A813 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A814 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A312 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A358 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A813 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A814 |
| 28.5 | 28.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 28.5 | 28.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel — Pipes and Tubes (3)(4a)** | | | | | | | | | | | | | | | |
| 22Cr–5Ni–3Mo–N | Tube | A789 | 2205 | S32205 | ... | ... | 10H | (25) | −60 | 95 | 70 | 31.7 | 31.7 | 30.6 | 29.4 |
| 22Cr–5Ni–3Mo–N | Pipe | A790 | 2205 | S32205 | ... | ... | 10H | (25) | −60 | 95 | 70 | 31.7 | 31.7 | 30.6 | 29.4 |
| 21Cr–5Mn–1½Ni–Cu–N | Tube | A789 | ... | S32101 | ... | $\le 3/16$ | 10H | (25) | −20 | 101 | 77 | 33.7 | 33.7 | 32.1 | 31.0 |
| 21Cr–5Mn–1½Ni–Cu–N | Pipe | A790 | ... | S32101 | ... | $\le 3/16$ | 10H | (25) | −20 | 101 | 77 | 33.7 | 33.7 | 32.1 | 31.0 |
| 21Cr–3½Ni–1¾Mo–N | ... | A789 | ... | S32003 | ... | >0.187 thk. | 10H | (25) | −60 | 95 | 65 | 31.7 | 30.7 | 28.9 | 28.6 |
| 21Cr–3½Ni–1¾Mo–N | ... | A790 | ... | S32003 | ... | >0.187 thk. | 10H | (25) | −60 | 95 | 65 | 31.7 | 30.7 | 28.9 | 28.6 |
| 21Cr–3½Ni–1¾Mo–N | Wld pipe | A928 | ... | S32003 | ... | >0.187 thk. | 10H | (25) | −60 | 95 | 65 | 31.7 | 30.7 | 28.9 | 28.6 |
| 22Cr–5Ni–3Mo–N | Wld pipe | A928 | 2205 | S32205 | ... | ... | 10H | (25) | −60 | 95 | 65 | 31.7 | 31.7 | 30.6 | 29.4 |
| 24Cr–4Ni–3Mn–1.5Mo–N | Smls. & wld. tube | A789 | ... | S82441 | ... | ≥0.40 thk. | 10H | (25) | −60 | 99 | 70 | 32.9 | 32.9 | 32.9 | 32.9 |
| 24Cr–4Ni–3Mn–1.5Mo–N | Smls. & wld. pipe | A790 | ... | S82441 | ... | ≥0.40 thk. | 10H | (25) | −60 | 99 | 70 | 32.9 | 32.9 | 32.9 | 32.9 |
| 21Cr–3½Ni–1¾Mo–N | ... | A789 | ... | S32003 | ... | ≤0.187 thk. | 10H | (25) | −60 | 100 | 70 | 33.3 | 32.3 | 30.4 | 30.1 |
| 21Cr–3½Ni–1¾Mo–N | ... | A790 | ... | S32003 | ... | ≤0.187 thk. | 10H | (25) | −60 | 100 | 70 | 33.3 | 32.3 | 30.4 | 30.1 |
| 21Cr–3½Ni–1¾Mo–N | Wld. pipe | A928 | ... | S32003 | ... | ≤0.187 thk. | 10H | (25) | −60 | 100 | 70 | 33.3 | 32.3 | 30.4 | 30.1 |
| 24Cr–4Ni–3Mn–1.5Mo–N | Smls. & wld. tube | A789 | ... | S82441 | ... | <0.40 thk. | 10H | (25) | −60 | 107 | 78 | 35.8 | 35.8 | 35.8 | 35.8 |
| 24Cr–4Ni–3Mn–1.5Mo–N | Smls. & wld. pipe | A790 | ... | S82441 | ... | <0.40 thk. | 10H | (25) | −60 | 107 | 78 | 35.8 | 35.8 | 35.8 | 35.8 |
| 25Cr–8Ni–3Mo–W–Cu–N | ... | A789 | ... | S32760 | ... | ... | 10H | (25) | −60 | 109 | 80 | 36.3 | 35.9 | 34.4 | 34.0 |
| 25Cr–8Ni–3Mo–W–Cu–N | ... | A790 | ... | S32760 | ... | ... | 10H | (25) | −60 | 109 | 80 | 36.3 | 35.9 | 34.4 | 34.0 |
| 29Cr–6.5Ni–2Mo–N | Tube | A789 | ... | S32906 | ... | ≥0.40 thk. | 10H | (25) | −60 | 109 | 80 | 36.3 | 36.3 | 34.0 | 33.5 |
| 29Cr–6.5Ni–2Mo–N | Pipe | A790 | ... | S32906 | ... | ≥0.40 thk. | 10H | (25) | −60 | 109 | 80 | 36.3 | 36.3 | 34.0 | 33.5 |
| 24Cr–17Ni–6Mn–4½Mo–N | ... | A358 | ... | S34565 | ... | ... | 8 | (36) | −325 | 115 | 60 | 38.3 | *38.1* | *35.8* | *34.5* |
| 25Cr–7Ni–4Mo–N | Smls. & wld. tube | A789 | ... | S32750 | ... | ... | 10H | (25) | −60 | 116 | 80 | 38.7 | 38.5 | 36.4 | 35.1 |
| 25Cr–7Ni–4Mo–N | Smls. & wld. pipe | A790 | 2507 | S32750 | ... | ... | 10H | (25) | −60 | 116 | 80 | 38.7 | 38.5 | 36.4 | 35.1 |
| 25Cr–7Ni–4Mo–N | Wld. pipe | A928 | 2507 | S32750 | ... | ... | 10H | (25) | −60 | 116 | 80 | 38.7 | 38.5 | 36.4 | 35.1 |
| 29Cr–6.5Ni–2Mo–N | Tube | A789 | ... | S32906 | ... | <0.40 thk. | 10H | (25) | −60 | 116 | 94 | 38.7 | 38.6 | 36.8 | 35.6 |
| 29Cr–6.5Ni–2Mo–N | Pipe | A790 | ... | S32906 | ... | <0.40 thk. | 10H | (25) | −60 | 116 | 94 | 38.7 | 38.6 | 36.8 | 35.6 |
| **Stainless Steel — Plates and Sheets (3)(4a)** | | | | | | | | | | | | | | | |
| 18Cr–11Ni | ... | A240 | 305 | S30500 | ... | ... | 8 | (26)(36)(39) | −325 | 70 | 25 | 16.7 | ... | ... | ... |
| 12Cr–Al | ... | A240 | 405 | S40500 | ... | ... | 7 | (35) | −20 | 60 | 25 | 16.7 | 15.3 | 14.8 | 14.5 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | | | | | | | | | | **Stainless Steel — Pipes and Tubes (3)(4a) (Cont'd)** |
| 28.7 | 28.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2205 | A789 |
| 28.7 | 28.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2205 | A790 |
| 30.9 | 30.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 30.9 | 30.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |
| 28.6 | 28.6 | 28.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 28.6 | 28.6 | 28.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |
| 28.6 | 28.6 | 28.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A928 |
| 28.7 | 28.4 | 28.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2205 | A928 |
| 32.9 | 32.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 32.9 | 32.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |
| 30.1 | 30.1 | 30.1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 30.1 | 30.1 | 30.1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |
| 30.1 | 30.1 | 30.1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A928 |
| 35.8 | 35.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 35.8 | 35.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |
| 34.0 | 34.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 34.0 | 34.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |
| 33.0 | 33.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 33.0 | 33.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |
| *33.8* | *33.2* | *33.1* | *32.7* | *32.4* | *32.0* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A358 |
| 34.5 | 34.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 34.5 | 34.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2507 | A790 |
| 34.5 | 34.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2507 | A928 |
| 35.2 | 35.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A789 |
| 35.2 | 35.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A790 |
| | | | | | | | | | | | | | | | | | | | | | **Stainless Steel — Plates and Sheets (3)(4a)** |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 305 | A240 |
| 14.3 | 14.0 | 13.8 | 13.5 | 13.1 | 12.6 | 12.0 | 11.3 | 8.4 | 4.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 405 | A240 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel — Plates and Sheets (3)(4a)** | | | | | | | | | | | | | | | |
| 18Cr–8Ni | ... | A240 | 304L | S30403 | ... | ... | 8 | (36) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.8** |
| 16Cr–12Ni–2Mo | ... | A240 | 316L | S31603 | ... | ... | 8 | (36) | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.7** |
| 18Cr–Ti | ... | A240 | 439 | S43035 | ... | ... | ... | (35) | −20 | 60 | 30 | 20.0 | ... | ... | ... |
| 18Cr–8Ni | ... | A240 | 302 | S30200 | ... | ... | 8 | (26)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 12Cr–1Ni | ... | A1010 | 40 | S41003 | ... | ... | 7 | ... | −20 | 66 | 40 | 22.0 | 22.0 | 22.0 | 21.5 |
| 12Cr–1Ni | ... | A1010 | 50 | S41003 | ... | ... | 7 | ... | −20 | 70 | 50 | 23.3 | 23.3 | 23.3 | 22.8 |
| 13Cr | ... | A240 | 410S | S41008 | ... | ... | 7 | (35)(50) | −20 | 60 | 30 | 20.0 | 18.4 | 17.8 | 17.4 |
| 13Cr | ... | A240 | 410 | S41000 | ... | ... | 6 | (35) | −20 | 65 | 30 | 20.0 | 18.4 | 17.8 | 17.4 |
| 15Cr | ... | A240 | 429 | S42900 | ... | ... | 6 | (35) | −20 | 65 | 30 | 20.0 | 18.4 | 17.8 | 17.4 |
| 17Cr | ... | A240 | 430 | S43000 | ... | ... | 7 | (35) | −20 | 65 | 30 | 20.0 | 18.4 | 17.8 | 17.4 |
| 18Cr–13Ni–3Mo | ... | A240 | 317L | S31703 | ... | ... | 8 | (36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.9** |
| 25Cr–20Ni | ... | A240 | 310S | S31008 | ... | ... | 8 | (28)(31)(35)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Plate, sheet, strip | A240 | 321 | S32100 | ... | ... | 8 | (28)(31)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 23Cr–12Ni | ... | A240 | 309S | S30908 | ... | ... | 8 | (28)(35)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A240 | 347 | S34700 | ... | ... | 8 | (36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A240 | 348 | S34800 | ... | ... | 8 | (36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 25Cr–20Ni | ... | A240 | 310S | S31008 | ... | ... | 8 | (28)(29)(35)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Plate, sheet, strip | A240 | 321 | S32100 | ... | ... | 8 | (28)(30)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Plate, sheet, strip | A240 | 321H | S32109 | ... | ... | 8 | (30)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 16Cr–12Ni–2Mo | ... | A240 | 316 | S31600 | ... | ... | 8 | (26)(28)(36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 18Cr–13Ni–3Mo | ... | A240 | 317 | S31700 | ... | ... | 8 | (26)(28)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 18Cr–10Ni–Cb | ... | A240 | 347 | S34700 | ... | ... | 8 | (28)(36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A240 | 348 | S34800 | ... | ... | 8 | (28)(36) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–8Ni | ... | A240 | 304 | S30400 | ... | ... | 8 | (26)(28)(36) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | | | | | **Stainless Steel — Plates and Sheets (3)(4a) (Cont'd)** | | | | | |
| **14.7** | **14.0** | **13.7** | **13.5** | **13.3** | **13.0** | **12.8** | *12.6* | *12.3* | 12.0 | 6.3 | 5.1 | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | 304L | A240 |
| **14.8** | **14.0** | **13.7** | **13.5** | **13.2** | **12.9** | **12.7** | **12.4** | **12.1** | **11.8** | **10.8** | *10.2* | *8.8* | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | 316L | A240 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 439 | A240 |
| **17.5** | **16.6** | **16.2** | **15.8** | **15.5** | **15.2** | **14.9** | **14.6** | **14.3** | *14.0* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 302 | A240 |
| 20.8 | 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 40 | A1010 |
| 22.1 | 21.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 50 | A1010 |
| 17.2 | 16.8 | 16.6 | 16.2 | 15.7 | 15.1 | 14.4 | 12.3 | 8.8 | 6.4 | 4.4 | 2.9 | 1.8 | 1.0 | ... | ... | ... | ... | ... | ... | 410S | A240 |
| 17.2 | 16.8 | 16.6 | 16.2 | 15.7 | 15.1 | 14.4 | 12.3 | 8.8 | 6.4 | 4.4 | 2.9 | 1.8 | 1.0 | ... | ... | ... | ... | ... | ... | 410 | A240 |
| 17.2 | 16.8 | 16.6 | 16.2 | 15.7 | 15.1 | 14.4 | 12.0 | 9.2 | 6.5 | 4.5 | 3.2 | 2.4 | 1.8 | ... | ... | ... | ... | ... | ... | 429 | A240 |
| 17.2 | 16.8 | 16.6 | 16.2 | 15.7 | 15.1 | 14.4 | 12.0 | 9.2 | 6.5 | 4.5 | 3.2 | 2.4 | 1.8 | ... | ... | ... | ... | ... | ... | 430 | A240 |
| **17.7** | **16.9** | **16.5** | **16.2** | **15.8** | **15.5** | **15.2** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 317L | A240 |
| *19.3* | **18.5** | **18.2** | **17.9** | **17.7** | **17.4** | *17.2* | *16.9* | *15.9* | *9.9* | 7.1 | 5.0 | 3.6 | 2.5 | 1.5 | 0.8 | 0.5 | 0.4 | 0.3 | 0.2 | 310S | A240 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | 321 | A240 |
| *19.4* | **18.8** | **18.5** | **18.2** | **18.0** | **17.7** | *17.5* | *17.2* | *16.9* | 13.8 | 10.3 | 7.6 | 5.5 | 4.0 | 3.0 | 2.2 | 1.7 | 1.3 | 1.0 | 0.8 | 309S | A240 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | *18.2* | *18.1* | *18.1* | *16.0* | *12.1* | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | 347 | A240 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | *18.2* | *18.1* | *18.1* | *16.0* | *12.1* | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | 348 | A240 |
| *19.3* | **18.5** | **18.2** | **17.9** | **17.7** | **17.4** | *17.2* | *16.9* | *16.7* | 13.8 | 10.3 | 7.6 | 5.5 | 4.0 | 3.0 | 2.2 | 1.7 | 1.3 | 1.0 | 0.8 | 310S | A240 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | 321 | A240 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | 321H | A240 |
| **18.0** | **17.0** | **16.6** | **16.3** | **16.1** | **15.9** | **15.7** | **15.6** | **15.4** | **15.3** | *15.1* | *12.4* | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | 316 | A240 |
| **18.0** | **17.0** | **16.6** | **16.3** | **16.1** | **15.9** | **15.7** | **15.6** | **15.4** | **15.3** | *15.1* | *12.4* | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | 317 | A240 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | **18.2** | **18.1** | **18.1** | **18.1** | **17.4** | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | 347 | A240 |
| *20.0* | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | **18.2** | **18.1** | **18.1** | **18.1** | **17.4** | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | 348 | A240 |
| **17.5** | **16.6** | **16.2** | **15.8** | **15.5** | **15.2** | **14.9** | **14.6** | **14.3** | *14.0* | *12.4* | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | 304 | A240 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel — Plates and Sheets (3)(4a)** | | | | | | | | | | | | | | | |
| 44Fe–25Ni–21Cr–Mo | ... | A240 | 904L | N08904 | ... | ... | 45 | ... | –325 | 71 | 31 | 20.7 | *20.7* | **20.4** | **18.7** |
| 23Cr–4Ni–Mo–Cu–N | ... | A240 | 2304 | S32304 | ... | ... | 10H | (25) | –60 | 87 | 58 | 29.0 | 27.9 | 26.1 | 24.7 |
| 22Cr–5Ni–3Mo–N | ... | A240 | ... | S31803 | ... | ... | 10H | (25) | –60 | 90 | 65 | 30.0 | 30.0 | 28.9 | 27.8 |
| 16Cr–4Ni–6Mn | ... | A240 | 201LN | S20153 | ... | ... | 8 | ... | –325 | 95 | 45 | 30.0 | *27.6* | *24.7* | *23.4* |
| 20Cr–18Ni–6Mo | ... | A240 | ... | S31254 | ... | $>\frac{3}{16}$ thk. | 8 | (8) | –325 | 95 | 45 | 30.0 | *30.0* | *29.5* | *27.3* |
| 20Cr–18Ni–6Mo | ... | A240 | ... | S31254 | ... | $\leq\frac{3}{16}$ thk. | 8 | (8) | –325 | 98 | 45 | 30.0 | *30.0* | *29.5* | *27.3* |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Plate | A240 | ... | N08367 | ... | $>\frac{3}{16}$ | 45 | (26) | –325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Sheet & strip | A240 | ... | N08367 | ... | $\leq\frac{3}{16}$ | 45 | (26) | –325 | 100 | 45 | 30.0 | *30.0* | *30.0* | **29.6** |
| 21Cr–5Mn–1$\frac{1}{2}$Ni–Cu–N | ... | A240 | ... | S32101 | ... | $>\frac{3}{16}$ thk. | 10H | (25) | –20 | 94 | 65 | 31.3 | 31.3 | 29.8 | 28.5 |
| 24Cr–4Ni–3Mn–1.5Mo–N | ... | A240 | ... | S82441 | ... | ≥0.40 thk. | 10H | (25) | –60 | 99 | 70 | 32.9 | 32.9 | 32.9 | 32.9 |
| 21Cr–5Mn–1$\frac{1}{2}$Ni–Cu–N | ... | A240 | ... | S32101 | ... | $\leq\frac{3}{16}$ thk. | 10H | (25) | –20 | 101 | 77 | 33.7 | 33.7 | 32.1 | 31.0 |
| 22Cr–5Ni–3Mo–N | ... | A240 | 2205 | S32205 | ... | ... | 10H | (25) | –60 | 95 | 65 | 31.7 | 31.7 | 30.6 | 29.4 |
| 21Cr–3$\frac{1}{2}$Ni–1$\frac{3}{4}$Mo–N | ... | A240 | ... | S32003 | ... | >0.187 thk. | 10H | (25) | –60 | 95 | 65 | 31.7 | 30.7 | 28.9 | 28.6 |
| 21Cr–3$\frac{1}{2}$Ni–1$\frac{3}{4}$Mo–N | ... | A240 | ... | S32003 | ... | ≤0.187 thk. | 10H | (25) | –60 | 100 | 70 | 33.3 | 32.3 | 30.4 | 30.1 |
| 24Cr–4Ni–3Mn–1.5Mo–N | ... | A240 | ... | S82441 | ... | <0.40 thk. | 10H | (25) | –60 | 107 | 78 | 35.8 | 35.8 | 35.8 | 35.8 |
| 29Cr–6.5Ni–2Mo–N | ... | A240 | ... | S32906 | ... | ≥0.40 thk. | 10H | (25) | –60 | 109 | 80 | 36.3 | 36.3 | 34.5 | 33.5 |
| 29Cr–6.5Ni–2Mo–N | ... | A240 | ... | S32906 | ... | <0.40 thk. | 10H | (25) | –60 | 116 | 94 | 38.7 | 38.6 | 36.8 | 35.6 |
| 25Cr–8Ni–3Mo–W–Cu–N | ... | A240 | ... | S32760 | ... | ... | 10H | (25) | –60 | 109 | 80 | 36.3 | 36.3 | 34.8 | 34.0 |
| 25Cr–7Ni–4Mo–N | ... | A240 | 2507 | S32750 | ... | ... | 10H | (25) | –60 | 116 | 80 | 38.7 | 38.5 | 36.4 | 35.1 |
| **Stainless Steel — Forgings and Fittings (3)(4a)** | | | | | | | | | | | | | | | |
| 18Cr–13Ni–3Mo | ... | A182 | F317L | S31703 | ... | ≤5 thk. | 8 | (9)(21a) | –325 | 70 | 25 | 16.7 | *16.7* | **16.7** | **15.7** |
| 18Cr–8Ni | ... | A182 | F304L | S30403 | ... | ... | 8 | (9)(21a) | –425 | 70 | 25 | 16.7 | *16.7* | *16.7* | *15.8* |
| 18Cr–8Ni | ... | A403 | WP304L | S30403 | ... | ... | 8 | (32)(37) | –425 | 70 | 25 | 16.7 | *16.7* | *16.7* | *15.8* |
| 16Cr–12Ni–2Mo | ... | A182 | F316L | S31603 | ... | ... | 8 | (9)(21a) | –425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.7** |
| 16Cr–12Ni–2Mo | ... | A403 | WP316L | S31603 | ... | ... | 8 | (32)(37) | –425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.7** |
| 20Ni–8Cr | ... | A182 | F10 | S33100 | ... | ... | 8 | (26)(28)(39) | –325 | 80 | 30 | 20.0 | ... | ... | ... |
| 18Cr–13Ni–3Mo | ... | A403 | WP317L | S31703 | ... | ... | 8 | (32)(37) | –325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.9** |
| 25Cr–20Ni | ... | A182 | F310H | S31009 | ... | ... | 8 | (9)(35)(39) | –325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 25Cr–20Ni | ... | A403 | WP310 | S31008 | ... | ... | 8 | (28)(32)(35)(37)(39) | –325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | | | | | | | | | **Stainless Steel — Plates and Sheets (3)(4a) (Cont'd)** | |
| **17.1** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 904L | A240 |
| 22.9 | 19.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2304 | A240 |
| 27.2 | 26.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| *23.0* | *22.9* | *22.8* | *22.6* | *22.3* | *21.8* | *21.5* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 201LN | A240 |
| *25.8* | *24.7* | *24.3* | *24.1* | *23.9* | *23.7* | *23.6* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| *25.8* | *24.7* | *24.3* | *24.1* | *23.9* | *23.7* | *23.6* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| 28.5 | 28.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| 32.9 | 32.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| 30.9 | 30.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| 28.7 | 28.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2205 | A240 |
| 28.6 | 28.6 | 28.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| 30.1 | 30.1 | 30.1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| 35.8 | 35.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| 33.0 | 33.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| 35.2 | 35.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| 33.9 | 33.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A240 |
| 34.5 | 34.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2507 | A240 |
| | | | | | | | | | | | | | | | | | | | | **Stainless Steel — Forgings and Fittings (3)(4a)** | |
| **14.8** | **14.0** | **13.7** | **13.5** | **13.2** | **12.9** | **12.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F317L | A182 |
| *14.7* | *14.0* | **13.7** | **13.5** | **13.3** | **13.0** | **12.8** | *12.6* | *12.3* | 12.0 | 6.3 | 5.1 | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | F304L | A182 |
| *14.7* | *14.0* | **13.7** | **13.5** | **13.3** | **13.0** | **12.8** | *12.6* | *12.3* | 12.0 | 6.3 | 5.1 | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | WP304L | A403 |
| **14.8** | **14.0** | **13.7** | **13.5** | **13.2** | **12.9** | **12.7** | **12.4** | **12.1** | **11.8** | **10.8** | *10.2* | *8.8* | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | F316L | A182 |
| **14.8** | **14.0** | **13.7** | **13.5** | **13.2** | **12.9** | **12.7** | **12.4** | **12.1** | **11.8** | **10.8** | *10.2* | *8.8* | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | WP316L | A403 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F10 | A182 |
| **17.7** | **16.9** | **16.5** | **16.2** | **15.8** | **15.5** | **15.2** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WP317L | A403 |
| *19.3* | **18.5** | **18.2** | **17.9** | **17.7** | **17.4** | *17.2* | *16.9* | *15.9* | 9.9 | 7.1 | 5.0 | 3.6 | 2.5 | 1.5 | 0.8 | 0.5 | 0.4 | 0.3 | 0.2 | F310H | A182 |
| *19.3* | **18.5** | **18.2** | **17.9** | **17.7** | **17.4** | *17.2* | *16.9* | *15.9* | 9.9 | 7.1 | 5.0 | 3.6 | 2.5 | 1.5 | 0.8 | 0.5 | 0.4 | 0.3 | 0.2 | WP310 | A403 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel — Forgings and Fittings (3)(4a)** | | | | | | | | | | | | | | | |
| 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321 | S32100 | ... | $>\frac{3}{8}$ thk. | 8 | (28) | −325 | 70 | 25 | 16.7 | *16.7* | *16.7* | *16.7* |
| 18Cr–10Ni–Ti | Forgings | A182 | F321 | S32100 | ... | ... | 8 | (9)(21)(28) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321 | S32100 | ... | $\leq\frac{3}{8}$ thk. | 8 | (28) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Wld. fittings | A403 | WP321 | S32100 | ... | ... | 8 | (28) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 23Cr–12Ni | ... | A403 | WP309 | S30900 | ... | ... | 8 | (28)(32)(35)(37)(39) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 25Cr–20Ni | ... | A182 | F310H | S31009 | ... | ... | 8 | (9)(21)(29)(35)(39) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 25Cr–20Ni | ... | A403 | WP310 | S31008 | ... | ... | 8 | (28)(29)(32)(35)(37)(39) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A182 | F347 | S34700 | ... | ... | 8 | (9)(21) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A403 | WP347 | S34700 | ... | ... | 8 | (32)(37) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A182 | F348 | S34800 | ... | ... | 8 | (9)(21) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A403 | WP348 | S34800 | ... | ... | 8 | (32)(37) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321 | S32100 | ... | $>\frac{3}{8}$ thk. | 8 | (28)(30) | −325 | 70 | 25 | 16.7 | *16.7* | *16.7* | *16.7* |
| 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321H | S32109 | ... | $>\frac{3}{8}$ thk. | 8 | (30) | −325 | 70 | 25 | 16.7 | *16.7* | *16.7* | *16.7* |
| 18Cr–10Ni–Ti | Forgings | A182 | F321 | S32100 | ... | ... | 8 | (9)(21)(28)(30) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Forgings | A182 | F321H | S32109 | ... | ... | 8 | (9)(21) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321 | S32100 | ... | $\leq\frac{3}{8}$ thk. | 8 | (28)(30) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321H | S32109 | ... | $\leq\frac{3}{8}$ thk. | 8 | (30) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Wld. fittings | A403 | WP321 | S32100 | ... | ... | 8 | (28)(30) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Wld. fittings | A403 | WP321H | S32109 | ... | ... | 8 | (30) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 16Cr–12Ni–2Mo | ... | A403 | WP316H | S31609 | ... | ... | 8 | (26)(32)(37) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 16Cr–12Ni–2Mo | ... | A182 | F316H | S31609 | ... | ... | 8 | (9)(21)(26) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 18Cr–10Ni–Cb | ... | A403 | WP347H | S34709 | ... | ... | 8 | (32)(37) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A182 | F347 | S34700 | ... | ... | 8 | (9)(21)(28) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A403 | WP347 | S34700 | ... | ... | 8 | (28)(32)(37) | −425 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A182 | F348 | S34800 | ... | ... | 8 | (9)(21)(28) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A403 | WP348 | S34800 | ... | ... | 8 | (28)(32)(37) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A182 | F347H | S34709 | ... | ... | 8 | (9)(21) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| **Stainless Steel — Forgings and Fittings (3)(4a) (Cont'd)** | | | | | | | | | | | | | | | | | | | | | |
| 16.1 | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | WP321 | A403 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | F321 | A182 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | WP321 | A403 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | WP321 | A403 |
| 19.4 | 18.8 | 18.5 | 18.2 | 18.0 | 17.7 | 17.5 | 17.2 | 16.9 | 13.8 | 10.3 | 7.6 | 5.5 | 4.0 | 3.0 | 2.2 | 1.7 | 1.3 | 1.0 | 0.8 | WP309 | A403 |
| 19.3 | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 16.7 | 13.8 | 10.3 | 7.6 | 5.5 | 4.0 | 3.0 | 2.2 | 1.7 | 1.3 | 1.0 | 0.8 | F310H | A182 |
| 19.3 | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 16.7 | 13.8 | 10.3 | 7.6 | 5.5 | 4.0 | 3.0 | 2.2 | 1.7 | 1.3 | 1.0 | 0.8 | WP310 | A403 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0 | 12.1 | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | F347 | A182 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0 | 12.1 | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | WP347 | A403 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0 | 12.1 | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | F348 | A182 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0 | 12.1 | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | WP348 | A403 |
| 16.1 | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | WP321 | A403 |
| 16.1 | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | WP321H | A403 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | F321 | A182 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | F321H | A182 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | WP321 | A403 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | WP321H | A403 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | WP321 | A403 |
| 19.3 | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | WP321H | A403 |
| 18.0 | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3 | 15.1 | 12.4 | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | WP316H | A403 |
| 18.0 | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3 | 15.1 | 12.4 | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | F316H | A182 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | WP347H | A403 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | F347 | A182 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | WP347 | A403 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | F348 | A182 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | WP348 | A403 |
| 20.0 | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | F347H | A182 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel — Forgings and Fittings (3)(4a)** | | | | | | | | | | | | | | | |
| 18Cr–10Ni–Cb | ... | A182 | F348H | S34809 | ... | ... | 8 | (9)(21) | –325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 16Cr–12Ni–2Mo | ... | A182 | F316 | S31600 | ... | ... | 8 | (9)(21) (26)(28) | –325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 16Cr–12Ni–2Mo | ... | A403 | WP316 | S31600 | ... | ... | 8 | (26)(28) (32)(37) | –425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 18Cr–13Ni–3Mo | ... | A403 | WP317 | S31700 | ... | ... | 8 | (26)(28) (32) | –325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 18Cr–8Ni | ... | A182 | F304 | S30400 | ... | ... | 8 | (9)(21) (26)(28) | –425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–8Ni | ... | A403 | WP304 | S30400 | ... | ... | 8 | (26)(28) (32)(37) | –425 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–8Ni | ... | A403 | WP304H | S30409 | ... | ... | 8 | (26)(32) (37) | –325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 18Cr–8Ni | ... | A182 | F304H | S30409 | ... | ... | 8 | (9)(21) (26) | –325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 44Fe–25Ni–21Cr–Mo | ... | A182 | F904L | N08904 | ... | ... | 45 | ... | –325 | 71 | 31 | 20.7 | *20.7* | **20.4** | **18.7** |
| 13Cr | ... | A182 | F6a | S41000 | 1 | ... | 6 | (35) | –20 | 70 | 40 | 23.3 | 23.3 | 22.9 | 22.5 |
| 13Cr | ... | A182 | F6a | S41000 | 2 | ... | 6 | (35) | –20 | 85 | 55 | 28.3 | 28.3 | 27.8 | 27.3 |
| 20Cr–18Ni–6Mo | ... | A182 | F44 | S31254 | ... | ... | 8 | (8) | –325 | 94 | 44 | 29.3 | *29.3* | *28.9* | *26.7* |
| 20Cr–18Ni–6Mo | ... | A403 | WPS31254 | S31254 | ... | ... | 8 | (8) | –325 | 94 | 44 | 29.3 | *29.3* | *28.9* | *26.7* |
| 20Cr–18Ni–6Mo | ... | A403 | CRS31254 | S31254 | ... | ... | 8 | (8) | –325 | 94 | 44 | 29.3 | *29.3* | *28.9* | *26.7* |
| 23Cr–4Ni–Mo–Cu–N | ... | A182 | F68 | S32304 | ... | ... | 10H | (25) | –60 | 87 | 58 | 29.0 | 27.9 | 26.1 | 24.7 |
| 22Cr–5Ni–3Mo–N | ... | A182 | F51 | S31803 | ... | ... | 10H | (25) | –60 | 90 | 65 | 30.0 | 30.0 | 28.9 | 27.8 |
| 22Cr–5Ni–3Mo–N | ... | A815 | WPS31803 | S31803 | ... | ... | 10H | (25) | –60 | 90 | 65 | 30.0 | 30.0 | 28.9 | 27.8 |
| 22Cr–5Ni–3Mo–N | ... | A815 | CRS31803 | S31803 | ... | ... | 10H | (25) | –60 | 90 | 65 | 30.0 | 30.0 | 28.9 | 27.8 |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Forgings | A182 | F62 | N08367 | ... | ... | 45 | (26) | –325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Fittings | A403 | WP6XN | N08367 | ... | ... | 45 | (26) | –325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | Fittings | A403 | CR6XN | N08367 | ... | ... | 45 | (26) | –325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* |
| 21Cr–5Mn–$1\frac{1}{2}$Ni–Cu–N | ... | A815 | ... | S32101 | ... | ... | 10H | (25) | –20 | 94 | 65 | 31.3 | 31.3 | 29.8 | 28.5 |
| 22Cr–5Ni–3Mo–N | ... | A182 | F60 | S32205 | ... | ... | 10H | (25) | –60 | 95 | 65 | 31.7 | 31.7 | 30.6 | 29.4 |
| 22Cr–5Ni–3Mo–N | ... | A815 | 2205 | S32205 | ... | ... | 10H | (25) | –60 | 95 | 65 | 31.7 | 31.7 | 30.6 | 29.4 |
| 25Cr–8Ni–3Mo–W–Cu–N | ... | A182 | ... | S32760 | ... | ... | 10H | (25) | –60 | 109 | 80 | 36.3 | 36.3 | 34.8 | 34.0 |
| 25Cr–8Ni–3Mo–W–Cu–N | ... | A815 | ... | S32760 | ... | ... | 10H | (25) | –60 | 109 | 80 | 36.3 | 36.3 | 34.8 | 34.0 |
| 13Cr | ... | A182 | F6a | S41000 | 3 | ... | 6 | (35) | –20 | 110 | 85 | 36.7 | ... | ... | ... |
| 13Cr–$\frac{1}{2}$Mo | ... | A182 | F6b | S41026 | ... | ... | 6 | (35) | ... | 110–135 | 90 | 36.7 | ... | ... | ... |
| 25Cr–7Ni–4Mo–N | Forgings | A182 | F53 | S32750 | ... | ... | 10H | (25) | –60 | 116 | 80 | 38.7 | 38.5 | 36.4 | 35.1 |
| 25Cr–7Ni–4Mo–N | Fittings | A815 | WPS32750 | S32750 | ... | ... | 10H | (25) | –60 | 116 | 80 | 38.7 | 38.5 | 36.4 | 35.1 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | | | Stainless Steel — Forgings and Fittings (3)(4a) (Cont'd) | | | | | | | |
| *20.0* | *19.3* | **19.0** | **18.7** | **18.5** | **18.3** | **18.2** | **18.1** | **18.1** | **18.1** | *17.4* | *14.1* | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | F348H | A182 |
| **18.0** | **17.0** | **16.6** | **16.3** | **16.1** | **15.9** | **15.7** | **15.6** | **15.4** | **15.3** | *15.1* | *12.4* | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | F316 | A182 |
| **18.0** | **17.0** | **16.6** | **16.3** | **16.1** | **15.9** | **15.7** | **15.6** | **15.4** | **15.3** | *15.1* | *12.4* | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | WP316 | A403 |
| **18.0** | **17.0** | **16.6** | **16.3** | **16.1** | **15.9** | **15.7** | **15.6** | **15.4** | **15.3** | *15.1* | *12.4* | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | WP317 | A403 |
| **17.5** | **16.6** | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | *12.4* | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | F304 | A182 |
| **17.5** | **16.6** | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | *12.4* | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | WP304 | A403 |
| **17.5** | **16.6** | **16.2** | **15.8** | **15.5** | **15.2** | **14.9** | **14.6** | **14.3** | *14.0* | *12.4* | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | WP304H | A403 |
| **17.5** | **16.6** | **16.2** | **15.8** | **15.5** | **15.2** | **14.9** | **14.6** | **14.3** | *14.0* | *12.4* | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | F304H | A182 |
| **17.1** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F904L | A182 |
| 22.1 | 21.6 | 21.2 | 20.6 | 20.0 | 19.2 | 17.2 | 12.3 | 8.8 | 6.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F6a Cl. 1 | A182 |
| 26.9 | 26.2 | 25.7 | 25.1 | 24.3 | 23.3 | 17.2 | 12.3 | 8.8 | 6.4 | 4.4 | 2.9 | 1.8 | 1.0 | ... | ... | ... | ... | ... | ... | F6a Cl. 2 | A182 |
| *25.2* | *24.1* | *23.8* | *23.6* | *23.4* | *23.2* | *23.0* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F44 | A182 |
| *25.2* | *24.1* | *23.8* | *23.6* | *23.4* | *23.2* | *23.0* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WPS31254 | A403 |
| *25.2* | *24.1* | *23.8* | *23.6* | *23.4* | *23.2* | *23.0* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CRS31254 | A403 |
| 22.9 | 19.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F68 | A182 |
| 27.2 | 26.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F51 | A182 |
| 27.2 | 26.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WPS31803 | A815 |
| 27.2 | 26.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CRS31803 | A815 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F62 | A182 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WP6XN | A403 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CR6XN | A403 |
| 28.5 | 28.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A815 |
| 28.7 | 28.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F60 | A182 |
| 28.7 | 28.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2205 | A815 |
| 33.9 | 33.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A182 |
| 33.9 | 33.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A815 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F6a Cl. 3 | A182 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F6b | A182 |
| 34.5 | 34.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F53 | A182 |
| 34.5 | 34.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | WPS32750 | A815 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel — Forgings and Fittings (3)(4a)** | | | | | | | | | | | | | | | |
| 25Cr–7Ni–4Mo–N | Fittings | A815 | CRS32750 | S32750 | ... | ... | 10H | (25) | −60 | 116 | 80 | 38.7 | 38.5 | 36.4 | 35.1 |
| 13Cr | ... | A182 | F6a | S41000 | 4 | ... | 6 | (35) | −20 | 130 | 110 | 43.3 | ... | ... | ... |
| **Stainless Steel — Bar (3)(4a)** | | | | | | | | | | | | | | | |
| 18Cr–8Ni | ... | A479 | 304 | S30400 | ... | ... | 8 | (26)(28) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 18.6 |
| 18Cr–8Ni | ... | A479 | 304H | S30409 | ... | ... | 8 | (26) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **18.7** |
| 18Cr–8Ni | ... | A479 | 304L | S30403 | ... | ... | 8 | ... | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | *15.8* |
| 16Cr–12Ni–2Mo | ... | A479 | 316 | S31600 | ... | ... | 8 | (26)(28) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 16Cr–12Ni–2Mo | ... | A479 | 316H | S31609 | ... | ... | 8 | (26) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | **19.3** |
| 16Cr–12Ni–2Mo | ... | A479 | 316L | S31603 | ... | ... | 8 | ... | −425 | 70 | 25 | 16.7 | *16.7* | *16.7* | **15.5** |
| 18Cr–10Ni–Ti | Bar | A479 | 321 | S32100 | ... | ... | 8 | (28) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Bar | A479 | 321 | S32100 | ... | ... | 8 | (28)(30) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Ti | Bar | A479 | 321H | S32109 | ... | ... | 8 | (30) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A479 | 347 | S34700 | ... | ... | 8 | ... | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | ... | A479 | 347 | S34700 | ... | ... | 8 | (28)(30) | −425 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | ... | A479 | 347H | S34709 | ... | ... | 8 | ... | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 |
| 44Fe–25Ni–21Cr–Mo | ... | A479 | 904L | N08904 | ... | ... | 45 | ... | −325 | 71 | 31 | 20.7 | *20.7* | **20.4** | **18.7** |
| 22Cr–5Ni–3Mo–N | ... | A479 | ... | S31803 | ... | ... | 10H | (25) | −60 | 90 | 65 | 30.0 | 30.0 | 28.9 | 27.8 |
| 20Cr–18Ni–6Mo | ... | A479 | ... | S31254 | ... | ... | 8 | (8) | −325 | 95 | 45 | 30.0 | *30.0* | *29.5* | *27.3* |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | ... | A479 | ... | N08367 | ... | ... | 45 | (26) | −325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* |
| 21Cr–5Mn–1.5Ni–Cu–N | ... | A479 | ... | S32101 | ... | ... | 10H | (25) | −20 | 94 | 65 | 31.3 | 31.3 | 29.8 | 28.5 |
| 22Cr–5Ni–3Mo–N | ... | A479 | 2205 | S32205 | ... | ... | 10H | (25) | −60 | 95 | 65 | 31.7 | 31.7 | 30.6 | 29.4 |
| 24Cr–4Ni–3Mn–1.5Mo–N | ... | A479 | ... | S82441 | ... | ≥$^7/_{16}$ thk. | 10H | (25) | −60 | 99 | 70 | 32.9 | 32.9 | 32.9 | 32.9 |
| 22Cr–13Ni–5Mn | ... | A479 | XM-19 | S20910 | ... | ... | 8 | ... | −20 | 100 | 55 | 33.3 | *33.1* | *31.4* | *30.4* |
| 24Cr–4Ni–3Mn–1.5Mo–N | ... | A479 | ... | S82441 | ... | <$^7/_{16}$ thk. | 10H | (25) | −60 | 107 | 78 | 35.8 | 35.8 | 35.8 | 35.8 |
| 29Cr–6.5Ni–2Mo–N | ... | A479 | ... | S32906 | ... | ... | 10H | (25) | −60 | 109 | 80 | 36.3 | 36.3 | 34.5 | 33.5 |
| 25Cr–7Ni–4Mo–N | ... | A479 | ... | S32750 | ... | ≤2 thk. | 10H | (25) | −60 | 116 | 80 | 38.7 | 38.5 | 36.4 | 35.1 |
| **Stainless Steel — Castings (3)(4a)** | | | | | | | | | | | | | | | |
| 29Ni–20Cr–3Cu–2Mo | ... | A351 | CN7M | N08007 | ... | ... | 45 | (9)(30) | −325 | 62 | 25 | 16.7 | ... | ... | ... |
| 35Ni–15Cr–½Mo | ... | A351 | HT30 | N08603 | ... | ... | 45 | (36)(39) | −325 | 65 | 28 | 18.7 | ... | ... | ... |
| 25Cr–12Ni | ... | A351 | CH8 | J93400 | ... | ... | 8 | (9)(31) | −325 | 65 | 28 | 18.7 | *18.7* | *18.5* | *18.0* |
| 25Cr–20Ni | ... | A351 | CK20 | J94202 | ... | ... | 8 | (9)(27)(31)(35)(39) | −325 | 65 | 28 | 18.7 | *18.7* | *18.5* | *18.0* |
| 16Cr–14Ni–2Mo | ... | A351 | CF10MC | ... | ... | ... | 8 | (30) | −325 | 70 | 30 | 20.0 | ... | ... | ... |
| 18Cr–8Ni | ... | A351 | CF3 | J92500 | ... | ... | 8 | (9) | −425 | 70 | 30 | 20.0 | *20.0* | **20.0** | **18.6** |
| 18Cr–12Ni–2Mo | ... | A351 | CF3M | J92800 | ... | ... | 8 | (9) | −425 | 70 | 30 | 20.0 | *20.0* | 20.0 | 19.2 |
| 18Cr–8Ni | ... | A351 | CF8 | J92600 | ... | ... | 8 | (9)(26)(27)(31) | −425 | 70 | 30 | 20.0 | *20.0* | **20.0** | **18.6** |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | | | | | | | | | **Stainless Steel — Forgings and Fittings (3)(4a)** | **(Cont'd)** |
| 34.5 | 34.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CRS32750 | A815 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | F6a Cl. 4 | A182 |
| | | | | | | | | | | | | | | | | | | | | **Stainless Steel — Bar (3)(4a)** | |
| 17.5 | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | 304 | A479 |
| **17.5** | **16.4** | **16.2** | **16.0** | **15.6** | **15.2** | **14.9** | **14.6** | **14.4** | *13.8* | *12.2* | 9.7 | 7.7 | 6.0 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | 304H | A479 |
| *14.8* | *14.0* | **13.7** | **13.5** | **13.3** | **13.0** | **12.8** | *11.9* | *9.9* | 7.8 | 6.3 | 5.1 | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | 304L | A479 |
| **17.9** | **17.0** | **16.7** | **16.3** | **16.1** | **15.9** | **15.7** | **15.5** | **15.4** | **15.3** | *14.5* | *12.4* | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | 316 | A479 |
| **17.9** | **17.0** | **16.7** | **16.3** | **16.1** | **15.9** | **15.7** | **15.5** | **15.4** | **15.3** | *14.5* | *12.4* | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | 316H | A479 |
| **14.4** | **13.5** | **13.2** | **12.9** | **12.6** | **12.4** | **12.1** | **11.8** | **11.5** | **11.2** | **10.8** | *10.2* | *8.8* | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | 316L | A479 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | 321 | A479 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | 321 | A479 |
| **19.3** | **18.3** | **17.8** | **17.5** | **17.2** | **16.9** | **16.7** | **16.5** | **16.4** | **16.2** | 12.3 | 9.1 | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | 321H | A479 |
| 20.0 | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | *18.2* | *18.1* | *18.1* | *16.0* | *12.1* | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | 347 | A479 |
| 20.0 | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | **18.2** | **18.1** | **18.1** | **18.1** | *17.4* | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | 347 | A479 |
| 20.0 | **19.3** | **19.0** | **18.7** | **18.5** | **18.3** | **18.2** | **18.1** | **18.1** | **18.1** | *17.4* | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | 347H | A479 |
| **17.1** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 904L | A479 |
| 27.2 | 26.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A479 |
| *25.8* | *24.7* | *24.3* | *24.1* | *23.9* | *23.7* | *23.6* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A479 |
| **27.7** | **26.2** | **25.7** | **25.1** | **24.7** | **24.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A479 |
| 28.5 | 28.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A479 |
| 28.7 | 28.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2205 | A479 |
| 32.9 | 32.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A479 |
| *29.7* | 29.2 | *29.0* | *28.8* | *28.6* | *28.3* | *27.9* | *27.5* | *27.0* | *26.3* | *25.5* | 20.4 | 13.0 | 8.3 | ... | ... | ... | ... | ... | ... | XM-19 | A479 |
| 35.8 | 35.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A479 |
| 33.0 | 33.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A479 |
| 34.5 | 34.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A479 |
| | | | | | | | | | | | | | | | | | | | | **Stainless Steel — Castings (3)(4a)** | |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CN7M | A351 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | HT30 | A351 |
| *17.7* | **17.1** | **16.7** | **16.3** | **15.9** | **15.4** | *14.9* | *14.4* | *13.9* | 11.1 | 8.5 | 6.5 | 5.0 | 3.8 | 2.9 | 2.3 | 1.8 | 1.3 | 0.9 | 0.8 | CH8 | A351 |
| *17.7* | **17.1** | **16.7** | **16.3** | **15.9** | **15.4** | *14.9* | *14.4* | *13.9* | 11.3 | 9.8 | 8.5 | 7.3 | 6.0 | 4.8 | 3.5 | 2.4 | 1.6 | 1.1 | 0.8 | CK20 | A351 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CF10MC | A351 |
| **17.5** | **16.6** | **16.2** | **15.8** | **15.5** | **15.2** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CF3 | A351 |
| 17.9 | 17.0 | 16.6 | 16.3 | 16.0 | 15.8 | 15.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CF3M | A351 |
| **17.5** | **16.6** | **16.2** | **15.8** | **15.5** | **15.2** | *14.9* | *14.6* | *14.3* | *12.2* | 9.5 | 7.5 | 6.0 | 4.8 | 3.9 | 3.3 | 2.7 | 2.3 | 2.0 | 1.7 | CF8 | A351 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi Tensile | Specified Min. Strength, ksi Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)] Min. Temp. to 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel — Castings (3)(4a)** | | | | | | | | | | | | | | | |
| 25Cr–12Ni | ... | A351 | CH10 | J93401 | ... | ... | 8 | (27)(31)(35) | −325 | 70 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 25Cr–12Ni | ... | A351 | CH20 | J93402 | ... | ... | 8 | (9)(27)(31)(35)(39) | −325 | 70 | 30 | 20.0 | *20.0* | *20.0* | *20.0* |
| 18Cr–10Ni–Cb | ... | A351 | CF8C | J92710 | ... | ... | 8 | (9)(28) | −325 | 70 | 30 | 20.0 | *20.0* | *20.0* | *19.5* |
| 18Cr–12Ni–2Mo | ... | A351 | CF8M | J92900 | ... | ... | 8 | (9)(26)(27)(30) | −425 | 70 | 30 | 20.0 | *20.0* | *20.0* | **18.6** |
| 25Cr–20Ni–½Mo | ... | A351 | HK40 | J94204 | ... | ... | 8 | (35)(36)(39) | −325 | 62 | 35 | 20.7 | ... | ... | ... |
| 25Cr–20Ni–½Mo | ... | A351 | HK30 | J94203 | ... | ... | 8 | (35)(39) | −325 | 65 | 35 | 21.7 | ... | ... | ... |
| 18Cr–8Ni | ... | A351 | CF3A | J92500 | ... | ... | 8 | (9)(56) | −425 | 77 | 35 | 23.3 | 23.3 | 22.7 | 21.7 |
| 18Cr–8Ni | ... | A351 | CF8A | J92600 | ... | ... | 8 | (9)(26)(56) | −425 | 77 | 35 | 23.3 | 23.3 | 22.7 | 21.7 |
| 25Cr–8Ni–N | ... | A351 | CE20N | J92802 | ... | ... | 8 | (35)(39) | −325 | 80 | 40 | 26.7 | 26.7 | 26.7 | 26.7 |
| 12Cr | ... | A217 | CA15 | J91150 | ... | ... | 6 | (35) | −20 | 90 | 65 | 30.0 | 30.0 | 29.4 | 28.9 |
| 24Cr–10Ni–4Mo–N | ... | A995 | 2A | J93345 | ... | ... | 10H | (9) | −60 | 95 | 65 | 31.7 | 31.6 | 29.3 | 28.2 |
| 25Cr–8Ni–3Mo–W–Cu–N | ... | A995 | 6A | J93380 | ... | ... | 10H | (9)(25) | −60 | 100 | 65 | 33.3 | 33.2 | 31.4 | 30.3 |
| 13Cr–4Ni | ... | A487 | CA6NM | J91540 | A | ... | 6 | (9)(35) | −20 | 110 | 80 | 36.7 | 36.7 | 35.9 | 35.3 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | | | | | Stainless Steel — Castings (3)(4a) (Cont'd) | | | | | |
| *20.0* | **20.0** | **20.0** | **20.0** | **20.0** | **20.0** | *20.0* | *20.0* | *20.0* | 11.1 | 8.5 | 6.5 | 5.0 | 3.8 | 2.9 | 2.3 | 1.8 | 1.3 | 0.9 | 0.8 | CH10 | A351 |
| *20.0* | **20.0** | **20.0** | **20.0** | **20.0** | **20.0** | *20.0* | *20.0* | *20.0* | 11.1 | 8.5 | 6.5 | 5.0 | 3.8 | 2.9 | 2.3 | 1.8 | 1.3 | 0.9 | 0.8 | CH20 | A351 |
| *18.8* | *18.4* | *18.3* | *18.3* | *18.2* | **18.2** | **18.1** | **18.0** | **18.0** | **18.0** | 12.1 | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | CF8C | A351 |
| **17.5** | **16.6** | **16.2** | **15.8** | **15.5** | **15.2** | *14.9* | *14.6* | *14.3* | *14.0* | 12.1 | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | CF8M | A351 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | HK40 | A351 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | HK30 | A351 |
| 20.4 | 19.3 | 18.9 | 18.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CF3A | A351 |
| 20.4 | 19.3 | 18.9 | 18.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CF8A | A351 |
| 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CE20N | A351 |
| 28.4 | 27.7 | 27.2 | 26.5 | 17.5 | 16.8 | 14.9 | 11.0 | 7.6 | 5.0 | 3.3 | 2.3 | 1.5 | 1.0 | ... | ... | ... | ... | ... | ... | CA15 | A217 |
| 28.2 | 28.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2A | A995 |
| 29.8 | 29.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 6A | A995 |
| 34.8 | 33.9 | 33.3 | 32.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CA6NM Cl. A | A487 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition | Product Form | Spec. No. | UNS No. | Class/ Condition/ Temper | Size Range, in. | P-No. (5)(7) | Notes | Min. Temp., °F (6) | Specified Minimum Strength, ksi Tensile | Specified Minimum Strength, ksi Yield |
|---|---|---|---|---|---|---|---|---|---|---|
| **Copper and Copper Alloy — Pipes and Tubes** | | | | | | | | | | |
| 99.95Cu–P | Pipe | B42 | C10200 | O61 | ... | 31 | ... | −452 | 30 | 9 |
| 99.9Cu–P | Pipe | B42 | C12000 | O61 | ... | 31 | ... | −452 | 30 | 9 |
| 99.9Cu–P | Pipe | B42 | C12200 | O61 | ... | 31 | ... | −452 | 30 | 9 |
| 99.95Cu–P | Tube | B75 | C10200 | O50 | ... | 31 | ... | −452 | 30 | 9 |
| 99.95Cu–P | Tube | B75 | C10200 | O60 | ... | 31 | ... | −452 | 30 | 9 |
| 99.9Cu–P | Tube | B75 | C12000 | O50 | ... | 31 | ... | −452 | 30 | 9 |
| 99.9Cu–P | Tube | B75 | C12000 | O60 | ... | 31 | ... | −452 | 30 | 9 |
| 99.9Cu–P | Tube | B75 | C12200 | O50 | ... | 31 | ... | −452 | 30 | 9 |
| 99.9Cu–P | Tube | B75 | C12200 | O60 | ... | 31 | ... | −452 | 30 | 9 |
| 99.9Cu–P | Tube | B68 | C12200 | O50 | ... | 31 | (24) | −452 | 30 | 9 |
| 99.9Cu–P | Tube | B68 | C12200 | O60 | ... | 31 | (24) | −452 | 30 | 9 |
| 99.9Cu–P | Tube | B88 | C12200 | O50 | ... | 31 | (24) | −452 | 30 | 9 |
| 99.9Cu–P | Tube | B88 | C12200 | O60 | ... | 31 | (24) | −452 | 30 | 9 |
| 99.9Cu–P | Tube | B280 | C12200 | O60 | ... | 31 | (24) | −452 | 30 | 9 |
| 85Cu–15Zn | Pipe | B43 | C23000 | O61 | ... | 32 | ... | −452 | 40 | 12 |
| 90Cu–10Ni | ... | B467 | C70600 | WO50 | >4.5 O.D. | 34 | (14) | −452 | 38 | 13 |
| 90Cu–10Ni | ... | B467 | C70600 | WO61 | >4.5 O.D. | 34 | (14) | −452 | 38 | 13 |
| 90Cu–10Ni | ... | B466 | C70600 | Annealed | ... | 34 | (14) | −452 | 38 | 13 |
| 90Cu–10Ni | ... | B467 | C70600 | WO50 | ≤4.5 O.D. | 34 | (14) | −452 | 40 | 15 |
| 90Cu–10Ni | ... | B467 | C70600 | WO61 | ≤4.5 O.D. | 34 | (14) | −452 | 40 | 15 |
| 70Cu–30Ni | ... | B467 | C71500 | WO50 | >4.5 O.D. | 34 | (14) | −452 | 45 | 15 |
| 70Cu–30Ni | ... | B467 | C71500 | WO61 | >4.5 O.D. | 34 | (14) | −452 | 45 | 15 |
| 80Cu–20Ni | ... | B466 | C71000 | Annealed | ≤4.5 O.D. | 34 | (14) | −452 | 45 | 16 |
| 99.95Cu–P | Pipe | B42 | C10200 | H55 | NPS 2½ thru 12 | 31 | (14)(34) | −452 | 36 | 30 |
| 99.9Cu–P | Pipe | B42 | C12000 | H55 | NPS 2½ thru 12 | 31 | (14)(34) | −452 | 36 | 30 |
| 99.9Cu–P | Pipe | B42 | C12200 | H55 | NPS 2½ thru 12 | 31 | (14)(34) | −452 | 36 | 30 |
| 99.95Cu–P | Tube | B75 | C10200 | H58 | ... | 31 | (14)(34) | −452 | 36 | 30 |
| 99.9Cu–P | Tube | B75 | C12000 | H58 | ... | 31 | (14)(34) | −452 | 36 | 30 |
| 99.9Cu–P | Tube | B75 | C12200 | H58 | ... | 31 | (14)(34) | −452 | 36 | 30 |
| 99.9Cu–P | Tube | B88 | C12200 | H58 | ... | 31 | (14)(24)(34) | −452 | 36 | 30 |
| 70Cu–30Ni | ... | B466 | C71500 | O60 | ... | 34 | (14) | −452 | 52 | 18 |
| 70Cu–30Ni | ... | B467 | C71500 | WO50 | ≤4.5 O.D. | 34 | (14) | −452 | 50 | 20 |
| 70Cu–30Ni | ... | B467 | C71500 | WO61 | ≤4.5 O.D. | 34 | (14) | −452 | 50 | 20 |
| 99.95Cu–P | Pipe | B42 | C10200 | H80 | NPS ⅛ thru 2 | 31 | (14)(34) | −452 | 45 | 40 |
| 99.9Cu–P | Pipe | B42 | C12000 | H80 | NPS ⅛ thru 2 | 31 | (14)(34) | −452 | 45 | 40 |
| 99.9Cu–P | Pipe | B42 | C12200 | H80 | NPS ⅛ thru 2 | 31 | (14)(34) | −452 | 45 | 40 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Min. Temp. to 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 | UNS No. | Spec. No. |
| | | | | | | | | | | **Copper and Copper Alloy — Pipes and Tubes** | | | | |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C10200 | B42 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12000 | B42 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12200 | B42 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C10200 | B75 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C10200 | B75 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12000 | B75 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12000 | B75 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12200 | B75 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12200 | B75 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12200 | B68 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12200 | B68 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12200 | B88 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12200 | B88 |
| 6.0 | 5.1 | 4.9 | 4.8 | 4.7 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12200 | B280 |
| 8.0 | 7.9 | 7.9 | 7.9 | 7.9 | 7.0 | 5.0 | 2.0 | ... | ... | ... | ... | ... | C23000 | B43 |
| 8.7 | 8.4 | 8.2 | 8.0 | 7.8 | 7.7 | 7.5 | 7.4 | 7.3 | 7.0 | 6.0 | ... | ... | C70600 | B467 |
| 8.7 | 8.4 | 8.2 | 8.0 | 7.8 | 7.7 | 7.5 | 7.4 | 7.3 | 7.0 | 6.0 | ... | ... | C70600 | B467 |
| 8.7 | 8.4 | 8.2 | 8.0 | 7.8 | 7.7 | 7.5 | 7.4 | 7.3 | 7.0 | 6.0 | ... | ... | C70600 | B466 |
| 10.0 | 9.7 | 9.5 | 9.3 | 9.1 | 8.9 | 8.7 | 8.5 | 8.0 | 7.0 | 6.0 | ... | ... | C70600 | B467 |
| 10.0 | 9.7 | 9.5 | 9.3 | 9.1 | 8.9 | 8.7 | 8.5 | 8.0 | 7.0 | 6.0 | ... | ... | C70600 | B467 |
| 10.0 | 9.6 | 9.4 | 9.2 | 9.0 | 8.8 | 8.6 | 8.4 | 8.2 | 8.1 | 8.0 | 7.9 | 7.8 | C71500 | B467 |
| 10.0 | 9.6 | 9.4 | 9.2 | 9.0 | 8.8 | 8.6 | 8.4 | 8.2 | 8.1 | 8.0 | 7.9 | 7.8 | C71500 | B467 |
| 10.7 | 10.6 | 10.5 | 10.4 | 10.2 | 10.1 | 9.9 | 9.6 | 9.3 | 8.9 | 8.4 | 7.7 | 7.0 | C71000 | B466 |
| 12.0 | 11.6 | 10.9 | 10.4 | 10.0 | 9.8 | 9.5 | ... | ... | ... | ... | ... | ... | C10200 | B42 |
| 12.0 | 11.6 | 10.9 | 10.4 | 10.0 | 9.8 | 9.5 | ... | ... | ... | ... | ... | ... | C12000 | B42 |
| 12.0 | 11.6 | 10.9 | 10.4 | 10.0 | 9.8 | 9.5 | ... | ... | ... | ... | ... | ... | C12200 | B42 |
| 12.0 | 11.6 | 10.9 | 10.4 | 10.0 | 9.8 | 9.5 | ... | ... | ... | ... | ... | ... | C10200 | B75 |
| 12.0 | 11.6 | 10.9 | 10.4 | 10.0 | 9.8 | 9.5 | ... | ... | ... | ... | ... | ... | C12000 | B75 |
| 12.0 | 11.6 | 10.9 | 10.4 | 10.0 | 9.8 | 9.5 | ... | ... | ... | ... | ... | ... | C12200 | B75 |
| 12.0 | 11.6 | 10.9 | 10.4 | 10.0 | 9.8 | 9.5 | ... | ... | ... | ... | ... | ... | C12200 | B88 |
| 12.0 | 11.6 | 11.3 | 11.0 | 10.8 | 10.6 | 10.3 | 10.1 | 9.9 | 9.8 | 9.6 | 9.5 | 9.4 | C71500 | B466 |
| 13.3 | 12.9 | 12.6 | 12.3 | 12.0 | 11.7 | 11.5 | 11.2 | 11.0 | 10.8 | 10.7 | 10.5 | 10.4 | C71500 | B467 |
| 13.3 | 12.9 | 12.6 | 12.3 | 12.0 | 11.7 | 11.5 | 11.2 | 11.0 | 10.8 | 10.7 | 10.5 | 10.4 | C71500 | B467 |
| 15.0 | 14.5 | 13.6 | 13.0 | 12.6 | 12.2 | 4.3 | ... | ... | ... | ... | ... | ... | C10200 | B42 |
| 15.0 | 14.5 | 13.6 | 13.0 | 12.6 | 12.2 | 4.3 | ... | ... | ... | ... | ... | ... | C12000 | B42 |
| 15.0 | 14.5 | 13.6 | 13.0 | 12.6 | 12.2 | 4.3 | ... | ... | ... | ... | ... | ... | C12200 | B42 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | UNS No. | Class/ Condition/ Temper | Size Range, in. | P-No. (5)(7) | Notes | Min. Temp., °F (6) | Specified Minimum Strength, ksi | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Tensile | Yield |
| **Copper and Copper Alloy — Pipes and Tubes** | | | | | | | | | | |
| 99.95Cu–P | Tube | B75 | C10200 | H80 | ... | 31 | (14)(34) | −452 | 45 | 40 |
| 99.9Cu–P | Tube | B75 | C12000 | H80 | ... | 31 | (14)(34) | −452 | 45 | 40 |
| 99.9Cu–P | Tube | B75 | C12200 | H80 | ... | 31 | (14)(34) | −452 | 45 | 40 |
| **Copper and Copper Alloy — Plates and Sheets** | | | | | | | | | | |
| 99.95Cu–P | ... | B152 | C10200 | O25 | ... | 31 | (14)(24) | −452 | 30 | 10 |
| 99.95Cu–Ag | ... | B152 | C10400 | O25 | ... | 31 | (14)(24) | −452 | 30 | 10 |
| 99.95Cu–Ag | ... | B152 | C10500 | O25 | ... | 31 | (14)(24) | −452 | 30 | 10 |
| 99.95Cu–Ag | ... | B152 | C10700 | O25 | ... | 31 | (14)(24) | −452 | 30 | 10 |
| 99.9Cu–P | ... | B152 | C12200 | O25 | ... | 31 | (14)(24) | −452 | 30 | 10 |
| 99.9Cu–P | ... | B152 | C12300 | O25 | ... | 31 | (14)(24) | −452 | 30 | 10 |
| 90Cu–10Ni | ... | B171 | C70600 | ... | ≤2.5 thk. | 34 | (14) | −452 | 40 | 15 |
| 97Cu–3Si | ... | B96 | C65500 | O61 | ... | 33 | ... | −452 | 50 | 18 |
| 70Cu–30Ni | ... | B171 | C71500 | ... | ≤2.5 thk. | 34 | (14) | −452 | 50 | 20 |
| 90Cu–7Al–3Fe | ... | B169 | C61400 | O25 | ≤2.0 thk. | 35 | (13) | −452 | 70 | 30 |
| 90Cu–7Al–3Fe | ... | B169 | C61400 | O60 | ≤2.0 thk. | 35 | (13) | −452 | 70 | 30 |
| **Copper and Copper Alloy — Forgings** | | | | | | | | | | |
| 99.9Cu | ... | B283 | C11000 | ... | ... | 31 | (14) | −452 | 33 | 11 |
| 97Cu–3Si | ... | B283 | C65500 | ... | ... | 33 | (14) | −452 | 52 | 18 |
| 60Cu–38Zn–2Pb | ... | B283 | C37700 | ... | ... | a | (14) | −325 | 58 | 23 |
| 60Cu–37Zn–2Pb–Sn | ... | B283 | C48500 | ... | ... | a | (14) | −325 | 62 | 24 |
| 60Cu–39Zn–Sn | ... | B283 | C46400 | ... | ... | 32 | (14) | −425 | 64 | 26 |
| 59Cu–39Zn–Fe–Sn | ... | B283 | C67500 | ... | ... | 32 | (14) | −325 | 72 | 34 |
| **Copper and Copper Alloy — Castings** | | | | | | | | | | |
| 85Cu–5Sn–5Zn–5Pb | ... | B62 | C83600 | ... | ... | a | (9) | −325 | 30 | 14 |
| 57Cu–20Zn–12Ni–9Pb–2Sn | ... | B584 | C97300 | ... | ... | a | ... | −325 | 30 | 15 |
| 64Cu–20Ni–8Zn–4Sn–4Pb | ... | B584 | C97600 | ... | ... | a | ... | −325 | 40 | 17 |
| 87Cu–8Sn–4Zn–1Pb | ... | B584 | C92300 | ... | ... | a | ... | −325 | 36 | 16 |
| 88Cu–Sn–Zn–Pb | ... | B584 | C92200 | ... | ... | a | ... | −325 | 34 | 16 |
| 88Cu–Sn–Zn–Pb | ... | B61 | C92200 | ... | ... | a | (9) | −325 | 34 | 16 |
| 88Cu–8Sn–4Zn | ... | B584 | C90300 | ... | ... | b | ... | −325 | 40 | 18 |
| 88Cu–10Sn–2Zn | ... | B584 | C90500 | ... | ... | b | ... | −325 | 40 | 18 |
| 58Cu–38Zn–1Sn–1Pb–1Fe | ... | B584 | C86400 | ... | ... | a | (9) | −325 | 60 | 20 |
| 66Cu–25Ni–5Sn–2Pb–2Zn | ... | B584 | C97800 | ... | ... | a | ... | −325 | 50 | 22 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Min. Temp. to 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 | UNS No. | Spec. No. |
| **Copper and Copper Alloy — Pipes and Tubes (Cont'd)** | | | | | | | | | | | | | | |
| 15.0 | 14.5 | 13.6 | 13.0 | 12.6 | 12.2 | 4.3 | ... | ... | ... | ... | ... | ... | C10200 | B75 |
| 15.0 | 14.5 | 13.6 | 13.0 | 12.6 | 12.2 | 4.3 | ... | ... | ... | ... | ... | ... | C12000 | B75 |
| 15.0 | 14.5 | 13.6 | 13.0 | 12.6 | 12.2 | 4.3 | ... | ... | ... | ... | ... | ... | C12200 | B75 |
| **Copper and Copper Alloy — Plates and Sheets** | | | | | | | | | | | | | | |
| 6.7 | 5.7 | 5.4 | 5.3 | 5.0 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C10200 | B152 |
| 6.7 | 5.7 | 5.4 | 5.3 | 5.0 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C10400 | B152 |
| 6.7 | 5.7 | 5.4 | 5.3 | 5.0 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C10500 | B152 |
| 6.7 | 5.7 | 5.4 | 5.3 | 5.0 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C10700 | B152 |
| 6.7 | 5.7 | 5.4 | 5.3 | 5.0 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12200 | B152 |
| 6.7 | 5.7 | 5.4 | 5.3 | 5.0 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C12300 | B152 |
| 10.0 | 9.7 | 9.5 | 9.3 | 9.1 | 8.9 | 8.7 | 8.5 | 8.0 | 7.0 | 6.0 | ... | ... | C70600 | B171 |
| 12.0 | 12.0 | 11.9 | 11.9 | 11.9 | 10.7 | 6.8 | ... | ... | ... | ... | ... | ... | C65500 | B96 |
| 13.3 | 12.9 | 12.6 | 12.3 | 12.0 | 11.7 | 11.5 | 11.2 | 11.0 | 10.8 | 10.7 | 10.5 | 10.4 | C71500 | B171 |
| 20.0 | 19.9 | 19.8 | 19.7 | 19.5 | 19.4 | 19.2 | 19.0 | 18.8 | ... | ... | ... | ... | C61400 | B169 |
| 20.0 | 19.9 | 19.8 | 19.7 | 19.5 | 19.4 | 19.2 | 19.0 | 18.8 | ... | ... | ... | ... | C61400 | B169 |
| **Copper and Copper Alloy — Forgings** | | | | | | | | | | | | | | |
| 7.3 | 6.2 | 6.0 | 5.8 | 5.0 | 4.0 | 3.0 | 2.3 | 1.7 | ... | ... | ... | ... | C11000 | B283 |
| 12.0 | 12.0 | 11.9 | 11.9 | 11.9 | 10.7 | 6.8 | ... | ... | ... | ... | ... | ... | C65500 | B283 |
| 15.3 | 14.5 | 13.9 | 13.3 | 10.5 | 7.5 | 2.0 | ... | ... | ... | ... | ... | ... | C37700 | B283 |
| 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | ... | ... | ... | ... | ... | ... | C48500 | B283 |
| 17.3 | 17.3 | 17.3 | 17.3 | 17.1 | 6.3 | 2.5 | ... | ... | ... | ... | ... | ... | C46400 | B283 |
| 22.7 | 22.7 | 22.7 | 22.7 | 22.7 | 22.7 | 22.7 | ... | ... | ... | ... | ... | ... | C67500 | B283 |
| **Copper and Copper Alloy — Castings** | | | | | | | | | | | | | | |
| 9.3 | 9.3 | 9.2 | 8.6 | 8.1 | 7.7 | 7.4 | 7.3 | ... | ... | ... | ... | ... | C83600 | B62 |
| 10.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C97300 | B584 |
| 11.3 | 10.1 | 9.5 | 9.1 | 8.7 | ... | ... | ... | ... | ... | ... | ... | ... | C97600 | B584 |
| 10.7 | 10.7 | 10.7 | 10.7 | 10.7 | 10.7 | 10.7 | ... | ... | ... | ... | ... | ... | C92300 | B584 |
| 10.7 | 9.6 | 9.5 | 9.4 | 9.2 | 8.9 | 8.6 | ... | ... | ... | ... | ... | ... | C92200 | B584 |
| 10.7 | 9.6 | 9.5 | 9.4 | 9.2 | 8.9 | 8.6 | 8.4 | 8.3 | 8.3 | ... | ... | ... | C92200 | B61 |
| 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | ... | ... | ... | ... | ... | ... | C90300 | B584 |
| 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | ... | ... | ... | ... | ... | ... | C90500 | B584 |
| 13.3 | 13.3 | 13.3 | 13.3 | 13.3 | 13.3 | ... | ... | ... | ... | ... | ... | ... | C86400 | B584 |
| 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | ... | ... | ... | ... | ... | ... | ... | C97800 | B584 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition | Product Form | Spec. No. | UNS No. | Class/ Condition/ Temper | Size Range, in. | P-No. (5)(7) | Notes | Min. Temp., °F (6) | Specified Minimum Strength, ksi Tensile | Specified Minimum Strength, ksi Yield |
|---|---|---|---|---|---|---|---|---|---|---|
| **Copper and Copper Alloy — Castings** | | | | | | | | | | |
| 58Cu–39Zn–1Fe–1Al–1Mn | ... | B584 | C86500 | ... | ... | b | ... | −325 | 65 | 25 |
| 88Cu–9Al–3Fe | ... | B148 | C95200 | ... | ... | 35 | (9) | −425 | 65 | 25 |
| 89Cu–10Al–1Fe | ... | B148 | C95300 | ... | ... | 35 | (9) | −425 | 65 | 25 |
| 90Cu–7Al–3Si | ... | B148 | C95600 | ... | ... | 35 | ... | −325 | 60 | 28 |
| 85Cu–11Al–4Fe | ... | B148 | C95400 | ... | ... | 35 | ... | −325 | 75 | 30 |
| 58Cu–34Zn–2Fe–2Al–2Mn | ... | B584 | C86700 | ... | ... | a | ... | −325 | 80 | 32 |
| 82Cu–11Al–4Fe–3Mn | ... | B148 | C95500 | ... | ... | 35 | ... | −452 | 90 | 40 |
| 63Cu–27Zn–4Al–3Fe–3Mn | ... | B584 | C86200 | ... | ... | b | ... | −325 | 90 | 45 |
| 61Cu–27Zn–6Al–3Fe–3Mn | ... | B584 | C86300 | ... | ... | b | ... | −325 | 110 | 60 |
| **Copper and Copper Alloy — Rod** | | | | | | | | | | |
| 75Cu–21.5Zn–3Si | ... | B371 | C69300 | H02 | ≤$\frac{1}{2}$ | a | ... | −325 | 85 | 45 |
| 75Cu–21.5Zn–3Si | ... | B371 | C69300 | H02 | >$\frac{1}{2}$, ≤1 | a | ... | −325 | 75 | 35 |
| 75Cu–21.5Zn–3Si | ... | B371 | C69300 | H02 | >1, ≤2 | a | ... | −325 | 70 | 30 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Min. Temp. to 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 | UNS No. | Spec. No. |
| | | | | | | | | | | **Copper and Copper Alloy — Castings (Cont'd)** | | | | |
| 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | ... | ... | ... | ... | ... | ... | ... | C86500 | B584 |
| 16.7 | 15.7 | 15.2 | 14.8 | 14.5 | 14.3 | 14.2 | 14.1 | 14.1 | 11.7 | 7.4 | ... | ... | C95200 | B148 |
| 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | ... | ... | C95300 | B148 |
| 18.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C95600 | B148 |
| 20.0 | 19.0 | 18.7 | 18.5 | 18.5 | 18.5 | 18.5 | 16.0 | 13.9 | ... | ... | ... | ... | C95400 | B148 |
| 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | ... | ... | ... | ... | ... | ... | ... | C86700 | B584 |
| 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | ... | ... | ... | ... | C95500 | B148 |
| 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | ... | ... | ... | ... | ... | ... | ... | C86200 | B584 |
| 36.7 | 36.7 | 36.7 | 36.7 | 36.7 | 36.7 | ... | ... | ... | ... | ... | ... | ... | C86300 | B584 |
| | | | | | | | | | | **Copper and Copper Alloy — Rod** | | | | |
| 28.3 | 25.9 | 25.4 | 25.4 | 25.4 | ... | ... | ... | ... | ... | ... | ... | ... | C69300 | B371 |
| 23.3 | 20.2 | 19.8 | 19.8 | 19.8 | ... | ... | ... | ... | ... | ... | ... | ... | C69300 | B371 |
| 20.0 | 17.3 | 17.0 | 17.0 | 17.0 | ... | ... | ... | ... | ... | ... | ... | ... | C69300 | B371 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Spec. No. | UNS No. | Class/ Condition/ Temper | Size Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi Tensile | Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)] Min. Temp. to 100 | 200 | 300 | 400 | 500 | 600 | 650 | 700 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nickel and Nickel Alloy — Pipes and Tubes (4a)** | | | | | | | | | | | | | | | | | |
| 99.0Ni–Low C | B161 | N02201 | Annealed | >5 O.D. | 41 | ... | −325 | 50 | 10 | 6.7 | 6.4 | 6.3 | 6.3 | 6.3 | 6.3 | 6.2 | 6.2 |
| 99.0Ni–Low C | B725 | N02201 | Annealed | >5 O.D. | 41 | ... | −325 | 50 | 10 | 6.7 | 6.4 | 6.3 | 6.3 | 6.3 | 6.3 | 6.2 | 6.2 |
| 99.0Ni | B161 | N02200 | Annealed | >5 O.D. | 41 | ... | −325 | 55 | 12 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | ... | ... |
| 99.0Ni | B725 | N02200 | Annealed | >5 O.D. | 41 | ... | −325 | 55 | 12 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | ... | ... |
| 99.0Ni–Low C | B161 | N02201 | Annealed | ≤5 O.D. | 41 | ... | −325 | 50 | 12 | 8.0 | 7.7 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.4 |
| 99.0Ni–Low C | B725 | N02201 | Annealed | ≤5 O.D. | 41 | ... | −325 | 50 | 12 | 8.0 | 7.7 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.4 |
| 99.0Ni | B161 | N02200 | Annealed | ≤5 O.D. | 41 | ... | −325 | 55 | 15 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | ... | ... |
| 99.0Ni | B725 | N02200 | Annealed | ≤5 O.D. | 41 | ... | −325 | 55 | 15 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | ... | ... |
| 67Ni–30Cu | B165 | N04400 | Annealed | >5 O.D. | 42 | ... | −325 | 70 | 25 | 16.7 | 14.6 | 13.6 | 13.2 | 13.1 | 13.1 | 13.1 | 13.0 |
| 67Ni–30Cu | B725 | N04400 | Annealed | >5 O.D. | 42 | ... | −325 | 70 | 25 | 16.7 | 14.6 | 13.6 | 13.2 | 13.1 | 13.1 | 13.1 | 13.0 |
| 33Ni–42Fe–21Cr | B407 | N08800 | H.F. or H.F. ann. | ... | 45 | ... | −325 | 65 | 25 | 16.7 | *16.7* | *16.7* | *16.7* | *16.7* | *16.7* | *16.7* | *16.7* |
| 72Ni–15Cr–8Fe | B167 | N06600 | H.F. or H.F. ann. | >5 O.D. | 43 | ... | −325 | 75 | 25 | 16.7 | *16.7* | *16.7* | *16.7* | *16.7* | *16.7* | *16.7* | *16.7* |
| 33Ni–42Fe–21Cr | B407 | N08810 | C.D. sol. ann. or H.F. ann. | ... | 45 | (62) | −325 | 65 | 25 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 | 16.1 | 15.7 |
| 33Ni–42Fe–21Cr | B514 | N08810 | Annealed | ... | 45 | (62) | −325 | 65 | 25 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 | 16.1 | 15.7 |
| 33Ni–42Fe–21Cr–Al–Ti | B407 | N08811 | C.D. sol. ann. or H.F. ann. | ... | 45 | (62) | −325 | 65 | 25 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 | 16.1 | 15.7 |
| 67Ni–30Cu | B165 | N04400 | Annealed | ≤5 O.D. | 42 | ... | −325 | 70 | 28 | 18.7 | 16.4 | 15.2 | 14.7 | 14.7 | 14.7 | 14.7 | 14.6 |
| 67Ni–30Cu | B725 | N04400 | Annealed | ≤5 O.D. | 42 | ... | −325 | 70 | 28 | 18.7 | 16.4 | 15.2 | 14.7 | 14.7 | 14.7 | 14.7 | 14.6 |
| 26Ni–22Cr–5Mo–Ti | B619 | N08320 | Sol. ann. | ... | 45 | ... | −325 | 75 | 28 | 18.7 | *18.7* | *18.7* | *18.7* | *18.7* | *18.6* | *18.2* | *17.8* |
| 26Ni–22Cr–5Mo–Ti | B622 | N08320 | Sol. ann. | ... | 45 | ... | −325 | 75 | 28 | 18.7 | 18.7 | *18.7* | *18.7* | *18.7* | *18.6* | *18.2* | *17.8* |
| 99.0Ni–Low C | B161 | N02201 | Str. rel. | ... | 41 | ... | −325 | 60 | 30 | 20.0 | 20.0 | 19.8 | 19.8 | 19.7 | 19.0 | ... | ... |
| 99.0Ni–Low C | B725 | N02201 | Str. rel. | ... | 41 | ... | −325 | 60 | 30 | 20.0 | 20.0 | 19.8 | 19.8 | 19.7 | 19.0 | ... | ... |
| 33Ni–42Fe–21Cr | B514 | N08800 | Annealed | ... | 45 | ... | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| 72Ni–15Cr–8Fe | B167 | N06600 | H.F. or H.F. ann. | ≤5 O.D. | 43 | ... | −325 | 80 | 30 | 20.0 | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| 72Ni–15Cr–8Fe | B167 | N06600 | C.D. ann. | >5 O.D. | 43 | ... | −325 | 80 | 30 | 20.0 | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| 33Ni–42Fe–21Cr | B407 | N08800 | C.D. ann. | ... | 45 | (61) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| 31Ni–31Fe–29Cr–Mo | B668 | N08028 | Sol. ann. | ... | 45 | ... | −325 | 73 | 31 | 20.7 | *20.7* | *20.7* | *20.7* | *20.7* | **19.5** | **18.9** | **18.3** |
| 99.0Ni | B161 | N02200 | Str. rel. | ... | 41 | ... | −325 | 65 | 40 | 21.7 | 21.7 | 21.6 | 21.6 | 21.4 | 20.6 | ... | ... |
| 99.0Ni | B725 | N02200 | Str. rel. | ... | 41 | ... | −325 | 65 | 40 | 21.7 | 21.7 | 21.6 | 21.6 | 21.4 | 20.6 | ... | ... |
| 35Ni–35Fe–20Cr–Cb | B464 | N08020 | Annealed | ... | 45 | ... | −325 | 80 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | 23.3 | 23.3 |
| 35Ni–35Fe–20Cr–Cb | B474 | N08020 | Annealed | ... | 45 | ... | −325 | 80 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | 23.3 | 23.3 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | UNS No. | Spec. No. |
| **Nickel and Nickel Alloy — Pipes and Tubes (4a)** | | | | | | | | | | | | | | | | | | | | |
| 6.1 | 6.0 | 5.8 | 4.5 | 3.7 | 3.0 | 2.4 | 2.0 | 1.5 | 1.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02201 | B161 |
| 6.1 | 6.0 | 5.8 | 4.5 | 3.7 | 3.0 | 2.4 | 2.0 | 1.5 | 1.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02201 | B725 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B161 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B725 |
| 7.3 | 7.2 | 5.8 | 4.5 | 3.7 | 3.0 | 2.4 | 2.0 | 1.5 | 1.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02201 | B161 |
| 7.3 | 7.2 | 5.8 | 4.5 | 3.7 | 3.0 | 2.4 | 2.0 | 1.5 | 1.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02201 | B725 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B161 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B725 |
| 12.9 | 12.7 | 11.0 | 8.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B165 |
| 12.9 | 12.7 | 11.0 | 8.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B725 |
| *16.7* | *16.7* | *16.7* | *16.7* | *16.7* | *16.6* | *16.3* | *13.0* | 9.8 | 6.6 | 4.2 | 2.0 | 1.6 | 1.1 | 1.0 | 0.8 | ... | ... | ... | N08800 | B407 |
| *16.7* | *16.7* | *16.7* | *16.0* | *10.6* | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06600 | B167 |
| 15.3 | *15.0* | *14.7* | *14.5* | *14.2* | *14.0* | *13.8* | *11.6* | 9.3 | 7.4 | 5.9 | 4.7 | 3.8 | 3.0 | 2.4 | 1.9 | 1.4 | 1.1 | 0.86 | N08810 | B407 |
| 15.3 | *15.0* | *14.7* | *14.5* | *14.2* | *14.0* | *13.8* | *11.6* | 9.3 | 7.4 | 5.9 | 4.7 | 3.8 | 3.0 | 2.4 | 1.9 | 1.4 | 1.1 | 0.86 | N08810 | B514 |
| 15.3 | *15.0* | *14.7* | *14.5* | *14.2* | *14.0* | *13.8* | 12.9 | 10.4 | 8.3 | 6.7 | 5.4 | 4.3 | 3.4 | 2.7 | 2.2 | 1.6 | 1.2 | 0.91 | N08811 | B407 |
| 14.5 | 14.3 | 11.0 | 8.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B165 |
| 14.5 | 14.3 | 11.0 | 8.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B725 |
| *17.5* | *17.2* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08320 | B619 |
| *17.5* | *17.2* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08320 | B622 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02201 | B161 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02201 | B725 |
| *20.0* | *20.0* | 20.0 | 20.0 | 20.0 | 19.9 | 17.0 | 13.0 | 9.8 | 6.6 | 4.2 | 2.0 | 1.6 | 1.1 | 1.0 | 0.8 | ... | ... | ... | N08800 | B514 |
| *20.0* | *20.0* | *20.0* | *16.0* | 10.6 | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06600 | B167 |
| *20.0* | *20.0* | *20.0* | *16.0* | 10.6 | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06600 | B167 |
| 20.0 | *20.0* | *20.0* | *20.0* | *20.0* | *19.9* | *17.0* | 13.0 | 9.8 | 6.6 | 4.2 | 2.0 | 1.6 | 1.1 | 1.0 | 0.8 | ... | ... | ... | N08800 | B407 |
| **17.7** | **17.2** | **16.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08028 | B668 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B161 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B725 |
| 23.2 | *22.7* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08020 | B464 |
| 23.2 | *22.7* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08020 | B474 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition | Spec. No. | UNS No. | Class/ Condition/ Temper | Size Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 | 500 | 600 | 650 | 700 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nickel and Nickel Alloy — Pipes and Tubes (4a)** | | | | | | | | | | | | | | | | | |
| 35Ni–35Fe–20Cr–Cb | B729 | N08020 | Annealed | ... | 45 | ... | −325 | 80 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | 23.3 | 23.3 |
| 42Ni–21.5Cr–3Mo–2.3Cu | B163 | N08825 | Annealed | ... | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 42Ni–21.5Cr–3Mo–2.3Cu | B423 | N08825 | C.D. ann. | ... | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 42Ni–21.5Cr–3Mo–2.3Cu | B474 | N08825 | Annealed | ... | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 42Ni–21.5Cr–3Mo–2.3Cu | B704 | N08825 | Annealed | ... | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 42Ni–21.5Cr–3Mo–2.3Cu | B705 | N08825 | ... | ... | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 47Ni–22Cr–19Fe–6Mo | B619 | N06007 | Sol. ann. | ... | 45 | ... | −325 | 90 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | 23.3 | **22.7** | **22.4** | **22.2** |
| 47Ni–22Cr–19Fe–6Mo | B622 | N06007 | Sol. ann. | ... | 45 | ... | −325 | 90 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | 23.3 | **22.7** | **22.4** | **22.2** |
| 40Ni–29Cr–15Fe–5Mo | B619 | N06030 | Sol. ann. | ... | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **23.2** | **22.1** | **21.3** | **20.9** | **20.5** |
| 40Ni–29Cr–15Fe–5Mo | B622 | N06030 | Sol. ann. | ... | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **23.2** | **22.1** | **21.3** | **20.9** | **20.5** |
| 40Ni–29Cr–15Fe–5Mo | B626 | N06030 | Sol. ann. | ... | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **23.2** | **22.1** | **21.3** | **20.9** | **20.5** |
| 72Ni–15Cr–8Fe | B167 | N06600 | C.D. ann. | ≤5 O.D. | 43 | ... | −325 | 80 | 35 | 23.3 | *23.3* | *23.3* | **23.3** | 23.3 | *23.3* | *23.3* | *23.3* |
| 72Ni–15Cr–8Fe | B517 | N06600 | C.D. ann. | ... | 43 | ... | −325 | 80 | 35 | 23.3 | *23.3* | *23.3* | **23.3** | 23.3 | *23.3* | *23.3* | *23.3* |
| 58Ni–29Cr–9Fe | B163 | N06690 | C.D. ann. | ≤3 O.D. | 43 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 58Ni–29Cr–9Fe | B167 | N06690 | C.D. ann. | ≤5 O.D. | 43 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 37Ni–33Fe–25Cr | B163 | N08120 | Sol. ann. | ... | 45 | ... | −325 | 90 | 40 | 26.7 | *26.7* | *26.7* | *26.7* | **25.1** | **24.4** | **23.3** | **22.9** |
| 37Ni–33Fe–25Cr | B407 | N08120 | Sol. ann. | ... | 45 | ... | −325 | 90 | 40 | 26.7 | *26.7* | *26.7* | *26.7* | **25.1** | **24.4** | **23.3** | **22.9** |
| 37Ni–33Fe–25Cr | B514 | N08120 | Sol. ann. | ... | 45 | ... | −325 | 90 | 40 | 26.7 | *26.7* | *26.7* | *26.7* | **25.1** | **24.4** | **23.3** | **22.9** |
| 37Ni–33Fe–25Cr | B515 | N08120 | Sol. ann. | ... | 45 | ... | −325 | 90 | 40 | 26.7 | *26.7* | *26.7* | *26.7* | **25.1** | **24.4** | **23.3** | **22.9** |
| 61Ni–16Mo–16Cr | B619 | N06455 | Sol. ann. | ... | 43 | ... | −325 | 100 | 40 | 26.7 | *26.7* | *26.7* | **26.7** | 26.7 | *26.7* | *26.7* | *26.5* |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | UNS No. | Spec. No. |
| | | | | | | | | | | | | | | **Nickel and Nickel Alloy — Pipes and Tubes (4a) (Cont'd)** | | | | | | |
| 23.2 | *22.7* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08020 | B729 |
| **23.2** | **23.0** | **22.9** | **22.8** | **22.6** | **22.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08825 | B163 |
| **23.2** | **23.0** | **22.9** | **22.8** | **22.6** | **22.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08825 | B423 |
| **23.2** | **23.0** | **22.9** | **22.8** | **22.6** | **22.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08825 | B474 |
| **23.2** | **23.0** | **22.9** | **22.8** | **22.6** | **22.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08825 | B704 |
| **23.2** | **23.0** | **22.9** | **22.8** | **22.6** | **22.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08825 | B705 |
| **22.0** | **21.8** | *21.7* | *20.0* | *19.5* | *18.9* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06007 | B619 |
| **22.0** | **21.8** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06007 | B622 |
| **20.1** | **19.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06030 | B619 |
| **20.1** | **19.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06030 | B622 |
| **20.1** | **19.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06030 | B626 |
| *23.3* | *23.3* | *23.3* | 16.0 | 10.6 | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06600 | B167 |
| *23.3* | *23.3* | *23.3* | 16.0 | 10.6 | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06600 | B517 |
| *23.3* | *23.3* | *23.3* | *23.3* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06690 | B163 |
| *23.3* | *23.3* | *23.3* | *23.3* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06690 | B167 |
| **22.6** | **22.4** | **22.2** | **22.1** | **22.0** | **21.9** | **21.9** | 17.9 | 14.2 | 12.3 | 9.4 | 7.6 | 6.2 | 5.0 | 4.0 | 3.2 | 2.6 | 2.0 | 1.4 | N08120 | B163 |
| **22.6** | **22.4** | **22.2** | **22.1** | **22.0** | **21.9** | **21.9** | 17.9 | 14.2 | 12.3 | 9.4 | 7.6 | 6.2 | 5.0 | 4.0 | 3.2 | 2.6 | 2.0 | 1.4 | N08120 | B407 |
| **22.6** | **22.4** | **22.2** | **22.1** | **22.0** | **21.9** | **21.9** | 17.9 | 14.2 | 12.3 | 9.4 | 7.6 | 6.2 | 5.0 | 4.0 | 3.2 | 2.6 | 2.0 | 1.4 | N08120 | B514 |
| **22.6** | **22.4** | **22.2** | **22.1** | **22.0** | **21.9** | **21.9** | 17.9 | 14.2 | 12.3 | 9.4 | 7.6 | 6.2 | 5.0 | 4.0 | 3.2 | 2.6 | 2.0 | 1.4 | N08120 | B515 |
| *26.2* | *25.8* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06455 | B619 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 | 500 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nickel and Nickel Alloy — Pipes and Tubes (4a)** | | | | | | | | | | | | | | | | | |
| 47Ni–22Cr–9Mo–18Fe | ... | B619 | ... | N06002 | Sol. ann. | ... | 43 | ... | −325 | 100 | 40 | 26.7 | *26.7* | *26.7* | *26.7* | *25.5* | *24.2* |
| 47Ni–22Cr–9Mo–18Fe | ... | B622 | ... | N06002 | Sol. ann. | ... | 43 | ... | −325 | 100 | 40 | 26.7 | *26.7* | *26.7* | *26.7* | *25.5* | *24.2* |
| 31Ni–33Fe–27Cr–6.5Mo–Cu–N | ... | B619 | ... | N08031 | Annealed | ... | 45 | ... | −325 | 94 | 40 | 26.7 | *26.7* | **26.7** | **24.7** | **23.3** | **22.2** |
| 31Ni–33Fe–27Cr–6.5Mo–Cu–N | ... | B622 | ... | N08031 | Annealed | ... | 45 | ... | −325 | 94 | 40 | 26.7 | *26.7* | **26.7** | **24.7** | **23.3** | **22.2** |
| 61Ni–16Mo–16Cr | ... | B622 | ... | N06455 | Sol. ann. | ... | 43 | ... | −325 | 100 | 40 | 26.7 | *26.7* | *26.7* | *26.7* | *26.7* | *26.7* |
| 54Ni–16Mo–15Cr | ... | B619 | ... | N10276 | Sol. ann. | ... | 43 | ... | −325 | 100 | 41 | 27.3 | *27.3* | *27.3* | *27.3* | **26.9** | **25.2** |
| 54Ni–16Mo–15Cr | ... | B622 | ... | N10276 | Sol. ann. | ... | 43 | ... | −325 | 100 | 41 | 27.3 | *27.3* | *27.3* | *27.3* | **26.9** | **25.2** |
| 54Ni–16Mo–15Cr | ... | B626 | ... | N10276 | Sol. ann. | ... | 43 | ... | −325 | 100 | 41 | 27.3 | *27.3* | *27.3* | *27.3* | **26.9** | **25.2** |
| 67Ni–30Cu | ... | B165 | ... | N04400 | Str. rel. | ... | 42 | (54) | −325 | 85 | 55 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | ... |
| 67Ni–30Cu | ... | B725 | ... | N04400 | Str. rel. | ... | 42 | (54) | −325 | 85 | 55 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | ... |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | ... | B675 | ... | N08367 | Annealed | >3/16 | 45 | ... | −325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* | **27.7** | **26.2** |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | ... | B690 | ... | N08367 | Annealed | >3/16 | 45 | ... | −325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* | **27.7** | **26.2** |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | ... | B804 | ... | N08367 | Annealed | >3/16 | 45 | ... | −325 | 95 | 45 | 30.0 | *30.0* | *29.9* | *28.6* | **27.7** | **26.2** |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | ... | B675 | ... | N08367 | Annealed | ≤3/16 | 45 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | **29.6** | **27.7** | **26.2** |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | ... | B690 | ... | N08367 | Annealed | ≤3/16 | 45 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | **29.6** | **27.7** | **26.2** |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | ... | B804 | ... | N08367 | Annealed | ≤3/16 | 45 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *29.9* | **28.6** | **27.7** | **26.2** |
| 55Ni–21Cr–13.5Mo | ... | B619 | ... | N06022 | Sol. ann. | ... | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **29.0** | **27.6** |
| 55Ni–21Cr–13.5Mo | ... | B622 | ... | N06022 | Sol. ann. | ... | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **29.0** | **27.6** |
| 58Ni–33Cr–8Mo | ... | B619 | ... | N06035 | Sol. ann. | ... | 43 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **22.2** | **20.6** | **19.7** |
| 58Ni–33Cr–8Mo | ... | B622 | ... | N06035 | Sol. ann. | ... | 43 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **22.2** | **20.6** | **19.7** |
| 58Ni–33Cr–8Mo | ... | B626 | ... | N06035 | Sol. ann. | ... | 43 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **22.2** | **20.6** | **19.7** |
| 59Ni–23Cr–16Mo | ... | B619 | ... | N06059 | Sol. ann. | ... | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **29.7** | **28.2** |
| 59Ni–23Cr–16Mo | ... | B622 | ... | N06059 | Sol. ann. | ... | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **29.7** | **28.2** |
| 59Ni–23Cr–16Mo | ... | B626 | ... | N06059 | Sol. ann. | All | 43 | ... | −325 | 100 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | **29.7** | **28.2** |
| 59Ni–23Cr–16Mo–1.6Cu | ... | B619 | ... | N06200 | Sol. ann. | All | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **28.6** | **26.9** |
| 59Ni–23Cr–16Mo–1.6Cu | ... | B622 | ... | N06200 | Sol. ann. | All | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **28.6** | **26.9** |
| 59Ni–23Cr–16Mo–1.6Cu | ... | B626 | ... | N06200 | Sol. ann. | All | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **28.6** | **26.9** |
| 62Ni–22Mo–15Cr | ... | B619 | ... | N10362 | Sol. ann. | All | 43 | ... | −325 | 105 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **28.9** | **27.7** |
| 62Ni–22Mo–15Cr | ... | B622 | ... | N10362 | Sol. ann. | All | 43 | ... | −325 | 105 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **28.9** | **27.7** |
| 62Ni–22Mo–15Cr | ... | B626 | ... | N10362 | Sol. ann. | All | 43 | ... | −325 | 105 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **28.9** | **27.7** |
| 62Ni–28Mo–5Fe | ... | B619 | ... | N10001 | Sol. ann. | ... | 44 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | *30.0* | *30.0* |
| 62Ni–28Mo–5Fe | ... | B622 | ... | N10001 | Sol. ann. | ... | 44 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | *30.0* | *30.0* |
| 65Ni–28Mo–2Fe | ... | B619 | ... | N10665 | Sol. ann. | ... | 44 | ... | −325 | 110 | 51 | 34.0 | *34.0* | *34.0* | *34.0* | *34.0* | *34.0* |
| 65Ni–28Mo–2Fe | ... | B622 | ... | N10665 | Sol. ann. | ... | 44 | ... | −325 | 110 | 51 | 34.0 | *34.0* | *34.0* | *34.0* | *34.0* | *34.0* |
| 65Ni–29.5Mo–2Fe–2Cr | ... | B619 | ... | N10675 | Sol. ann. | ... | 44 | ... | −325 | 110 | 51 | 34.0 | *34.0* | *34.0* | *34.0* | *34.0* | *34.0* |
| 65Ni–29.5Mo–2Fe–2Cr | ... | B622 | ... | N10675 | Sol. ann. | ... | 44 | ... | −325 | 110 | 51 | 34.0 | *34.0* | *34.0* | *34.0* | *34.0* | *34.0* |
| 65Ni–29.5Mo–2Fe–2Cr | ... | B626 | ... | N10675 | Sol. ann. | ... | 44 | ... | −325 | 110 | 51 | 34.0 | *34.0* | *34.0* | *34.0* | *34.0* | *34.0* |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | UNS No. or Grade | Spec. No. |
| Nickel and Nickel Alloy — Pipes and Tubes (4a) | | | | | | | | | | | | | | | | | | | | | | |
| 23.7 | 23.3 | 22.9 | 22.7 | 22.5 | 19.6 | 19.5 | 19.3 | 19.3 | 17.5 | 14.1 | 11.3 | 9.3 | 7.7 | 6.1 | 4.8 | 3.8 | 3.0 | ... | ... | ... | N06002 | B619 |
| 23.7 | 23.3 | 22.9 | 22.7 | 22.5 | 19.6 | 19.5 | 19.3 | 19.3 | 17.5 | 14.1 | 11.3 | 9.3 | 7.7 | 6.1 | 4.8 | 3.8 | 3.0 | ... | ... | ... | N06002 | B622 |
| 21.7 | 11.1 | 8.9 | 7.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08031 | B619 |
| 21.7 | 11.1 | 8.9 | 7.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08031 | B622 |
| 26.7 | 26.5 | 26.1 | 25.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06455 | B622 |
| 24.6 | 24.0 | 23.5 | 23.1 | 22.8 | 22.6 | 22.4 | 22.3 | 18.5 | 15.0 | 12.2 | 9.8 | 7.8 | ... | ... | ... | ... | ... | ... | ... | ... | N10276 | B619 |
| 24.6 | 24.0 | 23.5 | 23.1 | 22.8 | 22.6 | 22.4 | 22.3 | 18.5 | 15.0 | 12.2 | 9.8 | 7.8 | ... | ... | ... | ... | ... | ... | ... | ... | N10276 | B622 |
| 24.6 | 24.0 | 23.5 | 23.1 | 22.8 | 22.6 | 22.4 | 22.3 | 18.5 | 15.0 | 12.2 | 9.8 | 7.8 | ... | ... | ... | ... | ... | ... | ... | ... | N10276 | B626 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B165 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B725 |
| 25.6 | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08367 | B675 |
| 25.6 | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08367 | B690 |
| 25.6 | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08367 | B804 |
| 25.6 | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08367 | B675 |
| 25.6 | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08367 | B690 |
| 25.6 | 25.1 | 24.7 | 24.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08367 | B804 |
| 27.0 | 26.5 | 26.1 | 25.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06022 | B619 |
| 27.0 | 26.5 | 26.1 | 25.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06022 | B622 |
| 19.4 | 19.2 | 19.0 | 18.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06035 | B619 |
| 19.4 | 19.2 | 19.0 | 18.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06035 | B622 |
| 19.4 | 19.2 | 19.0 | 18.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06035 | B626 |
| 27.5 | 26.8 | 26.1 | 25.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06059 | B619 |
| 27.5 | 26.8 | 26.1 | 25.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06059 | B622 |
| 27.5 | 26.8 | 26.1 | 25.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06059 | B626 |
| 26.2 | 25.7 | 25.4 | 25.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06200 | B619 |
| 26.2 | 25.7 | 25.4 | 25.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06200 | B622 |
| 26.2 | 25.7 | 25.4 | 25.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06200 | B626 |
| 27.3 | 27.0 | 26.7 | 26.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10362 | B619 |
| 27.3 | 27.0 | 26.7 | 26.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10362 | B622 |
| 27.3 | 27.0 | 26.7 | 26.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10362 | B626 |
| 30.0 | 30.0 | 30.0 | 29.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10001 | B619 |
| 30.0 | 30.0 | 30.0 | 29.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10001 | B622 |
| 34.0 | 34.0 | 34.0 | 34.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10665 | B619 |
| 34.0 | 34.0 | 34.0 | 34.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10665 | B622 |
| 34.0 | 34.0 | 33.9 | 33.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10675 | B619 |
| 34.0 | 34.0 | 33.9 | 33.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10675 | B622 |
| 34.0 | 34.0 | 33.9 | 33.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10675 | B626 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 | 500 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nickel and Nickel Alloy — Pipes and Tubes (4a)** | | | | | | | | | | | | | | | | | |
| 60Ni–22Cr–9Mo–3.5Cb | ... | B444 | 1 | N06625 | Annealed | ... | 43 | (64)(70) | −325 | 120 | 60 | 40.0 | *40.0* | *39.6* | *39.2* | *38.6* | *37.8* |
| 60Ni–22Cr–9Mo–3.5Cb | ... | B705 | 1 | N06625 | Annealed | ... | 43 | (64)(70) | −325 | 120 | 60 | 40.0 | *40.0* | *39.6* | *39.2* | *38.6* | *37.8* |
| 57Ni–22Cr–14W–2Mo–La | ... | B619 | ... | N06230 | Sol. ann. | ... | 43 | ... | −325 | 110 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | *30.0* | **29.6** |
| 57Ni–22Cr–14W–2Mo–La | ... | B622 | ... | N06230 | Sol. ann. | ... | 43 | ... | −325 | 110 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | *30.0* | **29.6** |
| 57Ni–22Cr–14W–2Mo–La | ... | B626 | ... | N06230 | Sol. ann. | ... | 43 | ... | −325 | 110 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | *30.0* | **29.6** |
| 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | ... | B619 | ... | R20033 | Sol. ann. | All | 45 | ... | −325 | 109 | 55 | 36.3 | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |
| 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | ... | B622 | ... | R20033 | Sol. ann. | All | 45 | ... | −325 | 109 | 55 | 36.3 | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |
| 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | ... | B626 | ... | R20033 | Sol. ann. | All | 45 | ... | −325 | 109 | 55 | 36.3 | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |
| **Nickel and Nickel Alloy — Plates and Sheets (4a)** | | | | | | | | | | | | | | | | | |
| 99.0Ni–Low C | Plate | B162 | ... | N02201 | H.R. ann. | ... | 41 | ... | −325 | 50 | 12 | 8.0 | 7.7 | 7.5 | 7.5 | 7.5 | 7.5 |
| 99.0Ni–Low C | Plate | B162 | ... | N02201 | H.R. as R. | ... | 41 | ... | −325 | 50 | 12 | 8.0 | 7.7 | 7.5 | 7.5 | 7.5 | 7.5 |
| 99.0Ni | Plate | B162 | ... | N02200 | H.R. ann. | ... | 41 | ... | −325 | 55 | 15 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 99.0Ni | Plate | B162 | ... | N02200 | H.R. as R. | ... | 41 | ... | −325 | 55 | 20 | 13.3 | 13.3 | 13.3 | 13.3 | 13.3 | 13.3 |
| 33Ni–42Fe–21Cr | ... | B409 | ... | N08810 | Annealed | All | 45 | ... | −325 | 65 | 25 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.6 |
| 33Ni–42Fe–21Cr–Al–Ti | ... | B409 | ... | N08811 | Annealed | All | 45 | ... | −325 | 65 | 25 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 26Ni–22Cr–5Mo–Ti | ... | B620 | ... | N08320 | Sol. ann. | All | 45 | ... | −325 | 75 | 28 | 18.7 | *18.7* | *18.7* | *18.7* | *18.7* | *18.6* |
| 67Ni–30Cu | Plate | B127 | ... | N04400 | H.R. ann. | ... | 42 | ... | −325 | 70 | 28 | 18.7 | 16.4 | *15.2* | 14.7 | 14.7 | 14.7 |
| 47Ni–22Cr–19Fe–6Mo | ... | B582 | ... | N06007 | Sol. ann. | >¾ | 45 | ... | −325 | 85 | 30 | 20.0 | *20.0* | *20.0* | *20.0* | *20.0* | **19.5** |
| 33Ni–42Fe–21Cr | ... | B409 | ... | N08800 | Annealed | All | 45 | ... | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| 31Ni–31Fe–29Cr–Mo | ... | B709 | ... | N08028 | Sol. ann. | ... | 45 | ... | −325 | 73 | 31 | 20.7 | *20.7* | *20.7* | *20.7* | *20.7* | **19.5** |
| 42Ni–21.5Cr–3Mo–2.3Cu | ... | B424 | ... | N08825 | Annealed | ... | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 35Ni–35Fe–20Cr–Cb | ... | B463 | ... | N08020 | Annealed | All | 45 | ... | −325 | 80 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 40Ni–29Cr–15Fe–5Mo | ... | B582 | ... | N06030 | Sol. ann. | All | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **23.2** | **22.1** | **21.3** |
| 47Ni–22Cr–19Fe–6Mo | ... | B582 | ... | N06007 | Sol. ann. | ≤¾ | 45 | ... | −325 | 90 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *22.7* |
| 47Ni–22Cr–9Mo–18Fe | ... | B435 | ... | N06002 | H.R. sol. ann. | All | 43 | ... | −325 | 95 | 35 | 23.3 | 23.3 | 23.3 | 23.3 | 22.3 | 21.2 |
| 72Ni–15Cr–8Fe | Plate | B168 | ... | N06600 | H.R. ann. | ... | 43 | ... | −325 | 80 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 72Ni–15Cr–8Fe | Plate | B168 | ... | N06600 | H.R. as R. | ... | 43 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 58Ni–29Cr–9Fe | Plate | B168 | ... | N06690 | Annealed | ≥3/16 | 43 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 58Ni–29Cr–9Fe | Sheet | B168 | ... | N06690 | Annealed | 0.018–0.250 | 43 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 67Ni–30Cu | Plate | B127 | ... | N04400 | H.R. as R. | ... | 42 | ... | −325 | 75 | 40 | 25.0 | 25.0 | 24.7 | 23.9 | 23.4 | 23.1 |
| 37Ni–33Fe–25Cr | ... | B409 | ... | N08120 | Sol. ann. | All | 45 | ... | −325 | 90 | 40 | 26.7 | *26.7* | *26.7* | *26.7* | **25.1** | **24.4** |
| 31Ni–33Fe–27Cr–6.5Mo–Cu–N | ... | B625 | ... | N08031 | Annealed | All | 45 | ... | −325 | 94 | 40 | 26.7 | *26.7* | **26.7** | **24.7** | **23.3** | **22.2** |
| 61Ni–16Mo–16Cr | ... | B575 | ... | N06455 | Sol. ann. | All | 43 | ... | −325 | 100 | 40 | 26.7 | *26.7* | *26.7* | *26.7* | *26.7* | *26.7* |
| 54Ni–16Mo–15Cr | ... | B575 | ... | N10276 | Sol. ann. | All | 43 | ... | −325 | 100 | 41 | 27.3 | *27.3* | *27.3* | *27.3* | **26.9** | **25.2** |
| 60Ni–22Cr–9Mo–3.5Cb | Plate | B443 | 1 | N06625 | Annealed | All | 43 | (64)(70) | −325 | 110 | 55 | 36.7 | 36.7 | 36.3 | 35.9 | 35.4 | 34.7 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | UNS No. or Grade | Spec. No. |
| **Nickel and Nickel Alloy — Pipes and Tubes (4a) (Cont'd)** | | | | | | | | | | | | | | | | | | | | | | |
| *37.4* | *37.0* | 36.6 | 36.3 | *36.1* | *35.8* | *35.4* | *31.2* | *31.2* | 23.1 | 21.0 | 13.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06625 | B444 |
| *37.4* | *37.0* | *36.6* | *36.3* | *36.1* | *35.8* | *35.4* | *31.2* | *31.2* | *23.1* | *21.0* | *13.2* | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06625 | B705 |
| **29.1** | **28.7** | **28.4** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | 23.2 | 19.0 | 15.6 | 12.9 | 10.6 | 8.5 | 6.7 | 5.3 | 4.1 | 2.9 | 2.1 | 1.5 | N06230 | B619 |
| **29.1** | **28.7** | **28.4** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | 23.2 | 19.0 | 15.6 | 12.9 | 10.6 | 8.5 | 6.7 | 5.3 | 4.1 | 2.9 | 2.1 | 1.5 | N06230 | B622 |
| **29.1** | **28.7** | **28.4** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | 23.2 | 19.0 | 15.6 | 12.9 | 10.6 | 8.5 | 6.7 | 5.3 | 4.1 | 2.9 | 2.1 | 1.5 | N06230 | B626 |
| 23.5 | 23.1 | 22.9 | 22.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | R20033 | B619 |
| 23.5 | 23.1 | 22.9 | 22.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | R20033 | B622 |
| 23.5 | 23.1 | 22.9 | 22.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | R20033 | B626 |
| **Nickel and Nickel Alloy — Plates and Sheets (4a)** | | | | | | | | | | | | | | | | | | | | | | |
| 7.5 | 7.4 | 7.4 | 7.2 | 5.8 | 4.5 | 3.7 | 3.0 | 2.4 | 2.0 | 1.5 | 1.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02201 | B162 |
| 7.5 | 7.4 | 7.4 | 7.2 | 5.8 | 4.5 | 3.7 | 3.0 | 2.4 | 2.0 | 1.5 | 1.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02201 | B162 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B162 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B162 |
| 16.2 | 15.8 | 15.5 | 15.1 | 14.9 | 14.6 | 14.3 | 14.0 | 13.8 | 11.6 | 9.3 | 7.4 | 5.9 | 4.7 | 3.8 | 3.0 | 2.4 | 1.9 | 1.4 | 1.1 | 0.86 | N08810 | B409 |
| 16.1 | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0 | 13.7 | 12.9 | 10.4 | 8.3 | 6.7 | 5.4 | 4.3 | 3.4 | 2.7 | 2.2 | 1.6 | 1.2 | 0.91 | N08811 | B409 |
| *18.2* | *17.8* | **17.5** | **17.2** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08320 | B620 |
| 14.7 | 14.6 | 14.5 | 14.3 | 11.0 | 8.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B127 |
| **19.2** | **19.0** | **18.8** | **18.7** | *18.6* | *18.5* | *18.4* | *18.3* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06007 | B582 |
| *20.0* | *20.0* | *20.0* | *20.0* | 20.0 | 20.0 | 20.0 | 19.9 | 17.0 | 13.0 | 9.8 | 6.6 | 4.2 | 2.0 | 1.6 | 1.1 | 1.0 | 0.8 | ... | ... | ... | N08800 | B409 |
| **18.9** | **18.3** | **17.7** | **17.2** | **16.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08028 | B709 |
| *23.3* | *23.3* | **23.2** | **23.0** | **22.9** | **22.8** | **22.6** | **22.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08825 | B424 |
| *23.3* | *23.3* | *23.2* | 22.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08020 | B463 |
| **20.9** | **20.5** | **20.1** | **19.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06030 | B582 |
| *22.4* | *22.2* | *22.0* | *21.8* | *21.7* | *20.0* | *19.5* | *18.9* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06007 | B582 |
| 20.7 | 20.3 | 20.1 | 19.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06002 | B435 |
| *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | 16.0 | 10.6 | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06600 | B168 |
| *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *16.0* | *10.6* | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06600 | B168 |
| *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06690 | B168 |
| *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06690 | B168 |
| 22.9 | 22.7 | 20.0 | 14.5 | 8.5 | 4.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B127 |
| **23.3** | **22.9** | **22.6** | **22.4** | **22.2** | **22.1** | **22.0** | **21.9** | **21.9** | 17.9 | 14.2 | 12.3 | 9.4 | 7.6 | 6.2 | 5.0 | 4.0 | 3.2 | 2.6 | 2.0 | 1.4 | N08120 | B409 |
| **21.7** | **21.3** | **20.9** | **20.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08031 | B625 |
| *26.7* | **26.5** | **26.1** | **25.8** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06455 | B575 |
| **24.6** | **24.0** | **23.5** | **23.1** | **22.8** | **22.6** | **22.4** | **22.3** | 18.5 | 15.0 | 12.2 | 9.8 | 7.8 | ... | ... | ... | ... | ... | ... | ... | ... | N10276 | B575 |
| 34.3 | 33.9 | 33.6 | 33.3 | 33.1 | 32.8 | 32.5 | 31.2 | 31.2 | 23.1 | 21.0 | 13.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06625 | B443 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 | 500 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nickel and Nickel Alloy — Plates and Sheets (4a)** | | | | | | | | | | | | | | | | | |
| 57Ni–22Cr–14W–2Mo–La | ... | B435 | ... | N06230 | Sol. ann. | All | 43 | ... | −325 | 110 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | *30.0* | **29.6** |
| 55Ni–21Cr–13.5Mo | Sheet | B575 | ... | N06022 | Sol. ann. | $<\frac{3}{16}$ | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **29.0** | **27.6** |
| 58Ni–33Cr–8Mo | ... | B575 | ... | N06035 | Sol. ann. | All | 43 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **22.2** | **20.6** | **19.7** |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | ... | B688 | ... | N08367 | Annealed | $>\frac{3}{16}$ | 45 | ... | −325 | 95 | 45 | 30.0 | *30.0* | *29.9* | 28.6 | **27.7** | **26.2** |
| 46Fe–24Ni–21Cr–6Mo–Cu–N | ... | B688 | ... | N08367 | Annealed | $\leq\frac{3}{16}$ | 45 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | **29.6** | **27.7** | **26.2** |
| 59Ni–23Cr–16Mo | ... | B575 | ... | N06059 | Sol. ann. | All | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | 29.6 | 28.1 |
| 59Ni–23Cr–16Mo–1.6Cu | ... | B575 | ... | N06200 | Sol. ann. | All | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **28.6** | **26.9** |
| 62Ni–22Mo–15Cr | ... | B575 | ... | N10362 | Sol. ann. | All | 43 | ... | −325 | 105 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **28.9** | **27.7** |
| 62Ni–28Mo–5Fe | Plate | B333 | ... | N10001 | Sol. ann. | $\geq\frac{3}{16}$, $\leq 2\frac{1}{2}$ | 44 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | *30.0* | *30.0* |
| 62Ni–28Mo–5Fe | Sheet | B333 | ... | N10001 | Sol. ann. | $<\frac{3}{16}$ | 44 | ... | −325 | 115 | 50 | 33.3 | *33.3* | *33.3* | *33.3* | *33.3* | *33.3* |
| 65Ni–28Mo–2Fe | ... | B333 | ... | N10665 | Sol. ann. | All | 44 | ... | −325 | 110 | 51 | 34.0 | *34.0* | *34.0* | *34.0* | *34.0* | *34.0* |
| 65Ni–29.5Mo–2Fe–2Cr | ... | B333 | ... | N10675 | Sol. ann. | All | 44 | ... | −325 | 110 | 51 | 34.0 | *34.0* | *34.0* | *34.0* | *34.0* | *34.0* |
| 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | ... | B625 | ... | R20033 | Sol. ann. | All | 45 | ... | −325 | 109 | 55 | 36.3 | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |
| **Nickel and Nickel Alloy — Forgings and Fittings (4a)** | | | | | | | | | | | | | | | | | |
| 99.0Ni–Low C | ... | B160 | ... | N02201 | Annealed | All | 41 | (9)(9a) | −325 | 50 | 10 | 6.7 | 6.4 | 6.3 | 6.3 | 6.3 | 6.3 |
| 99.0Ni–Low C | ... | B366 | ... | N02201 | Annealed | All | 41 | (32)(74) | −325 | 50 | 10 | 6.7 | 6.4 | 6.3 | 6.3 | 6.3 | 6.3 |
| 99.0Ni | ... | B366 | ... | N02200 | Annealed | All | 41 | (32)(74) | −325 | 55 | 15 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 33Ni–42Fe–21Cr | ... | B564 | ... | N08810 | Annealed | ... | 45 | (9) | −325 | 65 | 25 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 33Ni–42Fe–21Cr–Al–Ti | ... | B564 | ... | N08811 | Annealed | ... | 45 | (9) | −325 | 65 | 25 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 33Ni–42Fe–21Cr | ... | B366 | ... | N08810 | Annealed | All | 45 | (9)(74) | −325 | 65 | 25 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 33Ni–42Fe–21Cr–Al–Ti | ... | B366 | ... | N08811 | Annealed | All | 45 | (9)(74) | −325 | 65 | 25 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 67Ni–30Cu | ... | B564 | ... | N04400 | Annealed | ... | 42 | (9) | −325 | 70 | 25 | 16.7 | 14.6 | 13.6 | 13.2 | 13.1 | 13.1 |
| 67Ni–30Cu | ... | B366 | ... | N04400 | Annealed | All | 42 | (32)(74) | −325 | 70 | 25 | 16.7 | 14.6 | 13.6 | 13.2 | 13.1 | 13.1 |
| 72Ni–15Cr–8Fe | ... | B366 | ... | N06600 | Annealed | All | 43 | (32)(74) | −325 | 75 | 25 | 16.7 | *16.7* | *16.7* | *16.7* | *16.7* | *16.7* |
| 40Ni–29Cr–15Fe–5Mo | ... | B366 | ... | N06030 | Sol. ann. | All | 45 | (74) | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **23.2** | **22.1** | **21.3** |
| 40Ni–29Cr–15Fe–5Mo | ... | B462 | ... | N06030 | Sol. ann. | All | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **23.2** | **22.1** | **21.3** |
| 33Ni–42Fe–21Cr | ... | B366 | ... | N08800 | C.D. ann. | All | 45 | (74) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| 33Ni–42Fe–21Cr | ... | B564 | ... | N08800 | Annealed | ... | 45 | (9) | −325 | 75 | 30 | 20.0 | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| 35Ni–35Fe–20Cr–Cb | ... | B366 | ... | N08020 | Annealed | All | 45 | (74) | −325 | 80 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | 23.3 | *23.3* |
| 35Ni–35Fe–20Cr–Cb | ... | B462 | ... | N08020 | Annealed | ... | 45 | (9) | −325 | 80 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | 23.3 | *23.3* |
| 72Ni–15Cr–8Fe | ... | B564 | ... | N06600 | Annealed | All | 43 | (9) | −325 | 80 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 42Ni–21.5Cr–3Mo–2.3Cu | ... | B366 | ... | N08825 | C.D. ann. | All | 45 | (74) | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 42Ni–21.5Cr–3Mo–2.3Cu | ... | B564 | ... | N08825 | Annealed | ... | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 58Ni–29Cr–9Fe | Forg. | B564 | ... | N06690 | Annealed | All | 43 | (9) | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | UNS No. or Grade | Spec. No. |
| **Nickel and Nickel Alloy — Plates and Sheets (4a) (Cont'd)** | | | | | | | | | | | | | | | | | | | | | | |
| **29.1** | **28.7** | **28.4** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | 23.2 | 19.0 | 15.6 | 12.9 | 10.6 | 8.5 | 6.7 | 5.3 | 4.1 | 2.9 | 2.1 | 1.5 | N06230 | B435 |
| **27.0** | **26.5** | **26.1** | **25.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06022 | B575 |
| **19.4** | **19.2** | **19.0** | **18.8** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06035 | B575 |
| **25.6** | **25.1** | **24.7** | **24.3** | **23.9** | **23.6** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08367 | B688 |
| **25.6** | **25.1** | **24.7** | **24.3** | **23.9** | **23.6** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08367 | B688 |
| 27.5 | **26.7** | **26.1** | **25.6** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06059 | B575 |
| **26.2** | **25.7** | **25.4** | **25.2** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06200 | B575 |
| **27.3** | **27.0** | **26.7** | **26.4** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10362 | B575 |
| *30.0* | *30.0* | *30.0* | **29.8** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10001 | B333 |
| *33.3* | *33.3* | *33.3* | **33.2** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10001 | B333 |
| *34.0* | *34.0* | 34.0 | 34.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10665 | B333 |
| *34.0* | *34.0* | **33.9** | **33.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10675 | B333 |
| 23.5 | 23.1 | 22.9 | 22.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | R20033 | B625 |
| **Nickel and Nickel Alloy — Forgings and Fittings (4a)** | | | | | | | | | | | | | | | | | | | | | | |
| 6.2 | 6.2 | 6.1 | 6.0 | 5.8 | 4.5 | 3.7 | 3.0 | 2.4 | 2.0 | 1.5 | 1.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02201 | B160 |
| 6.2 | 6.2 | 6.1 | 6.0 | 5.8 | 4.5 | 3.7 | 3.0 | 2.4 | 2.0 | 1.5 | 1.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02201 | B366 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B366 |
| 16.1 | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0 | 13.8 | 11.6 | 9.3 | 7.4 | 5.9 | 4.7 | 3.8 | 3.0 | 2.4 | 1.9 | 1.4 | 1.1 | 0.86 | N08810 | B564 |
| 16.1 | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0 | 13.8 | 12.9 | 10.4 | 8.3 | 6.7 | 5.4 | 4.3 | 3.4 | 2.7 | 2.2 | 1.6 | 1.2 | 0.91 | N08811 | B564 |
| 16.1 | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0 | 13.8 | 11.6 | 9.3 | 7.4 | 5.9 | 4.7 | 3.8 | 3.0 | 2.4 | 1.9 | 1.4 | 1.1 | 0.86 | N08810 | B366 |
| 16.1 | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0 | 13.8 | 12.9 | 10.4 | 8.3 | 6.7 | 5.4 | 4.3 | 3.4 | 2.7 | 2.2 | 1.6 | 1.2 | 0.91 | N08811 | B366 |
| 13.1 | 13.0 | 12.9 | 12.7 | 11.0 | 8.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B564 |
| 13.1 | 13.0 | 12.9 | 12.7 | 11.0 | 8.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B366 |
| *16.7* | *16.7* | *16.7* | *16.7* | *16.5* | *15.9* | 10.6 | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06600 | B366 |
| **20.9** | **20.5** | **20.1** | **19.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06030 | B366 |
| **20.9** | **20.5** | **20.1** | **19.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06030 | B462 |
| *20.0* | *20.0* | *20.0* | *20.0* | 20.0 | 20.0 | 20.0 | 19.9 | 17.0 | 13.0 | 9.8 | 6.6 | 4.2 | 2.0 | 1.6 | 1.1 | 1.0 | 0.8 | ... | ... | ... | N08800 | B366 |
| *20.0* | *20.0* | *20.0* | *20.0* | 20.0 | 20.0 | 20.0 | 19.9 | 17.0 | 13.0 | 9.8 | 6.6 | 4.2 | 2.0 | 1.6 | 1.1 | 1.0 | 0.8 | ... | ... | ... | N08800 | B564 |
| *23.3* | 23.3 | 23.2 | 22.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08020 | B366 |
| *23.3* | 23.3 | 23.2 | 22.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08020 | B462 |
| *23.3* | *23.3* | *23.3* | *23.3* | 23.3 | 16.0 | 10.6 | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06600 | B564 |
| *23.3* | *23.3* | **23.2** | **23.0** | **22.9** | **22.8** | **22.6** | **22.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08825 | B366 |
| *23.3* | *23.3* | **23.2** | **23.0** | **22.9** | **22.8** | **22.6** | **22.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08825 | B564 |
| *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06690 | B564 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 | 500 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nickel and Nickel Alloy — Forgings and Fittings (4a)** | | | | | | | | | | | | | | | | | |
| 37Ni–33Fe–25Cr | ... | B366 | ... | N08120 | Sol. ann. | All | 45 | ... | −325 | 90 | 40 | 26.7 | 26.7 | 26.7 | 26.7 | 25.1 | 24.4 |
| 37Ni–33Fe–25Cr | ... | B564 | ... | N08120 | Sol. ann. | All | 45 | ... | −325 | 90 | 40 | 26.7 | 26.7 | 26.7 | 26.7 | 25.1 | 24.4 |
| 47Ni–22Cr–9Mo–18Fe | ... | B366 | ... | N06002 | Sol. ann. | All | 43 | (32) | −325 | 100 | 40 | 26.7 | 26.7 | 26.7 | 26.7 | 25.5 | 24.2 |
| 31Ni–33Fe–27Cr–6.5Mo–Cu–N | ... | B366 | ... | N08031 | Sol. ann. | All | 45 | (74) | −325 | 94 | 40 | 26.7 | 26.7 | 26.7 | 24.7 | 23.3 | 22.2 |
| 31Ni–33Fe–27Cr–6.5Mo–Cu–N | ... | B564 | ... | N08031 | Annealed H.W. | All | 45 | ... | −325 | 94 | 40 | 26.7 | 26.7 | 26.7 | 24.7 | 23.3 | 22.2 |
| 54Ni–16Mo–15Cr | ... | B366 | ... | N10276 | Sol. ann. | All | 43 | (74) | −325 | 100 | 41 | 27.3 | 27.3 | 27.3 | 27.3 | 26.9 | 25.2 |
| 54Ni–16Mo–15Cr | ... | B462 | ... | N10276 | Sol. ann. | All | 43 | (9) | −325 | 100 | 41 | 27.3 | 27.3 | 27.3 | 27.3 | 26.9 | 25.2 |
| 54Ni–16Mo–15Cr | ... | B564 | ... | N10276 | Sol. ann. | All | 43 | (9) | −325 | 100 | 41 | 27.3 | 27.3 | 27.3 | 27.3 | 26.9 | 25.2 |
| 62Ni–28Mo–5Fe | ... | B366 | ... | N10001 | Sol. ann. | All | 44 | (32) | −325 | 100 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |
| 55Ni–21Cr–13.5Mo | ... | B366 | ... | N06022 | Sol. ann. | All | 43 | (32)(74) | −325 | 100 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 29.0 | 27.6 |
| 55Ni–21Cr–13.5Mo | ... | B462 | ... | N06022 | Sol. ann. | All | 43 | (9) | −325 | 100 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 27.6 |
| 55Ni–21Cr–13.5Mo | ... | B564 | ... | N06022 | Sol. ann. | All | 43 | (9) | −325 | 100 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 29.0 | 27.6 |
| 58Ni–33Cr–8Mo | ... | B366 | ... | N06035 | Sol. ann. | All | 43 | (32)(74) | −325 | 85 | 35 | 23.3 | 23.3 | 23.3 | 22.2 | 20.6 | 19.7 |
| 58Ni–33Cr–8Mo | ... | B462 | ... | N06035 | Sol. ann. | All | 43 | (9) | −325 | 85 | 35 | 23.3 | 23.3 | 23.3 | 22.2 | 20.6 | 19.7 |
| 58Ni–33Cr–8Mo | ... | B564 | ... | N06035 | Sol. ann. | All | 43 | (9) | −325 | 85 | 35 | 23.3 | 23.3 | 23.3 | 22.2 | 20.6 | 19.7 |
| 59Ni–23Cr–16Mo | ... | B366 | ... | N06059 | Sol. ann. | All | 43 | (74) | −325 | 100 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 29.7 | 28.2 |
| 59Ni–23Cr–16Mo | ... | B564 | ... | N06059 | H.W. sol. ann. | All | 43 | ... | −325 | 100 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 29.7 | 28.2 |
| 59Ni–23Cr–16Mo–1.6Cu | ... | B366 | ... | N06200 | Sol. ann. | All | 43 | (74) | −325 | 100 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 28.6 | 26.9 |
| 59Ni–23Cr–16Mo–1.6Cu | ... | B462 | ... | N06200 | Sol. ann. | All | 43 | ... | −325 | 100 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 28.6 | 26.9 |
| 59Ni–23Cr–16Mo–1.6Cu | ... | B564 | ... | N06200 | Sol. ann. | All | 43 | ... | −325 | 100 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 28.6 | 26.9 |
| 62Ni–22Mo–15Cr | ... | B366 | ... | N10362 | Sol. ann. | All | 43 | (9) | −325 | 105 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 28.9 | 27.7 |
| 62Ni–22Mo–15Cr | ... | B462 | ... | N10362 | Sol. ann. | All | 43 | (9) | −325 | 105 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 28.9 | 27.7 |
| 62Ni–22Mo–15Cr | ... | B564 | ... | N10362 | Sol. ann. | All | 43 | (9) | −325 | 105 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 28.9 | 27.7 |
| 60Ni–22Cr–9Mo–3.5Cb | ... | B564 | ... | N06625 | Annealed | ≤4 | 43 | (9)(64) | −325 | 120 | 60 | 40.0 | 40.0 | 39.6 | 39.2 | 38.6 | 37.8 |
| 65Ni–28Mo–2Fe | ... | B366 | ... | N10665 | Sol. ann. | All | 44 | (74) | −325 | 110 | 51 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |
| 65Ni–29.5Mo–2Fe–2Cr | ... | B366 | ... | N10675 | Sol. ann. | All | 44 | (74) | −325 | 110 | 51 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |
| 65Ni–29.5Mo–2Fe–2Cr | ... | B462 | ... | N10675 | Sol. ann. | All | 44 | ... | −325 | 110 | 51 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |
| 65Ni–29.5Mo–2Fe–2Cr | ... | B564 | ... | N10675 | Sol. ann. | All | 44 | ... | −325 | 110 | 51 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |
| 57Ni–22Cr–14W–2Mo–La | ... | B564 | ... | N06230 | Sol. ann. | All | 43 | ... | −325 | 110 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 29.6 |
| 57Ni–22Cr–14W–2Mo–La | ... | B366 | ... | N06230 | Sol. ann. | All | 43 | (74) | −325 | 110 | 45 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 29.6 |
| 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | ... | B366 | ... | R20033 | Sol. ann. | All | 45 | ... | −325 | 109 | 55 | 36.3 | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |
| 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | ... | B462 | ... | R20033 | Sol. ann. | All | 45 | ... | −325 | 109 | 55 | 36.3 | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |
| 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | ... | B564 | ... | R20033 | Sol. ann. | All | 45 | ... | −325 | 109 | 55 | 36.3 | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

**Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)]**

**Nickel and Nickel Alloy — Forgings and Fittings (4a) (Cont'd)**

| 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | UNS No. or Grade | Spec. No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **23.3** | **22.9** | **22.6** | **22.4** | **22.2** | **22.1** | **22.0** | **21.9** | **21.9** | 17.9 | 14.2 | 12.3 | 9.4 | 7.6 | 6.2 | 5.0 | 4.0 | 3.2 | 2.6 | 2.0 | 1.4 | N08120 | B366 |
| **23.3** | **22.9** | **22.6** | **22.4** | **22.2** | **22.1** | **22.0** | **21.9** | **21.9** | 17.9 | 14.2 | 12.3 | 9.4 | 7.6 | 6.2 | 5.0 | 4.0 | 3.2 | 2.6 | 2.0 | 1.4 | N08120 | B564 |
| *23.7* | *23.3* | *22.9* | *22.7* | *22.5* | *19.6* | *19.5* | *19.3* | *19.3* | *17.5* | 14.1 | 11.3 | 9.3 | 7.7 | 6.1 | 4.8 | 3.8 | 3.0 | ... | ... | ... | N06002 | B366 |
| **21.7** | **21.3** | **20.9** | **20.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08031 | B366 |
| **21.7** | **21.3** | **20.9** | **20.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08031 | B564 |
| **24.6** | **24.0** | **23.5** | **23.1** | **22.8** | **22.6** | **22.4** | **22.3** | 18.5 | 15.0 | 12.2 | 9.8 | 7.8 | ... | ... | ... | ... | ... | ... | ... | ... | N10276 | B366 |
| **24.6** | **24.0** | **23.5** | **23.1** | **22.8** | **22.6** | **22.4** | **22.3** | 18.5 | 15.0 | 12.2 | 9.8 | 7.8 | ... | ... | ... | ... | ... | ... | ... | ... | N10276 | B462 |
| **24.6** | **24.0** | **23.5** | **23.1** | **22.8** | **22.6** | **22.4** | **22.3** | 18.5 | 15.0 | 12.2 | 9.8 | 7.8 | ... | ... | ... | ... | ... | ... | ... | ... | N10276 | B564 |
| *30.0* | *30.0* | *30.0* | *29.9* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10001 | B366 |
| **27.0** | **26.5** | **26.1** | **25.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06022 | B366 |
| **27.0** | **26.5** | **26.1** | **25.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06022 | B462 |
| **27.0** | **26.5** | **26.1** | **25.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06022 | B564 |
| **19.4** | **19.2** | **19.0** | **18.8** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06035 | B366 |
| **19.4** | **19.2** | **19.0** | **18.8** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06035 | B462 |
| **19.4** | **19.2** | **19.0** | **18.8** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06035 | B564 |
| **27.5** | **26.8** | **26.1** | **25.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06059 | B366 |
| **27.5** | **26.8** | **26.1** | **25.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06059 | B564 |
| **26.2** | **25.7** | **25.4** | **25.2** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06200 | B366 |
| **26.2** | **25.7** | **25.4** | **25.2** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06200 | B462 |
| **26.2** | **25.7** | **25.4** | **25.2** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06200 | B564 |
| **27.3** | **27.0** | **26.7** | **26.4** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10362 | B366 |
| **27.3** | **27.0** | **26.7** | **26.4** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10362 | B462 |
| **27.3** | **27.0** | **26.7** | **26.4** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10362 | B564 |
| **37.4** | 37.0 | 36.6 | 36.3 | 36.1 | 35.8 | 35.4 | 31.2 | 31.2 | 23.1 | 21.0 | 13.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06625 | B564 |
| *34.0* | *34.0* | *34.0* | *34.0* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10665 | B366 |
| *34.0* | *34.0* | **33.9** | **33.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10675 | B366 |
| *34.0* | *34.0* | **33.9** | **33.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10675 | B462 |
| *34.0* | *34.0* | **33.9** | **33.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10675 | B564 |
| **29.1** | **28.7** | **28.4** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | 23.2 | 19.0 | 15.6 | 12.9 | 10.6 | 8.5 | 6.7 | 5.3 | 4.1 | 2.9 | 2.1 | 1.5 | N06230 | B564 |
| **29.1** | **28.7** | **28.4** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | 23.2 | 19.0 | 15.6 | 12.9 | 10.6 | 8.5 | 6.7 | 5.3 | 4.1 | 2.9 | 2.1 | 1.5 | N06230 | B366 |
| 23.5 | 23.1 | 22.9 | 22.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | R20033 | B366 |
| 23.5 | 23.1 | 22.9 | 22.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | R20033 | B462 |
| 23.5 | 23.1 | 22.9 | 22.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | R20033 | B564 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | | | | | | | | | | Specified Min. Strength, ksi | | Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Tensile | Yield | Min. Temp. to 100 | 200 | 300 | 400 | 500 | 600 |
| **Nickel and Nickel Alloy — Rod and Bar (4a)** | | | | | | | | | | | | | | | | | |
| 99.0Ni | ... | B160 | ... | N02200 | H.W. | All | 41 | (9) | −325 | 60 | 15 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 99.0Ni | ... | B160 | ... | N02200 | Annealed | All | 41 | (9) | −325 | 55 | 15 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 67Ni–30Cu | ... | B164 | ... | N04400 | Ann. forg. | All | 42 | (13) | −325 | 70 | 25 | 16.7 | 14.6 | 13.6 | 13.2 | 13.1 | 13.1 |
| 33Ni–42Fe–21Cr | Bar | B408 | ... | N08810 | Sol. tr. or ann. | ... | 45 | ... | −325 | 65 | 25 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 33Ni–42Fe–21Cr–Al–Ti | Bar | B408 | ... | N08811 | Sol. tr. or ann. | ... | 45 | ... | −325 | 65 | 25 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 33Ni–42Fe–21Cr | Bar | B408 | ... | N08800 | H.F. | ... | 45 | ... | −325 | 75 | 30 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 26Ni–22Cr–5Mo–Ti | ... | B621 | ... | N08320 | Sol. ann. | All | 45 | ... | −325 | 75 | 28 | 18.7 | *18.7* | *18.7* | *18.7* | *18.7* | *18.6* |
| 47Ni–22Cr–19Fe–6Mo | ... | B581 | ... | N06007 | Sol. ann. | >3/4 | 45 | ... | −325 | 85 | 30 | 20.0 | *20.0* | *20.0* | *20.0* | *20.0* | **19.5** |
| 42Ni–21.5Cr–3Mo–2.3Cu | ... | B425 | ... | N08825 | Annealed | ... | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 58Ni–29Cr–9Fe | Bar | B166 | ... | N06690 | H.R. | >3 | 43 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 58Ni–29Cr–9Fe | Bar | B166 | ... | N06690 | H.R or C.D. ann. | All | 43 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* |
| 47Ni–22Cr–19Fe–6Mo | ... | B581 | ... | N06007 | Sol. ann. | ≤3/4 | 45 | ... | −325 | 90 | 35 | 23.3 | *23.3* | *23.3* | *23.3* | *23.3* | **22.7** |
| 40Ni–29Cr–15Fe–5Mo | ... | B581 | ... | N06030 | Sol. ann. | All | 45 | ... | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **23.2** | **22.1** | **21.3** |
| 37Ni–33Fe–25Cr | ... | B408 | ... | N08120 | Sol. ann. | All | 45 | ... | −325 | 90 | 40 | 26.7 | *26.7* | *26.7* | *26.7* | **25.1** | **24.4** |
| 31Ni–33Fe–27Cr–6.5Mo–Cu–N | ... | B649 | ... | N08031 | Annealed | All | 45 | ... | −325 | 94 | 40 | 26.7 | *26.7* | *26.7* | *24.7* | **23.3** | **22.2** |
| 67Ni–30Cu | ... | B164 | ... | N04400 | H.W. | All except hex. >2 1/8 | 42 | ... | −325 | 80 | 40 | 26.7 | 25.8 | 24.8 | 23.9 | 23.4 | 23.1 |
| 58Ni–33Cr–8Mo | ... | B574 | ... | N06035 | Sol. ann. | All | 43 | (9) | −325 | 85 | 35 | 23.3 | *23.3* | *23.3* | **22.2** | **20.6** | **19.7** |
| 61Ni–16Mo–16Cr | ... | B574 | ... | N06455 | Sol. ann. | All | 43 | (9) | −325 | 100 | 40 | 26.7 | *26.7* | *26.7* | *26.7* | *26.7* | *26.7* |
| 54Ni–16Mo–15Cr | ... | B574 | ... | N10276 | Sol. ann. | All | 43 | ... | −325 | 100 | 41 | 27.3 | *27.3* | *27.3* | *27.3* | **26.9** | **25.2** |
| 62Ni–22Mo–15Cr | ... | B574 | ... | N10362 | Sol. ann. | All | 43 | (9) | −325 | 105 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **28.9** | **27.7** |
| 60Ni–22Cr–9Mo–3.5Cb | ... | B446 | 1 | N06625 | Annealed | >4 to 10 | 43 | (9)(64) (70) | −325 | 110 | 50 | 33.3 | *33.3* | *33.3* | *33.3* | 33.3 | 33.3 |
| 60Ni–22Cr–9Mo–3.5Cb | ... | B446 | 1 | N06625 | Annealed | ≤4 | 43 | (9)(64) (70) | −325 | 120 | 60 | 40.0 | *40.0* | *40.0* | *40.0* | **38.3** | **38.0** |
| 57Ni–22Cr–14W–2Mo–La | ... | B572 | ... | N06230 | Sol. ann. | All | 43 | ... | −325 | 110 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | *30.0* | **29.6** |
| 59Ni–23Cr–16Mo | ... | B574 | ... | N06059 | Sol. ann. | All | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **29.7** | **28.2** |
| 59Ni–23Cr–16Mo–1.6Cu | ... | B574 | ... | N06200 | Sol. ann. | All | 43 | ... | −325 | 100 | 45 | 30.0 | *30.0* | *30.0* | *30.0* | **28.6** | **26.9** |
| 65Ni–29.5Mo–2Fe–2Cr | ... | B335 | ... | N10675 | Sol. ann. | All | 44 | ... | −325 | 110 | 51 | 34.0 | *34.0* | *34.0* | *34.0* | *34.0* | *34.0* |
| 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | ... | B649 | ... | R20033 | Sol. ann. | All | 45 | ... | −325 | 109 | 55 | 36.3 | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | UNS No. or Grade | Spec. No. |
| | | | | | | | | | | | | | | | | | | | | | Nickel and Nickel Alloy — Rod and Bar (4a) | |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B160 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B160 |
| 13.1 | 13.0 | 12.9 | 12.7 | 11.0 | 8.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B164 |
| 16.1 | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0 | 13.8 | 11.6 | 9.3 | 7.4 | 5.9 | 4.7 | 3.8 | 3.0 | 2.4 | 1.9 | 1.4 | 1.1 | 0.86 | N08810 | B408 |
| 16.1 | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0 | 13.7 | 12.9 | 10.4 | 8.3 | 6.7 | 5.4 | 4.3 | 3.4 | 2.7 | 2.2 | 1.6 | 1.2 | 0.91 | N08811 | B408 |
| 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 19.9 | 17.0 | 13.0 | 9.8 | 6.6 | 4.2 | 2.0 | 1.6 | 1.1 | 1.0 | 0.8 | ... | ... | ... | N08800 | B408 |
| *18.2* | *17.8* | *17.5* | *17.2* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08320 | B621 |
| **19.2** | **19.0** | 18.8 | **18.7** | 18.6 | 18.5 | 18.4 | 18.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06007 | B581 |
| *23.3* | *23.3* | **23.2** | **23.0** | **22.9** | **22.8** | **22.6** | **22.3** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08825 | B425 |
| *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06690 | B166 |
| *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | *23.3* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06690 | B166 |
| **22.4** | *22.2* | *22.0* | *21.8* | *21.7* | *20.0* | *19.5* | *18.9* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06007 | B581 |
| **20.9** | **20.5** | **20.1** | **19.7** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06030 | B581 |
| **23.3** | **22.9** | **22.6** | **22.4** | **22.2** | **22.1** | **22.0** | **21.9** | **21.9** | 17.9 | 14.2 | 12.3 | 9.4 | 7.6 | 6.2 | 5.0 | 4.0 | 3.2 | 2.6 | 2.0 | 1.4 | N08120 | B408 |
| **21.7** | **21.3** | **20.9** | **20.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N08031 | B649 |
| 22.9 | 22.7 | 20.0 | 14.5 | 8.5 | 4.0 | 1.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B164 |
| **19.4** | **19.2** | **19.0** | **18.8** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06035 | B574 |
| *26.7* | *26.5* | *26.1* | *25.8* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06455 | B574 |
| **24.6** | **24.0** | **23.5** | **23.1** | **22.8** | **22.6** | **22.4** | **22.3** | 18.5 | 15.0 | 12.2 | 9.8 | 7.8 | ... | ... | ... | ... | ... | ... | ... | ... | N10276 | B574 |
| **27.3** | **27.0** | **26.7** | **26.4** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10362 | B574 |
| 33.3 | 33.3 | 33.3 | 33.3 | 33.1 | 32.8 | 32.5 | 31.2 | 31.2 | 23.1 | 21.0 | 13.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06625 | B446 |
| 37.7 | 37.4 | 37.4 | 37.4 | 37.4 | 37.4 | 37.4 | 37.4 | 37.4 | 37.4 | 27.7 | 21.0 | 13.2 | ... | ... | ... | ... | ... | ... | ... | ... | N06625 | B446 |
| **29.1** | **28.7** | **28.4** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | **28.2** | 23.2 | 19.0 | 15.6 | 12.9 | 10.6 | 8.5 | 6.7 | 5.3 | 4.1 | 2.9 | 2.1 | 1.5 | N06230 | B572 |
| **27.5** | **26.8** | **26.1** | **25.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06059 | B574 |
| **26.2** | **25.7** | **25.4** | **25.2** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06200 | B574 |
| *34.0* | *34.0* | **33.9** | **33.5** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10675 | B335 |
| 23.5 | 23.1 | 22.9 | 22.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | R20033 | B649 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 | 500 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nickel and Nickel Alloy — Castings (4a)** | | | | | | | | | | | | | | | | | |
| 53Ni–17Mo–16Cr–6Fe–5W | ... | A494 | CW12MW | N30002 | ... | ... | ... | (9)(44) | −325 | 72 | 40 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| 56Ni–19Mo–18Cr–2Fe | ... | A494 | CW6M | N30107 | ... | ... | ... | (9) | −325 | 72 | 40 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| 59Ni–22Cr–14Mo–4Fe–3W | ... | A494 | CX2MW | N26022 | Sol. ann. | ... | 43 | (9) | −325 | 80 | 45 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | ... |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | UNS No. or Grade | Spec. No. |
| **Nickel and Nickel Alloy — Castings (4a)** | | | | | | | | | | | | | | | | | | | | | | |
| 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 22.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CW12MW | A494 |
| 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 22.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CW6M | A494 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | CX2MW | A494 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi Tensile | Specified Min. Strength, ksi Yield |
|---|---|---|---|---|---|---|---|---|---|---|
| **Titanium and Titanium Alloy — Pipes and Tubes** | | | | | | | | | | |
| Ti | Smls. & wld. tube | B338 | 1 | R50250 | Annealed | 51 | ... | −75 | 35 | 20 |
| Ti | Smls. pipe | B861 | 1 | R50250 | Annealed | 51 | ... | −75 | 35 | 20 |
| Ti | Wld. pipe | B862 | 1 | R50250 | Annealed | 51 | ... | −75 | 35 | 20 |
| Ti | Smls. & wld. tube | B338 | 2 | R50400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti | Smls. pipe | B861 | 2 | R50400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti | Wld. pipe | B862 | 2 | R50400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti | Smls. & wld. tube | B338 | 3 | R50550 | Annealed | 52 | ... | −75 | 65 | 55 |
| Ti | Smls. pipe | B861 | 3 | R50550 | Annealed | 52 | ... | −75 | 65 | 55 |
| Ti | Wld. pipe | B862 | 3 | R50550 | Annealed | 52 | ... | −75 | 65 | 55 |
| Ti–Pd | Smls. & wld. tube | B338 | 7 | R52400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti–Pd | Smls. pipe | B861 | 7 | R52400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti–Pd | Wld. pipe | B862 | 7 | R52400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti–0.3Mo–0.8Ni | Smls. & wld. tube | B338 | 12 | R53400 | Annealed | 52 | ... | −75 | 70 | 50 |
| Ti–0.3Mo–0.8Ni | Smls. pipe | B861 | 12 | R53400 | Annealed | 52 | ... | −75 | 70 | 50 |
| Ti–0.3Mo–0.8Ni | Wld. pipe | B862 | 12 | R53400 | Annealed | 52 | ... | −75 | 70 | 50 |
| **Titanium and Titanium Alloy — Plates, Sheets, and Strips** | | | | | | | | | | |
| Ti | ... | B265 | 1 | R50250 | Annealed | 51 | ... | −75 | 35 | 20 |
| Ti | ... | B265 | 2 | R50400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti | ... | B265 | 3 | R50550 | Annealed | 52 | ... | −75 | 65 | 55 |
| Ti–Pd | ... | B265 | 7 | R52400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti–0.3Mo–0.8Ni | ... | B265 | 12 | R53400 | Annealed | 52 | ... | −75 | 70 | 50 |
| **Titanium and Titanium Alloy — Forgings and Fittings** | | | | | | | | | | |
| Ti | Fittings | B363 | WPT1 | R50250 | Annealed | 51 | ... | −75 | 35 | 20 |
| Ti | Forgings | B381 | F-1 | R50250 | Annealed | 51 | ... | −75 | 35 | 20 |
| Ti | Fittings | B363 | WPT2 | R50400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti | Forgings | B381 | F-2 | R50400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti | Fittings | B363 | WPT3 | R50550 | Annealed | 52 | ... | −75 | 65 | 55 |
| Ti | Forgings | B381 | F-3 | R50550 | Annealed | 52 | ... | −75 | 65 | 55 |
| Ti–Pd | Fittings | B363 | WPT7 | R52400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti–Pd | Forgings | B381 | F-7 | R52400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti–0.3Mo–0.8Ni | Fittings | B363 | WPT12 | R53400 | Annealed | 52 | ... | −75 | 70 | 50 |
| Ti–0.3Mo–0.8Ni | Forgings | B381 | F-12 | R53400 | Annealed | 52 | ... | −75 | 70 | 50 |
| **Titanium and Titanium Alloy — Bars** | | | | | | | | | | |
| Ti | ... | B348 | 1 | R50250 | Annealed | 51 | ... | −75 | 35 | 20 |
| Ti | ... | B348 | 2 | R50400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti | ... | B348 | 3 | R50550 | Annealed | 52 | ... | −75 | 65 | 55 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Min. Temp. to 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 | UNS No. | Spec. No. |
| | | | | | | | | | | | | | | **Titanium and Titanium Alloy — Pipes and Tubes** |
| 11.7 | 10.7 | 9.3 | 8.2 | 7.2 | 6.3 | 5.5 | 4.7 | 4.2 | 3.8 | 3.5 | ... | ... | R50250 | B338 |
| 11.7 | 10.7 | 9.3 | 8.2 | 7.2 | 6.3 | 5.5 | 4.7 | 4.2 | 3.8 | 3.5 | ... | ... | R50250 | B861 |
| 11.7 | 10.7 | 9.3 | 8.2 | 7.2 | 6.3 | 5.5 | 4.7 | 4.2 | 3.8 | 3.5 | ... | ... | R50250 | B862 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R50400 | B338 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R50400 | B861 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R50400 | B862 |
| 21.7 | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9 | 9.3 | 8.6 | ... | ... | R50550 | B338 |
| 21.7 | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9 | 9.3 | 8.6 | ... | ... | R50550 | B861 |
| 21.7 | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9 | 9.3 | 8.6 | ... | ... | R50550 | B862 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R52400 | B338 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R52400 | B861 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R52400 | B862 |
| 23.3 | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400 | B338 |
| 23.3 | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400 | B861 |
| 23.3 | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400 | B862 |
| | | | | | | | | | | | | | | **Titanium and Titanium Alloy — Plates, Sheets, and Strips** |
| 11.7 | 10.7 | 9.3 | 8.2 | 7.2 | 6.3 | 5.5 | 4.7 | 4.2 | 3.8 | 3.5 | ... | ... | R50250 | B265 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R50400 | B265 |
| 21.7 | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9 | 9.3 | 8.6 | ... | ... | R50550 | B265 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R52400 | B265 |
| 23.3 | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400 | B265 |
| | | | | | | | | | | | | | | **Titanium and Titanium Alloy — Forgings and Fittings** |
| 11.7 | 10.7 | 9.3 | 8.2 | 7.2 | 6.3 | 5.5 | 4.7 | 4.2 | 3.8 | 3.5 | ... | ... | R50250 | B363 |
| 11.7 | 10.7 | 9.3 | 8.2 | 7.2 | 6.3 | 5.5 | 4.7 | 4.2 | 3.8 | 3.5 | ... | ... | R50250 | B381 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R50400 | B363 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R50400 | B381 |
| 21.7 | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9 | 9.3 | 8.6 | ... | ... | R50550 | B363 |
| 21.7 | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9 | 9.3 | 8.6 | ... | ... | R50550 | B381 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R52400 | B363 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R52400 | B381 |
| 23.3 | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400 | B363 |
| 23.3 | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400 | B381 |
| | | | | | | | | | | | | | | **Titanium and Titanium Alloy — Bars** |
| 11.7 | 10.7 | 9.3 | 8.2 | 7.2 | 6.3 | 5.5 | 4.7 | 4.2 | 3.8 | 3.5 | ... | ... | R50250 | B348 |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R50400 | B348 |
| 21.7 | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9 | 9.3 | 8.6 | ... | ... | R50550 | B348 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield |
|---|---|---|---|---|---|---|---|---|---|---|
| **Titanium and Titanium Alloy — Bars** | | | | | | | | | | |
| Ti–Pd | ... | B348 | 7 | R52400 | Annealed | 51 | ... | −75 | 50 | 40 |
| Ti–0.3Mo–0.8Ni | ... | B348 | 12 | R53400 | Annealed | 52 | ... | −75 | 70 | 50 |
| **Titanium and Titanium Alloy — Castings** | | | | | | | | | | |
| Ti | ... | B367 | C-2 | R52550 | ... | 51 | (14)(44) | −75 | 50 | 40 |
| Ti | ... | B367 | C-3 | R52550 | ... | 52 | (14)(44) | −75 | 65 | 55 |
| Ti–Pd | ... | B367 | C-7 | R52700 | ... | 51 | (14)(44) | −75 | 50 | 40 |
| **Zirconium and Zirconium Alloy — Pipes and Tubes** | | | | | | | | | | |
| 99.2Zr | | B523 | ... | R60702 | | 61 | ... | −75 | 55 | 30 |
| 99.2Zr | | B658 | ... | R60702 | | 61 | ... | −75 | 55 | 30 |
| 95.5Zr + 2.5Cb | | B523 | ... | R60705 | | 62 | (73) | −75 | 80 | 55 |
| 95.5Zr + 2.5Cb | | B658 | ... | R60705 | | 62 | (73) | −75 | 80 | 55 |
| **Zirconium and Zirconium Alloy — Plates and Sheets** | | | | | | | | | | |
| 99.2Zr | | B551 | ... | R60702 | | 61 | ... | −75 | 55 | 30 |
| 95.5Zr + 2.5Cb | | B551 | ... | R60705 | | 62 | (73) | −75 | 80 | 55 |
| **Zirconium and Zirconium Alloy — Forgings and Bar** | | | | | | | | | | |
| 99.2Zr | | B493 | ... | R60702 | | 61 | ... | −75 | 55 | 30 |
| 99.2Zr | | B550 | ... | R60702 | | 61 | ... | −75 | 55 | 30 |
| 95.5Zr + 2.5Cb | | B493 | ... | R60705 | | 62 | (73) | −75 | 70 | 55 |
| 95.5Zr + 2.5Cb | | B550 | ... | R60705 | | 62 | (73) | −75 | 80 | 55 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Min. Temp. to 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 | UNS No. | Spec. No. |
| **Titanium and Titanium Alloy — Bars (Cont'd)** | | | | | | | | | | | | | | |
| 16.7 | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6 | 8.9 | 8.2 | 7.6 | ... | ... | R52400 | B348 |
| 23.3 | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400 | B348 |
| **Titanium and Titanium Alloy — Castings** | | | | | | | | | | | | | | |
| 16.7 | 15.2 | 13.8 | 12.6 | 11.4 | 10.4 | 9.5 | 8.7 | 7.9 | ... | ... | ... | ... | R52550 | B367 |
| 21.7 | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9 | ... | ... | ... | ... | R52550 | B367 |
| 16.7 | 15.2 | 13.8 | 12.6 | 11.4 | 10.4 | 9.5 | 8.7 | 7.9 | ... | ... | ... | ... | R52700 | B367 |
| **Zirconium and Zirconium Alloy — Pipes and Tubes** | | | | | | | | | | | | | | |
| 18.3 | 17.2 | 15.4 | 13.6 | 12.0 | 10.6 | 9.3 | 8.3 | 7.4 | 6.6 | 6.0 | 5.6 | 5.2 | R60702 | B523 |
| 18.3 | 17.2 | 15.4 | 13.6 | 12.0 | 10.6 | 9.3 | 8.3 | 7.4 | 6.6 | 6.0 | 5.6 | 5.2 | R60702 | B658 |
| 26.7 | 24.4 | 22.1 | 20.4 | 18.9 | 17.7 | 16.7 | 15.8 | 15.0 | 14.4 | 13.9 | 13.5 | 13.2 | R60705 | B523 |
| 26.7 | 24.4 | 22.1 | 20.4 | 18.9 | 17.7 | 16.7 | 15.8 | 15.0 | 14.4 | 13.9 | 13.5 | 13.2 | R60705 | B658 |
| **Zirconium and Zirconium Alloy — Plates and Sheets** | | | | | | | | | | | | | | |
| 18.3 | 17.2 | 15.4 | 13.6 | 12.0 | 10.6 | 9.3 | 8.3 | 7.4 | 6.6 | 6.0 | 5.6 | 5.2 | R60702 | B551 |
| 26.7 | 24.4 | 22.1 | 20.4 | 18.9 | 17.7 | 16.7 | 15.8 | 15.0 | 14.4 | 13.9 | 13.5 | 13.2 | R60705 | B551 |
| **Zirconium and Zirconium Alloy — Forgings and Bar** | | | | | | | | | | | | | | |
| 18.3 | 17.2 | 15.4 | 13.6 | 12.0 | 10.6 | 9.3 | 8.3 | 7.4 | 6.6 | 6.0 | 5.6 | 5.2 | R60702 | B493 |
| 18.3 | 17.2 | 15.4 | 13.6 | 12.0 | 10.6 | 9.3 | 8.3 | 7.4 | 6.6 | 6.0 | 5.6 | 5.2 | R60702 | B550 |
| 26.7 | 24.4 | 22.1 | 20.4 | 18.9 | 17.7 | 16.7 | 15.8 | 15.0 | 14.4 | 13.9 | 13.5 | 13.2 | R60705 | B493 |
| 26.7 | 24.4 | 22.1 | 20.4 | 18.9 | 17.7 | 16.7 | 15.8 | 15.0 | 14.4 | 13.9 | 13.5 | 13.2 | R60705 | B550 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size or Thickness Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 150 | 200 | 250 | 300 | 350 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aluminum Alloy — Seamless Pipes and Tubes** | | | | | | | | | | | | | | | | | |
| Al–Mn–Cu | B210 | Alclad 3003 | A83003 | O | ... | 21 | (14)(33) | −452 | 13 | 4.5 | 3.0 | 2.9 | 2.8 | 2.7 | 2.5 | 1.9 | 1.5 |
| Al–Mn–Cu | B210 | Alclad 3003 | A83003 | H112 | ... | 21 | (14)(33) | −452 | 13 | 4.5 | 3.0 | 2.9 | 2.8 | 2.7 | 2.5 | 1.9 | 1.5 |
| Al–Mn–Cu | B241 | Alclad 3003 | A83003 | O | ... | 21 | (14)(33) | −452 | 13 | 4.5 | 3.0 | 2.9 | 2.8 | 2.7 | 2.5 | 1.9 | 1.5 |
| Al–Mn–Cu | B241 | Alclad 3003 | A83003 | H112 | ... | 21 | (14)(33) | −452 | 13 | 4.5 | 3.0 | 2.9 | 2.8 | 2.7 | 2.5 | 1.9 | 1.5 |
| Al–Mn–Cu | B210 | Alclad 3003 | A83003 | H14 | ... | 21 | (14)(33) | −452 | 19 | 16 | 6.3 | 6.3 | 6.3 | 6.1 | 4.3 | 3.0 | 2.3 |
| Al–Mn–Cu | B210 | Alclad 3003 | A83003 | H18 | ... | 21 | (14)(33) | −452 | 26 | 23 | 8.7 | 8.7 | 8.7 | 8.4 | 4.3 | 3.0 | 2.3 |
| 99.60Al | B210 | 1060 | A91060 | O | ... | 21 | (14)(33) | −452 | 8.5 | 2.5 | 1.7 | 1.7 | 1.6 | 1.4 | 1.2 | 1.1 | 0.8 |
| 99.60Al | B210 | 1060 | A91060 | H112 | ... | 21 | (14)(33) | −452 | 8.5 | 2.5 | 1.7 | 1.7 | 1.6 | 1.4 | 1.2 | 1.1 | 0.8 |
| 99.60Al | B210 | 1060 | A91060 | H113 | ... | 21 | (14)(33) | −452 | 8.5 | 2.5 | 1.7 | 1.7 | 1.6 | 1.4 | 1.2 | 1.1 | 0.8 |
| 99.60Al | B241 | 1060 | A91060 | O | ... | 21 | (14)(33) | −452 | 8.5 | 2.5 | 1.7 | 1.7 | 1.6 | 1.4 | 1.2 | 1.1 | 0.8 |
| 99.60Al | B241 | 1060 | A91060 | H112 | ... | 21 | (14)(33) | −452 | 8.5 | 2.5 | 1.7 | 1.7 | 1.6 | 1.4 | 1.2 | 1.1 | 0.8 |
| 99.60Al | B241 | 1060 | A91060 | H113 | ... | 21 | (14)(33) | −452 | 8.5 | 2.5 | 1.7 | 1.7 | 1.6 | 1.4 | 1.2 | 1.1 | 0.8 |
| 99.60Al | B210 | 1060 | A91060 | H14 | ... | 21 | (14)(33) | −452 | 12 | 10 | 4.0 | 4.0 | 4.0 | 4.0 | 2.7 | 1.8 | 1.1 |
| 99.0Al–Cu | B241 | 1100 | A91100 | O | ... | 21 | (14)(33) | −452 | 11 | 3 | 2.0 | 2.0 | 2.0 | 1.9 | 1.7 | 1.3 | 1.0 |
| 99.0Al–Cu | B241 | 1100 | A91100 | H112 | ... | 21 | (14)(33) | −452 | 11 | 3 | 2.0 | 2.0 | 2.0 | 1.9 | 1.7 | 1.3 | 1.0 |
| 99.0Al–Cu | B210 | 1100 | A91100 | H113 | ... | 21 | (14)(33) | −452 | 11 | 3.5 | 2.3 | 2.3 | 2.3 | 2.3 | 1.7 | 1.3 | 1.0 |
| 99.0Al–Cu | B210 | 1100 | A91100 | H14 | ... | 21 | (14)(33) | −452 | 16 | 14 | 5.3 | 5.3 | 5.3 | 4.9 | 2.8 | 1.9 | 1.1 |
| Al–Mn–Cu | B210 | 3003 | A93003 | O | ... | 21 | (14)(33) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B210 | 3003 | A93003 | H112 | ... | 21 | (14)(33) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B241 | 3003 | A93003 | O | ... | 21 | (14)(33) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B241 | 3003 | A93003 | H112 | ... | 21 | (14)(33) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B491 | 3003 | A93003 | O | ... | 21 | (14)(33) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B491 | 3003 | A93003 | H112 | ... | 21 | (14)(33) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B210 | 3003 | A93003 | H14 | ... | 21 | (14)(33) | −452 | 20 | 17 | 6.7 | 6.7 | 6.5 | 4.8 | 4.3 | 3.0 | 2.3 |
| Al–Mn–Cu | B210 | 3003 | A93003 | H18 | ... | 21 | (14)(33) | −452 | 27 | 24 | 9.0 | 9.0 | 8.7 | 8.0 | 5.3 | 3.5 | 2.5 |
| Al–Mn–Cu | B241 | 3003 | A93003 | H18 | ... | 21 | (14)(33) | −452 | 27 | 24 | 9.0 | 9.0 | 8.7 | 8.0 | 5.3 | 3.5 | 2.5 |
| Al–2.5Mg | B210 | 5052 | A95052 | O | ... | 22 | (14) | −452 | 25 | 10 | 6.7 | 6.7 | 6.7 | 6.6 | 6.1 | 4.1 | 2.3 |
| Al–2.5Mg | B241 | 5052 | A95052 | O | ... | 22 | (14) | −452 | 25 | 10 | 6.7 | 6.7 | 6.7 | 6.6 | 6.1 | 4.1 | 2.3 |
| Al–2.5Mg | B210 | 5052 | A95052 | H32 | ... | 22 | (14)(33) | −452 | 31 | 23 | 10.3 | 10.3 | 10.3 | 10.3 | 6.1 | 4.1 | 2.3 |
| Al–2.5Mg | B210 | 5052 | A95052 | H34 | ... | 22 | (14)(33) | −452 | 34 | 26 | 11.3 | 11.3 | 11.3 | 11.3 | 6.1 | 4.1 | 2.3 |
| Al–4.4Mg–Mn | B210 | 5083 | A95083 | O | ... | 25 | (33) | −452 | 39 | 16 | 10.7 | 10.7 | ... | ... | ... | ... | ... |
| Al–4.4Mg–Mn | B210 | 5083 | A95083 | H112 | ... | 25 | (33) | −452 | 39 | 16 | 10.7 | 10.7 | ... | ... | ... | ... | ... |
| Al–4.4Mg–Mn | B241 | 5083 | A95083 | O | ... | 25 | (33) | −452 | 39 | 16 | 10.7 | 10.7 | ... | ... | ... | ... | ... |
| Al–4.4Mg–Mn | B241 | 5083 | A95083 | H112 | ... | 25 | (33) | −452 | 39 | 16 | 10.7 | 10.7 | ... | ... | ... | ... | ... |
| Al–4.0Mg–Mn | B210 | 5086 | A95086 | O | ... | 25 | (33) | −452 | 35 | 14 | 9.3 | 9.3 | ... | ... | ... | ... | ... |
| Al–4.0Mg–Mn | B210 | 5086 | A95086 | H112 | ... | 25 | (33) | −452 | 35 | 14 | 9.3 | 9.3 | ... | ... | ... | ... | ... |
| Al–4.0Mg–Mn | B241 | 5086 | A95086 | O | ... | 25 | (33) | −452 | 35 | 14 | 9.3 | 9.3 | ... | ... | ... | ... | ... |
| Al–4.0Mg–Mn | B241 | 5086 | A95086 | H112 | ... | 25 | (33) | −452 | 35 | 14 | 9.3 | 9.3 | ... | ... | ... | ... | ... |
| Al–4.0Mg–Mn | B210 | 5086 | A95086 | H32 | ... | 25 | (33) | −452 | 40 | 28 | 13.3 | 13.3 | ... | ... | ... | ... | ... |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size or Thickness Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 150 | 200 | 250 | 300 | 350 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aluminum Alloy — Seamless Pipes and Tubes (Cont'd)** | | | | | | | | | | | | | | | | | |
| Al–4.0Mg–Mn | B210 | 5086 | A95086 | H34 | ... | 25 | (33) | −452 | 44 | 34 | 14.7 | 14.7 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B210 | 5154 | A95154 | O | ... | 22 | ... | −452 | 30 | 11 | 7.3 | 7.3 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B210 | 5154 | A95154 | H34 | ... | 22 | (33) | −452 | 39 | 29 | 13.3 | 13.0 | ... | ... | ... | ... | ... |
| Al–2.7Mg–Mn | B241 | 5454 | A95454 | O | ... | 22 | (33) | −452 | 31 | 12 | 8.0 | 8.0 | 8.0 | 7.4 | 5.5 | 4.1 | 3.0 |
| Al–2.7Mg–Mn | B241 | 5454 | A95454 | H112 | ... | 22 | (33) | −452 | 31 | 12 | 8.0 | 8.0 | 8.0 | 7.4 | 5.5 | 4.1 | 3.0 |
| Al–5.1Mg–Mn | B210 | 5456 | A95456 | O | ... | 25 | (33) | −452 | 41 | 19 | 12.7 | 12.7 | ... | ... | ... | ... | ... |
| Al–5.1Mg–Mn | B210 | 5456 | A95456 | H112 | ... | 25 | (33) | −452 | 41 | 19 | 12.7 | 12.7 | ... | ... | ... | ... | ... |
| Al–5.1Mg–Mn | B241 | 5456 | A95456 | O | ... | 25 | (33) | −452 | 41 | 19 | 12.7 | 12.7 | ... | ... | ... | ... | ... |
| Al–5.1Mg–Mn | B241 | 5456 | A95456 | H112 | ... | 25 | (33) | −452 | 41 | 19 | 12.7 | 12.7 | ... | ... | ... | ... | ... |
| Al–Mg–Si–Cu | B210 | 6061 | A96061 | T4 wld. | ... | 23 | (22)(63) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B210 | 6061 | A96061 | T6 wld. | ... | 23 | (22)(63) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B241 | 6061 | A96061 | T4 wld. | ... | 23 | (22)(63) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B241 | 6061 | A96061 | T6 wld. | ... | 23 | (22)(63) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B241 | 6061 | A96061 | T4 | ... | 23 | (33)(63) | −452 | 26 | 16 | 8.7 | 8.7 | 8.7 | 8.7 | 8.3 | 7.4 | 5.2 |
| Al–Mg–Si–Cu | B210 | 6061 | A96061 | T4 | ... | 23 | (33) | −452 | 30 | 16 | 10.0 | 10.0 | 10.0 | 9.9 | 9.5 | 8.4 | 5.2 |
| Al–Mg–Si–Cu | B241 | 6061 | A96061 | T6 | ... | 23 | (33)(63) | −452 | 38 | 35 | 12.7 | 12.7 | 12.7 | 12.3 | 10.5 | 8.1 | 5.2 |
| Al–Mg–Si–Cu | B210 | 6061 | A96061 | T6 | ... | 23 | (33) | −452 | 42 | 35 | 14.0 | 14.0 | 14.0 | 13.6 | 11.7 | 8.9 | 5.2 |
| Al–Mg–Si | B210 | 6063 | A96063 | T4 wld. | ... | 23 | ... | −452 | 17 | ... | 5.7 | 5.7 | 5.6 | 5.3 | 4.8 | 3.8 | 2.0 |
| Al–Mg–Si | B210 | 6063 | A96063 | T5 wld. | ... | 23 | ... | −452 | 17 | ... | 5.7 | 5.7 | 5.6 | 5.3 | 4.8 | 3.8 | 2.0 |
| Al–Mg–Si | B210 | 6063 | A96063 | T6 wld. | ... | 23 | ... | −452 | 17 | ... | 5.7 | 5.7 | 5.6 | 5.3 | 4.8 | 3.8 | 2.0 |
| Al–Mg–Si | B241 | 6063 | A96063 | T4 wld. | ... | 23 | ... | −452 | 17 | ... | 5.7 | 5.7 | 5.6 | 5.3 | 4.8 | 3.8 | 2.0 |
| Al–Mg–Si | B241 | 6063 | A96063 | T5 wld. | ... | 23 | ... | −452 | 17 | ... | 5.7 | 5.7 | 5.6 | 5.3 | 4.8 | 3.8 | 2.0 |
| Al–Mg–Si | B241 | 6063 | A96063 | T6 wld. | ... | 23 | ... | −452 | 17 | ... | 5.7 | 5.7 | 5.6 | 5.3 | 4.8 | 3.8 | 2.0 |
| Al–Mg–Si | B241 | 6063 | A96063 | T4 | ≤0.500 | 23 | (33) | −452 | 19 | 10 | 6.3 | 6.3 | 6.3 | 6.3 | 5.8 | 3.9 | 1.5 |
| Al–Mg–Si | B210 | 6063 | A96063 | T4 | ... | 23 | (33) | −452 | 22 | 10 | 6.7 | 6.5 | 6.5 | 6.3 | 6.3 | 4.5 | 1.7 |
| Al–Mg–Si | B241 | 6063 | A96063 | T5 | ≤0.500 | 23 | (33) | −452 | 22 | 16 | 7.3 | 7.3 | 7.3 | 7.3 | 7.1 | 3.8 | 2.0 |
| Al–Mg–Si | B241 | 6063 | A96063 | T6 | ... | 23 | (33) | −452 | 30 | 25 | 10.0 | 10.0 | 10.0 | 9.1 | 7.2 | 3.4 | 2.0 |
| Al–Mg–Si | B210 | 6063 | A96063 | T6 | ... | 23 | (33) | −452 | 33 | 28 | 11.0 | 11.0 | 11.0 | 9.6 | 7.3 | 3.8 | 2.0 |
| **Aluminum Alloy — Welded Pipes and Tubes** | | | | | | | | | | | | | | | | | |
| Al–4.4Mg–Mn | B547 | 5083 | A95083 | O | ... | 25 | ... | −452 | 40 | 18 | 12.0 | 12.0 | ... | ... | ... | ... | ... |
| **Aluminum Alloy — Structural Tubes** | | | | | | | | | | | | | | | | | |
| Al–Mn–Cu | B221 | Alclad 3003 | A83003 | O | ... | 21 | (33)(69) | −452 | 13 | 4.5 | 3.0 | 2.9 | 2.8 | 2.7 | 2.5 | 1.9 | 1.5 |
| Al–Mn–Cu | B221 | Alclad 3003 | A83003 | H112 | ... | 21 | (33)(69) | −452 | 13 | 4.5 | 3.0 | 2.9 | 2.8 | 2.7 | 2.5 | 1.9 | 1.5 |
| 99.0Al | B221 | 1060 | A91060 | O | ... | 21 | (33)(69) | −452 | 8.5 | 2.5 | 1.7 | 1.7 | 1.6 | 1.4 | 1.2 | 1.1 | 0.8 |
| 99.0Al | B221 | 1060 | A91060 | H112 | ... | 21 | (33)(69) | −452 | 8.5 | 2.5 | 1.7 | 1.7 | 1.6 | 1.4 | 1.2 | 1.1 | 0.8 |
| 99.0Al–Cu | B221 | 1100 | A91100 | O | ... | 21 | (33)(69) | −452 | 11 | 3 | 2.0 | 2.0 | 2.0 | 1.9 | 1.7 | 1.3 | 1.0 |
| 99.0Al–Cu | B221 | 1100 | A91100 | H112 | ... | 21 | (33)(69) | −452 | 11 | 3 | 2.0 | 2.0 | 2.0 | 1.9 | 1.7 | 1.3 | 1.0 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size or Thickness Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 150 | 200 | 250 | 300 | 350 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aluminum Alloy — Structural Tubes (Cont'd)** | | | | | | | | | | | | | | | | | |
| Al–Mn–Cu | B221 | 3003 | A93003 | O | ... | 21 | (33)(69) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B221 | 3003 | A93003 | H112 | ... | 21 | (33)(69) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–2.5Mg | B221 | 5052 | A95052 | O | ... | 22 | (69) | −452 | 25 | 10 | 6.7 | 6.7 | 6.7 | 6.6 | 6.1 | 4.1 | 2.3 |
| Al–4.4Mg–Mn | B221 | 5083 | A95083 | O | ... | 25 | (69) | −452 | 39 | 16 | 10.7 | 10.7 | ... | ... | ... | ... | ... |
| Al–4.0Mg–Mn | B221 | 5086 | A95086 | O | ... | 25 | (69) | −452 | 35 | 14 | 9.3 | 9.3 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B221 | 5154 | A95154 | O | ... | 22 | (69) | −452 | 30 | 11 | 7.3 | 7.3 | ... | ... | ... | ... | ... |
| Al–2.7Mg–Mn | B221 | 5454 | A95454 | O | ... | 22 | (69) | −452 | 31 | 12 | 8.0 | 8.0 | 8.0 | 7.4 | 5.5 | 4.1 | 3.0 |
| Al–5.1Mg–Mn | B221 | 5456 | A95456 | O | ... | 25 | (69) | −452 | 41 | 19 | 12.7 | 12.7 | ... | ... | ... | ... | ... |
| Al–Mg–Si–Cu | B221 | 6061 | A96061 | T4 wld. | ... | 23 | (22)(63)(69) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B221 | 6061 | A96061 | T6 wld. | ... | 23 | (22)(63)(69) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B221 | 6061 | A96061 | T4 | ... | 23 | (33)(63)(69) | −452 | 26 | 16 | 8.7 | 8.7 | 8.7 | 8.7 | 8.3 | 7.4 | 5.2 |
| Al–Mg–Si–Cu | B221 | 6061 | A96061 | T6 | ... | 23 | (33)(63)(69) | −452 | 38 | 35 | 12.7 | 12.7 | 12.7 | 12.3 | 10.5 | 8.1 | 5.2 |
| Al–Mg–Si | B221 | 6063 | A96063 | T4 wld. | ... | 23 | (69) | −452 | 17 | ... | 5.7 | 5.7 | 5.6 | 5.3 | 4.8 | 3.8 | 2.0 |
| Al–Mg–Si | B221 | 6063 | A96063 | T5 wld. | ... | 23 | (69) | −452 | 17 | ... | 5.7 | 5.7 | 5.6 | 5.3 | 4.8 | 3.8 | 2.0 |
| Al–Mg–Si | B221 | 6063 | A96063 | T6 wld. | ... | 23 | (69) | −452 | 17 | ... | 5.7 | 5.7 | 5.6 | 5.3 | 4.8 | 3.8 | 2.0 |
| Al–Mg–Si | B221 | 6063 | A96063 | T4 | ≤0.500 | 23 | (13)(33)(69) | −452 | 19 | 10 | 6.3 | 6.3 | 6.3 | 6.3 | 5.8 | 3.9 | 1.5 |
| Al–Mg–Si | B221 | 6063 | A96063 | T5 | ≤0.500 | 23 | (13)(33)(69) | −452 | 22 | 16 | 7.3 | 7.3 | 7.3 | 7.3 | 7.1 | 3.8 | 2.0 |
| Al–Mg–Si | B221 | 6063 | A96063 | T6 | ... | 23 | (33)(69) | −452 | 30 | 25 | 10.0 | 10.0 | 10.0 | 9.1 | 7.2 | 3.4 | 2.0 |
| **Aluminum Alloy — Plates and Sheets** | | | | | | | | | | | | | | | | | |
| Al–Mn–Cu | B209 | Alclad 3003 | A83003 | O | 0.006–0.499 | 21 | (66) | −452 | 13 | 4.5 | 3.0 | 2.9 | 2.8 | 2.7 | 2.5 | 1.9 | 1.5 |
| Al–Mn–Cu | B209 | Alclad 3003 | A83003 | O | 0.500–3.000 | 21 | (68) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B209 | Alclad 3003 | A83003 | H112 | 0.500–2.000 | 21 | (33)(66) | −452 | 15 | 6 | 4.0 | 3.9 | 3.7 | 3.6 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B209 | Alclad 3003 | A83003 | H12 | 0.017–0.499 | 21 | (33)(66) | −452 | 16 | 11 | 5.3 | 5.3 | 5.2 | 4.9 | 4.3 | 3.0 | 2.3 |
| Al–Mn–Cu | B209 | Alclad 3003 | A83003 | H12 | 0.500–2.000 | 21 | (33)(68) | −452 | 17 | 12 | 5.7 | 5.7 | 5.7 | 5.7 | 4.3 | 3.0 | 2.3 |
| Al–Mn–Cu | B209 | Alclad 3003 | A83003 | H14 | 0.009–0.499 | 21 | (33)(66) | −452 | 19 | 16 | 6.3 | 6.3 | 6.3 | 6.1 | 4.3 | 3.0 | 2.3 |
| Al–Mn–Cu | B209 | Alclad 3003 | A83003 | H14 | 0.500–1.000 | 21 | (33)(68) | −452 | 20 | 17 | 6.7 | 6.7 | 6.7 | 6.5 | 4.3 | 3.0 | 2.3 |
| Al–Mn–Mg | B209 | Alclad 3004 | A83004 | O | 0.006–0.499 | 22 | (66) | −452 | 21 | 8 | 5.3 | 5.3 | 5.3 | 5.3 | 5.3 | 3.8 | 2.3 |
| Al–Mn–Mg | B209 | Alclad 3004 | A83004 | O | 0.500–3.000 | 22 | (68) | −452 | 22 | 8.5 | 5.7 | 5.6 | 5.6 | 5.6 | 5.6 | 3.8 | 2.3 |
| Al–Mn–Mg | B209 | Alclad 3004 | A83004 | H112 | 0.250–0.499 | 22 | (33)(66) | −452 | 22 | 8.5 | 5.7 | 5.6 | 5.6 | 5.6 | 5.6 | 3.8 | 2.3 |
| Al–Mn–Mg | B209 | Alclad 3004 | A83004 | H112 | 0.500–3.000 | 22 | (33)(68) | −452 | 23 | 9 | 6.0 | 6.0 | 6.0 | 6.0 | 5.7 | 3.8 | 2.3 |
| Al–Mn–Mg | B209 | Alclad 3004 | A83004 | H32 | 0.017–0.499 | 22 | (33)(66) | −452 | 27 | 20 | 9.0 | 9.0 | 9.0 | 9.0 | 5.7 | 3.8 | 2.3 |
| Al–Mn–Mg | B209 | Alclad 3004 | A83004 | H32 | 0.500–2.000 | 22 | (33)(68) | −452 | 28 | 21 | 9.3 | 9.3 | 9.3 | 9.3 | 5.7 | 3.8 | 2.3 |
| Al–Mn–Mg | B209 | Alclad 3004 | A83004 | H34 | 0.009–0.499 | 22 | (33)(66) | −452 | 31 | 24 | 10.3 | 10.3 | 10.3 | 10.3 | 5.7 | 3.8 | 2.3 |
| Al–Mn–Mg | B209 | Alclad 3004 | A83004 | H34 | 0.500–1.000 | 22 | (33)(68) | −452 | 32 | 25 | 10.7 | 10.7 | 10.7 | 10.7 | 5.7 | 3.8 | 2.3 |
| Al–Mg–Si–Cu | B209 | Alclad 6061 | A86061 | T4 wld. | ... | 23 | (22)(63) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B209 | Alclad 6061 | A86061 | T6 wld. | ... | 23 | (22)(63) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size or Thickness Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 150 | 200 | 250 | 300 | 350 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aluminum Alloy — Plates and Sheets (Cont'd)** | | | | | | | | | | | | | | | | | |
| Al–Mg–Si–Cu | B209 | Alclad 6061 | A86061 | T4 | ... | 23 | (33)(66) | −452 | 27 | 14 | 9.0 | 9.0 | 9.0 | 8.9 | 8.6 | 7.6 | 5.2 |
| Al–Mg–Si–Cu | B209 | Alclad 6061 | A86061 | T451 | 0.250–0.499 | 23 | (33)(66) | −452 | 27 | 14 | 9.0 | 9.0 | 9.0 | 8.9 | 8.6 | 7.6 | 5.2 |
| Al–Mg–Si–Cu | B209 | Alclad 6061 | A86061 | T451 | 0.500–3.000 | 23 | (33)(68) | −452 | 30 | 16 | 9.0 | 9.0 | 9.0 | 8.9 | 8.5 | 8.4 | 5.2 |
| Al–Mg–Si–Cu | B209 | Alclad 6061 | A86061 | T6 | ... | 23 | (33)(66) | −452 | 38 | 32 | 12.7 | 12.7 | 12.7 | 12.3 | 10.6 | 8.1 | 5.2 |
| Al–Mg–Si–Cu | B209 | Alclad 6061 | A86061 | T651 | 0.250–0.499 | 23 | (33)(66) | −452 | 38 | 32 | 12.7 | 12.7 | 12.7 | 12.3 | 10.6 | 8.1 | 5.2 |
| Al–Mg–Si–Cu | B209 | Alclad 6061 | A86061 | T651 | 0.500–4.000 | 23 | (33)(68) | −452 | 42 | 35 | 14.0 | 14.0 | 14.0 | 13.6 | 11.7 | 8.9 | 5.2 |
| 99.60Al | B209 | 1060 | A91060 | O | ... | 21 | ... | −452 | 8 | 2.5 | 1.7 | 1.6 | 1.6 | 1.4 | 1.2 | 1.1 | 0.8 |
| 99.60Al | B209 | 1060 | A91060 | H112 | 0.500–1.000 | 21 | (13)(33) | −452 | 10 | 5 | 3.3 | 3.2 | 2.9 | 2.5 | 2.0 | 1.5 | 0.9 |
| 99.60Al | B209 | 1060 | A91060 | H12 | ... | 21 | (33) | −452 | 11 | 9 | 3.7 | 3.7 | 3.4 | 3.1 | 2.7 | 1.8 | 1.1 |
| 99.60Al | B209 | 1060 | A91060 | H14 | ... | 21 | (33) | −452 | 12 | 10 | 4.0 | 4.0 | 4.0 | 4.0 | 2.7 | 1.8 | 1.1 |
| 99.0Al–Cu | B209 | 1100 | A91100 | O | ... | 21 | ... | −452 | 11 | 3.5 | 2.3 | 2.3 | 2.3 | 2.3 | 1.7 | 1.3 | 1.0 |
| 99.0Al–Cu | B209 | 1100 | A91100 | H112 | 0.500–2.000 | 21 | (13)(33) | −452 | 12 | 5 | 3.3 | 3.3 | 3.3 | 3.2 | 2.4 | 1.7 | 1.0 |
| 99.0Al–Cu | B209 | 1100 | A91100 | H12 | ... | 21 | (33) | −452 | 14 | 11 | 4.7 | 4.7 | 4.6 | 3.8 | 2.8 | 1.9 | 1.1 |
| 99.0Al–Cu | B209 | 1100 | A91100 | H14 | ... | 21 | (33) | −452 | 16 | 14 | 5.3 | 5.3 | 5.3 | 4.9 | 2.8 | 1.9 | 1.1 |
| Al–Mn–Cu | B209 | 3003 | A93003 | O | ... | 21 | ... | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B209 | 3003 | A93003 | H112 | 0.500–2.000 | 21 | (13)(33) | −452 | 15 | 6 | 4.0 | 3.9 | 3.7 | 3.6 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B209 | 3003 | A93003 | H12 | ... | 21 | (33) | −452 | 17 | 12 | 5.7 | 5.7 | 5.6 | 5.2 | 4.3 | 3.0 | 2.3 |
| Al–Mn–Cu | B209 | 3003 | A93003 | H14 | ... | 21 | (33) | −452 | 20 | 17 | 6.7 | 6.7 | 6.7 | 6.5 | 4.3 | 3.0 | 2.3 |
| Al–Mn–Mg | B209 | 3004 | A93004 | O | ... | 22 | ... | −452 | 22 | 8.5 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 3.8 | 2.3 |
| Al–Mn–Mg | B209 | 3004 | A93004 | H112 | ... | 22 | (33) | −452 | 23 | 9 | 6.0 | 6.0 | 6.0 | 6.0 | 5.8 | 3.8 | 2.3 |
| Al–Mn–Mg | B209 | 3004 | A93004 | H32 | ... | 22 | (33) | −452 | 28 | 21 | 9.3 | 9.3 | 9.3 | 9.3 | 5.7 | 3.8 | 2.3 |
| Al–Mn–Mg | B209 | 3004 | A93004 | H34 | ... | 22 | (33) | −452 | 32 | 25 | 10.7 | 10.7 | 10.7 | 10.7 | 5.7 | 3.8 | 2.3 |
| Al–1.5Mg | B209 | 5050 | A95050 | O | ... | 21 | ... | −452 | 18 | 6 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 2.8 | 1.4 |
| Al–1.5Mg | B209 | 5050 | A95050 | H112 | ... | 21 | (33) | −452 | 20 | 8 | 5.3 | 5.3 | 5.3 | 5.2 | 5.2 | 2.8 | 1.4 |
| Al–1.5Mg | B209 | 5050 | A95050 | H32 | ... | 21 | (33) | −452 | 22 | 16 | 7.3 | 7.3 | 7.3 | 7.3 | 5.3 | 2.8 | 1.4 |
| Al–1.5Mg | B209 | 5050 | A95050 | H34 | ... | 21 | (33) | −452 | 25 | 20 | 8.3 | 8.3 | 8.3 | 7.8 | 5.3 | 2.8 | 1.4 |
| Al–2.5Mg | B209 | 5052 | A95052 | O | ... | 22 | ... | −452 | 25 | 9.5 | 6.3 | 6.3 | 6.3 | 6.2 | 6.1 | 4.1 | 2.3 |
| Al–2.5Mg | B209 | 5052 | A95052 | H112 | 0.500–3.000 | 22 | (13)(33) | −452 | 25 | 9.5 | 6.3 | 6.3 | 6.3 | 6.3 | 6.1 | 4.1 | 2.3 |
| Al–2.5Mg | B209 | 5052 | A95052 | H32 | ... | 22 | (33) | −452 | 31 | 23 | 10.3 | 10.3 | 10.3 | 10.3 | 6.1 | 4.1 | 2.3 |
| Al–2.5Mg | B209 | 5052 | A95052 | H34 | ... | 22 | (33) | −452 | 34 | 26 | 11.3 | 11.3 | 11.3 | 11.3 | 6.1 | 4.1 | 2.3 |
| Al–4.4Mg–Mn | B209 | 5083 | A95083 | O | 0.051–1.500 | 25 | (13) | −452 | 40 | 18 | 12.0 | 12.0 | ... | ... | ... | ... | ... |
| Al–4.4Mg–Mn | B209 | 5083 | A95083 | H32 | 0.188–1.500 | 25 | (13)(33) | −452 | 44 | 31 | 14.7 | 14.7 | ... | ... | ... | ... | ... |
| Al–4.0Mg–Mn | B209 | 5086 | A95086 | O | ... | 25 | ... | −452 | 35 | 14 | 9.3 | 9.3 | ... | ... | ... | ... | ... |
| Al–4.0Mg–Mn | B209 | 5086 | A95086 | H112 | 0.500–1.000 | 25 | (13)(33) | −452 | 35 | 16 | 9.3 | 9.3 | ... | ... | ... | ... | ... |
| Al–4.0Mg–Mn | B209 | 5086 | A95086 | H32 | ... | 25 | (33) | −452 | 40 | 28 | 13.3 | 13.3 | ... | ... | ... | ... | ... |
| Al–4.0Mg–Mn | B209 | 5086 | A95086 | H34 | ... | 25 | (33) | −452 | 44 | 34 | 14.7 | 14.7 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B209 | 5154 | A95154 | O | ... | 22 | ... | −452 | 30 | 11 | 7.3 | 7.3 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B209 | 5154 | A95154 | H112 | 0.500–3.000 | 22 | (13)(33) | −452 | 30 | 11 | 7.3 | 7.3 | ... | ... | ... | ... | ... |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size or Thickness Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 150 | 200 | 250 | 300 | 350 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aluminum Alloy — Plates and Sheets (Cont'd)** | | | | | | | | | | | | | | | | | |
| Al–3.5Mg | B209 | 5154 | A95154 | H32 | ... | 22 | (33) | −452 | 36 | 26 | 12.0 | 12.0 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B209 | 5154 | A95154 | H34 | ... | 22 | (33) | −452 | 39 | 29 | 13.0 | 13.0 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B209 | 5254 | A95254 | O | ... | 22 | ... | −452 | 30 | 11 | 7.3 | 7.3 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B209 | 5254 | A95254 | H112 | 0.500–3.000 | 22 | (13)(33) | −452 | 30 | 11 | 7.3 | 7.3 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B209 | 5254 | A95254 | H32 | ... | 22 | (33) | −452 | 36 | 26 | 12.0 | 12.0 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B209 | 5254 | A95254 | H34 | ... | 22 | (33) | −452 | 39 | 29 | 13.0 | 13.0 | ... | ... | ... | ... | ... |
| Al–2.7Mg–Mn | B209 | 5454 | A95454 | O | ... | 22 | ... | −452 | 31 | 12 | 8.0 | 8.0 | 8.0 | 7.4 | 5.5 | 4.1 | 3.0 |
| Al–2.7Mg–Mn | B209 | 5454 | A95454 | H112 | 0.500–3.000 | 22 | (13)(33) | −452 | 31 | 12 | 8.0 | 8.0 | 8.0 | 7.4 | 5.5 | 4.1 | 3.0 |
| Al–2.7Mg–Mn | B209 | 5454 | A95454 | H32 | ... | 22 | (33) | −452 | 36 | 26 | 12.0 | 12.0 | 12.0 | 7.5 | 5.5 | 4.1 | 3.0 |
| Al–2.7Mg–Mn | B209 | 5454 | A95454 | H34 | ... | 22 | (33) | −452 | 39 | 29 | 13.0 | 13.0 | 13.0 | 7.5 | 5.5 | 4.1 | 3.0 |
| Al–5.1Mg–Mn | B209 | 5456 | A95456 | O | 0.051–1.500 | 25 | (13) | −452 | 42 | 19 | 12.7 | 12.7 | ... | ... | ... | ... | ... |
| Al–5.1Mg–Mn | B209 | 5456 | A95456 | H32 | 0.188–0.499 | 25 | (13)(33) | −452 | 46 | 33 | 15.3 | 15.3 | ... | ... | ... | ... | ... |
| Al–2.5Mg | B209 | 5652 | A95652 | O | ... | 22 | ... | −452 | 25 | 9.5 | 6.3 | 6.3 | 6.3 | 6.2 | 6.1 | 4.1 | 2.3 |
| Al–2.5Mg | B209 | 5652 | A95652 | H112 | 0.500–3.000 | 22 | (13)(33) | −452 | 25 | 9.5 | 6.3 | 6.3 | 6.3 | 6.3 | 6.1 | 4.1 | 2.3 |
| Al–2.5Mg | B209 | 5652 | A95652 | H32 | ... | 22 | (33) | −452 | 31 | 23 | 10.3 | 10.3 | 10.3 | 10.3 | 6.1 | 4.1 | 2.3 |
| Al–2.5Mg | B209 | 5652 | A95652 | H34 | ... | 22 | (33) | −452 | 34 | 26 | 11.3 | 11.3 | 11.3 | 11.3 | 6.1 | 4.1 | 2.3 |
| Al–Mg–Si–Cu | B209 | 6061 | A96061 | T4 wld. | ... | 23 | (22)(63) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B209 | 6061 | A96061 | T6 wld. | ... | 23 | (22)(63) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B209 | 6061 | A96061 | T4 | ... | 23 | (33)(63) | −452 | 30 | 16 | 10.0 | 10.0 | 10.0 | 9.9 | 9.5 | 8.4 | 5.2 |
| Al–Mg–Si–Cu | B209 | 6061 | A96061 | T6 | ... | 23 | (33) | −452 | 42 | 35 | 14.0 | 14.0 | 14.0 | 13.6 | 11.7 | 8.9 | 5.2 |
| Al–Mg–Si–Cu | B209 | 6061 | A96061 | T651 | 0.250–4.000 | 23 | (13)(33) | −452 | 42 | 35 | 14.0 | 14.0 | 14.0 | 13.6 | 11.7 | 8.9 | 5.2 |
| **Aluminum Alloy — Forgings and Fittings** | | | | | | | | | | | | | | | | | |
| Al–Mn–Cu | B361 | WP Alclad 3003 | A83003 | O | ... | 21 | (13)(14)(32)(33)(66) | −452 | 13 | 4.5 | 3.0 | 2.9 | 2.8 | 2.7 | 2.5 | 1.9 | 1.5 |
| Al–Mn–Cu | B361 | WP Alclad 3003 | A83003 | H112 | ... | 21 | (13)(14)(32)(33)(66) | −452 | 13 | 4.5 | 3.0 | 2.9 | 2.8 | 2.7 | 2.5 | 1.9 | 1.5 |
| 99.60Al | B361 | WP1060 | A91060 | O | ... | 21 | (13)(14)(32)(33) | −452 | 8 | 2.5 | 1.7 | 1.6 | 1.6 | 1.4 | 1.2 | 1.1 | 0.8 |
| 99.60Al | B361 | WP1060 | A91060 | H112 | ... | 21 | (13)(14)(32)(33) | −452 | 8 | 2.5 | 1.7 | 1.6 | 1.6 | 1.4 | 1.2 | 1.1 | 0.8 |
| 99.0Al–Cu | B361 | WP1100 | A91100 | O | ... | 21 | (13)(14)(32)(33) | −452 | 11 | 3 | 2.0 | 2.0 | 2.0 | 1.9 | 1.7 | 1.3 | 1.0 |
| 99.0Al–Cu | B361 | WP1100 | A91100 | H112 | ... | 21 | (13)(14)(32)(33) | −452 | 11 | 3 | 2.0 | 2.0 | 2.0 | 1.9 | 1.7 | 1.3 | 1.0 |
| Al–Mn–Cu | B247 | 3003 | A93003 | H112 | ... | 21 | (9)(45) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B247 | 3003 | A93003 | H112 wld. | ... | 21 | (9)(45) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B361 | WP3003 | A93003 | O | ... | 21 | (13)(14)(32)(33) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B361 | WP3003 | A93003 | H112 | ... | 21 | (13)(14)(32)(33) | −452 | 14 | 5 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 | 1.9 | 1.5 |
| Al–Mn–Cu | B247 | 5083 | A95083 | O | ... | 25 | (9)(32)(33) | −452 | 39 | 16 | 10.7 | 10.7 | ... | ... | ... | ... | ... |

## Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size or Thickness Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Yield | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 150 | 200 | 250 | 300 | 350 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aluminum Alloy — Forgings and Fittings (Cont'd)** | | | | | | | | | | | | | | | | | |
| Al–Mn–Cu | B247 | 5083 | A95083 | H112 | ... | 25 | (9)(32)(33) | −452 | 39 | 16 | 10.7 | 10.7 | ... | ... | ... | ... | ... |
| Al–Mn–Cu | B247 | 5083 | A95083 | H112 wld. | ... | 25 | (9)(32)(33) | −452 | 39 | 16 | 10.7 | 10.7 | ... | ... | ... | ... | ... |
| Al–4.4Mg–Mn | B361 | WP5083 | A95083 | O | ... | 25 | (13)(32)(33) | −452 | 39 | 16 | 10.7 | 10.7 | ... | ... | ... | ... | ... |
| Al–4.4Mg–Mn | B361 | WP5083 | A95083 | H112 | ... | 25 | (13)(32)(33) | −452 | 39 | 16 | 10.7 | 10.7 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B361 | WP5154 | A95154 | O | ... | 22 | (32)(33) | −452 | 30 | 11 | 7.3 | 7.3 | ... | ... | ... | ... | ... |
| Al–3.5Mg | B361 | WP5154 | A95154 | H112 | ... | 22 | (32)(33) | −452 | 30 | 11 | 7.3 | 7.3 | ... | ... | ... | ... | ... |
| Al–Mg–Si–Cu | B247 | 6061 | A96061 | T6 wld. | ... | 23 | (9)(22) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B361 | WP6061 | A96061 | T4 wld. | ... | 23 | (22)(32)(63) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B361 | WP6061 | A96061 | T6 wld. | ... | 23 | (22)(32)(63) | −452 | 24 | ... | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 6.9 | 5.1 |
| Al–Mg–Si–Cu | B361 | WP6061 | A96061 | T4 | ... | 23 | (13)(32)(33)(63) | −452 | 26 | 16 | 8.7 | 8.7 | 8.7 | 8.7 | 8.3 | 7.4 | 5.2 |
| Al–Mg–Si–Cu | B247 | 6061 | A96061 | T6 | ... | 23 | (9)(33) | −452 | 38 | 35 | 12.7 | 12.7 | 12.7 | 12.3 | 10.5 | 8.1 | 5.2 |
| Al–Mg–Si–Cu | B361 | WP6061 | A96061 | T6 | ... | 23 | (13)(32)(33)(63) | −452 | 38 | 35 | 12.7 | 12.7 | 12.7 | 12.3 | 10.5 | 8.1 | 5.2 |
| Al–Mg–Si | B361 | WP6063 | A96063 | T4 wld. | ... | 23 | (32) | −452 | 17 | ... | 5.7 | 5.7 | 5.7 | 5.7 | 5.5 | 3.8 | 2.0 |
| Al–Mg–Si | B361 | WP6063 | A96063 | T6 wld. | ... | 23 | (32) | −452 | 17 | ... | 5.7 | 5.7 | 5.7 | 5.7 | 5.5 | 3.8 | 2.0 |
| Al–Mg–Si | B361 | WP6063 | A96063 | T4 | ... | 23 | (13)(32)(33) | −452 | 18 | 9 | 6.0 | 5.9 | 5.8 | 5.7 | 5.5 | 3.7 | 1.4 |
| Al–Mg–Si | B361 | WP6063 | A96063 | T6 | ... | 23 | (13)(32)(33) | −452 | 30 | 25 | 10.0 | 10.0 | 10.0 | 9.1 | 7.2 | 3.4 | 2.0 |
| **Aluminum Alloy — Castings** | | | | | | | | | | | | | | | | | |
| Al–Si–Mg | B26 | 356.0 | A03560 | T71 | ... | 26 | (9)(43) | −452 | 25 | 18 | 8.3 | 8.3 | 8.3 | 8.1 | 7.3 | 5.5 | 2.4 |
| Al–Si–Mg | B26 | 356.0 | A03560 | T6 | ... | 26 | (9)(43) | −452 | 30 | 20 | 10.0 | 10.0 | 10.0 | 8.4 | ... | ... | ... |
| Al–Si | B26 | 443.0 | A04430 | F | ... | ... | (9)(43) | −452 | 17 | 7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 3.5 |

(18)

# Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Notes | Min. Temp., °C (6) | Min. Tensile Strgth., MPa | Min. Yield Strgth., MPa | Max. Use Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Fe | Castings | A48 | 20 | F11401 | ... | (8e)(48) | −29 | 138 | ... | 204 |
| 2 | Fe | Castings | A278 | 20 | F11401 | ... | (8e)(48) | −29 | 138 | ... | 204 |
| 3 | Fe | Castings | A126 | A | F11501 | ... | (8e)(9)(48) | −29 | 145 | ... | 204 |
| 4 | Fe | Castings | A48 | 25 | F11701 | ... | (8e)(48) | −29 | 172 | ... | 204 |
| 5 | Fe | Castings | A278 | 25 | F11701 | ... | (8e)(48) | −29 | 172 | ... | 204 |
| 6 | Fe | Castings | A48 | 30 | F12101 | ... | (8e)(48) | −29 | 207 | ... | 204 |
| 7 | Fe | Castings | A278 | 30 | F12101 | ... | (8e)(48) | −29 | 207 | ... | 204 |
| 8 | Fe | Castings | A126 | B | F12102 | ... | (8e)(9)(48) | −29 | 214 | ... | 204 |
| 9 | Fe | Castings | A48 | 35 | F12401 | ... | (8e)(48) | −29 | 241 | ... | 204 |
| 10 | Fe | Castings | A278 | 35 | F12401 | ... | (8e)(48) | −29 | 241 | ... | 204 |
| 11 | Fe | Castings | A48 | 40 | F12801 | ... | (8e)(9)(48) | −29 | 276 | ... | 204 |
| 12 | Fe | Castings | A126 | C | F12802 | ... | (8e)(9)(48) | −29 | 283 | ... | 204 |
| 13 | Fe | Castings | A278 | 40 | F12803 | ... | (8e)(9)(53) | −29 | 276 | ... | 343 |
| 14 | Fe | Castings | A48 | 45 | F13101 | ... | (8e)(48) | −29 | 310 | ... | 204 |
| 15 | Fe | Castings | A48 | 50 | F13501 | ... | (8e)(48) | −29 | 345 | ... | 204 |
| 16 | Fe | Castings | A278 | 50 | F13502 | ... | (8e)(53) | −29 | 345 | ... | 343 |
| 17 | Fe | Castings | A48 | 55 | F13801 | ... | (8e)(48) | −29 | 379 | ... | 204 |
| 18 | Fe | Castings | A48 | 60 | F14101 | ... | (8e)(48) | −29 | 414 | ... | 204 |
| 19 | Fe | Castings | A278 | 60 | F14102 | ... | (8e)(53) | −29 | 414 | ... | 343 |
| 20 | Fe | Castings | A197 | ... | F22000 | ... | (8e)(9) | −29 | 276 | 207 | 343 |
| 21 | Fe | Castings | A47 | 32510 | F22200 | ... | (8e)(9) | −29 | 345 | 224 | 343 |
| 22 | Fe | Castings | A395 | 60-40-18 | F32800 | ... | (8d)(9) | −29 | 414 | 276 | 343 |
| 23 | Fe | Castings | A571 | D-2M | F43010 | 1 | (8d) | −29 | 448 | 207 | 40 |
| 24 | Fe | Castings | A536 | 65-45-12 | F33100 | ... | (8d)(9) | −29 | 448 | 310 | 260 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 |
| 1 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | ... | ... | ... | ... | ... |
| 2 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | ... | ... | ... | ... | ... |
| 3 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | ... | ... | ... | ... | ... |
| 4 | 17.2 | 17.2 | 17.2 | 17.2 | 17.2 | 17.2 | 17.2 | 17.2 | ... | ... | ... | ... | ... |
| 5 | 17.2 | 17.2 | 17.2 | 17.2 | 17.2 | 17.2 | 17.2 | 17.2 | ... | ... | ... | ... | ... |
| 6 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | ... | ... | ... | ... | ... |
| 7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | ... | ... | ... | ... | ... |
| 8 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | ... | ... | ... | ... | ... |
| 9 | 24.1 | 24.1 | 24.1 | 24.1 | 24.1 | 24.1 | 24.1 | 24.1 | ... | ... | ... | ... | ... |
| 10 | 24.1 | 24.1 | 24.1 | 24.1 | 24.1 | 24.1 | 24.1 | 24.1 | ... | ... | ... | ... | ... |
| 11 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | ... | ... | ... | ... | ... |
| 12 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | ... | ... | ... | ... | ... |
| 13 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 |
| 14 | 31.0 | 31.0 | 31.0 | 31.0 | 31.0 | 31.0 | 31.0 | 31.0 | ... | ... | ... | ... | ... |
| 15 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | ... | ... | ... | ... | ... |
| 16 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 |
| 17 | 37.9 | 37.9 | 37.9 | 37.9 | 37.9 | 37.9 | 37.9 | 37.9 | ... | ... | ... | ... | ... |
| 18 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | ... | ... | ... | ... | ... |
| 19 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 |
| 20 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 |
| 21 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 22 | 137 | 133 | 128 | 125 | 122 | 119 | 116 | 112 | 109 | 106 | 103 | 98.0 | 93.5 |
| 23 | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 24 | 149 | 149 | 149 | 149 | 149 | 149 | 148 | 148 | 148 | 147 | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Cond./ Temper | Size, mm | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Carbon steel | Pipe & tube | A134 | ... | ... | ... | ... | 1 | (8b)(57) | B | 310 | 165 | 482 |
| 2 | Carbon steel | Pipe & tube | A672 | A45 | K01700 | ... | ... | 1 | (57)(59)(67) | B | 310 | 165 | 593 |
| 3 | Carbon steel | Pipe & tube | API 5L | A25 | ... | ... | ... | 1 | (8a)(77) | −29 | 310 | 172 | 204 |
| 4 | Carbon steel | Pipe & tube | API 5L | A25 | ... | ... | ... | 1 | (57)(59)(77) | B | 310 | 172 | 204 |
| 5 | Carbon steel | Pipe & tube | A179 | ... | K01200 | ... | ... | 1 | (57)(59) | −29 | 324 | 179 | 593 |
| 6 | Carbon steel | Pipe & tube | A53 | A | K02504 | ... | ... | 1 | (8a) | −7 | 331 | 207 | 204 |
| 7 | Carbon steel | Pipe & tube | A139 | A | ... | ... | ... | 1 | (8b) | A | 331 | 207 | 149 |
| 8 | Carbon steel | Pipe & tube | A587 | ... | K11500 | ... | ... | 1 | (57)(59) | −29 | 331 | 207 | 454 |
| 9 | Carbon steel | Pipe & tube | A53 | A | K02504 | ... | ... | 1 | (57)(59) | B | 331 | 207 | 593 |
| 10 | Carbon steel | Pipe & tube | A106 | A | K02501 | ... | ... | 1 | (57) | B | 331 | 207 | 593 |
| 11 | Carbon steel | Pipe & tube | A135 | A | ... | ... | ... | 1 | (57)(59) | B | 331 | 207 | 593 |
| 12 | Carbon steel | Pipe & tube | A369 | FPA | K02501 | ... | ... | 1 | (57) | B | 331 | 207 | 593 |
| 13 | Carbon steel | Pipe & tube | API 5L | A | ... | ... | ... | 1 | (57)(59) | B | 331 | 207 | 593 |
| 14 | Carbon steel | Pipe & tube | A134 | ... | ... | ... | ... | 1 | (8b)(57) | B | 345 | 186 | 482 |
| 15 | Carbon steel | Pipe & tube | A672 | A50 | K02200 | ... | ... | 1 | (57)(59)(67) | B | 345 | 186 | 593 |
| 16 | Carbon steel | Pipe & tube | A134 | ... | ... | ... | ... | 1 | (8b)(57) | A | 379 | 207 | 482 |
| 17 | Carbon steel | Pipe & tube | A524 | II | K02104 | ... | ... | 1 | (57) | −29 | 379 | 207 | 538 |
| 18 | Carbon steel | Pipe & tube | A333 | 1 | K03008 | ... | ... | 1 | (57)(59) | −46 | 379 | 207 | 593 |
| 19 | Carbon steel | Pipe & tube | A334 | 1 | K03008 | ... | ... | 1 | (57)(59) | −46 | 379 | 207 | 593 |
| 20 | Carbon steel | Pipe & tube | A671 | CA55 | K02801 | ... | ... | 1 | (59)(67) | A | 379 | 207 | 593 |
| 21 | Carbon steel | Pipe & tube | A672 | A55 | K02801 | ... | ... | 1 | (57)(59)(67) | A | 379 | 207 | 593 |
| 22 | Carbon steel | Pipe & tube | A672 | C55 | K01800 | ... | ... | 1 | (57)(67) | C | 379 | 207 | 593 |
| 23 | Carbon steel | Pipe & tube | A671 | CC60 | K02100 | ... | ... | 1 | (57)(67) | C | 414 | 221 | 538 |
| 24 | Carbon steel | Pipe & tube | A671 | CB60 | K02401 | ... | ... | 1 | (57)(67) | B | 414 | 221 | 593 |
| 25 | Carbon steel | Pipe & tube | A672 | B60 | K02401 | ... | ... | 1 | (57)(67) | B | 414 | 221 | 593 |
| 26 | Carbon steel | Pipe & tube | A672 | C60 | K02100 | ... | ... | 1 | (57)(67) | C | 414 | 221 | 593 |
| 27 | Carbon steel | Pipe & tube | A139 | B | K03003 | ... | ... | 1 | (8b) | A | 414 | 241 | 149 |
| 28 | Carbon steel | Pipe & tube | A135 | B | K03018 | ... | ... | 1 | (57)(59) | B | 414 | 241 | 538 |
| 29 | Carbon steel | Pipe & tube | A524 | I | K02104 | ... | ... | 1 | (57) | −29 | 414 | 241 | 538 |
| 30 | Carbon steel | Pipe & tube | A53 | B | K03005 | ... | ... | 1 | (57)(59) | B | 414 | 241 | 593 |
| 31 | Carbon steel | Pipe & tube | A106 | B | K03006 | ... | ... | 1 | (57) | B | 414 | 241 | 593 |
| 32 | Carbon steel | Pipe & tube | A333 | 6 | K03006 | ... | ... | 1 | (57) | −46 | 414 | 241 | 593 |
| 33 | Carbon steel | Pipe & tube | A334 | 6 | K03006 | ... | ... | 1 | (57) | −46 | 414 | 241 | 593 |
| 34 | Carbon steel | Pipe & tube | A369 | FPB | K03006 | ... | ... | 1 | (57) | −29 | 414 | 241 | 593 |
| 35 | Carbon steel | Pipe & tube | A381 | Y35 | ... | ... | ... | 1 | ... | A | 414 | 241 | 593 |
| 36 | Carbon steel | Pipe & tube | API 5L | B | ... | ... | ... | 1 | (57)(59)(77) | B | 414 | 241 | 593 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Line No.** | **Min. Temp. to 40** | **65** | **100** | **150** | **200** | **250** | **300** | **325** | **350** | **375** | **400** | **425** | **450** | **475** | **500** | **525** | **550** | **575** | **600** |
| 1 | *103* | *103* | 101 | 97.5 | 94.6 | 90.8 | 86.1 | 83.6 | 81.1 | 78.6 | **73.3** | **64.0** | **55.8** | **43.9** | **40.7** | ... | ... | ... | ... |
| 2 | *103* | *103* | 101 | 97.5 | 94.6 | 90.8 | 86.1 | 83.6 | 81.1 | 78.6 | **73.3** | **64.0** | **55.8** | **43.9** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 3 | *103* | *103* | *103* | 102 | 98.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 4 | *103* | *103* | *103* | 102 | 98.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 5 | *108* | *108* | *108* | 106 | 102 | 98.3 | 93.3 | 90.6 | 87.8 | **84.3** | **73.3** | **64.0** | **55.8** | **43.9** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 6 | *110* | *110* | *110* | *110* | *110* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 7 | *110* | *110* | *110* | *110* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 8 | *110* | *110* | *110* | *110* | *110* | *110* | 108 | 105 | **97.0** | **84.3** | **73.3** | **64.0** | **55.8** | **54.5** | ... | ... | ... | ... | ... |
| 9 | *110* | *110* | *110* | *110* | *110* | *110* | 108 | 105 | **97.0** | **84.3** | **73.3** | **64.0** | **55.8** | **43.9** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 10 | *110* | *110* | *110* | *110* | *110* | *110* | 108 | 105 | **97.0** | **84.3** | **73.3** | **64.0** | **55.8** | **43.9** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 11 | *110* | *110* | *110* | *110* | *110* | *110* | 108 | 105 | **97.0** | **84.3** | **73.3** | **64.0** | **55.8** | **43.9** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 12 | *110* | *110* | *110* | *110* | *110* | *110* | 108 | 105 | **97.0** | **84.3** | **73.3** | **64.0** | **55.8** | **43.9** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 13 | *110* | *110* | *110* | *110* | *110* | *110* | 108 | 105 | **97.0** | **84.3** | **73.3** | **64.0** | **55.8** | **43.9** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 14 | *115* | *115* | 113 | 110 | 106 | 102 | 96.9 | 94.1 | 91.2 | **84.3** | **73.3** | **64.0** | **55.8** | **43.9** | **40.7** | ... | ... | ... | ... |
| 15 | *115* | *115* | 113 | 110 | 106 | 102 | 96.9 | 94.1 | 91.2 | **84.3** | **73.3** | **64.0** | **55.8** | **43.9** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 16 | *126* | *126* | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **89.0** | **75.3** | **62.1** | **45.0** | **40.7** | ... | ... | ... | ... |
| 17 | *126* | *126* | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **89.0** | **75.3** | **62.1** | **45.0** | **31.7** | **21.4** | **17.2** | ... | ... |
| 18 | *126* | *126* | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **89.0** | **75.3** | **62.1** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 19 | *126* | *126* | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **89.0** | **75.3** | **62.1** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 20 | *126* | *126* | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **89.0** | **75.3** | **62.1** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 21 | *126* | *126* | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **89.0** | **75.3** | **62.1** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 22 | *126* | *126* | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **89.0** | **75.3** | **62.1** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 23 | *138* | *138* | 134 | 130 | 126 | 121 | 115 | 111 | 108 | 105 | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **17.2** | ... | ... |
| 24 | *138* | *138* | 134 | 130 | 126 | 121 | 115 | 111 | 108 | 105 | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 25 | *138* | *138* | 134 | 130 | 126 | 121 | 115 | 111 | 108 | 105 | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 26 | *138* | *138* | 134 | 130 | 126 | 121 | 115 | 111 | 108 | 105 | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 27 | *138* | *138* | *138* | *138* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 28 | *138* | *138* | *138* | *138* | *138* | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **17.2** | ... | ... |
| 29 | *138* | *138* | *138* | *138* | *138* | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **17.2** | ... | ... |
| 30 | *138* | *138* | *138* | *138* | *138* | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 31 | *138* | *138* | *138* | *138* | *138* | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 32 | *138* | *138* | *138* | *138* | *138* | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 33 | *138* | *138* | *138* | *138* | *138* | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 34 | *138* | *138* | *138* | *138* | *138* | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 35 | *138* | *138* | *138* | *138* | *138* | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 36 | *138* | *138* | *138* | *138* | *138* | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Cond./ Temper | Size, mm | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37 | Carbon steel | Pipe & tube | A139 | C | K03004 | ... | ... | 1 | (8b) | A | 414 | 290 | 149 |
| 38 | Carbon steel | Pipe & tube | A139 | D | K03010 | ... | ... | 1 | (8b) | A | 414 | 317 | 149 |
| 39 | Carbon steel | Pipe & tube | API 5L | X42 | ... | ... | ... | 1 | (55)(77) | A | 414 | 290 | 204 |
| 40 | Carbon steel | Pipe & tube | A381 | Y42 | ... | ... | ... | 1 | ... | A | 414 | 290 | 204 |
| 41 | Carbon steel | Pipe & tube | A381 | Y48 | ... | ... | ... | 1 | ... | A | 427 | 331 | 343 |
| 42 | Carbon steel | Pipe & tube | API 5L | X46 | ... | ... | ... | 1 | (55)(77) | A | 434 | 317 | 204 |
| 43 | Carbon steel | Pipe & tube | A381 | Y46 | ... | ... | ... | 1 | ... | A | 434 | 317 | 204 |
| 44 | Carbon steel | Pipe & tube | A381 | Y50 | ... | ... | ... | 1 | ... | A | 441 | 345 | 343 |
| 45 | Carbon steel | Pipe & tube | A671 | CC65 | K02403 | ... | ... | 1 | (57)(67) | B | 448 | 241 | 538 |
| 46 | Carbon steel | Pipe & tube | A671 | CB65 | K02800 | ... | ... | 1 | (57)(67) | A | 448 | 241 | 593 |
| 47 | Carbon steel | Pipe & tube | A672 | B65 | K02800 | ... | ... | 1 | (57)(67) | A | 448 | 241 | 593 |
| 48 | Carbon steel | Pipe & tube | A672 | C65 | K02403 | ... | ... | 1 | (57)(67) | B | 448 | 241 | 593 |
| 49 | Carbon steel | Pipe & tube | A139 | E | K03012 | ... | ... | 1 | (8b) | A | 455 | 359 | 149 |
| 50 | Carbon steel | Pipe & tube | API 5L | X52 | ... | ... | ... | 1 | (55)(77) | A | 455 | 359 | 204 |
| 51 | Carbon steel | Pipe & tube | A381 | Y52 | ... | ... | ... | 1 | ... | A | 455 | 359 | 204 |
| 52 | Carbon steel | Pipe & tube | A671 | CC70 | K02700 | ... | ... | 1 | (57)(67) | B | 483 | 262 | 538 |
| 53 | Carbon steel | Pipe & tube | A671 | CB70 | K03101 | ... | ... | 1 | (57)(67) | A | 483 | 262 | 593 |
| 54 | Carbon steel | Pipe & tube | A672 | B70 | K03101 | ... | ... | 1 | (57)(67) | A | 483 | 262 | 593 |
| 55 | Carbon steel | Pipe & tube | A672 | C70 | K02700 | ... | ... | 1 | (57)(67) | B | 483 | 262 | 593 |
| 56 | Carbon steel | Pipe & tube | A106 | C | K03501 | ... | ... | 1 | (57) | B | 483 | 276 | 427 |
| 57 | Carbon steel | Pipe & tube | A671 | CD70 | K12437 | ... | ≤64 | 1 | (67) | D | 483 | 345 | 371 |
| 58 | Carbon steel | Pipe & tube | A672 | D70 | K12437 | ... | ≤64 | 1 | (67) | D | 483 | 345 | 371 |
| 59 | Carbon steel | Pipe & tube | A691 | CMSH-70 | K12437 | ... | ≤64 | 1 | (67) | D | 483 | 345 | 371 |
| 60 | Carbon steel | Pipe & tube | API 5L | X56 | ... | ... | ... | 1 | (51)(55)(71)(77) | A | 490 | 386 | 204 |
| 61 | Carbon steel | Pipe & tube | A381 | Y56 | ... | ... | ... | 1 | (51)(55)(71) | A | 490 | 386 | 204 |
| 62 | Carbon steel | Pipe & tube | A671 | CK75 | K02803 | ... | >25 | 1 | (57)(67) | A | 517 | 276 | 593 |
| 63 | Carbon steel | Pipe & tube | A672 | N75 | K02803 | ... | >25 | 1 | (57)(67) | A | 517 | 276 | 593 |
| 64 | Carbon steel | Pipe & tube | A691 | CMS-75 | K02803 | ... | >25 | 1 | (57)(67) | A | 517 | 276 | 593 |
| 65 | Carbon steel | Pipe & tube | A671 | CK75 | K02803 | ... | ≤25 | 1 | (57)(67) | A | 517 | 290 | 371 |
| 66 | Carbon steel | Pipe & tube | A672 | N75 | K02803 | ... | ≤25 | 1 | (57)(67) | A | 517 | 290 | 371 |
| 67 | Carbon steel | Pipe & tube | A691 | CMS-75 | K02803 | ... | ≤25 | 1 | (57)(67) | A | 517 | 290 | 371 |
| 68 | Carbon steel | Pipe & tube | API 5L | X60 | ... | ... | ... | 1 | (51)(55)(71)(77) | A | 517 | 414 | 204 |
| 69 | Carbon steel | Pipe & tube | API 5L | X65 | ... | ... | ... | 1 | (51)(55)(71)(77) | A | 531 | 448 | 204 |
| 70 | Carbon steel | Pipe & tube | API 5L | X70 | ... | ... | ... | 1 | (51)(55)(71)(77) | A | 565 | 483 | 204 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40 | 65 | 100 | 150 | 200 | 250 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37 | *138* | *138* | *138* | *138* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 38 | *138* | *138* | *138* | *138* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 39 | *138* | *138* | *138* | *138* | *138* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 40 | *138* | *138* | *138* | *138* | *138* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 41 | *142* | *142* | *142* | *142* | *142* | *142* | *142* | *142* | *129* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 42 | *145* | *145* | *145* | *145* | *145* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 43 | *145* | *145* | *145* | *145* | *145* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 44 | *147* | *147* | *147* | *147* | *147* | *147* | *147* | *147* | *129* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 45 | *149* | *149* | 147 | 142 | 138 | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **64.4** | **47.7** | **32.5** | **21.4** | **17.2** | ... | ... |
| 46 | *149* | *149* | 147 | 142 | 138 | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **64.4** | **47.7** | **32.5** | **21.4** | **14.2** | **9.40** | **6.89** |
| 47 | *149* | *149* | 147 | 142 | 138 | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **64.4** | **47.7** | **32.5** | **21.4** | **14.2** | **9.40** | **6.89** |
| 48 | *149* | *149* | 147 | 142 | 138 | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **64.4** | **47.7** | **32.5** | **21.4** | **14.2** | **9.40** | **6.89** |
| 49 | *152* | *152* | *152* | *152* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 50 | *152* | *152* | *152* | *152* | *152* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 51 | *152* | *152* | *152* | *152* | *152* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 52 | *161* | *161* | 159 | 154 | 150 | 144 | 136 | 132 | 128 | **122** | **101** | **83.8** | **66.8** | **50.3** | **33.2** | **21.4** | **17.2** | ... | ... |
| 53 | *161* | *161* | 159 | 154 | 150 | 144 | 136 | 132 | 128 | **122** | **101** | **83.8** | **66.8** | **50.3** | **33.2** | **21.4** | **14.2** | **9.40** | **6.89** |
| 54 | *161* | *161* | 159 | 154 | 150 | 144 | 136 | 132 | 128 | **122** | **101** | **83.8** | **66.8** | **50.3** | **33.2** | **21.4** | **14.2** | **9.40** | **6.89** |
| 55 | *161* | *161* | 159 | 154 | 150 | 144 | 136 | 132 | 128 | **122** | **101** | **83.8** | **66.8** | **50.3** | **33.2** | **21.4** | **14.2** | **9.40** | **6.89** |
| 56 | *161* | *161* | *161* | *161* | 158 | 151 | 144 | 139 | 135 | **122** | **101** | **83.8** | **82.7** | ... | ... | ... | ... | ... | ... |
| 57 | *161* | *161* | *161* | *157* | *156* | *156* | 156 | 154 | **148** | **126** | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 58 | *161* | *161* | *161* | *157* | *156* | *156* | 156 | 154 | **148** | **126** | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 59 | *161* | *161* | *161* | *157* | *156* | *156* | 156 | 154 | **148** | **126** | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 60 | *163* | *163* | *163* | *163* | *163* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 61 | *163* | *163* | *163* | *163* | *163* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 62 | *172* | *172* | 168 | 163 | 158 | 151 | 144 | 139 | 135 | **131** | **107** | **88.0** | **67.3** | **50.3** | **33.2** | **21.4** | **14.2** | **9.40** | **6.89** |
| 63 | *172* | *172* | 168 | 163 | 158 | 151 | 144 | 139 | 135 | **131** | **107** | **88.0** | **67.3** | **50.3** | **33.2** | **21.4** | **14.2** | **9.40** | **6.89** |
| 64 | *172* | *172* | 168 | 163 | 158 | 151 | 144 | 139 | 135 | **131** | **107** | **88.0** | **67.3** | **50.3** | **33.2** | **21.4** | **14.2** | **9.40** | **6.89** |
| 65 | *172* | *172* | *172* | 171 | 165 | 159 | 151 | 146 | 142 | **131** | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 66 | *172* | *172* | *172* | 171 | 165 | 159 | 151 | 146 | 142 | **131** | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 67 | *172* | *172* | *172* | 171 | 165 | 159 | 151 | 146 | 142 | **131** | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 68 | *172* | *172* | *172* | *172* | *172* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 69 | *177* | *177* | *177* | *177* | *177* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 70 | *188* | *188* | *188* | *188* | *188* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Cond./ Temper | Size, mm | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 71 | Carbon steel | Pipe & tube | API 5L | X80 | ... | ... | ... | 1 | (51)(55)(71)(77) | A | 621 | 552 | 204 |
| 72 | Carbon steel | Pipe & tube | A381 | Y60 | ... | ... | ... | 1 | (51)(71) | A | 517 | 414 | 204 |
| 73 | Carbon steel | Pipe | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −29 | 311 | 165 | 204 |
| 74 | Carbon steel | Pipe | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −29 | 338 | 207 | 204 |
| 75 | Carbon steel | Pipe | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −29 | 345 | 186 | 149 |
| 76 | Carbon steel | Pipe | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −29 | 359 | 228 | 204 |
| 77 | Carbon steel | Pipe | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −29 | 365 | 248 | 204 |
| 78 | Carbon steel | Pipe | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −29 | 379 | 276 | 204 |
| 79 | Carbon steel | Pipe | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −29 | 400 | 248 | 204 |
| 80 | Carbon steel | Pipe | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −29 | 414 | 228 | 149 |
| 81 | Carbon steel | Pipe | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −29 | 414 | 310 | 204 |
| 82 | Carbon steel | Pipe | A134 | ... | ... | ... | ... | 1 | (8a)(8c) | −29 | 448 | 345 | 204 |
| 83 | Carbon steel | Plate, bar, shps., sheet | A285 | A | K01700 | ... | ... | 1 | (57)(59) | B | 310 | 165 | 593 |
| 84 | Carbon steel | Plate, bar, shps., sheet | A285 | B | K02200 | ... | ... | 1 | (57)(59) | B | 345 | 186 | 593 |
| 85 | Carbon steel | Plate, bar, shps., sheet | A516 | 55 | K01800 | ... | ... | 1 | (57) | C | 379 | 207 | 454 |
| 86 | Carbon steel | Plate, bar, shps., sheet | A285 | C | K02801 | ... | ... | 1 | (57)(59) | A | 379 | 207 | 593 |
| 87 | Carbon steel | Plate, bar, shps., sheet | A516 | 60 | K02100 | ... | ... | 1 | (57) | C | 414 | 221 | 454 |
| 88 | Carbon steel | Plate, bar, shps., sheet | A515 | 60 | K02401 | ... | ... | 1 | (57) | B | 414 | 221 | 538 |
| 89 | Carbon steel | Plate, bar, shps., sheet | A696 | B | K03200 | ... | ... | 1 | (57) | A | 415 | 240 | 371 |
| 90 | Carbon steel | Plate, bar, shps., sheet | A516 | 65 | K02403 | ... | ... | 1 | (57) | B | 448 | 241 | 454 |
| 91 | Carbon steel | Plate, bar, shps., sheet | A515 | 65 | K02800 | ... | ... | 1 | (57) | A | 448 | 241 | 538 |
| 92 | Carbon steel | Plate, bar, shps., sheet | A516 | 70 | K02700 | ... | ... | 1 | (57) | B | 483 | 262 | 454 |
| 93 | Carbon steel | Plate, bar, shps., sheet | A515 | 70 | K03101 | ... | ... | 1 | (57) | A | 483 | 262 | 538 |
| 94 | Carbon steel | Plate, bar, shps., sheet | A696 | C | K03200 | ... | ... | 1 | (57) | A | 485 | 275 | 371 |
| 95 | Carbon steel | Plate, bar, shps., sheet | A537 | ... | K12437 | 1 | ≤64 | 1 | ... | D | 483 | 345 | 371 |
| 96 | Carbon steel | Plate, bar, shps., sheet | A299 | A | K02803 | ... | >25 | 1 | (57) | A | 517 | 276 | 593 |
| 97 | Carbon steel | Plate, bar, shps., sheet | A299 | A | K02803 | ... | ≤25 | 1 | (57) | A | 517 | 290 | 593 |
| 98 | Carbon steel | Plate, bar, shps., sheet | A283 | A | K01400 | ... | ... | 1 | (8c)(57) | A | 310 | 165 | 399 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40 | 65 | 100 | 150 | 200 | 250 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 71 | *207* | *207* | *207* | *207* | *207* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 72 | *172* | *172* | *172* | *172* | *172* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 73 | *103* | *103* | 101 | 97.5 | 94.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 74 | *113* | *113* | *113* | *113* | *113* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 75 | *115* | *115* | 113 | 110 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 76 | *120* | *120* | *120* | *120* | *120* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 77 | *122* | *122* | *122* | *122* | *122* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 78 | *126* | *126* | *126* | *126* | *126* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 79 | *133* | *133* | *133* | *133* | *133* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 80 | *138* | *138* | *138* | 134 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 81 | *138* | *138* | *138* | *138* | *138* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 82 | *149* | *149* | *149* | *149* | *149* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 83 | *103* | *103* | 101 | 97.5 | 94.6 | 90.8 | 86.1 | 83.6 | 81.1 | 78.6 | **73.3** | **64.0** | **55.8** | **43.9** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 84 | *115* | *115* | 113 | 110 | 106 | 102 | 96.9 | 94.1 | 91.2 | **84.3** | **73.3** | **64.0** | **55.8** | **43.9** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 85 | *126* | *126* | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **89.0** | **75.3** | **62.1** | **60.0** | ... | ... | ... | ... | ... |
| 86 | *126* | *126* | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **89.0** | **75.3** | **62.1** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 87 | *138* | *138* | 134 | 130 | 126 | 121 | 115 | 111 | 108 | 105 | **95.1** | **79.5** | **62.6** | **60.0** | ... | ... | ... | ... | ... |
| 88 | *138* | *138* | 134 | 130 | 126 | 121 | 115 | 111 | 108 | 105 | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **17.2** | ... | ... |
| 89 | *138* | *138* | *138* | *138* | 138 | 132 | 125 | 122 | 118 | 115 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 90 | *149* | *149* | 147 | 142 | 138 | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **64.4** | **62.1** | ... | ... | ... | ... | ... |
| 91 | *149* | *149* | 147 | 142 | 138 | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **64.4** | **47.7** | **32.5** | **21.4** | **17.2** | ... | ... |
| 92 | *161* | *161* | 159 | 154 | 150 | 144 | 136 | 132 | 128 | **122** | **101** | **83.8** | **66.8** | **64.1** | ... | ... | ... | ... | ... |
| 93 | *161* | *161* | 159 | 154 | 150 | 144 | 136 | 132 | 128 | **122** | **101** | **83.8** | **66.8** | **50.3** | **33.2** | **21.4** | **17.2** | ... | ... |
| 94 | *161* | *161* | *161* | *161* | 158 | 151 | 144 | 139 | 135 | 131 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 95 | *161* | *161* | *161* | *157* | *156* | *156* | 156 | 154 | **148** | **126** | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 96 | *172* | *172* | 168 | 163 | 158 | 151 | 144 | 139 | 135 | **131** | **107** | **88.0** | **67.3** | **50.3** | **33.2** | **21.4** | **14.2** | **9.40** | **6.89** |
| 97 | *172* | *172* | *172* | 171 | 165 | 159 | 151 | 146 | 142 | **131** | **107** | **88.0** | **67.3** | **50.3** | **33.2** | **21.4** | **14.2** | **9.40** | **6.89** |
| 98 | *103* | *103* | 101 | 97.5 | 94.6 | 90.8 | 86.1 | 83.6 | 81.1 | 78.6 | 73.8 | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Cond./ Temper | Size, mm | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99 | Carbon steel | Plate, bar, shps., sheet | A1011 | 30 | K02502 | ... | ... | 1 | (8c)(57) | A | 338 | 207 | 399 |
| 100 | Carbon steel | Plate, bar, shps., sheet | A283 | B | K01702 | ... | ... | 1 | (8c)(57) | A | 345 | 186 | 399 |
| 101 | Carbon steel | Plate, bar, shps., sheet | A1011 | 33 | K02502 | ... | ... | 1 | (8c)(57) | A | 359 | 228 | 399 |
| 102 | Carbon steel | Plate, bar, shps., sheet | A1011 | 36 | K02502 | ... | ... | 1 | (8c)(57) | A | 365 | 248 | 399 |
| 103 | Carbon steel | Plate, bar, shps., sheet | A283 | C | K02401 | ... | ... | 1 | (8c)(57) | A | 379 | 207 | 399 |
| 104 | Carbon steel | Plate, bar, shps., sheet | A1011 | 40 | K02502 | ... | ... | 1 | (8c)(57) | A | 379 | 276 | 399 |
| 105 | Carbon steel | Plate, bar, shps., sheet | A36 | ... | K02600 | ... | ... | 1 | (8c) | A | 400 | 248 | 371 |
| 106 | Carbon steel | Plate, bar, shps., sheet | A283 | D | K02702 | ... | ... | 1 | (8c)(57) | A | 414 | 228 | 399 |
| 107 | Carbon steel | Plate, bar, shps., sheet | A1011 | 45 | K02507 | ... | ... | 1 | (8c)(57) | A | 414 | 310 | 399 |
| 108 | Carbon steel | Plate, bar, shps., sheet | A1011 | 50 | K02507 | ... | ... | 1 | (8c)(57) | A | 448 | 344 | 399 |
| 109 | Carbon steel | Plate, bar, shps., sheet | A992 | ... | ... | ... | ... | 1 | (8c)(57) | A | 448 | 344 | 427 |
| 110 | Carbon steel | Forgings & fittings | A350 | LF1 | K03009 | ... | ... | 1 | (9)(57)(59) | −29 | 414 | 207 | 538 |
| 111 | Carbon steel | Forgings & fittings | A181 | ... | K03502 | 60 | ... | 1 | (9)(57)(59) | A | 414 | 207 | 593 |
| 112 | Carbon steel | Forgings & fittings | A420 | WPL6 | K03006 | ... | ... | 1 | (57) | −46 | 414 | 241 | 538 |
| 113 | Carbon steel | Forgings & fittings | A234 | WPB | K03006 | ... | ... | 1 | (57)(59) | B | 414 | 241 | 593 |
| 114 | Carbon steel | Forgings & fittings | A694 | F42 | K03014 | ... | ... | 1 | (9) | −29 | 415 | 290 | 260 |
| 115 | Carbon steel | Forgings & fittings | A707 | L1 | K02302 | 1 | ... | 1 | (9) | −29 | 415 | 290 | 260 |
| 116 | Carbon steel | Forgings & fittings | A707 | L2 | K03301 | 1 | ... | 1 | (9) | −46 | 415 | 290 | 260 |
| 117 | Carbon steel | Forgings & fittings | A707 | L3 | K12510 | 1 | ... | 1 | (9) | −46 | 415 | 290 | 260 |
| 118 | Carbon steel | Forgings & fittings | A860 | WPHY 42 | ... | ... | ... | 1 | ... | −46 | 415 | 290 | 260 |
| 119 | Carbon steel | Forgings & fittings | A694 | F46 | K03014 | ... | ... | 1 | (9) | −29 | 435 | 317 | 260 |
| 120 | Carbon steel | Forgings & fittings | A860 | WPHY 46 | ... | ... | ... | 1 | ... | −46 | 435 | 317 | 260 |
| 121 | Carbon steel | Forgings & fittings | A694 | F52 | K03014 | ... | ... | 1 | (9) | −29 | 455 | 360 | 260 |
| 122 | Carbon steel | Forgings & fittings | A707 | L1 | K02302 | 2 | ... | 1 | (9) | −29 | 455 | 360 | 260 |
| 123 | Carbon steel | Forgings & fittings | A707 | L2 | K03301 | 2 | ... | 1 | (9) | −46 | 455 | 360 | 260 |
| 124 | Carbon steel | Forgings & fittings | A707 | L3 | K12510 | 2 | ... | 1 | (9) | −46 | 455 | 360 | 260 |
| 125 | Carbon steel | Forgings & fittings | A860 | WPHY 52 | ... | ... | ... | 1 | ... | −46 | 455 | 360 | 260 |
| 126 | Carbon steel | Forgings & fittings | A350 | LF2 | K03011 | 1 | ... | 1 | (9)(57) | −46 | 483 | 248 | 538 |
| 127 | Carbon steel | Forgings & fittings | A350 | LF2 | K03011 | 2 | ... | 1 | (9)(57) | −18 | 483 | 248 | 538 |
| 128 | Carbon steel | Forgings & fittings | A105 | ... | K03504 | ... | ... | 1 | (9)(57)(59) | −29 | 483 | 248 | 593 |
| 129 | Carbon steel | Forgings & fittings | A181 | ... | K03502 | 70 | ... | 1 | (9)(57)(59) | A | 483 | 248 | 593 |
| 130 | Carbon steel | Forgings & fittings | A234 | WPC | K03501 | ... | ... | 1 | (57)(59) | B | 483 | 276 | 427 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Line No.** | **Min. Temp. to 40** | **65** | **100** | **150** | **200** | **250** | **300** | **325** | **350** | **375** | **400** | **425** | **450** | **475** | **500** | **525** | **550** | **575** | **600** |
| 99 | *113* | *113* | *113* | *113* | *113* | *113* | 108 | 105 | **97.0** | **84.3** | **73.8** | … | … | … | … | … | … | … | … |
| 100 | *115* | *115* | 113 | 110 | 106 | 102 | 96.9 | 94.1 | 91.2 | **84.3** | **73.8** | … | … | … | … | … | … | … | … |
| 101 | *120* | *120* | *120* | *120* | *120* | *120* | 118 | 115 | **97.0** | **84.3** | **73.8** | … | … | … | … | … | … | … | … |
| 102 | *122* | *122* | *122* | *122* | *122* | *122* | *122* | *122* | **97.0** | **84.3** | **73.8** | … | … | … | … | … | … | … | … |
| 103 | *126* | *126* | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | 89.6 | … | … | … | … | … | … | … | … |
| 104 | *126* | *126* | *126* | *126* | *126* | *126* | *126* | *126* | **124** | **105** | **89.6** | … | … | … | … | … | … | … | … |
| 105 | *133* | *133* | *133* | *133* | *133* | *133* | 129 | 125 | 122 | 108 | … | … | … | … | … | … | … | … | … |
| 106 | *138* | *138* | *138* | 134 | 130 | 125 | 118 | 115 | 111 | 108 | 95.8 | … | … | … | … | … | … | … | … |
| 107 | *138* | *138* | *138* | *138* | *138* | *138* | *138* | *138* | **135** | **113** | **95.8** | … | … | … | … | … | … | … | … |
| 108 | *149* | *149* | *149* | *149* | *149* | *149* | *149* | *149* | **135** | **113** | **95.8** | … | … | … | … | … | … | … | … |
| 109 | 142 | 142 | 142 | 142 | 142 | 142 | 142 | 142 | **121** | **108** | **90.3** | **75.6** | **59.9** | … | … | … | … | … | … |
| 110 | *138* | 130 | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **17.2** | … | … |
| 111 | *138* | 130 | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 112 | *138* | *138* | *138* | *138* | *138* | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **17.2** | … | … |
| 113 | *138* | *138* | *138* | *138* | *138* | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 114 | *138* | *138* | *138* | *138* | *138* | 137 | 132 | … | … | … | … | … | … | … | … | … | … | … | … |
| 115 | *138* | *138* | *138* | *138* | *138* | 137 | 132 | … | … | … | … | … | … | … | … | … | … | … | … |
| 116 | *138* | *138* | *138* | *138* | *138* | 137 | 132 | … | … | … | … | … | … | … | … | … | … | … | … |
| 117 | *138* | *138* | *138* | *138* | *138* | 137 | 132 | … | … | … | … | … | … | … | … | … | … | … | … |
| 118 | *138* | *138* | *138* | *138* | *138* | 137 | 132 | … | … | … | … | … | … | … | … | … | … | … | … |
| 119 | *145* | *145* | *145* | *145* | *145* | *145* | 144 | … | … | … | … | … | … | … | … | … | … | … | … |
| 120 | *145* | *145* | *145* | *145* | *145* | *145* | 144 | … | … | … | … | … | … | … | … | … | … | … | … |
| 121 | *150* | *150* | *150* | *150* | *150* | *150* | *150* | … | … | … | … | … | … | … | … | … | … | … | … |
| 122 | *150* | *150* | *150* | *150* | *150* | *150* | *150* | … | … | … | … | … | … | … | … | … | … | … | … |
| 123 | *150* | *150* | *150* | *150* | *150* | *150* | *150* | … | … | … | … | … | … | … | … | … | … | … | … |
| 124 | *150* | *150* | *150* | *150* | *150* | *150* | *150* | … | … | … | … | … | … | … | … | … | … | … | … |
| 125 | *150* | *150* | *150* | *150* | *150* | *150* | *150* | … | … | … | … | … | … | … | … | … | … | … | … |
| 126 | *161* | 156 | 151 | 146 | 142 | 136 | 129 | 125 | 122 | 118 | **101** | **83.8** | **66.8** | **50.3** | **33.2** | **21.4** | **17.2** | … | … |
| 127 | *161* | 156 | 151 | 146 | 142 | 136 | 129 | 125 | 122 | 118 | **101** | **83.8** | **66.8** | **50.3** | **33.2** | **21.4** | **17.2** | … | … |
| 128 | *161* | 156 | 151 | 146 | 142 | 136 | 129 | 125 | 122 | 118 | **101** | **83.8** | **66.8** | **50.3** | **33.2** | **21.4** | **14.2** | **9.40** | **6.89** |
| 129 | *161* | 156 | 151 | 146 | 142 | 136 | 129 | 125 | 122 | 118 | **101** | **83.8** | **66.8** | **50.3** | **33.2** | **21.4** | **14.2** | **9.40** | **6.89** |
| 130 | *161* | *161* | *161* | *161* | 158 | 151 | 144 | 139 | 135 | **122** | **101** | **83.8** | **82.7** | … | … | … | … | … | … |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Cond./ Temper | Size, mm | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131 | Carbon steel | Forgings & fittings | A694 | F56 | K03014 | ... | ... | 1 | (9) | −29 | 490 | 385 | 260 |
| 132 | Carbon steel | Forgings & fittings | A694 | F60 | K03014 | ... | ... | 1 | (9) | −29 | 515 | 415 | 260 |
| 133 | Carbon steel | Forgings & fittings | A707 | L2 | K03301 | 3 | ... | 1 | (9) | −46 | 515 | 415 | 260 |
| 134 | Carbon steel | Forgings & fittings | A707 | L3 | K12510 | 3 | ... | 1 | (9) | −46 | 515 | 415 | 260 |
| 135 | Carbon steel | Forgings & fittings | A860 | WPHY 60 | ... | ... | ... | 1 | ... | −46 | 515 | 415 | 260 |
| 136 | Carbon steel | Forgings & fittings | A694 | F65 | K03014 | ... | ... | 1 | (9) | −29 | 530 | 450 | 260 |
| 137 | Carbon steel | Forgings & fittings | A860 | WPHY 65 | ... | ... | ... | 1 | ... | −46 | 530 | 450 | 260 |
| 138 | Carbon steel | Forgings & fittings | A694 | F70 | K03014 | ... | ... | 1 | (9)(79) | ... | 565 | 485 | 204 |
| 139 | Carbon steel | Forgings & fittings | A860 | WPHY 70 | ... | ... | ... | 1 | ... | −46 | 565 | 485 | 204 |
| 140 | Carbon steel | Castings | A216 | WCA | J02502 | ... | ... | 1 | (57) | −29 | 414 | 207 | 593 |
| 141 | Carbon steel | Castings | A352 | LCB | J03003 | ... | ... | 1 | (9)(57) | −46 | 448 | 241 | 593 |
| 142 | Carbon steel | Castings | A352 | LCC | J02505 | ... | ... | 1 | (9) | −46 | 483 | 276 | 371 |
| 143 | Carbon steel | Castings | A216 | WCB | J03002 | ... | ... | 1 | (9)(57) | −29 | 483 | 248 | 593 |
| 144 | Carbon steel | Castings | A216 | WCC | J02503 | ... | ... | 1 | (9)(57) | −29 | 483 | 276 | 538 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Min. Temp. to 40 | 65 | 100 | 150 | 200 | 250 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 |
| 131 | *163* | *163* | *163* | *163* | *163* | *163* | *163* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 132 | *172* | *172* | *172* | *172* | *172* | *172* | *172* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 133 | *172* | *172* | *172* | *172* | *172* | *172* | *172* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 134 | *172* | *172* | *172* | *172* | *172* | *172* | *172* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 135 | *172* | *172* | *172* | *172* | *172* | *172* | *172* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 136 | *177* | *177* | *177* | *177* | *177* | *177* | *177* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 137 | *177* | *177* | *177* | *177* | *177* | *177* | *177* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 138 | *188* | *188* | *188* | *188* | *188* | *188* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 139 | *188* | *188* | *188* | *188* | *188* | *188* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 140 | *138* | 130 | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | **95.1** | **79.5** | **62.6** | **45.0** | **31.7** | **21.4** | **14.2** | **9.40** | **6.89** |
| 141 | *149* | *149* | 147 | 142 | 138 | 132 | 126 | 122 | 118 | **113** | **95.1** | **79.5** | **64.4** | **47.7** | **32.5** | **21.4** | **14.2** | **9.40** | **6.89** |
| 142 | *161* | *161* | 161 | 161 | 158 | 151 | 139 | 137 | 136 | 132 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 143 | *161* | 156 | 151 | 146 | 142 | 136 | 129 | 125 | 122 | 118 | **101** | **83.8** | **66.8** | **50.3** | **33.2** | **21.4** | **14.2** | **9.40** | **6.89** |
| 144 | *161* | *161* | *161* | *161* | 158 | 151 | 144 | 139 | 135 | **122** | **101** | **83.8** | **66.8** | **50.3** | **33.2** | **21.4** | **17.2** | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ½Cr–½Mo | Pipe | A335 | P2 | K11547 | ... | ... | 3 | ... | −29 | 379 | 207 | 538 |
| 2 | ½Cr–½Mo | Pipe | A691 | ½CR | K12143 | ... | ... | 3 | (11)(67) | −29 | 379 | 228 | 538 |
| 3 | C–½Mo | Pipe | A335 | P1 | K11522 | ... | ... | 3 | (58) | −29 | 379 | 207 | 593 |
| 4 | C–½Mo | Pipe | A369 | FP1 | K11522 | ... | ... | 3 | (58) | −29 | 379 | 207 | 593 |
| 5 | ½Cr–½Mo | Pipe | A369 | FP2 | K11547 | ... | ... | 3 | ... | −29 | 379 | 207 | 593 |
| 6 | 1Cr–½Mo | Pipe | A691 | 1CR | K11757 | ... | ... | 4 | (11)(67) | −29 | 379 | 228 | 649 |
| 7 | ½Cr–½Mo | Pipe | A426 | CP2 | J11547 | ... | ... | 3 | (10) | −29 | 414 | 207 | 593 |
| 8 | 1½Si–½Mo | Pipe | A335 | P15 | K11578 | ... | ... | 3 | ... | −29 | 414 | 207 | 593 |
| 9 | C–½Mo–Si | Pipe | A426 | CP15 | J11522 | ... | ... | 3 | (10) | −29 | 414 | 207 | 593 |
| 10 | 1Cr–½Mo | Pipe | A426 | CP12 | J11562 | ... | ... | 4 | (10) | −29 | 414 | 207 | 649 |
| 11 | 5Cr–1½Si–½Mo | Pipe | A426 | CP5b | J51545 | ... | ... | 5B | (10) | −29 | 414 | 207 | 649 |
| 12 | 3Cr–Mo | Pipe | A426 | CP21 | J31545 | ... | ... | 5A | (10) | −29 | 414 | 207 | 649 |
| 13 | ¾Cr–¾Ni–Cu–Al | Pipe | A333 | 4 | K11267 | ... | ... | 4 | ... | −101 | 414 | 241 | 40 |
| 14 | 2Cr–½Mo | Pipe | A369 | FP3b | K21509 | ... | ... | 4 | ... | −29 | 414 | 207 | 649 |
| 15 | 1Cr–½Mo | Pipe | A335 | P12 | K11562 | ... | ... | 4 | ... | −29 | 414 | 221 | 649 |
| 16 | 1Cr–½Mo | Pipe | A369 | FP12 | K11562 | ... | ... | 4 | ... | −29 | 414 | 221 | 649 |
| 17 | 1¼Cr–½Mo–Si | Pipe | A335 | P11 | K11597 | ... | ... | 4 | ... | −29 | 414 | 207 | 649 |
| 18 | 1¼Cr–½Mo–Si | Pipe | A369 | FP11 | K11597 | ... | ... | 4 | ... | −29 | 414 | 207 | 649 |
| 19 | 1¼Cr–½Mo–Si | Pipe | A691 | 1¼CR | K11789 | ... | ... | 4 | (11)(67) | −29 | 414 | 241 | 649 |
| 20 | 5Cr–½Mo | Pipe | A691 | 5CR | K41545 | ... | ... | 5B | (11)(67) | −29 | 414 | 207 | 649 |
| 21 | 5Cr–½Mo | Pipe | A335 | P5 | K41545 | ... | ... | 5B | ... | −29 | 414 | 207 | 649 |
| 22 | 5Cr–½Mo–Si | Pipe | A335 | P5b | K51545 | ... | ... | 5B | ... | −29 | 414 | 207 | 649 |
| 23 | 5Cr–½Mo–Ti | Pipe | A335 | P5c | K41245 | ... | ... | 5B | ... | −29 | 414 | 207 | 649 |
| 24 | 5Cr–½Mo | Pipe | A369 | FP5 | K41545 | ... | ... | 5B | ... | −29 | 414 | 207 | 649 |
| 25 | 9Cr–1Mo | Pipe | A335 | P9 | K90941 | ... | ... | 5B | ... | −29 | 414 | 207 | 649 |
| 26 | 9Cr–1Mo | Pipe | A369 | FP9 | K90941 | ... | ... | 5B | ... | −29 | 414 | 207 | 649 |
| 27 | 9Cr–1Mo | Pipe | A691 | 9CR | K90941 | ... | ... | 5B | (11)(67) | −29 | 414 | 207 | 649 |
| 28 | 3Cr–1Mo | Pipe | A335 | P21 | K31545 | ... | ... | 5A | ... | −29 | 414 | 207 | 649 |
| 29 | 3Cr–1Mo | Pipe | A369 | FP21 | K31545 | ... | ... | 5A | ... | −29 | 414 | 207 | 649 |
| 30 | 3Cr–1Mo | Pipe | A691 | 3CR | K31545 | ... | ... | 5A | (11)(67) | −29 | 414 | 207 | 649 |
| 31 | 2¼Cr–1Mo | Pipe | A691 | 2¼CR | K21590 | ... | ... | 5A | (11)(67)(72)(75) | −29 | 414 | 207 | 649 |
| 32 | 2¼Cr–1Mo | Pipe | A369 | FP22 | K21590 | ... | ... | 5A | (72)(75) | −29 | 414 | 207 | 649 |
| 33 | 2¼Cr–1Mo | Pipe | A335 | P22 | K21590 | ... | ... | 5A | (72)(75) | −29 | 414 | 207 | 649 |
| 34 | 2Ni–1Cu | Pipe | A333 | 9 | K22035 | ... | ... | 9A | ... | −73 | 434 | 317 | 40 |
| 35 | 2Ni–1Cu | Pipe | A334 | 9 | K22035 | ... | ... | 9A | ... | −73 | 434 | 317 | 40 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 | 625 | 650 |
| 1 | 126 | 126 | 126 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103 | 100 | 97.1 | 74.4 | 49.9 | 40.7 | ... | ... | ... | ... |
| 2 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 125 | 123 | 121 | 119 | 116 | 114 | 110 | 107 | 74.4 | 49.9 | 40.7 | ... | ... | ... | ... |
| 3 | 126 | 126 | 126 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103 | 100 | 97.1 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 4 | 126 | 126 | 126 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103 | 100 | 97.1 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 5 | 126 | 126 | 126 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103 | 100 | 97.1 | 93.5 | 49.9 | 34.7 | 23.9 | 17.2 | ... | ... |
| 6 | 126 | 126 | 123 | 122 | 122 | 122 | 122 | 121 | 120 | 118 | 116 | 115 | 114 | 112 | 110 | 109 | 106 | 104 | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |
| 7 | 138 | 133 | 129 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103 | 100 | 97.1 | 74.4 | 49.9 | 34.3 | 23.2 | 16.5 | ... | ... |
| 8 | 138 | 133 | 129 | 127 | 125 | 124 | 122 | 121 | 120 | 118 | 117 | 115 | 114 | 112 | 110 | 107 | 103 | 88.4 | 74.7 | 53.7 | 35.6 | 23.2 | 16.5 | ... | ... |
| 9 | 138 | 133 | 129 | 127 | 125 | 124 | 122 | 121 | 120 | 118 | 117 | 115 | 114 | 112 | 110 | 107 | 103 | 88.4 | 74.7 | 53.7 | 35.6 | 23.2 | 16.5 | ... | ... |
| 10 | 138 | 129 | 124 | 120 | 117 | 115 | 112 | 110 | 109 | 107 | 106 | 105 | 103 | 102 | 100 | 98.7 | 96.8 | 94.6 | 92.0 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |
| 11 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 12 | 138 | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122 | 121 | 89.2 | 68.8 | 54.2 | 43.4 | 34.0 | 25.1 | 17.1 | 10.3 |
| 13 | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 14 | 138 | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122 | 121 | 118 | 74.7 | 53.3 | 36.0 | 24.6 | 15.5 | 9.21 | 6.89 |
| 15 | 138 | 138 | 132 | 128 | 125 | 122 | 120 | 118 | 116 | 114 | 113 | 112 | 110 | 109 | 107 | 105 | 103 | 101 | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |
| 16 | 138 | 138 | 132 | 128 | 125 | 122 | 120 | 118 | 116 | 114 | 113 | 112 | 110 | 109 | 107 | 105 | 103 | 101 | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |
| 17 | 138 | 131 | 126 | 124 | 121 | 119 | 116 | 115 | 113 | 111 | 109 | 107 | 106 | 104 | 102 | 99.6 | 97.2 | 94.5 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |
| 18 | 138 | 131 | 126 | 124 | 121 | 119 | 116 | 115 | 113 | 111 | 109 | 107 | 106 | 104 | 102 | 99.6 | 97.2 | 94.5 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |
| 19 | 138 | 138 | 138 | 138 | 138 | 138 | 136 | 134 | 131 | 129 | 127 | 125 | 123 | 121 | 119 | 116 | 113 | 104 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |
| 20 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 21 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 22 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 23 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 24 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 25 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 98.3 | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |
| 26 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 98.3 | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |
| 27 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 98.3 | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |
| 28 | 138 | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122 | 121 | 89.2 | 68.8 | 54.2 | 43.4 | 34.0 | 25.1 | 17.1 | 10.3 |
| 29 | 138 | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122 | 121 | 89.2 | 68.8 | 54.2 | 43.4 | 34.0 | 25.1 | 17.1 | 10.3 |
| 30 | 138 | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122 | 121 | 89.2 | 68.8 | 54.2 | 43.4 | 34.0 | 25.1 | 17.1 | 10.3 |
| 31 | 138 | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122 | 121 | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |
| 32 | 138 | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122 | 121 | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |
| 33 | 138 | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122 | 121 | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |
| 34 | 145 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 35 | 145 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 | 2¼Ni | Pipe | A333 | 7 | K21903 | ... | ... | 9A | ... | −73 | 448 | 241 | 593 |
| 37 | 2¼Ni | Pipe | A334 | 7 | K21903 | ... | ... | 9A | ... | −73 | 448 | 241 | 593 |
| 38 | 3½Ni | Pipe | A333 | 3 | K31918 | ... | ... | 9B | ... | −101 | 448 | 241 | 593 |
| 39 | 3½Ni | Pipe | A334 | 3 | K31918 | ... | ... | 9B | ... | −101 | 448 | 241 | 593 |
| 40 | C–½Mo | Pipe | A426 | CP1 | J12521 | ... | ... | 3 | (10)(58) | −29 | 448 | 241 | 593 |
| 41 | C–½Mo | Pipe | A672 | L65 | K11820 | ... | ... | 3 | (11)(58)(67) | −29 | 448 | 255 | 593 |
| 42 | C–½Mo | Pipe | A691 | CM-65 | K11820 | ... | ... | 3 | (11)(58)(67) | −29 | 448 | 255 | 593 |
| 43 | 2¼Ni | Pipe | A671 | CFB70 | K22103 | ... | ... | 9A | (11)(65)(67) | −29 | 483 | 276 | 40 |
| 44 | 3½Ni | Pipe | A671 | CFE70 | K32018 | ... | ... | 9B | (11)(65)(67) | −29 | 483 | 276 | 40 |
| 45 | C–½Mo | Pipe | A672 | L70 | K12020 | ... | ... | 3 | (11)(58)(67) | −29 | 483 | 276 | 593 |
| 46 | C–½Mo | Pipe | A691 | CM-70 | K12020 | ... | ... | 3 | (11)(58)(67) | −29 | 483 | 276 | 593 |
| 47 | 1¼Cr–½Mo | Pipe | A426 | CP11 | J12072 | ... | ... | 4 | (10) | −29 | 483 | 276 | 649 |
| 48 | 2¼Cr–1Mo | Pipe | A426 | CP22 | J21890 | ... | ... | 5A | (10)(72) | −29 | 483 | 276 | 649 |
| 49 | C–½Mo | Pipe | A672 | L75 | K12320 | ... | ... | 3 | (11)(58)(67) | −29 | 517 | 296 | 593 |
| 50 | C–½Mo | Pipe | A691 | CM-75 | K12320 | ... | ... | 3 | (11)(58)(67) | −29 | 517 | 296 | 593 |
| 51 | 9Cr–1Mo–V | Pipe | A335 | P91 | K90901 | ... | ≤75 | 15E | ... | −29 | 586 | 414 | 649 |
| 52 | 9Cr–1Mo–V | Pipe | A691 | 91 | K90901 | ... | ≤75 | 15E | (11)(67) | −29 | 586 | 414 | 649 |
| 53 | 5Cr–½Mo | Pipe | A426 | CP5 | J42045 | ... | ... | 5B | (10) | −29 | 621 | 414 | 649 |
| 54 | 9Cr–1Mo | Pipe | A426 | CP9 | J82090 | ... | ... | 5B | (10) | −29 | 621 | 414 | 649 |
| 55 | 9Ni | Pipe | A333 | 8 | K81340 | ... | ... | 11A | (47) | −196 | 689 | 517 | 93 |
| 56 | 9Ni | Pipe | A334 | 8 | K81340 | ... | ... | 11A | ... | −196 | 689 | 517 | 93 |
| 57 | ½Cr–½Mo | Plate | A387 | 2 | K12143 | 1 | ... | 3 | ... | −29 | 379 | 228 | 538 |
| 58 | 1Cr–½Mo | Plate | A387 | 12 | K11757 | 1 | ... | 4 | ... | −29 | 379 | 228 | 649 |
| 59 | 9Cr–1Mo | Plate | A387 | 9 | K90941 | 1 | ... | 5B | ... | −29 | 414 | 207 | 649 |
| 60 | 1¼Cr–½Mo–Si | Plate | A387 | 11 | K11789 | 1 | ... | 4 | ... | −29 | 414 | 241 | 649 |
| 61 | 5Cr–½Mo | Plate | A387 | 5 | K41545 | 1 | ... | 5B | ... | −29 | 414 | 207 | 649 |
| 62 | 3Cr–1Mo | Plate | A387 | 21 | K31545 | 1 | ... | 5A | ... | −29 | 414 | 207 | 649 |
| 63 | 2¼Cr–1Mo | Plate | A387 | 22 | K21590 | 1 | ... | 5A | (72) | −29 | 414 | 207 | 649 |
| 64 | 2¼Ni | Plate | A203 | A | K21703 | ... | ... | 9A | (12)(65) | −29 | 448 | 255 | 538 |
| 65 | 3½Ni | Plate | A203 | D | K31718 | ... | ... | 9B | (12)(65) | −29 | 448 | 255 | 538 |
| 66 | C–½Mo | Plate | A204 | A | K11820 | ... | ... | 3 | (58) | −29 | 448 | 255 | 593 |
| 67 | 1Cr–½Mo | Plate | A387 | 12 | K11757 | 2 | ... | 4 | ... | −29 | 448 | 276 | 649 |
| 68 | 2¼Ni | Plate | A203 | B | K22103 | ... | ... | 9A | (12)(65) | −29 | 483 | 276 | 538 |
| 69 | 3½Ni | Plate | A203 | E | K32018 | ... | ... | 9B | (12)(65) | −29 | 483 | 276 | 538 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 | 625 | 650 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 | 149 | 149 | 147 | 144 | 142 | 140 | 138 | 135 | 132 | 128 | 124 | 119 | 113 | 107 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 14.2 | 9.40 | 6.89 | ... | ... |
| 37 | 149 | 149 | 147 | 144 | 142 | 140 | 138 | 135 | 132 | 128 | 124 | 119 | 113 | 107 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 14.2 | 9.40 | 6.89 | ... | ... |
| 38 | 149 | 149 | 147 | 144 | 142 | 140 | 138 | 135 | 132 | 128 | 124 | 119 | 113 | 107 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 14.2 | 9.48 | 7.06 | ... | ... |
| 39 | 149 | 149 | 147 | 144 | 142 | 140 | 138 | 135 | 132 | 128 | 124 | 119 | 113 | 107 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 14.2 | 9.48 | 7.06 | ... | ... |
| 40 | 149 | 149 | 149 | 148 | 145 | 143 | 140 | 138 | 137 | 135 | 133 | 131 | 129 | 126 | 123 | 120 | 117 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 41 | 149 | 149 | 149 | 149 | 149 | 149 | 148 | 146 | 144 | 142 | 140 | 138 | 136 | 133 | 131 | 127 | 124 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 42 | 149 | 149 | 149 | 149 | 149 | 149 | 148 | 146 | 144 | 142 | 140 | 138 | 136 | 133 | 131 | 127 | 124 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 43 | 161 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 44 | 161 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 45 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 158 | 156 | 154 | 152 | 149 | 147 | 144 | 141 | 138 | 134 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 46 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 158 | 156 | 154 | 152 | 149 | 147 | 144 | 141 | 138 | 134 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 47 | 161 | 161 | 161 | 161 | 161 | 158 | 155 | 153 | 150 | 148 | 146 | 143 | 141 | 138 | 136 | 133 | 130 | 104 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |
| 48 | 161 | 161 | 160 | 157 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 119 | 88.4 | 64.0 | 44.6 | 30.0 | 19.7 | 12.8 | 8.27 |
| 49 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 170 | 168 | 165 | 163 | 161 | 158 | 155 | 152 | 148 | 144 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 50 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 170 | 168 | 165 | 163 | 161 | 158 | 155 | 152 | 148 | 144 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 51 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 194 | 193 | 192 | 190 | 187 | 183 | 178 | 172 | 165 | 156 | 147 | 137 | 115 | 87.0 | 64.7 | 45.1 | 29.6 |
| 52 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 194 | 193 | 192 | 190 | 187 | 183 | 178 | 172 | 165 | 156 | 147 | 137 | 115 | 87.0 | 64.7 | 45.1 | 29.6 |
| 53 | 207 | 207 | 205 | 202 | 200 | 199 | 199 | 199 | 198 | 198 | 196 | 194 | 191 | 187 | 182 | 176 | 169 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 54 | 207 | 207 | 205 | 202 | 200 | 199 | 199 | 199 | 198 | 198 | 196 | 194 | 191 | 187 | 182 | 176 | 169 | 160 | 87.5 | 61.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |
| 55 | 230 | 230 | 230 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 56 | 230 | 230 | 230 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 57 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 125 | 123 | 121 | 119 | 116 | 114 | 110 | 107 | 74.4 | 49.9 | 40.7 | ... | ... | ... | ... |
| 58 | 126 | 126 | 123 | 122 | 122 | 122 | 122 | 121 | 120 | 118 | 116 | 115 | 114 | 112 | 110 | 109 | 106 | 104 | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |
| 59 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 98.3 | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |
| 60 | 138 | 138 | 138 | 138 | 138 | 138 | 136 | 134 | 131 | 129 | 127 | 125 | 123 | 121 | 119 | 116 | 113 | 104 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |
| 61 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 62 | 138 | 130 | 126 | 123 | 121 | 119 | 117 | 116 | 115 | 114 | 112 | 111 | 110 | 109 | 107 | 105 | 103 | 89.2 | 68.8 | 54.2 | 43.4 | 34.0 | 25.1 | 17.1 | 10.3 |
| 63 | 138 | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122 | 121 | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |
| 64 | 149 | 149 | 149 | 149 | 149 | 148 | 146 | 143 | 140 | 136 | 131 | 126 | 120 | 113 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 17.2 | ... | ... | ... | ... |
| 65 | 149 | 149 | 149 | 149 | 149 | 148 | 146 | 143 | 140 | 136 | 131 | 126 | 120 | 113 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 17.2 | ... | ... | ... | ... |
| 66 | 149 | 149 | 149 | 149 | 149 | 149 | 148 | 146 | 144 | 142 | 140 | 138 | 136 | 133 | 131 | 127 | 124 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 67 | 149 | 149 | 146 | 144 | 144 | 144 | 144 | 144 | 144 | 143 | 141 | 139 | 138 | 136 | 134 | 132 | 129 | 126 | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |
| 68 | 161 | 161 | 161 | 161 | 161 | 160 | 158 | 155 | 151 | 147 | 142 | 136 | 130 | 113 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 17.2 | ... | ... | ... | ... |
| 69 | 161 | 161 | 161 | 161 | 161 | 160 | 158 | 155 | 151 | 147 | 142 | 136 | 130 | 122 | 101 | 83.8 | 66.8 | 49.2 | 35.4 | 22.6 | 17.2 | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | ½Cr–½Mo | Plate | A387 | 2 | K12143 | 2 | ... | 3 | ... | −29 | 483 | 310 | 538 |
| 71 | C–½Mo | Plate | A204 | B | K12020 | ... | ... | 3 | (58) | −29 | 483 | 276 | 593 |
| 72 | Mn–½Mo | Plate | A302 | A | K12021 | ... | ... | 3 | ... | −29 | 517 | 310 | 538 |
| 73 | C–½Mo | Plate | A204 | C | K12320 | ... | ... | 3 | (58) | −29 | 517 | 296 | 593 |
| 74 | 1¼Cr–½Mo–Si | Plate | A387 | 11 | K11789 | 2 | ... | 4 | ... | −29 | 517 | 310 | 649 |
| 75 | 5Cr–½Mo | Plate | A387 | 5 | K41545 | 2 | ... | 5B | ... | −29 | 517 | 310 | 649 |
| 76 | 3Cr–1Mo | Plate | A387 | 21 | K31545 | 2 | ... | 5A | ... | −29 | 517 | 310 | 649 |
| 77 | 2¼Cr–1Mo | Plate | A387 | 22 | K21590 | 2 | ... | 5A | (72) | −29 | 517 | 310 | 649 |
| 78 | Mn–½Mo | Plate | A302 | B | K12022 | ... | ... | 3 | ... | −29 | 552 | 345 | 538 |
| 79 | Mn–½Mo–½Ni | Plate | A302 | C | K12039 | ... | ... | 3 | ... | −29 | 552 | 345 | 538 |
| 80 | Mn–½Mo–¾Ni | Plate | A302 | D | K12054 | ... | ... | 3 | ... | −29 | 552 | 345 | 538 |
| 81 | 9Cr–1Mo–V | Plate | A387 | 91 | K90901 | 2 | ≤75 | 15E | ... | −29 | 586 | 414 | 649 |
| 82 | 8Ni | Plate | A553 | II | K71340 | ... | ... | 11A | (47) | −171 | 689 | 586 | 40 |
| 83 | 5Ni–¼Mo | Plate | A645 | A | K41583 | ... | ... | 11A | ... | −171 | 655 | 448 | 93 |
| 84 | 9Ni | Plate | A553 | I | K81340 | ... | ... | 11A | (47) | −196 | 689 | 586 | 93 |
| 85 | 9Ni | Plate | A353 | ... | K81340 | ... | ... | 11A | (47) | −196 | 689 | 517 | 93 |
| 86 | C–½Mo | Forg. & ftg. | A234 | WP1 | K12821 | ... | ... | 3 | (58) | −29 | 379 | 207 | 593 |
| 87 | 1Cr–½Mo | Forg. & ftg. | A182 | F12 | K11562 | 1 | ... | 4 | (9) | −29 | 414 | 221 | 649 |
| 88 | 1Cr–½Mo | Forg. & ftg. | A234 | WP12 | K12062 | 1 | ... | 4 | ... | −29 | 414 | 221 | 649 |
| 89 | 1¼Cr–½Mo–Si | Forg. & ftg. | A182 | F11 | K11597 | 1 | ... | 4 | (9) | −29 | 414 | 207 | 649 |
| 90 | 1¼Cr–½Mo–Si | Forg. & ftg. | A234 | WP11 | K11597 | 1 | ... | 4 | ... | −29 | 414 | 207 | 649 |
| 91 | 2¼Cr–1Mo | Forg. & ftg. | A182 | F22 | K21590 | 1 | ... | 5A | (9)(72)(75) | −29 | 414 | 207 | 649 |
| 92 | 2¼Cr–1Mo | Forg. & ftg. | A234 | WP22 | K21590 | 1 | ... | 5A | (72) | −29 | 414 | 207 | 649 |
| 93 | 5Cr–½Mo | Forg. & ftg. | A234 | WP5 | K41545 | ... | ... | 5B | ... | −29 | 414 | 207 | 649 |
| 94 | 9Cr–1Mo | Forg. & ftg. | A234 | WP9 | K90941 | ... | ... | 5B | ... | −29 | 414 | 207 | 649 |
| 95 | 3½Ni | Forg. & ftg. | A420 | WPL3 | K31918 | ... | ... | 9B | ... | −101 | 448 | 241 | 343 |
| 96 | 3½Ni | Forg. & ftg. | A350 | LF3 | K32025 | ... | ... | 9B | (9) | −101 | 483 | 259 | 343 |
| 97 | ½Cr–½Mo | Forg. & ftg. | A182 | F2 | K12122 | ... | ... | 3 | (9) | −29 | 483 | 276 | 538 |
| 98 | C–½Mo | Forg. & ftg. | A182 | F1 | K12822 | ... | ... | 3 | (9)(58) | −29 | 483 | 276 | 593 |
| 99 | 1Cr–½Mo | Forg. & ftg. | A182 | F12 | K11564 | 2 | ... | 4 | (9) | −29 | 483 | 276 | 649 |
| 100 | 1Cr–½Mo | Forg. & ftg. | A234 | WP12 | K12062 | 2 | ... | 4 | ... | −29 | 483 | 276 | 649 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 | 625 | 650 |
| 70 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 159 | 155 | 151 | 146 | 93.5 | 49.9 | 40.7 | ... | ... | ... | ... |
| 71 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 158 | 156 | 154 | 152 | 149 | 147 | 144 | 141 | 138 | 134 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 72 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 171 | 168 | 165 | 160 | 154 | 104 | 68.0 | 42.3 | 33.1 | ... | ... | ... | ... |
| 73 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 170 | 168 | 165 | 163 | 161 | 158 | 155 | 152 | 148 | 144 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 74 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 169 | 166 | 164 | 161 | 159 | 156 | 153 | 149 | 146 | 104 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |
| 75 | 172 | 172 | 171 | 169 | 167 | 166 | 165 | 165 | 165 | 164 | 164 | 162 | 159 | 156 | 130 | 126 | 104 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 76 | 172 | 172 | 171 | 168 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 98.2 | 73.5 | 54.7 | 40.6 | 29.2 | 20.6 | 15.2 | 8.96 |
| 77 | 172 | 172 | 171 | 168 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 119 | 88.4 | 64.0 | 44.6 | 30.0 | 19.7 | 12.8 | 8.27 |
| 78 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 183 | 178 | 172 | 104 | 68.0 | 42.3 | 33.1 | ... | ... | ... | ... |
| 79 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 183 | 178 | 172 | 104 | 68.0 | 42.3 | 33.1 | ... | ... | ... | ... |
| 80 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 183 | 178 | 172 | 104 | 68.0 | 42.3 | 33.1 | ... | ... | ... | ... |
| 81 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 194 | 193 | 192 | 190 | 187 | 183 | 178 | 172 | 165 | 156 | 147 | 137 | 115 | 87.0 | 64.7 | 45.1 | 29.6 |
| 82 | 230 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 83 | 218 | 218 | 218 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 84 | 230 | 230 | 230 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 85 | 230 | 230 | 230 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 86 | 126 | 126 | 126 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103 | 100 | 97.1 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 87 | 138 | 129 | 124 | 120 | 117 | 115 | 112 | 110 | 109 | 107 | 106 | 105 | 103 | 102 | 100 | 98.7 | 96.8 | 94.6 | 92.0 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |
| 88 | 138 | 138 | 132 | 128 | 125 | 122 | 120 | 118 | 116 | 114 | 113 | 112 | 110 | 109 | 107 | 105 | 103 | 101 | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |
| 89 | 138 | 131 | 126 | 124 | 121 | 119 | 116 | 115 | 113 | 111 | 109 | 107 | 106 | 104 | 102 | 99.6 | 97.2 | 94.5 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |
| 90 | 138 | 131 | 126 | 124 | 121 | 119 | 116 | 115 | 113 | 111 | 109 | 107 | 106 | 104 | 102 | 99.6 | 97.2 | 94.5 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |
| 91 | 138 | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122 | 121 | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |
| 92 | 138 | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122 | 121 | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |
| 93 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 94 | 138 | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106 | 103 | 98.3 | 87.5 | 61.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |
| 95 | 149 | 149 | 147 | 144 | 142 | 140 | 138 | 135 | 132 | 128 | 124 | 119 | 113 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 96 | 161 | 160 | 157 | 155 | 152 | 150 | 148 | 145 | 142 | 137 | 133 | 128 | 122 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 97 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 158 | 156 | 154 | 152 | 149 | 147 | 144 | 141 | 138 | 134 | 129 | 93.5 | 49.9 | 40.7 | ... | ... | ... | ... |
| 98 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 158 | 156 | 154 | 152 | 149 | 147 | 144 | 141 | 138 | 134 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 99 | 161 | 161 | 157 | 155 | 155 | 153 | 150 | 147 | 145 | 143 | 141 | 139 | 138 | 136 | 134 | 132 | 129 | 126 | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |
| 100 | 161 | 161 | 157 | 155 | 155 | 153 | 150 | 147 | 145 | 143 | 141 | 139 | 138 | 136 | 134 | 132 | 129 | 126 | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 1¼Cr–½Mo–Si | Forg. & ftg. | A182 | F11 | K11572 | 2 | ... | 4 | (9) | −29 | 483 | 276 | 649 |
| 102 | 1¼Cr–½Mo–Si | Forg. & ftg. | A234 | WP11 | K11572 | 2 | ... | 4 | ... | −29 | 483 | 276 | 649 |
| 103 | 5Cr–½Mo | Forg. & ftg. | A182 | F5 | K41545 | ... | ... | 5B | (9) | −29 | 483 | 276 | 649 |
| 104 | 3Cr–1Mo | Forg. & ftg. | A182 | F21 | K31545 | ... | ... | 5A | (9) | −29 | 517 | 310 | 649 |
| 105 | 2¼Cr–1Mo | Forg. & ftg. | A182 | F22 | K21590 | 3 | ... | 5A | (9)(72) | −29 | 517 | 310 | 649 |
| 106 | 2¼Cr–1Mo | Forg. & ftg. | A234 | WP22 | K21590 | 3 | ... | 5A | (72) | −29 | 517 | 310 | 649 |
| 107 | 9Cr–1Mo | Forg. & ftg. | A182 | F9 | K90941 | ... | ... | 5B | (9) | −29 | 586 | 379 | 649 |
| 108 | 9Cr–1Mo–V | Forg. & ftg. | A182 | F91 | K90901 | ... | ≤75 | 15E | ... | −29 | 586 | 414 | 649 |
| 109 | 9Cr–1Mo–V | Forg. & ftg. | A234 | WP91 | K90901 | ... | ≤75 | 15E | ... | −29 | 586 | 414 | 649 |
| 110 | 5Cr–½Mo | Forg. & ftg. | A182 | F5a | K42544 | ... | ... | 5B | (9) | −29 | 621 | 448 | 649 |
| 111 | 9Ni | Forg. & ftg. | A420 | WPL8 | K81340 | ... | ... | 11A | (47) | −196 | 689 | 517 | 93 |
| 112 | C–½Mo | Castings | A352 | LC1 | J12522 | ... | ... | 3 | (9)(58) | −59 | 448 | 241 | 371 |
| 113 | C–½Mo | Castings | A217 | WC1 | J12524 | ... | ... | 3 | (9)(58) | −29 | 448 | 241 | 593 |
| 114 | 2½Ni | Castings | A352 | LC2 | J22500 | ... | ... | 9A | (9) | −73 | 483 | 276 | 343 |
| 115 | 3½Ni | Castings | A352 | LC3 | J31550 | ... | ... | 9B | (9) | −101 | 483 | 276 | 343 |
| 116 | 1Ni–½Cr–½Mo | Castings | A217 | WC4 | J12082 | ... | ... | 4 | (9) | −29 | 483 | 276 | 538 |
| 117 | ¾Ni–1Mo–¾Cr | Castings | A217 | WC5 | J22000 | ... | ... | 4 | (9) | −29 | 483 | 276 | 593 |
| 118 | 1¼Cr–½Mo | Castings | A217 | WC6 | J12072 | ... | ... | 4 | (9) | −29 | 483 | 276 | 649 |
| 119 | 2¼Cr–1Mo | Castings | A217 | WC9 | J21890 | ... | ... | 5A | (9) | −29 | 483 | 276 | 649 |
| 120 | 5Cr–½Mo | Castings | A217 | C5 | J42045 | ... | ... | 5B | (9) | −29 | 621 | 414 | 649 |
| 121 | 9Cr–1Mo | Castings | A217 | C12 | J82090 | ... | ... | 5B | (9) | −29 | 621 | 414 | 649 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 | 625 | 650 |
| 101 | 161 | 161 | 161 | 161 | 161 | 158 | 155 | 153 | 150 | 148 | 146 | 143 | 141 | 138 | 136 | 133 | 130 | 104 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |
| 102 | 161 | 161 | 161 | 161 | 161 | 158 | 155 | 153 | 150 | 148 | 146 | 143 | 141 | 138 | 136 | 133 | 130 | 104 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |
| 103 | 161 | 161 | 160 | 157 | 156 | 155 | 155 | 155 | 154 | 154 | 153 | 151 | 149 | 146 | 142 | 137 | 131 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 104 | 172 | 172 | 172 | 169 | 168 | 167 | 166 | 166 | 165 | 165 | 164 | 164 | 162 | 161 | 158 | 155 | 152 | 98.2 | 73.5 | 54.7 | 40.6 | 29.2 | 20.6 | 15.2 | 8.96 |
| 105 | 172 | 172 | 171 | 168 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 119 | 88.4 | 64.0 | 44.6 | 30.0 | 19.7 | 12.8 | 8.27 |
| 106 | 172 | 172 | 171 | 168 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 119 | 88.4 | 64.0 | 44.6 | 30.0 | 19.7 | 12.8 | 8.27 |
| 107 | 195 | 195 | 194 | 191 | 189 | 188 | 188 | 188 | 187 | 187 | 186 | 184 | 181 | 177 | 172 | 166 | 159 | 151 | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |
| 108 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 194 | 193 | 192 | 190 | 187 | 183 | 178 | 172 | 165 | 156 | 147 | 137 | 115 | 87.0 | 64.7 | 45.1 | 29.6 |
| 109 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 194 | 193 | 192 | 190 | 187 | 183 | 178 | 172 | 165 | 156 | 147 | 137 | 115 | 87.0 | 64.7 | 45.1 | 29.6 |
| 110 | 207 | 207 | 205 | 202 | 200 | 199 | 199 | 199 | 198 | 198 | 196 | 194 | 191 | 187 | 182 | 176 | 169 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 111 | 230 | 230 | 230 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 112 | 149 | 149 | 149 | 148 | 145 | 143 | 140 | 138 | 137 | 135 | 133 | 131 | 129 | 127 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 113 | 149 | 149 | 149 | 148 | 145 | 143 | 140 | 138 | 137 | 135 | 133 | 131 | 129 | 126 | 123 | 120 | 117 | 109 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ... | ... |
| 114 | 161 | 161 | 161 | 161 | 161 | 160 | 158 | 155 | 151 | 147 | 142 | 136 | 131 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 115 | 161 | 161 | 161 | 161 | 161 | 160 | 158 | 155 | 151 | 147 | 142 | 136 | 131 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 116 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 159 | 158 | 156 | 154 | 152 | 149 | 146 | 142 | 137 | 131 | 74.4 | 49.9 | 40.7 | ... | ... | ... | ... |
| 117 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 159 | 158 | 156 | 154 | 152 | 149 | 146 | 142 | 137 | 131 | 74.4 | 49.9 | 34.3 | 23.2 | 16.5 | ... | ... |
| 118 | 161 | 161 | 161 | 161 | 161 | 158 | 155 | 153 | 150 | 148 | 146 | 143 | 141 | 138 | 136 | 133 | 130 | 104 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |
| 119 | 161 | 161 | 160 | 157 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 119 | 88.4 | 64.0 | 44.6 | 30.0 | 19.7 | 12.8 | 8.27 |
| 120 | 207 | 207 | 205 | 202 | 200 | 199 | 199 | 199 | 198 | 198 | 196 | 194 | 191 | 187 | 182 | 176 | 169 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |
| 121 | 207 | 207 | 205 | 202 | 200 | 199 | 199 | 199 | 198 | 198 | 196 | 194 | 191 | 187 | 182 | 176 | 169 | 160 | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 1 | 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321 | S32100 | ... | >10 | 8 |
| 2 | 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321 | S32100 | ... | >10 | 8 |
| 3 | 18Cr–8Ni | Tube | A213 | TP304L | S30403 | ... | ... | 8 |
| 4 | 18Cr–8Ni | Tube | A269 | TP304L | S30403 | ... | ... | 8 |
| 5 | 18Cr–8Ni | Tube | A270 | TP304L | S30403 | ... | ... | 8 |
| 6 | 18Cr–8Ni | Smls. & wld. pipe | A312 | TP304L | S30403 | ... | ... | 8 |
| 7 | 18Cr–8Ni | Wld. pipe | A358 | 304L | S30403 | ... | ... | 8 |
| 8 | 16Cr–12Ni–2Mo | Tube | A213 | TP316L | S31603 | ... | ... | 8 |
| 9 | 16Cr–12Ni–2Mo | Tube | A269 | TP316L | S31603 | ... | ... | 8 |
| 10 | 16Cr–12Ni–2Mo | Tube | A270 | TP316L | S31603 | ... | ... | 8 |
| 11 | 16Cr–12Ni–2Mo | Smls. & wld. pipe | A312 | TP316L | S31603 | ... | ... | 8 |
| 12 | 16Cr–12Ni–2Mo | Wld. pipe | A358 | 316L | S31603 | ... | ... | 8 |
| 13 | 16Cr–12Ni–2Mo–Ti | Tube | A213 | TP316Ti | S31635 | ... | ... | 8 |
| 14 | 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321 | S32100 | ... | >10 | 8 |
| 15 | 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321 | S32100 | ... | >10 | 8 |
| 16 | 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321H | S32109 | ... | >10 | 8 |
| 17 | 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321H | S32109 | ... | >10 | 8 |
| 18 | 25Cr–12Ni | Pipe & tube | A451 | CPH8 | J93400 | ... | ... | 8 |
| 19 | 25Cr–20Ni | Pipe & tube | A451 | CPK20 | J94202 | ... | ... | 8 |
| 20 | 11Cr–Ti | Tube | A268 | TP409 | S40900 | ... | ... | 7 |
| 21 | 18Cr–Ti | Tube | A268 | TP430Ti | S43036 | ... | ... | 7 |
| 22 | 16Cr–14Ni–2Mo | Pipe & tube | A451 | CPF10MC | J92971 | ... | ... | 8 |
| 23 | 16Cr–8Ni–2Mo | Pipe | A376 | 16-8-2H | S16800 | ... | ... | 8 |
| 24 | 12Cr–Al | Tube | A268 | TP405 | S40500 | ... | ... | 7 |
| 25 | 13Cr | Tube | A268 | TP410 | S41000 | ... | ... | 6 |
| 26 | 17Cr | Tube | A268 | TP430 | S43000 | ... | ... | 7 |
| 27 | 18Cr–13Ni–3Mo | Smls. & wld. pipe | A312 | TP317L | S31703 | ... | ... | 8 |
| 28 | 25Cr–20Ni | Smls. & wld. pipe | A312 | TP310 | S31009 | ... | ... | 8 |
| 29 | 25Cr–20Ni | Wld. pipe | A358 | 310S | S31008 | ... | ... | 8 |
| 30 | 25Cr–20Ni | Pipe | A409 | TP310S | S31008 | ... | ... | 8 |
| 31 | 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321 | S32100 | ... | ≤10 | 8 |
| 32 | 18Cr–10Ni–Ti | Wld. pipe | A312 | TP321 | S32100 | ... | ... | 8 |
| 33 | 18Cr–10Ni–Ti | Wld. pipe | A358 | 321 | S32100 | ... | ... | 8 |
| 34 | 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321 | S32100 | ... | ≤10 | 8 |
| 35 | 18Cr–10Ni–Ti | Wld. pipe | A409 | TP321 | S32100 | ... | ... | 8 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (28) | −254 | 485 | 170 | 816 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 2 | (28)(36) | −254 | 485 | 170 | 816 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 3 | (14)(36) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 114 | 110 |
| 4 | (14)(36) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 114 | 110 |
| 5 | (14) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 114 | 110 |
| 6 | ... | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 114 | 110 |
| 7 | (36) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 114 | 110 |
| 8 | (14)(36) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 113 | 109 |
| 9 | (14)(36) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 113 | 109 |
| 10 | (14) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 113 | 109 |
| 11 | ... | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 113 | 109 |
| 12 | (36) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 113 | 109 |
| 13 | (30) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 14 | (28)(30) | −254 | 485 | 170 | 816 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 15 | (28)(30)(36) | −254 | 485 | 170 | 816 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 16 | (30) | −198 | 485 | 170 | 816 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 17 | (30)(36) | −198 | 485 | 170 | 816 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 18 | (26)(28)(35) | −198 | 448 | 193 | 816 | 129 | 129 | 129 | 129 | *127* | *125* | *124* |
| 19 | (12)(28)(35)(39) | −198 | 448 | 193 | 816 | 129 | 129 | 129 | 129 | *127* | *125* | *124* |
| 20 | (35) | −29 | 414 | 207 | 40 | 138 | ... | ... | ... | ... | ... | ... |
| 21 | (35)(49) | −29 | 414 | 276 | 40 | 138 | ... | ... | ... | ... | ... | ... |
| 22 | (28) | −198 | 483 | 207 | 40 | 138 | ... | ... | ... | ... | ... | ... |
| 23 | (26)(31)(35) | −198 | 517 | 207 | 40 | 138 | ... | ... | ... | ... | ... | ... |
| 24 | (35) | −29 | 414 | 207 | 538 | 138 | 138 | 138 | *137* | *135* | *134* | *133* |
| 25 | (35) | −29 | 414 | 207 | 649 | 138 | 138 | 138 | *137* | *135* | *134* | *133* |
| 26 | (35)(49) | −29 | 414 | 241 | 649 | *138* | *138* | *138* | *137* | *135* | *134* | *133* |
| 27 | ... | −198 | 517 | 207 | 454 | 138 | 138 | 138 | 138 | 138 | 136 | 131 |
| 28 | (35)(39) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 29 | (28)(35)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 30 | (28)(31)(35)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 31 | (28) | −254 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 32 | (28) | −254 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 33 | (28)(36) | −254 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 34 | (28)(36) | −254 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 35 | (28)(36) | −254 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 115 | 112 | 109 | 106 | 104 | 102 | 100 | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 2 | 115 | 112 | 109 | 106 | 104 | 102 | 100 | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 3 | 106 | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 4 | 106 | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 5 | 106 | 103 | *99.9* | *97.7* | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 6 | 106 | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 7 | 106 | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 8 | 106 | 103 | 100 | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 9 | 106 | 103 | 100 | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 10 | 106 | 103 | 100 | 98.1 | 96.1 | 94.3 | *92.6* | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 11 | 106 | 103 | 100 | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 12 | 106 | 103 | 100 | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 13 | 129 | 124 | 120 | 117 | 115 | 113 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 14 | 115 | 112 | 109 | 106 | 104 | 102 | 100 | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 15 | 115 | 112 | 109 | 106 | 104 | 102 | 100 | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 16 | 115 | 112 | 109 | 106 | 104 | 102 | 100 | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 17 | 115 | 112 | 109 | 106 | 104 | 102 | 100 | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 18 | *124* | 123 | 121 | 119 | 117 | 115 | 112 | 109 | 106 | 103 | 100 | 96.9 | 93.7 |
| 19 | *124* | 123 | 121 | 119 | 117 | 115 | 112 | 109 | 106 | 103 | 100 | 96.9 | 93.7 |
| 20 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 21 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 22 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 23 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 24 | *132* | *131* | *130* | *129* | *127* | *124* | *121* | *118* | *114* | *109* | *103* | **70.1** | **38.8** |
| 25 | *132* | *131* | *130* | *129* | *127* | *124* | *121* | *118* | *114* | *109* | **92.5** | **68.4** | **51.1** |
| 26 | *132* | *131* | *130* | *129* | *127* | *124* | *121* | *118* | *114* | *109* | **88.7** | **69.8** | **52.6** |
| 27 | 127 | 123 | 120 | 118 | 115 | 113 | 111 | 109 | 107 | 105 | 103 | ... | ... |
| 28 | 137 | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116 | **84.9** |
| 29 | 137 | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116 | **84.9** |
| 30 | 137 | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116 | **84.9** |
| 31 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 32 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 33 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 34 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 35 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 1 | 88.7 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 2 | 88.7 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 3 | 81.4 | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 4 | 81.4 | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 5 | 81.4 | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 6 | 81.4 | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 7 | 81.4 | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 8 | 80.8 | 79.3 | 77.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 9 | 80.8 | 79.3 | 77.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 10 | 80.8 | *79.3* | *77.9* | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 11 | 80.8 | 79.3 | 77.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 12 | 80.8 | 73.0 | 67.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 13 | 106 | 101 | 80.3 | 65.5 | 50.4 | 38.6 | 29.6 | 23.0 | 17.7 | 13.4 | 10.4 | 8.05 |
| 14 | 92.7 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 15 | 92.7 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 16 | 92.7 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 17 | 92.7 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 18 | 68.1 | 53.5 | 42.1 | 33.2 | 25.9 | 20.3 | 16.5 | 13.2 | 10.1 | 7.35 | 5.89 | 5.52 |
| 19 | 73.2 | 64.4 | 56.5 | 49.0 | 41.0 | 33.5 | 25.4 | 18.3 | 12.8 | 9.01 | 6.59 | 5.52 |
| 20 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 21 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 22 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 23 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 24 | 27.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 25 | 37.4 | 26.3 | 17.8 | 11.4 | 6.89 | ... | ... | ... | ... | ... | ... | ... |
| 26 | 38.1 | 27.6 | 20.6 | 15.9 | 12.4 | ... | ... | ... | ... | ... | ... | ... |
| 27 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 28 | 59.0 | 43.5 | 31.9 | 23.6 | 16.9 | 10.7 | 6.10 | 3.90 | 2.99 | 2.36 | 1.73 | 1.38 |
| 29 | 59.0 | 43.5 | 31.9 | 23.6 | 16.9 | 10.7 | 6.10 | 3.90 | 2.99 | 2.36 | 1.73 | 1.38 |
| 30 | 59.0 | 43.5 | 31.9 | 23.6 | 16.9 | 10.7 | 6.10 | 3.90 | 2.99 | 2.36 | 1.73 | 1.38 |
| 31 | 88.7 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 32 | 88.7 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 33 | 88.7 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 34 | 88.7 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 35 | 88.7 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 36 | 23Cr–12Ni | Smls. & wld. pipe | A312 | TP309 | ... | ... | ... | 8 |
| 37 | 23Cr–12Ni | Wld. pipe | A358 | 309S | S30908 | ... | ... | 8 |
| 38 | 18Cr–8Ni | Pipe & tube | A451 | CPF8 | J92600 | ... | ... | 8 |
| 39 | 18Cr–10Ni–Cb | Smls. & wld. pipe | A312 | TP347 | S34700 | ... | ... | 8 |
| 40 | 18Cr–10Ni–Cb | Wld. pipe | A358 | 347 | S34700 | ... | ... | 8 |
| 41 | 18Cr–10Ni–Cb | Pipe | A376 | TP347 | S34700 | ... | ... | 8 |
| 42 | 18Cr–10Ni–Cb | Pipe | A409 | TP347 | S34700 | ... | ... | 8 |
| 43 | 18Cr–10Ni–Cb | Smls. & wld. pipe | A312 | TP348 | S34800 | ... | ... | 8 |
| 44 | 18Cr–10Ni–Cb | Wld. pipe | A358 | 348 | S34800 | ... | ... | 8 |
| 45 | 18Cr–10Ni–Cb | Pipe | A376 | TP348 | S34800 | ... | ... | 8 |
| 46 | 18Cr–10Ni–Cb | Pipe | A409 | TP348 | S34800 | ... | ... | 8 |
| 47 | 25Cr–12Ni | Pipe & tube | A451 | CPH10 | J93402 | ... | ... | 8 |
| 48 | 25Cr–12Ni | Pipe & tube | A451 | CPH20 | J93402 | ... | ... | 8 |
| 49 | 25Cr–20Ni | Smls. & wld. pipe | A312 | TP310H | S31009 | ... | ... | 8 |
| 50 | 25Cr–20Ni | Wld. pipe | A358 | 310S | S31008 | ... | ... | 8 |
| 51 | 18Cr–10Ni–Cb | Pipe & tube | A451 | CPF8C | J92710 | ... | ... | 8 |
| 52 | 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321 | S32100 | ... | ≤10 | 8 |
| 53 | 18Cr–10Ni–Ti | Wld. pipe | A312 | TP321 | S32100 | ... | ... | 8 |
| 54 | 18Cr–10Ni–Ti | Wld. pipe | A358 | 321 | S32100 | ... | ... | 8 |
| 55 | 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321 | S32100 | ... | ≤10 | 8 |
| 56 | 18Cr–10Ni–Ti | Wld. pipe | A409 | TP321 | S32100 | ... | ... | 8 |
| 57 | 18Cr–10Ni–Ti | Smls. pipe | A312 | TP321H | S32109 | ... | ≤10 | 8 |
| 58 | 18Cr–10Ni–Ti | Wld. pipe | A312 | TP321H | S32109 | ... | ... | 8 |
| 59 | 18Cr–10Ni–Ti | Wld. pipe | A358 | 321H | S32109 | ... | ... | 8 |
| 60 | 18Cr–10Ni–Ti | Smls. pipe | A376 | TP321H | S32109 | ... | ≤10 | 8 |
| 61 | 16Cr–12Ni–2Mo | Tube | A213 | TP316 | S31600 | ... | ... | 8 |
| 62 | 16Cr–12Ni–2Mo | Tube | A269 | TP316 | S31600 | ... | ... | 8 |
| 63 | 16Cr–12Ni–2Mo | Tube | A270 | TP316 | S31600 | ... | ... | 8 |
| 64 | 16Cr–12Ni–2Mo | Smls. & wld. pipe | A312 | TP316 | S31600 | ... | ... | 8 |
| 65 | 16Cr–12Ni–2Mo | Wld. pipe | A358 | 316 | S31600 | ... | ... | 8 |
| 66 | 16Cr–12Ni–2Mo | Pipe | A376 | TP316 | S31600 | ... | ... | 8 |
| 67 | 16Cr–12Ni–2Mo | Pipe | A409 | TP316 | S31600 | ... | ... | 8 |
| 68 | 18Cr–13Ni–3Mo | Smls. & wld. pipe | A312 | TP317 | S31700 | ... | ... | 8 |
| 69 | 18Cr–13Ni–3Mo | Pipe | A409 | TP317 | S31700 | ... | ... | 8 |
| 70 | 16Cr–12Ni–2Mo | Pipe | A376 | TP316H | S31609 | ... | ... | 8 |
| 71 | 16Cr–12Ni–2Mo | Smls. & wld. pipe | A312 | TP316H | S31609 | ... | ... | 8 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 | (28)(35)(39) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 37 | (28)(31)(35)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 38 | (26)(28) | −254 | 483 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 39 | ... | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 40 | (30)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 41 | (30)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 42 | (30)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 43 | ... | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 44 | (30)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 45 | (30)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 46 | (30)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 47 | (12)(14)(28)(35)(39) | −198 | 483 | 207 | 816 | 138 | 138 | 138 | 138 | *137* | *135* | *134* |
| 48 | (12)(14)(28)(35)(39) | −198 | 483 | 207 | 816 | 138 | 138 | 138 | 138 | *137* | *135* | *134* |
| 49 | (29)(35)(39) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 50 | (28)(29)(35)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 51 | (28) | −198 | 483 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 52 | (28)(30) | −254 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 53 | (28)(30) | −254 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 54 | (28)(30)(36) | −254 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 55 | (28)(30)(36) | −254 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 56 | (28)(30)(36) | −254 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 57 | (30) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 58 | (30) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 59 | (30)(36) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 60 | (30)(36) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 61 | (14)(26)(28)(31)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 62 | (14)(26)(28)(31)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 63 | (14)(26)(28) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 64 | (26)(28) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 65 | (26)(28)(31)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 66 | (26)(28)(31)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 67 | (26)(28)(31)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 68 | (26)(28) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 69 | (26)(28)(31)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 70 | (26)(31)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 71 | (26) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 36 | 138 | 135 | 133 | 131 | 129 | 127 | 125 | 124 | 122 | 121 | 119 | 117 | **108** |
| 37 | 138 | 135 | 133 | 131 | 129 | 127 | 125 | 124 | 122 | 121 | 119 | 117 | **108** |
| 38 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | **94.4** |
| 39 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 40 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 41 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 42 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 43 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 44 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 45 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 46 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 47 | 133 | 131 | 129 | 128 | 125 | 123 | 120 | 117 | 114 | 111 | 107 | 104 | 100 |
| 48 | 133 | 131 | 129 | 128 | 125 | 123 | 120 | 117 | 114 | 111 | 107 | 104 | 100 |
| 49 | 137 | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116 | **108** |
| 50 | 137 | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116 | **108** |
| 51 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 52 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 53 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 54 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 55 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 56 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 57 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 58 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 59 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 60 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 61 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 62 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 63 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 64 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 65 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 66 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 67 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 68 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 69 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 70 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 71 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 36 | 83.7 | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 37 | 83.7 | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 38 | 75.3 | 60.4 | 49.0 | 40.1 | 32.8 | 27.2 | 23.4 | 19.6 | 16.8 | 14.7 | 12.8 | 11.7 |
| 39 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 40 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 41 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 42 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 43 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 44 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 45 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 46 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 47 | 68.1 | 53.5 | 42.1 | 33.2 | 25.9 | 20.3 | 16.5 | 13.2 | 10.1 | 7.35 | 5.89 | 5.52 |
| 48 | 68.1 | 53.5 | 42.1 | 33.2 | 25.9 | 20.3 | 16.5 | 13.2 | 10.1 | 7.35 | 5.89 | 5.52 |
| 49 | 83.7 | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 50 | 83.7 | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 51 | 95.5 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 52 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 53 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 54 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 55 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 56 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 57 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 58 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 59 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 60 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 61 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 62 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 63 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 64 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 65 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 66 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 67 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 68 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 69 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 70 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 71 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 72 | 18Cr–10Ni–Cb | Pipe | A376 | TP347H | S34709 | ... | ... | 8 |
| 73 | 18Cr–10Ni–Cb | Smls. & wld. pipe | A312 | TP347 | S34700 | ... | ... | 8 |
| 74 | 18Cr–10Ni–Cb | Wld. pipe | A358 | 347 | S34700 | ... | ... | 8 |
| 75 | 18Cr–10Ni–Cb | Pipe | A376 | TP347 | S34700 | ... | ... | 8 |
| 76 | 18Cr–10Ni–Cb | Pipe | A409 | TP347 | S34700 | ... | ... | 8 |
| 77 | 18Cr–10Ni–Cb | Smls. & wld. pipe | A312 | TP348 | S34800 | ... | ... | 8 |
| 78 | 18Cr–10Ni–Cb | Wld. pipe | A358 | 348 | S34800 | ... | ... | 8 |
| 79 | 18Cr–10Ni–Cb | Pipe | A376 | TP348 | S34800 | ... | ... | 8 |
| 80 | 18Cr–10Ni–Cb | Pipe | A409 | TP348 | S34800 | ... | ... | 8 |
| 81 | 18Cr–10Ni–Cb | Smls. & wld. pipe | A312 | TP347H | S34709 | ... | ... | 8 |
| 82 | 18Cr–10Ni–Cb | Smls. & wld. pipe | A312 | TP348H | S34809 | ... | ... | 8 |
| 83 | 18Cr–8Ni | Tube | A213 | TP304 | S30400 | ... | ... | 8 |
| 84 | 18Cr–8Ni | Tube | A269 | TP304 | S30400 | ... | ... | 8 |
| 85 | 18Cr–8Ni | Tube | A270 | TP304 | S30400 | ... | ... | 8 |
| 86 | 18Cr–8Ni | Smls. & wld. pipe | A312 | TP304 | S30400 | ... | ... | 8 |
| 87 | 18Cr–8Ni | Wld. pipe | A358 | 304 | S30400 | ... | ... | 8 |
| 88 | 18Cr–8Ni | Pipe | A376 | TP304 | S30400 | ... | ... | 8 |
| 89 | 18Cr–8Ni | Pipe | A376 | TP304H | S30409 | ... | ... | 8 |
| 90 | 18Cr–8Ni | Pipe | A409 | TP304 | S30400 | ... | ... | 8 |
| 91 | 18Cr–8Ni | Smls. & wld. pipe | A312 | TP304H | S30409 | ... | ... | 8 |
| 92 | 18Cr–12Ni–2Mo | Pipe & tube | A451 | CPF8M | J92900 | ... | ... | 8 |
| 93 | 44Fe–25Ni–21Cr–Mo | Wld. tube | A249 | ... | N08904 | ... | ... | 45 |
| 94 | 44Fe–25Ni–21Cr–Mo | Smls. & wld. pipe | A312 | ... | N08904 | ... | ... | 45 |
| 95 | 20Cr–Cu | Tube | A268 | TP443 | S44300 | ... | ... | a |
| 96 | 27Cr | Tube | A268 | TP446-1 | S44600 | ... | ... | 10I |
| 97 | 12Cr | Wld. pipe | A1053 | 50 | S41003 | ... | ... | 7 |
| 98 | 25Cr–8Ni–N | Pipe & tube | A451 | CPE20N | J92802 | ... | ... | 8 |
| 99 | 23Cr–4Ni–Mo–Cu–N | Smls. & wld. tube | A789 | ... | S32304 | ... | ... | 10H |
| 100 | 23Cr–4Ni–Mo–Cu–N | Smls. & wld. pipe | A790 | ... | S32304 | ... | ... | 10H |
| 101 | 23Cr–4Ni–Mo–Cu–N | Pipe & tube | A928 | 2304 | S32304 | ... | ... | 10H |
| 102 | 20Cr–18Ni–6Mo | Pipe & tube | A813 | ... | S31254 | ... | ... | 8 |
| 103 | 20Cr–18Ni–6Mo | Pipe & tube | A814 | ... | S31254 | ... | ... | 8 |
| 104 | 13Cr | Pipe & tube | A426 | CPCA15 | J91150 | ... | ... | 6 |
| 105 | 20Cr–18Ni–6Mo | Wld. pipe | A358 | ... | S31254 | ... | >5.0 | 8 |
| 106 | 20Cr–18Ni–6Mo | Wld. pipe | A358 | ... | S31254 | ... | ≤5.0 | 8 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | | | | | | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 |
| 72 | (30)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 73 | (28) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 74 | (28)(30)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 75 | (28)(30)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 76 | (28)(30)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 77 | (28) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 78 | (28)(30)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 79 | (28)(30)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 80 | (28)(30)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 81 | ... | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 82 | ... | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 83 | (14)(26)(28)(31)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 84 | (14)(26)(28)(31)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 85 | (14)(26)(28) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 86 | (26)(28) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 87 | (26)(28)(31)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 88 | (20)(26)(28)(31)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 89 | (26)(31)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 90 | (26)(28)(31)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 91 | (26) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 92 | (26)(28) | −254 | 483 | 207 | 816 | 138 | 138 | 138 | 138 | 130 | 124 | 118 |
| 93 | (26) | −198 | 490 | 220 | 260 | 143 | 143 | 143 | 143 | 141 | 135 | 130 |
| 94 | (26) | −198 | 490 | 220 | 260 | 143 | 143 | 143 | 143 | 141 | 135 | 130 |
| 95 | (7)(35) | −29 | 483 | 276 | 538 | *161* | *161* | *161* | *161* | *161* | *161* | *161* |
| 96 | (35) | −29 | 483 | 276 | 538 | *161* | *161* | *161* | *158* | *155* | *153* | *152* |
| 97 | ... | −29 | 485 | 350 | 316 | 162 | 162 | 162 | 162 | 162 | 161 | 159 |
| 98 | (35)(39) | −198 | 552 | 276 | 482 | 184 | 184 | 184 | 184 | 184 | 184 | 184 |
| 99 | (25) | −51 | 600 | 400 | 316 | *200* | *200* | *191* | *185* | *180* | *175* | *171* |
| 100 | (25) | −51 | 600 | 400 | 316 | *200* | *200* | *191* | *185* | *180* | *175* | *171* |
| 101 | (25) | −51 | 600 | 400 | 316 | *200* | *200* | *191* | *185* | *180* | *175* | *171* |
| 102 | (8) | −198 | 650 | 300 | 454 | 202 | 202 | 202 | 202 | 199 | 192 | 185 |
| 103 | (8) | −198 | 650 | 300 | 454 | 202 | 202 | 202 | 202 | 199 | 192 | 185 |
| 104 | (10)(35) | −29 | 621 | 448 | 40 | *207* | ... | ... | ... | ... | ... | ... |
| 105 | ... | −198 | 655 | 310 | 475 | 207 | 207 | 207 | 207 | 203 | 196 | 189 |
| 106 | ... | −198 | 690 | 310 | 475 | 207 | 207 | 207 | 207 | 203 | 196 | 189 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 72 | 138 | 138 | *137* | 135 | 132 | 130 | 129 | 127 | 126 | 126 | 125 | 125 | 125 |
| 73 | 138 | 138 | *137* | 135 | 132 | 130 | 129 | 127 | 126 | 126 | 125 | 125 | 125 |
| 74 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 75 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 76 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 77 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 78 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 79 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 80 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 81 | 138 | 138 | *137* | 135 | 132 | 130 | 129 | 127 | 126 | 126 | 125 | 125 | 125 |
| 82 | 138 | 138 | *137* | 135 | 132 | 130 | 129 | 127 | 126 | 126 | 125 | 125 | 125 |
| 83 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 84 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 85 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 86 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 87 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 88 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 89 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 90 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 91 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 92 | 114 | 110 | 107 | 104 | 102 | 101 | 99.3 | 98.1 | 97.0 | 95.9 | 94.7 | 93.3 | 91.5 |
| 93 | 125 | 120 | 116 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 94 | 125 | 120 | 116 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 95 | *161* | *161* | *161* | *161* | *161* | **97.0** | **84.3** | **73.3** | **64.0** | **55.8** | **43.9** | **31.7** | **21.4** |
| 96 | *150* | *149* | *147* | *145* | *144* | *141* | *139* | *136* | *132* | *128* | *122* | *116* | *109* |
| 97 | 156 | 154 | 152 | 149 | 146 | ... | ... | ... | ... | ... | ... | ... | ... |
| 98 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | ... |
| 99 | *166* | *161* | *153* | *143* | 111 | ... | ... | ... | ... | ... | ... | ... | ... |
| 100 | *166* | *161* | *153* | *143* | 111 | ... | ... | ... | ... | ... | ... | ... | ... |
| 101 | *166* | *161* | *153* | *143* | *111* | ... | ... | ... | ... | ... | ... | ... | ... |
| 102 | 180 | 175 | 171 | 168 | 165 | 164 | 162 | 161 | 160 | 159 | 158 | ... | ... |
| 103 | 180 | 175 | 171 | 168 | 165 | 164 | 162 | 161 | 160 | 159 | 158 | ... | ... |
| 104 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 105 | 184 | 179 | 175 | 172 | 169 | 167 | 165 | 165 | 164 | 163 | 161 | ... | ... |
| 106 | 184 | 179 | 175 | 172 | 169 | 167 | 165 | 165 | 164 | 163 | 161 | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 72 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 73 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 74 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 75 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 76 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 77 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 78 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 79 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 80 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 81 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 82 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 83 | 95.5 | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 84 | 95.5 | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 85 | 95.5 | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 86 | 95.5 | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 87 | 95.5 | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 88 | 95.5 | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 89 | 95.5 | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 90 | 95.5 | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 91 | 95.5 | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 92 | 89.1 | 72.7 | 57.7 | 46.0 | 36.9 | 30.1 | 24.3 | 20.3 | 17.0 | 14.3 | 12.1 | 11.0 |
| 93 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 94 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 95 | **17.2** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 96 | *104* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 97 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 98 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 99 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 100 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 101 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 102 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 103 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 104 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 105 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 106 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 107 | 22Cr–5Ni–3Mo–N | Smls. & wld. tube | A789 | ... | S31803 | ... | ... | 10H |
| 108 | 22Cr–5Ni–3Mo–N | Smls. & wld. pipe | A790 | ... | S31803 | ... | ... | 10H |
| 109 | 22Cr–5Ni–3Mo–N | Pipe & tube | A928 | ... | S31803 | ... | ... | 10H |
| 110 | 20Cr–18Ni–6Mo | Pipe & tube | A249 | ... | S31254 | ... | >5.00 | 8 |
| 111 | 20Cr–18Ni–6Mo | Pipe & tube | A249 | ... | S31254 | ... | ≤5.00 | 8 |
| 112 | 20Cr–18Ni–6Mo | Pipe & tube | A312 | ... | S31254 | ... | >5.00 | 8 |
| 113 | 20Cr–18Ni–6Mo | Pipe & tube | A312 | ... | S31254 | ... | ≤5.00 | 8 |
| 114 | 26Cr–4Ni–Mo | Smls. & wld. tube | A789 | ... | S32900 | ... | ... | 10H |
| 115 | 26Cr–4Ni–Mo | Smls. & wld. pipe | A790 | ... | S32900 | ... | ... | 10H |
| 116 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Smls. & wld. pipe | A312 | ... | N08367 | ... | >5.0 | 45 |
| 117 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A358 | ... | N08367 | ... | >5.0 | 45 |
| 118 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A813 | ... | N08367 | ... | >5.0 | 45 |
| 119 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A814 | ... | N08367 | ... | >5.0 | 45 |
| 120 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Smls. & wld. pipe | A312 | ... | N08367 | ... | ≤5.0 | 45 |
| 121 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A358 | ... | N08367 | ... | ≤5.0 | 45 |
| 122 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A813 | ... | N08367 | ... | ≤5.0 | 45 |
| 123 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Wld. pipe | A814 | ... | N08367 | ... | ≤5.0 | 45 |
| 124 | 21Cr–5Mn–1½Ni–Cu–N | Smls. & wld. tube | A789 | ... | S32101 | ... | >5.0 | 10H |
| 125 | 21Cr–5Mn–1½Ni–Cu–N | Smls. & wld. pipe | A790 | ... | S32101 | ... | >5.0 | 10H |
| 126 | 24Cr–4Ni–3Mn–1.5Mo–N | Smls. & wld. tube | A789 | ... | S82441 | ... | ≥10.0 | 10H |
| 127 | 24Cr–4Ni–3Mn–1.5Mo–N | Smls. & wld. pipe | A790 | ... | S82441 | ... | ≥10.0 | 10H |
| 128 | 21Cr–5Mn–1½Ni–Cu–N | Smls. & wld. tube | A789 | ... | S32101 | ... | ≤5.0 | 10H |
| 129 | 21Cr–5Mn–1½Ni–Cu–N | Smls. & wld. pipe | A790 | ... | S32101 | ... | ≤5.0 | 10H |
| 130 | 21Cr–3½Ni–1¾Mo–N | Smls. & wld. tube | A789 | ... | S32003 | ... | >5.00 | 10H |
| 131 | 21Cr–3½Ni–1¾Mo–N | Smls. & wld. pipe | A790 | ... | S32003 | ... | >5.00 | 10H |
| 132 | 21Cr–3½Ni–1¾Mo–N | Pipe & tube | A928 | ... | S32003 | ... | >5.00 | 10H |
| 133 | 22Cr–5Ni–3Mo–N | Pipe & tube | A928 | 2205 | S32205 | ... | ... | 10H |
| 134 | 21Cr–3½Ni–1¾Mo–N | Smls. & wld. tube | A789 | ... | S32003 | ... | ≤5.00 | 10H |
| 135 | 21Cr–3½Ni–1¾Mo–N | Smls. & wld. pipe | A790 | ... | S32003 | ... | ≤5.00 | 10H |
| 136 | 21Cr–3½Ni–1¾Mo–N | Pipe & tube | A928 | ... | S32003 | ... | ≤5.00 | 10H |
| 137 | 24Cr–4Ni–3Mn–1.5Mo–N | Smls. & wld. tube | A789 | ... | S82441 | ... | <10.0 | 10H |
| 138 | 24Cr–4Ni–3Mn–1.5Mo–N | Smls. & wld. pipe | A790 | ... | S82441 | ... | <10.0 | 10H |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 107 | (25) | −51 | 621 | 448 | 316 | *207* | *207* | *207* | *204* | *199* | *196* | *193* |
| 108 | (25) | −51 | 621 | 448 | 316 | *207* | *207* | *207* | *204* | *199* | *196* | *193* |
| 109 | (25) | −51 | 621 | 448 | 316 | *207* | *207* | *207* | *204* | *199* | *196* | *193* |
| 110 | (8) | −198 | 655 | 310 | 454 | 207 | 207 | 207 | 207 | 203 | 196 | 190 |
| 111 | (8) | −198 | 675 | 310 | 454 | 207 | 207 | 207 | 207 | 203 | 196 | 190 |
| 112 | (8) | −198 | 655 | 310 | 454 | 207 | 207 | 207 | 207 | 203 | 196 | 190 |
| 113 | (8) | −198 | 675 | 310 | 454 | 207 | 207 | 207 | 207 | 203 | 196 | 190 |
| 114 | (25) | −29 | 621 | 483 | 40 | *207* | ... | ... | ... | ... | ... | ... |
| 115 | (25) | −29 | 621 | 483 | 40 | *207* | ... | ... | ... | ... | ... | ... |
| 116 | (26) | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | 206 | 202 | 198 |
| 117 | (26) | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | 206 | 202 | 198 |
| 118 | (26) | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | 206 | 202 | 198 |
| 119 | (26) | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | 206 | 202 | 198 |
| 120 | (26) | −198 | 690 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 205 |
| 121 | (26) | −198 | 690 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 205 |
| 122 | (26) | −198 | 690 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 205 |
| 123 | (26) | −198 | 690 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 205 |
| 124 | (25) | −29 | 650 | 450 | 316 | *217* | *217* | *215* | *211* | *206* | *203* | *199* |
| 125 | (25) | −29 | 650 | 450 | 316 | *217* | *217* | *215* | *211* | *206* | *203* | *199* |
| 126 | (25) | −51 | 680 | 480 | 316 | *227* | *227* | *227* | *227* | *227* | *227* | *227* |
| 127 | (25) | −51 | 680 | 480 | 316 | *227* | *227* | *227* | *227* | *227* | *227* | *227* |
| 128 | (25) | −29 | 700 | 530 | 316 | *233* | *233* | *231* | *227* | *222* | *219* | *215* |
| 129 | (25) | −29 | 700 | 530 | 316 | *233* | *233* | *231* | *227* | *222* | *219* | *215* |
| 130 | (25) | −51 | 655 | 450 | 343 | *218* | *218* | *210* | *203* | *199* | *197* | *197* |
| 131 | (25) | −51 | 655 | 450 | 343 | *218* | *218* | *210* | *203* | *199* | *197* | *197* |
| 132 | (25) | −51 | 655 | 450 | 343 | *218* | *218* | *210* | *203* | *199* | *197* | *197* |
| 133 | (25) | −51 | 655 | 450 | 343 | *218* | *218* | *218* | *215* | *210* | *206* | *203* |
| 134 | (25) | −51 | 690 | 485 | 343 | *230* | *230* | *221* | *214* | *209* | *207* | *207* |
| 135 | (25) | −51 | 690 | 485 | 343 | *230* | *230* | *221* | *214* | *209* | *207* | *207* |
| 136 | (25) | −51 | 690 | 485 | 343 | *230* | *230* | *221* | *214* | *209* | *207* | *207* |
| 137 | (25) | −51 | 740 | 540 | 316 | *247* | *247* | *247* | *247* | *247* | *247* | *247* |
| 138 | (25) | −51 | 740 | 540 | 316 | *247* | *247* | *247* | *247* | *247* | *247* | *247* |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 107 | *190* | *188* | *187* | *186* | *185* | … | … | … | … | … | … | … | … |
| 108 | *190* | *188* | *187* | *186* | *185* | … | … | … | … | … | … | … | … |
| 109 | *190* | *188* | *187* | *186* | *185* | … | … | … | … | … | … | … | … |
| 110 | 184 | 179 | 175 | 172 | 169 | 167 | 166 | 165 | 164 | 163 | 161 | … | … |
| 111 | 184 | 179 | 175 | 172 | 169 | 167 | 166 | 165 | 164 | 163 | 161 | … | … |
| 112 | 184 | 179 | 175 | 172 | 169 | 167 | 166 | 165 | 164 | 163 | 161 | … | … |
| 113 | 184 | 179 | 175 | 172 | 169 | 167 | 166 | 165 | 164 | 163 | 161 | … | … |
| 114 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 115 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 116 | 195 | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | … | … | … |
| 117 | 195 | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | … | … | … |
| 118 | 195 | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | … | … | … |
| 119 | 195 | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | … | … | … |
| 120 | 199 | 194 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | … | … | … |
| 121 | 199 | 194 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | … | … | … |
| 122 | 199 | 194 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | … | … | … |
| 123 | 199 | 194 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | … | … | … |
| 124 | *199* | *199* | *199* | *199* | *199* | … | … | … | … | … | … | … | … |
| 125 | *199* | *199* | *199* | *199* | *199* | … | … | … | … | … | … | … | … |
| 126 | *227* | *227* | *227* | *227* | *227* | … | … | … | … | … | … | … | … |
| 127 | *227* | *227* | *227* | *227* | *227* | … | … | … | … | … | … | … | … |
| 128 | *214* | *214* | *214* | *214* | *214* | … | … | … | … | … | … | … | … |
| 129 | *214* | *214* | *214* | *214* | *214* | … | … | … | … | … | … | … | … |
| 130 | *197* | *197* | *197* | *197* | *197* | *197* | … | … | … | … | … | … | … |
| 131 | *197* | *197* | *197* | *197* | *197* | *197* | … | … | … | … | … | … | … |
| 132 | *197* | *197* | *197* | *197* | *197* | *197* | … | … | … | … | … | … | … |
| 133 | *201* | *199* | *197* | *196* | *196* | *195* | … | … | … | … | … | … | … |
| 134 | *207* | *207* | *207* | *207* | *207* | *207* | … | … | … | … | … | … | … |
| 135 | *207* | *207* | *207* | *207* | *207* | *207* | … | … | … | … | … | … | … |
| 136 | *207* | *207* | *207* | *207* | *207* | *207* | … | … | … | … | … | … | … |
| 137 | *247* | *247* | *247* | *247* | *247* | … | … | … | … | … | … | … | … |
| 138 | *247* | *247* | *247* | *247* | *247* | … | … | … | … | … | … | … | … |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 107 | … | … | … | … | … | … | … | … | … | … | … | … |
| 108 | … | … | … | … | … | … | … | … | … | … | … | … |
| 109 | … | … | … | … | … | … | … | … | … | … | … | … |
| 110 | … | … | … | … | … | … | … | … | … | … | … | … |
| 111 | … | … | … | … | … | … | … | … | … | … | … | … |
| 112 | … | … | … | … | … | … | … | … | … | … | … | … |
| 113 | … | … | … | … | … | … | … | … | … | … | … | … |
| 114 | … | … | … | … | … | … | … | … | … | … | … | … |
| 115 | … | … | … | … | … | … | … | … | … | … | … | … |
| 116 | … | … | … | … | … | … | … | … | … | … | … | … |
| 117 | … | … | … | … | … | … | … | … | … | … | … | … |
| 118 | … | … | … | … | … | … | … | … | … | … | … | … |
| 119 | … | … | … | … | … | … | … | … | … | … | … | … |
| 120 | … | … | … | … | … | … | … | … | … | … | … | … |
| 121 | … | … | … | … | … | … | … | … | … | … | … | … |
| 122 | … | … | … | … | … | … | … | … | … | … | … | … |
| 123 | … | … | … | … | … | … | … | … | … | … | … | … |
| 124 | … | … | … | … | … | … | … | … | … | … | … | … |
| 125 | … | … | … | … | … | … | … | … | … | … | … | … |
| 126 | … | … | … | … | … | … | … | … | … | … | … | … |
| 127 | … | … | … | … | … | … | … | … | … | … | … | … |
| 128 | … | … | … | … | … | … | … | … | … | … | … | … |
| 129 | … | … | … | … | … | … | … | … | … | … | … | … |
| 130 | … | … | … | … | … | … | … | … | … | … | … | … |
| 131 | … | … | … | … | … | … | … | … | … | … | … | … |
| 132 | … | … | … | … | … | … | … | … | … | … | … | … |
| 133 | … | … | … | … | … | … | … | … | … | … | … | … |
| 134 | … | … | … | … | … | … | … | … | … | … | … | … |
| 135 | … | … | … | … | … | … | … | … | … | … | … | … |
| 136 | … | … | … | … | … | … | … | … | … | … | … | … |
| 137 | … | … | … | … | … | … | … | … | … | … | … | … |
| 138 | … | … | … | … | … | … | … | … | … | … | … | … |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 139 | 25Cr–8Ni–3Mo–W–Cu–N | Smls. & wld. tube | A789 | ... | S32760 | ... | ... | 10H |
| 140 | 25Cr–8Ni–3Mo–W–Cu–N | Smls. & wld. pipe | A790 | ... | S32760 | ... | ... | 10H |
| 141 | 29Cr–6.5Ni–2Mo–N | Smls. & wld. tube | A789 | ... | S32906 | ... | ≥10 | 10H |
| 142 | 29Cr–6.5Ni–2Mo–N | Smls. & wld. pipe | A790 | ... | S32906 | ... | ≥10 | 10H |
| 143 | 24Cr–17Ni–6Mn–4$^1/_2$Mo–N | Pipe & tube | A358 | ... | S34565 | ... | ... | 8 |
| 144 | 25Cr–7Ni–4Mo–N | Smls. & wld. tube | A789 | ... | S32750 | ... | ... | 10H |
| 145 | 25Cr–7Ni–4Mo–N | Smls. & wld. pipe | A790 | 2507 | S32750 | ... | ... | 10H |
| 146 | 25Cr–7Ni–4Mo–N | Pipe & tube | A928 | 2507 | S32750 | ... | ... | 10H |
| 147 | 29Cr–6.5Ni–2Mo–N | Smls. & wld. tube | A789 | ... | S32906 | ... | <10 | 10H |
| 148 | 29Cr–6.5Ni–2Mo–N | Smls. & wld. pipe | A790 | ... | S32906 | ... | <10 | 10H |
| 149 | 18Cr–11Ni | Plate & sheet | A240 | 305 | S30500 | ... | ... | 8 |
| 150 | 12Cr–Al | Plate & sheet | A240 | 405 | S40500 | ... | ... | 7 |
| 151 | 18Cr–8Ni | Plate & sheet | A240 | 304L | S30403 | ... | ... | 8 |
| 152 | 16Cr–12Ni–2Mo | Plate & sheet | A240 | 316L | S31603 | ... | ... | 8 |
| 153 | 18Cr–Ti | Plate & sheet | A240 | 439 | S43035 | ... | ... | ... |
| 154 | 18Cr–8Ni | Plate & sheet | A240 | 302 | S30200 | ... | ... | 8 |
| 155 | 12Cr–1Ni | Plate, sheet, strip | A1010 | 40 | S41003 | ... | ... | 7 |
| 156 | 12Cr–1Ni | Plate, sheet, strip | A1010 | 50 | S41003 | ... | ... | 7 |
| 157 | 13Cr | Plate & sheet | A240 | 410S | S41008 | ... | ... | 7 |
| 158 | 13Cr | Plate & sheet | A240 | 410 | S41000 | ... | ... | 6 |
| 159 | 15Cr | Plate & sheet | A240 | 429 | S42900 | ... | ... | 6 |
| 160 | 17Cr | Plate & sheet | A240 | 430 | S43000 | ... | ... | 7 |
| 161 | 18Cr–13Ni–3Mo | Plate & sheet | A240 | 317L | S31703 | ... | ... | 8 |
| 162 | 25Cr–20Ni | Plate & sheet | A240 | 310S | S31008 | ... | ... | 8 |
| 163 | 18Cr–10Ni–Ti | Plate, sheet, strip | A240 | 321 | S32100 | ... | ... | 8 |
| 164 | 23Cr–12Ni | Plate & sheet | A240 | 309S | S30908 | ... | ... | 8 |
| 165 | 18Cr–10Ni–Cb | Plate & sheet | A240 | 347 | S34700 | ... | ... | 8 |
| 166 | 18Cr–10Ni–Cb | Plate & sheet | A240 | 348 | S34800 | ... | ... | 8 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | | | | | | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 |
| 139 | (25) | −51 | 750 | 550 | 316 | *250* | *250* | *248* | *243* | *238* | *236* | *234* |
| 140 | (25) | −51 | 750 | 550 | 316 | *250* | *250* | *248* | *243* | *238* | *236* | *234* |
| 141 | (25) | −51 | 750 | 550 | 316 | *251* | *251* | *249* | *243* | *238* | *235* | *231* |
| 142 | (25) | −51 | 750 | 550 | 316 | *251* | *251* | *249* | *243* | *238* | *235* | *231* |
| 143 | (36) | −198 | 795 | 415 | 427 | *264* | *264* | 260 | *253* | 247 | 242 | 238 |
| 144 | (25) | −51 | 800 | 550 | 316 | *267* | *265* | *264* | *257* | *251* | *247* | *243* |
| 145 | (25) | −51 | 800 | 550 | 316 | *267* | *265* | *264* | *257* | *251* | *247* | *243* |
| 146 | (25) | −51 | 800 | 552 | 316 | *267* | *265* | *264* | *257* | *251* | *247* | *243* |
| 147 | (25) | −51 | 800 | 650 | 316 | *267* | *267* | *265* | *259* | *253* | *250* | *246* |
| 148 | (25) | −51 | 800 | 650 | 316 | *267* | *267* | *265* | *259* | *253* | *250* | *246* |
| 149 | (26)(36)(39) | −198 | 483 | 172 | 40 | 115 | ... | ... | ... | ... | ... | ... |
| 150 | (35) | −29 | 414 | 172 | 538 | 115 | 109 | 105 | 103 | 102 | 101 | 100 |
| 151 | (36) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 114 | 110 |
| 152 | (36) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 113 | 109 |
| 153 | (35) | −29 | 414 | 207 | 40 | 138 | ... | ... | ... | ... | ... | ... |
| 154 | (26)(36) | −198 | 517 | 207 | 538 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 155 | ... | −29 | 455 | 275 | 316 | 152 | 152 | 152 | 152 | 152 | 151 | 149 |
| 156 | ... | −29 | 485 | 350 | 316 | 162 | 162 | 162 | 162 | 162 | 161 | 159 |
| 157 | (35)(50) | −29 | 414 | 207 | 649 | *138* | 130 | 126 | 124 | 122 | 121 | 120 |
| 158 | (35) | −29 | 448 | 207 | 649 | 138 | 130 | 126 | 124 | 122 | 121 | 120 |
| 159 | (35) | −29 | 448 | 207 | 649 | 138 | 130 | 126 | 124 | 122 | 121 | 120 |
| 160 | (35) | −29 | 448 | 207 | 649 | 138 | 130 | 126 | 124 | 122 | 121 | 120 |
| 161 | (36) | −198 | 517 | 207 | 454 | 138 | 138 | 138 | 138 | 138 | 136 | 131 |
| 162 | (28)(31)(35)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 163 | (28)(31)(36) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 164 | (28)(35)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 165 | (36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 166 | (36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 139 | *233* | *233* | *233* | *233* | *233* | ... | ... | ... | ... | ... | ... | ... | ... |
| 140 | *233* | *233* | *233* | *233* | *233* | ... | ... | ... | ... | ... | ... | ... | ... |
| 141 | *230* | *228* | *228* | *228* | *228* | ... | ... | ... | ... | ... | ... | ... | ... |
| 142 | *230* | *228* | *228* | *228* | *228* | ... | ... | ... | ... | ... | ... | ... | ... |
| 143 | 235 | 234 | 232 | 231 | 229 | 228 | 226 | 223 | 221 | 218 | ... | ... | ... |
| 144 | *241* | *238* | *237* | *237* | *236* | ... | ... | ... | ... | ... | ... | ... | ... |
| 145 | *241* | *238* | *237* | *237* | *236* | ... | ... | ... | ... | ... | ... | ... | ... |
| 146 | *241* | *238* | *237* | *237* | *236* | ... | ... | ... | ... | ... | ... | ... | ... |
| 147 | *245* | *243* | *243* | *242* | *242* | ... | ... | ... | ... | ... | ... | ... | ... |
| 148 | *245* | *243* | *243* | *242* | *242* | ... | ... | ... | ... | ... | ... | ... | ... |
| 149 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 150 | 99.7 | 99.1 | 98.4 | 97.5 | 96.2 | 94.7 | 92.6 | 90.1 | 87.0 | 83.4 | 79.2 | **70.1** | **38.8** |
| 151 | 106 | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 152 | 106 | 103 | 100 | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 153 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 154 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 155 | 147 | 145 | 142 | 140 | 137 | ... | ... | ... | ... | ... | ... | ... | ... |
| 156 | 156 | 154 | 152 | 149 | 146 | ... | ... | ... | ... | ... | ... | ... | ... |
| 157 | 120 | 119 | 118 | 117 | 115 | 114 | 111 | 108 | 104 | 100 | **92.5** | **68.4** | **51.1** |
| 158 | 120 | 119 | 118 | 117 | 115 | 114 | 111 | 108 | 104 | 100 | **92.5** | **68.4** | **51.1** |
| 159 | 120 | 119 | 118 | 117 | 115 | 114 | 111 | 108 | 104 | 100 | **88.7** | **69.8** | **52.6** |
| 160 | 120 | 119 | 118 | 117 | 115 | 114 | 111 | 108 | 104 | 100 | **88.7** | **69.8** | **52.6** |
| 161 | 127 | 123 | 120 | 118 | 115 | 113 | 111 | 109 | 107 | 105 | 103 | ... | ... |
| 162 | 137 | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116 | **84.9** |
| 163 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 164 | 138 | 135 | 133 | 131 | 129 | 127 | 125 | 124 | 122 | 121 | 119 | 117 | **108** |
| 165 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 166 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 139 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 140 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 141 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 142 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 143 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 144 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 145 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 146 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 147 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 148 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 149 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 150 | **27.6** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 151 | 81.4 | **40.4** | **33.2** | **26.7** | **21.9** | **18.2** | **15.0** | **12.4** | **8.87** | **7.20** | **6.58** | **6.21** |
| 152 | 80.8 | **73.0** | **67.9** | **58.0** | **43.6** | **33.0** | **25.3** | **18.8** | **14.0** | **10.4** | **7.99** | **6.89** |
| 153 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 154 | 96.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 155 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 156 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 157 | **37.4** | **26.3** | **17.8** | **11.4** | **6.89** | ... | ... | ... | ... | ... | ... | ... |
| 158 | **37.4** | **26.3** | **17.8** | **11.4** | **6.89** | ... | ... | ... | ... | ... | ... | ... |
| 159 | **38.1** | **27.6** | **20.6** | **15.9** | **12.4** | ... | ... | ... | ... | ... | ... | ... |
| 160 | **38.1** | **27.6** | **20.6** | **15.9** | **12.4** | ... | ... | ... | ... | ... | ... | ... |
| 161 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 162 | **59.0** | **43.5** | **31.9** | **23.6** | **16.9** | **10.7** | **6.10** | **3.90** | **2.99** | **2.36** | **1.73** | **1.38** |
| 163 | **88.7** | **59.2** | **44.0** | **32.9** | **24.5** | **18.3** | **12.5** | **8.49** | **6.19** | **4.28** | **2.75** | **1.74** |
| 164 | **83.7** | **64.0** | **48.5** | **36.3** | **27.3** | **21.0** | **15.9** | **12.5** | **9.87** | **7.65** | **5.97** | **5.17** |
| 165 | **97.6** | **75.9** | **57.2** | **40.2** | **30.3** | **23.2** | **16.2** | **11.4** | **8.97** | **7.08** | **5.89** | **5.52** |
| 166 | **97.6** | **75.9** | **57.2** | **40.2** | **30.3** | **23.2** | **16.2** | **11.4** | **8.97** | **7.08** | **5.89** | **5.52** |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 167 | 25Cr–20Ni | Plate & sheet | A240 | 310S | S31008 | ... | ... | 8 |
| 168 | 18Cr–10Ni–Ti | Plate, sheet, strip | A240 | 321 | S32100 | ... | ... | 8 |
| 169 | 18Cr–10Ni–Ti | Plate, sheet, strip | A240 | 321H | S32109 | ... | ... | 8 |
| 170 | 16Cr–12Ni–2Mo | Plate & sheet | A240 | 316 | S31600 | ... | ... | 8 |
| 171 | 18Cr–13Ni–3Mo | Plate & sheet | A240 | 317 | S31700 | ... | ... | 8 |
| 172 | 18Cr–10Ni–Cb | Plate & sheet | A240 | 347 | S34700 | ... | ... | 8 |
| 173 | 18Cr–10Ni–Cb | Plate & sheet | A240 | 348 | S34800 | ... | ... | 8 |
| 174 | 18Cr–8Ni | Plate & sheet | A240 | 304 | S30400 | ... | ... | 8 |
| 175 | 44Fe–25Ni–21Cr–Mo | Plate & sheet | A240 | 904L | N08904 | ... | ... | 45 |
| 176 | 23Cr–4Ni–Mo–Cu–N | Plate & sheet | A240 | 2304 | S32304 | ... | ... | 10H |
| 177 | 22Cr–5Ni–3Mo–N | Plate & sheet | A240 | ... | S31803 | ... | ... | 10H |
| 178 | 16Cr–4Ni–6Mn | Plate & sheet | A240 | 201LN | S20153 | ... | ... | 8 |
| 179 | 20Cr–18Ni–6Mo | Plate | A240 | ... | S31254 | ... | >5.0 | 8 |
| 180 | 20Cr–18Ni–6Mo | Sheet | A240 | ... | S31254 | ... | ≤5.0 | 8 |
| 181 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Plate | A240 | ... | N08367 | ... | >5.0 | 45 |
| 182 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Sheet & strip | A240 | ... | N08367 | ... | ≤5.0 | 45 |
| 183 | 21Cr–5Mn–1.5Ni–Cu–N | Plate & sheet | A240 | ... | S32101 | ... | >5.0 | 10H |
| 184 | 24Cr–4Ni–3Mn–1.5Mo–N | Plate & sheet | A240 | ... | S82441 | ... | ≥10.0 | 10H |
| 185 | 21Cr–5Mn–1.5Ni–Cu–N | Plate & sheet | A240 | ... | S32101 | ... | ≤5.0 | 10H |
| 186 | 21Cr–3½Ni–1¾Mo–N | Plate & sheet | A240 | ... | S32003 | ... | >5.00 | 10H |
| 187 | 21Cr–3½Ni–1¾Mo–N | Plate & sheet | A240 | ... | S32003 | ... | ≤5.00 | 10H |
| 188 | 24Cr–4Ni–3Mn–1.5Mo–N | Plate & sheet | A240 | ... | S82441 | ... | <10.0 | 10H |
| 189 | 29Cr–6.5Ni–2Mo–N | Plate & sheet | A240 | ... | S32906 | ... | ≥10.0 | 10H |
| 190 | 29Cr–6.5Ni–2Mo–N | Plate & sheet | A240 | ... | S32906 | ... | ≤10.0 | 10H |
| 191 | 25Cr–8Ni–3Mo–W–Cu–N | Plate & sheet | A240 | ... | S32760 | ... | ... | 10H |
| 192 | 25Cr–7Ni–4Mo–N | Plate & sheet | A240 | 2507 | S32750 | ... | ... | 10H |
| 193 | 18Cr–13Ni–3Mo | Forgings & fittings | A182 | F317L | S31703 | ... | ≤125 | 8 |
| 194 | 18Cr–8Ni | Forgings & fittings | A182 | F304L | S30403 | ... | ... | 8 |
| 195 | 18Cr–8Ni | Forgings & fittings | A403 | WP304L | S30403 | ... | ... | 8 |
| 196 | 16Cr–12Ni–2Mo | Forgings & fittings | A182 | F316L | S31603 | ... | ... | 8 |
| 197 | 16Cr–12Ni–2Mo | Forgings & fittings | A403 | WP316L | S31603 | ... | ... | 8 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 167 | (28)(29)(35)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 168 | (28)(30)(36) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 169 | (30)(36) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 170 | (26)(28)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 171 | (26)(28)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 172 | (28)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 173 | (28)(36) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 174 | (26)(28)(36) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 175 | (26) | −198 | 490 | 220 | 260 | 143 | 143 | 143 | 143 | 141 | 135 | 130 |
| 176 | (25) | −51 | 600 | 400 | 316 | *200* | *200* | *191* | *185* | *180* | *175* | *171* |
| 177 | (25) | −51 | 620 | 450 | 316 | *207* | *207* | *207* | *204* | *199* | *196* | *193* |
| 178 | ... | −198 | 655 | 310 | 454 | 207 | *206* | *187* | *177* | *170* | *165* | *162* |
| 179 | (8) | −254 | 655 | 310 | 454 | 207 | 207 | 207 | 207 | 203 | 196 | 190 |
| 180 | (8) | −254 | 690 | 310 | 454 | 207 | 207 | 207 | 207 | 203 | 196 | 190 |
| 181 | (26) | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | 206 | 202 | 198 |
| 182 | (26) | −198 | 690 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 205 |
| 183 | (25) | −29 | 650 | 450 | 316 | *217* | *217* | *217* | *211* | *206* | *203* | *199* |
| 184 | (25) | −51 | 680 | 480 | 316 | *227* | *227* | *227* | *227* | *227* | *227* | *227* |
| 185 | (25) | −29 | 700 | 530 | 316 | *233* | *233* | *231* | *227* | *222* | *219* | *215* |
| 186 | (25) | −51 | 655 | 450 | 343 | 218 | 218 | 210 | 203 | 199 | 197 | 197 |
| 187 | (25) | −51 | 690 | 485 | 343 | 230 | 230 | 221 | 214 | 209 | 207 | 207 |
| 188 | (25) | −51 | 740 | 540 | 316 | *247* | *247* | *247* | *247* | *247* | *247* | *247* |
| 189 | (25) | −51 | 750 | 550 | 316 | *251* | *251* | *249* | *243* | *238* | *235* | *231* |
| 190 | (25) | −51 | 800 | 650 | 316 | *267* | *267* | *265* | *259* | *253* | *250* | *246* |
| 191 | (25) | −51 | 750 | 550 | 316 | *250* | *250* | *248* | *243* | *238* | *236* | *234* |
| 192 | (25) | −51 | 800 | 550 | 316 | *267* | *265* | *264* | *257* | *251* | *247* | *243* |
| 193 | (9)(21a) | −198 | 483 | 172 | 454 | 115 | 115 | 115 | 115 | 115 | 113 | 109 |
| 194 | (9)(21a) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 114 | 110 |
| 195 | (32)(37) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 114 | 110 |
| 196 | (9)(21a) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 113 | 109 |
| 197 | (32)(37) | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 113 | 109 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 167 | 137 | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116 | **108** |
| 168 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 169 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 170 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 171 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 172 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 173 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 174 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 175 | 125 | 120 | 116 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 176 | *166* | *161* | *153* | *143* | *111* | ... | ... | ... | ... | ... | ... | ... | ... |
| 177 | *190* | *188* | *187* | *186* | *185* | ... | ... | ... | ... | ... | ... | ... | ... |
| 178 | *160* | *159* | *158* | *158* | *158* | *157* | *156* | *154* | *152* | *149* | *146* | ... | ... |
| 179 | 184 | 179 | 175 | 172 | 169 | 167 | 166 | 165 | 164 | 163 | 161 | ... | ... |
| 180 | 184 | 179 | 175 | 172 | 169 | 167 | 166 | 165 | 164 | 163 | 161 | ... | ... |
| 181 | 195 | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 182 | 199 | 194 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 183 | *199* | *199* | *199* | *199* | *199* | ... | ... | ... | ... | ... | ... | ... | ... |
| 184 | *227* | *227* | *227* | *227* | *227* | ... | ... | ... | ... | ... | ... | ... | ... |
| 185 | *214* | *214* | *214* | *214* | *214* | ... | ... | ... | ... | ... | ... | ... | ... |
| 186 | 197 | 197 | 197 | 197 | 197 | 197 | ... | ... | ... | ... | ... | ... | ... |
| 187 | 207 | 207 | 207 | 207 | 207 | 207 | ... | ... | ... | ... | ... | ... | ... |
| 188 | *247* | *247* | *247* | *247* | *247* | ... | ... | ... | ... | ... | ... | ... | ... |
| 189 | *230* | *228* | *228* | *228* | *228* | ... | ... | ... | ... | ... | ... | ... | ... |
| 190 | *245* | *243* | *243* | *242* | *242* | ... | ... | ... | ... | ... | ... | ... | ... |
| 191 | *233* | *233* | *233* | *233* | *233* | ... | ... | ... | ... | ... | ... | ... | ... |
| 192 | *241* | *238* | *237* | *237* | *236* | ... | ... | ... | ... | ... | ... | ... | ... |
| 193 | 106 | 103 | 100 | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | ... | ... |
| 194 | 106 | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 195 | 106 | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 196 | 106 | 103 | 100 | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 197 | 106 | 103 | 100 | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 167 | 83.7 | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 168 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 169 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 170 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 171 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 172 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 173 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 174 | 95.5 | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 175 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 176 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 177 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 178 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 179 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 180 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 181 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 182 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 183 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 184 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 185 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 186 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 187 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 188 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 189 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 190 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 191 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 192 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 193 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 194 | 81.4 | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 195 | 81.4 | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 196 | 80.8 | 73.0 | 67.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 197 | 80.8 | 73.0 | 67.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 198 | 20Ni–8Cr | Forgings & fittings | A182 | F10 | S33100 | ... | ... | 8 |
| 199 | 18Cr–13Ni–3Mo | Forgings & fittings | A403 | WP317L | S31703 | ... | ... | 8 |
| 200 | 25Cr–20Ni | Forgings & fittings | A182 | F310H | S31009 | ... | ... | 8 |
| 201 | 25Cr–20Ni | Forgings & fittings | A403 | WP310 | S31008 | ... | ... | 8 |
| 202 | 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321 | S32100 | ... | >10 | 8 |
| 203 | 18Cr–10Ni–Ti | Forgings | A182 | F321 | S32100 | ... | ... | 8 |
| 204 | 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321 | S32100 | ... | ≤10 | 8 |
| 205 | 18Cr–10Ni–Ti | Wld. fittings | A403 | WP321 | S32100 | ... | ... | 8 |
| 206 | 23Cr–12Ni | Forgings & fittings | A403 | WP309 | S30900 | ... | ... | 8 |
| 207 | 25Cr–20Ni | Forgings & fittings | A182 | F310H | S31009 | ... | ... | 8 |
| 208 | 25Cr–20Ni | Forgings & fittings | A403 | WP310 | S31008 | ... | ... | 8 |
| 209 | 18Cr–10Ni–Cb | Forgings & fittings | A182 | F347 | S34700 | ... | ... | 8 |
| 210 | 18Cr–10Ni–Cb | Forgings & fittings | A403 | WP347 | S34700 | ... | ... | 8 |
| 211 | 18Cr–10Ni–Cb | Forgings & fittings | A182 | F348 | S34800 | ... | ... | 8 |
| 212 | 18Cr–10Ni–Cb | Forgings & fittings | A403 | WP348 | S34800 | ... | ... | 8 |
| 213 | 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321 | S32100 | ... | >10 | 8 |
| 214 | 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321H | S32109 | ... | >10 | 8 |
| 215 | 18Cr–10Ni–Ti | Forgings | A182 | F321 | S32100 | ... | ... | 8 |
| 216 | 18Cr–10Ni–Ti | Forgings | A182 | F321H | S32109 | ... | ... | 8 |
| 217 | 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321 | S32100 | ... | ≤10 | 8 |
| 218 | 18Cr–10Ni–Ti | Smls. fittings | A403 | WP321H | S32109 | ... | ≤10 | 8 |
| 219 | 18Cr–10Ni–Ti | Wld. fittings | A403 | WP321 | S32100 | ... | ... | 8 |
| 220 | 18Cr–10Ni–Ti | Wld. fittings | A403 | WP321H | S32109 | ... | ... | 8 |
| 221 | 16Cr–12Ni–2Mo | Forgings & fittings | A403 | WP316H | S31609 | ... | ... | 8 |
| 222 | 16Cr–12Ni–2Mo | Forgings & fittings | A182 | F316H | S31609 | ... | ... | 8 |
| 223 | 18Cr–10Ni–Cb | Forgings & fittings | A403 | WP347H | S34709 | ... | ... | 8 |
| 224 | 18Cr–10Ni–Cb | Forgings & fittings | A182 | F347 | S34700 | ... | ... | 8 |
| 225 | 18Cr–10Ni–Cb | Forgings & fittings | A403 | WP347 | S34700 | ... | ... | 8 |
| 226 | 18Cr–10Ni–Cb | Forgings & fittings | A182 | F348 | S34800 | ... | ... | 8 |
| 227 | 18Cr–10Ni–Cb | Forgings & fittings | A403 | WP348 | S34800 | ... | ... | 8 |
| 228 | 18Cr–10Ni–Cb | Forgings & fittings | A182 | F347H | S34709 | ... | ... | 8 |
| 229 | 18Cr–10Ni–Cb | Forgings & fittings | A182 | F348H | S34809 | ... | ... | 8 |
| 230 | 16Cr–12Ni–2Mo | Forgings & fittings | A182 | F316 | S31600 | ... | ... | 8 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 198 | (26)(28)(39) | −198 | 552 | 207 | 40 | 138 | ... | ... | ... | ... | ... | ... |
| 199 | (32)(37) | −198 | 517 | 207 | 454 | 138 | 138 | 138 | 138 | 138 | 136 | 131 |
| 200 | (9)(35)(39) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 201 | (28)(32)(35)(37)(39) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 202 | (28) | −198 | 485 | 170 | 816 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 203 | (9)(21)(28) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 204 | (28) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 205 | (28) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 206 | (28)(32)(35)(37)(39) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 207 | (9)(21)(29)(35)(39) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 208 | (28)(29)(32)(35)(37)(39) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 209 | (9)(21) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 210 | (32)(37) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 211 | (9)(21) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 212 | (32)(37) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 213 | (28)(30) | −198 | 485 | 170 | 816 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 214 | (30) | −198 | 485 | 170 | 816 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 215 | (9)(21)(28)(30) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 216 | (9)(21) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 217 | (28)(30) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 218 | (30) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 219 | (28)(30) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 220 | (30) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 221 | (26)(32)(37) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 222 | (9)(21)(26) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 223 | (32)(37) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 224 | (9)(21)(28) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 225 | (28)(32)(37) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 226 | (9)(21)(28) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 227 | (28)(32)(37) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 228 | (9)(21) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 229 | (9)(21) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 230 | (9)(21)(26)(28) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 198 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 199 | 127 | 123 | 120 | 118 | 115 | 113 | 111 | 109 | 107 | 105 | 103 | ... | ... |
| 200 | 137 | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116 | **84.9** |
| 201 | 137 | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116 | **84.9** |
| 202 | 115 | 112 | 109 | 106 | 104 | 102 | 100 | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 203 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 204 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 205 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 206 | 138 | 135 | 133 | 131 | 129 | 127 | 125 | 124 | 122 | 121 | 119 | 117 | **108** |
| 207 | 137 | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116 | **108** |
| 208 | 137 | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116 | **108** |
| 209 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 210 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 211 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 212 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 213 | 115 | 112 | 109 | 106 | 104 | 102 | 100 | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 214 | 115 | 112 | 109 | 106 | 104 | 102 | 100 | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 215 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 216 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 217 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 218 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 219 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 220 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 221 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 222 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 223 | 138 | 138 | *137* | 135 | 132 | 130 | 129 | 127 | 126 | 126 | 125 | 125 | 125 |
| 224 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 225 | 138 | 138 | *137* | 135 | 132 | 130 | 129 | 127 | 126 | 126 | 125 | 125 | 125 |
| 226 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 227 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 228 | 138 | 138 | *137* | 135 | 132 | 130 | 129 | 127 | 126 | 126 | 125 | 125 | 125 |
| 229 | 138 | 138 | *137* | 135 | 132 | 130 | 129 | 127 | 126 | 126 | 125 | 125 | 125 |
| 230 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 198 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 199 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 200 | 59.0 | 43.5 | 31.9 | 23.6 | 16.9 | 10.7 | 6.10 | 3.90 | 2.99 | 2.36 | 1.73 | 1.38 |
| 201 | 59.0 | 43.5 | 31.9 | 23.6 | 16.9 | 10.7 | 6.10 | 3.90 | 2.99 | 2.36 | 1.73 | 1.38 |
| 202 | 88.7 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 203 | 88.7 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 204 | 88.7 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 205 | 88.7 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 206 | 83.7 | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 207 | 83.7 | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 208 | 83.7 | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 209 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 210 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 211 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 212 | 97.6 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 213 | 92.7 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 214 | 92.7 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 215 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 216 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 217 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 218 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 219 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 220 | 100 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 221 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 222 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 223 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 224 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 225 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 226 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 227 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 228 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 229 | 125 | 112 | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 230 | 105 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 231 | 16Cr–12Ni–2Mo | Forgings & fittings | A403 | WP316 | S31600 | ... | ... | 8 |
| 232 | 18Cr–13Ni–3Mo | Forgings & fittings | A403 | WP317 | S31700 | ... | ... | 8 |
| 233 | 18Cr–8Ni | Forgings & fittings | A182 | F304 | S30400 | ... | ... | 8 |
| 234 | 18Cr–8Ni | Forgings & fittings | A403 | WP304 | S30400 | ... | ... | 8 |
| 235 | 18Cr–8Ni | Forgings & fittings | A403 | WP304H | S30409 | ... | ... | 8 |
| 236 | 18Cr–8Ni | Forgings & fittings | A182 | F304H | S30409 | ... | ... | 8 |
| 237 | 44Fe–25Ni–21Cr–Mo | Forgings | A182 | F904L | N08904 | ... | ... | 45 |
| 238 | 13Cr | Forgings & fittings | A182 | F6a | S41000 | 1 | ... | 6 |
| 239 | 13Cr | Forgings & fittings | A182 | F6a | S41000 | 2 | ... | 6 |
| 240 | 20Cr–18Ni–6Mo | Forgings | A182 | F44 | S31254 | ... | ... | 8 |
| 241 | 20Cr–18Ni–6Mo | Fittings | A403 | WPS31254 | S31254 | ... | ... | 8 |
| 242 | 20Cr–18Ni–6Mo | Fittings | A403 | CRS31254 | S31254 | ... | ... | 8 |
| 243 | 23Cr–4Ni–Mo–Cu–N | Forgings | A182 | F68 | S32304 | ... | ... | 10H |
| 244 | 22Cr–5Ni–3Mo–N | Forgings | A182 | F51 | S31803 | ... | ... | 10H |
| 245 | 22Cr–5Ni–3Mo–N | Fittings | A815 | WPS31803 | S31803 | ... | ... | 10H |
| 246 | 22Cr–5Ni–3Mo–N | Fittings | A815 | CRS31803 | S31803 | ... | ... | 10H |
| 247 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Forgings | A182 | F62 | N08367 | ... | ... | 45 |
| 248 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Fittings | A403 | WP6XN | N08367 | ... | ... | 45 |
| 249 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Fittings | A403 | CR6XN | N08367 | ... | ... | 45 |
| 250 | 21Cr–5Mn–1½Ni–Cu–N | Fittings | A815 | ... | S32101 | ... | ... | 10H |
| 251 | 25Cr–8Ni–3Mo–W–Cu–N | Forgings & fittings | A182 | ... | S32760 | ... | ... | 10H |
| 252 | 25Cr–8Ni–3Mo–W–Cu–N | Forgings & fittings | A815 | ... | S32760 | ... | ... | 10H |
| 253 | 13Cr | Forgings & fittings | A182 | F6a | S41000 | 3 | ... | 6 |
| 254 | 13Cr–½Mo | Forgings & fittings | A182 | F6b | S41026 | ... | ... | 6 |
| 255 | 25Cr–7Ni–4Mo–N | Forgings & fittings | A182 | F53 | S32750 | ... | ... | 10H |
| 256 | 25Cr–7Ni–4Mo–N | Forgings & fittings | A815 | WPS32750 | S32750 | ... | ... | 10H |
| 257 | 25Cr–7Ni–4Mo–N | Forgings & fittings | A815 | CRS32750 | S32750 | ... | ... | 10H |
| 258 | 13Cr | Forgings & fittings | A182 | F6a | S41000 | 4 | ... | 6 |
| 259 | 18Cr–8Ni | Bar | A479 | 304 | S30400 | ... | ... | 8 |
| 260 | 18Cr–8Ni | Bar | A479 | 304H | S30409 | ... | ... | 8 |
| 261 | 18Cr–8Ni | Bar | A479 | 304L | S30403 | ... | ... | 8 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 231 | (26)(28)(32)(37) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 232 | (26)(28)(32) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 233 | (9)(21)(26)(28) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 234 | (26)(28)(32)(37) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 235 | (26)(32)(37) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 236 | (9)(21)(26) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 237 | (26) | −198 | 490 | 220 | 260 | 143 | 143 | 143 | 143 | 141 | 135 | 130 |
| 238 | (35) | −29 | 483 | 276 | 538 | *161* | *161* | *161* | *160* | *158* | *156* | *155* |
| 239 | (35) | −29 | 586 | 379 | 649 | *195* | *195* | *195* | *194* | *191* | *190* | *188* |
| 240 | (8) | −198 | 650 | 300 | 454 | 202 | 202 | 202 | 202 | 199 | 192 | 185 |
| 241 | (8) | −198 | 650 | 300 | 454 | 202 | 202 | 202 | 202 | 199 | 192 | 185 |
| 242 | (8) | −198 | 650 | 300 | 454 | 202 | 202 | 202 | 202 | 199 | 192 | 185 |
| 243 | (25) | −51 | 600 | 400 | 316 | *200* | *200* | *191* | *185* | *180* | *175* | *171* |
| 244 | (25) | −51 | 620 | 450 | 316 | *207* | *207* | *207* | *204* | *199* | *196* | *193* |
| 245 | (25) | −51 | 620 | 450 | 316 | *207* | *207* | *207* | *204* | *199* | *196* | *193* |
| 246 | (25) | −51 | 620 | 450 | 316 | *207* | *207* | *207* | *204* | *199* | *196* | *193* |
| 247 | (26) | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | 206 | 202 | 198 |
| 248 | (26) | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | 206 | 202 | 198 |
| 249 | (26) | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | 206 | 202 | 198 |
| 250 | (25) | −29 | 650 | 450 | 316 | *217* | *217* | *215* | *211* | *206* | *203* | *199* |
| 251 | (25) | −51 | 750 | 550 | 316 | *250* | *250* | *248* | *243* | *238* | *236* | *234* |
| 252 | (25) | −51 | 750 | 550 | 316 | *250* | *250* | *248* | *243* | *238* | *236* | *234* |
| 253 | (35) | −29 | 758 | 586 | 40 | 253 | ... | ... | ... | ... | ... | ... |
| 254 | (35) | ... | 760–930 | 620 | 40 | 253 | ... | ... | ... | ... | ... | ... |
| 255 | (25) | −51 | 800 | 550 | 316 | *267* | *265* | *264* | *257* | *251* | *247* | *243* |
| 256 | (25) | −51 | 800 | 550 | 316 | *267* | *265* | *264* | *257* | *251* | *247* | *243* |
| 257 | (25) | −51 | 800 | 550 | 316 | *267* | *265* | *264* | *257* | *251* | *247* | *243* |
| 258 | (35) | −29 | 896 | 758 | 40 | 299 | ... | ... | ... | ... | ... | ... |
| 259 | (26)(28) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 260 | (26) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 261 | ... | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 114 | 110 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Line No.** | **225** | **250** | **275** | **300** | **325** | **350** | **375** | **400** | **425** | **450** | **475** | **500** | **525** |
| 231 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 232 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 233 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 234 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 235 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 236 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 237 | 125 | 120 | 116 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 238 | *154* | *153* | *152* | *150* | *148* | *145* | *142* | *137* | *133* | **125** | **92.5** | **68.4** | **51.1** |
| 239 | *187* | *186* | *184* | *182* | *180* | *176* | *172* | *167* | *161* | **125** | **92.5** | **68.4** | **51.1** |
| 240 | 180 | 175 | 171 | 168 | 165 | 164 | 162 | 161 | 160 | 159 | 158 | ... | ... |
| 241 | 180 | 175 | 171 | 168 | 165 | 164 | 162 | 161 | 160 | 159 | 158 | ... | ... |
| 242 | 180 | 175 | 171 | 168 | 165 | 164 | 162 | 161 | 160 | 159 | 158 | ... | ... |
| 243 | *166* | *161* | *153* | *143* | *111* | ... | ... | ... | ... | ... | ... | ... | ... |
| 244 | *190* | *188* | *187* | *186* | *185* | ... | ... | ... | ... | ... | ... | ... | ... |
| 245 | *190* | *188* | *187* | *186* | *185* | ... | ... | ... | ... | ... | ... | ... | ... |
| 246 | *190* | *188* | *187* | *186* | *185* | ... | ... | ... | ... | ... | ... | ... | ... |
| 247 | 195 | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 248 | 195 | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 249 | 195 | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 250 | *199* | *199* | *199* | *199* | *199* | ... | ... | ... | ... | ... | ... | ... | ... |
| 251 | *233* | *233* | *233* | *233* | *233* | ... | ... | ... | ... | ... | ... | ... | ... |
| 252 | *233* | *233* | *233* | *233* | *233* | ... | ... | ... | ... | ... | ... | ... | ... |
| 253 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 254 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 255 | *241* | *238* | *237* | *237* | *236* | ... | ... | ... | ... | ... | ... | ... | ... |
| 256 | *241* | *238* | *237* | *237* | *236* | ... | ... | ... | ... | ... | ... | ... | ... |
| 257 | *241* | *238* | *237* | *237* | *236* | ... | ... | ... | ... | ... | ... | ... | ... |
| 258 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 259 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 260 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 261 | 106 | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 231 | 105 | **97.8** | **80.8** | **65.0** | **50.4** | **38.6** | **29.6** | **23.0** | **17.4** | **13.3** | **10.4** | **8.96** |
| 232 | 105 | **97.8** | **80.8** | **65.0** | **50.4** | **38.6** | **29.6** | **23.0** | **17.4** | **13.3** | **10.4** | **8.96** |
| 233 | 95.5 | **78.9** | **63.8** | **51.6** | **41.6** | **32.9** | **26.5** | **21.3** | **17.2** | **14.1** | **11.2** | **9.65** |
| 234 | 95.5 | **78.9** | **63.8** | **51.6** | **41.6** | **32.9** | **26.5** | **21.3** | **17.2** | **14.1** | **11.2** | **9.65** |
| 235 | 95.5 | **78.9** | **63.8** | **51.6** | **41.6** | **32.9** | **26.5** | **21.3** | **17.2** | **14.1** | **11.2** | **9.65** |
| 236 | 95.5 | **78.9** | **63.8** | **51.6** | **41.6** | **32.9** | **26.5** | **21.3** | **17.2** | **14.1** | **11.2** | **9.65** |
| 237 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 238 | **44.1** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 239 | **37.4** | **26.3** | **17.8** | **11.4** | **6.89** | ... | ... | ... | ... | ... | ... | ... |
| 240 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 241 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 242 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 243 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 244 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 245 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 246 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 247 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 248 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 249 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 250 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 251 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 252 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 253 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 254 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 255 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 256 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 257 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 258 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 259 | 95.5 | **78.9** | **63.8** | **51.6** | **41.6** | **32.9** | **26.5** | **21.3** | **17.2** | **14.1** | **11.2** | **9.65** |
| 260 | 95.5 | **78.9** | **63.8** | **51.6** | **41.6** | **32.9** | **26.5** | **21.3** | **17.2** | **14.1** | **11.2** | **9.65** |
| 261 | 81.4 | **40.4** | **33.2** | **26.7** | **21.9** | **18.2** | **15.0** | **12.4** | **8.87** | **7.20** | **6.58** | **6.21** |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 262 | 16Cr–12Ni–2Mo | Bar | A479 | 316 | S31600 | ... | ... | 8 |
| 263 | 16Cr–12Ni–2Mo | Bar | A479 | 316H | S31609 | ... | ... | 8 |
| 264 | 16Cr–12Ni–2Mo | Bar | A479 | 316L | S31603 | ... | ... | 8 |
| 265 | 18Cr–10Ni–Ti | Bar | A479 | 321 | S32100 | ... | ... | 8 |
| 266 | 18Cr–10Ni–Ti | Bar | A479 | 321 | S32100 | ... | ... | 8 |
| 267 | 18Cr–10Ni–Ti | Bar | A479 | 321H | S32109 | ... | ... | 8 |
| 268 | 18Cr–10Ni–Cb | Bar | A479 | 347 | S34700 | ... | ... | 8 |
| 269 | 18Cr–10Ni–Cb | Bar | A479 | 347 | S34700 | ... | ... | 8 |
| 270 | 18Cr–10Ni–Cb | Bar | A479 | 347H | S34709 | ... | ... | 8 |
| 271 | 44Fe–25Ni–21Cr–Mo | Bar | A479 | 904L | N08904 | ... | ... | 45 |
| 272 | 22Cr–5Ni–3Mo–N | Bar | A479 | ... | S31803 | ... | ... | 10H |
| 273 | 20Cr–18Ni–6Mo | Bar | A479 | ... | S31254 | ... | ... | 8 |
| 274 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Bar | A479 | ... | N08367 | ... | ... | 45 |
| 275 | 21Cr–5Mn–1.5Ni–Cu–N | Bar | A479 | ... | S32101 | ... | ... | 10H |
| 276 | 24Cr–4Ni–3Mn–1.5Mo–N | Bar | A479 | ... | S82441 | ... | ≥11.0 | 10H |
| 277 | 22Cr–13Ni–5Mn | Bar | A479 | XM-19 | S20910 | ... | ... | 8 |
| 278 | 24Cr–4Ni–3Mn–1.5Mo–N | Bar | A479 | ... | S82441 | ... | <11.0 | 10H |
| 279 | 29Cr–6.5Ni–2Mo–N | Bar | A479 | ... | S32906 | ... | ... | 10H |
| 280 | 25Cr–7Ni–4Mo–N | Bar | A479 | ... | S32750 | ... | ≤50 | 10H |
| 281 | 29Ni–20Cr–3Cu–2Mo | Castings | A351 | CN7M | N08007 | ... | ... | 45 |
| 282 | 35Ni–15Cr–½Mo | Castings | A351 | HT30 | N08603 | ... | ... | 45 |
| 283 | 25Cr–12Ni | Castings | A351 | CH8 | J93400 | ... | ... | 8 |
| 284 | 25Cr–20Ni | Castings | A351 | CK20 | J94202 | ... | ... | 8 |
| 285 | 16Cr–14Ni–2Mo | Castings | A351 | CF10MC | ... | ... | ... | 8 |
| 286 | 18Cr–8Ni | Castings | A351 | CF3 | J92500 | ... | ... | 8 |
| 287 | 18Cr–12Ni–2Mo | Castings | A351 | CF3M | J92800 | ... | ... | 8 |
| 288 | 18Cr–8Ni | Castings | A351 | CF8 | J92600 | ... | ... | 8 |
| 289 | 25Cr–12Ni | Castings | A351 | CH10 | J93401 | ... | ... | 8 |
| 290 | 25Cr–12Ni | Castings | A351 | CH20 | J93402 | ... | ... | 8 |
| 291 | 18Cr–10Ni–Cb | Castings | A351 | CF8C | J92710 | ... | ... | 8 |
| 292 | 18Cr–12Ni–2Mo | Castings | A351 | CF8M | J92900 | ... | ... | 8 |
| 293 | 25Cr–20Ni–½Mo | Castings | A351 | HK40 | J94204 | ... | ... | 8 |
| 294 | 25Cr–20Ni–½Mo | Castings | A351 | HK30 | J94203 | ... | ... | 8 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | | | | | | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 |
| 262 | (26)(28) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 263 | (26) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 134 |
| 264 | ... | −254 | 483 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 113 | 109 |
| 265 | (28) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 266 | (28)(30) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 267 | (30) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 268 | ... | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 269 | (28)(30) | −254 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 270 | ... | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 271 | (26) | −198 | 490 | 220 | 260 | 143 | 143 | 143 | 143 | 141 | 135 | 130 |
| 272 | (25) | −51 | 620 | 450 | 316 | *207* | *207* | *207* | *204* | *199* | *196* | *193* |
| 273 | (8) | −198 | 655 | 310 | 454 | 207 | 207 | 207 | 207 | 203 | 196 | 190 |
| 274 | (26) | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | 206 | 202 | 198 |
| 275 | (25) | −29 | 650 | 450 | 316 | *217* | *217* | *215* | *211* | *206* | *203* | *199* |
| 276 | (25) | −51 | 680 | 480 | 316 | *227* | *227* | *227* | *227* | *227* | *227* | *227* |
| 277 | ... | −29 | 690 | 380 | 649 | 230 | *230* | *227* | *221* | *217* | *213* | *210* |
| 278 | (25) | −51 | 740 | 540 | 316 | *247* | *247* | *247* | *247* | *247* | *247* | *247* |
| 279 | (25) | −51 | 750 | 550 | 316 | *251* | *251* | *249* | *243* | *238* | *235* | *231* |
| 280 | (25) | −51 | 800 | 550 | 316 | *267* | *265* | *264* | *257* | *251* | *247* | *243* |
| 281 | (9)(30) | −198 | 427 | 172 | 40 | 115 | ... | ... | ... | ... | ... | ... |
| 282 | (36)(39) | −198 | 448 | 193 | 40 | 129 | ... | ... | ... | ... | ... | ... |
| 283 | (9)(31) | −198 | 448 | 193 | 816 | 129 | 129 | 129 | 129 | *127* | *125* | *124* |
| 284 | (9)(27)(31)(35)(39) | −198 | 448 | 193 | 816 | 129 | 129 | 129 | 129 | *127* | *125* | *124* |
| 285 | (30) | −198 | 483 | 207 | 40 | 138 | ... | ... | ... | ... | ... | ... |
| 286 | (9) | −254 | 483 | 207 | 427 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 287 | (9) | −254 | 483 | 207 | 454 | 138 | 138 | 138 | 138 | 138 | 138 | 133 |
| 288 | (9)(26)(27)(31) | −254 | 483 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 289 | (27)(31)(35) | −198 | 483 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 290 | (9)(27)(31)(35)(39) | −198 | 483 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 291 | (9)(28) | −198 | 485 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | *135* |
| 292 | (9)(26)(27)(30) | −254 | 483 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 134 | 129 |
| 293 | (35)(36)(39) | −198 | 427 | 241 | 40 | 142 | ... | ... | ... | ... | ... | ... |
| 294 | (35)(39) | −198 | 448 | 241 | 40 | 149 | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Line No.** | **225** | **250** | **275** | **300** | **325** | **350** | **375** | **400** | **425** | **450** | **475** | **500** | **525** |
| 262 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 263 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107 | 106 |
| 264 | 106 | 103 | 100 | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 265 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 266 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 267 | 138 | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113 | 112 |
| 268 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 269 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 270 | 138 | 138 | *137* | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125 | 125 |
| 271 | 125 | 120 | 116 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 272 | *190* | *188* | *187* | *186* | *185* | ... | ... | ... | ... | ... | ... | ... | ... |
| 273 | 184 | 179 | 175 | 172 | 169 | 167 | 166 | 165 | 164 | 163 | 161 | ... | ... |
| 274 | 195 | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 275 | *199* | *199* | *199* | *199* | *199* | ... | ... | ... | ... | ... | ... | ... | ... |
| 276 | *227* | *227* | *227* | *227* | *227* | ... | ... | ... | ... | ... | ... | ... | ... |
| 277 | *207* | *205* | *204* | *202* | *201* | *200* | *199* | *197* | *195* | *193* | *191* | *188* | *183* |
| 278 | *247* | *247* | *247* | *247* | *247* | ... | ... | ... | ... | ... | ... | ... | ... |
| 279 | *230* | *228* | *228* | *228* | *228* | ... | ... | ... | ... | ... | ... | ... | ... |
| 280 | *241* | *238* | *237* | *237* | *236* | ... | ... | ... | ... | ... | ... | ... | ... |
| 281 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 282 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 283 | *124* | 123 | 121 | 119 | 117 | 115 | 112 | 109 | 106 | 103 | 100 | 96.9 | 93.7 |
| 284 | *124* | 123 | 121 | 119 | 117 | 115 | 112 | 109 | 106 | 103 | 100 | 96.9 | 93.7 |
| 285 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 286 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | ... | ... | ... |
| 287 | 129 | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 109 | 108 | 107 | ... | ... |
| 288 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | **94.4** |
| 289 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 290 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 291 | *132* | *130* | *128* | *127* | *127* | *126* | *126* | *126* | 125 | 125 | 124 | 124 | 124 |
| 292 | 125 | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3 |
| 293 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 294 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 262 | 105 | **97.8** | **80.8** | **65.0** | **50.4** | **38.6** | **29.6** | **23.0** | **17.4** | **13.3** | **10.4** | **8.96** |
| 263 | 105 | **97.8** | **80.8** | **65.0** | **50.4** | **38.6** | **29.6** | **23.0** | **17.4** | **13.3** | **10.4** | **8.96** |
| 264 | 80.8 | **73.0** | **67.9** | **58.0** | **43.6** | **33.0** | **25.3** | **18.8** | **14.0** | **10.4** | **7.99** | **6.89** |
| 265 | **88.7** | **59.2** | **44.0** | **32.9** | **24.5** | **18.3** | **12.5** | **8.49** | **6.19** | **4.28** | **2.75** | **1.74** |
| 266 | **100** | **76.5** | **58.7** | **46.0** | **36.8** | **28.7** | **23.0** | **18.4** | **14.5** | **11.5** | **9.02** | **6.83** |
| 267 | **100** | **76.5** | **58.7** | **46.0** | **36.8** | **28.7** | **23.0** | **18.4** | **14.5** | **11.5** | **9.02** | **6.83** |
| 268 | **97.6** | **75.9** | **57.2** | **40.2** | **30.3** | **23.2** | **16.2** | **11.4** | **8.97** | **7.08** | **5.89** | **5.52** |
| 269 | 125 | **112** | **90.6** | **69.6** | **53.8** | **41.4** | **31.8** | **24.0** | **18.8** | **14.6** | **10.9** | **8.96** |
| 270 | 125 | **112** | **90.6** | **69.6** | **53.8** | **41.4** | **31.8** | **24.0** | **18.8** | **14.6** | **10.9** | **8.96** |
| 271 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 272 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 273 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 274 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 275 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 276 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 277 | *179* | *174* | 132 | 83.6 | 56.1 | ... | ... | ... | ... | ... | ... | ... |
| 278 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 279 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 280 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 281 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 282 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 283 | **68.1** | **53.5** | **42.1** | **33.2** | **25.9** | **20.3** | **16.5** | **13.2** | **10.1** | **7.35** | **5.89** | **5.52** |
| 284 | **73.2** | **64.4** | **56.5** | **49.0** | **41.0** | **33.5** | **25.4** | **18.3** | **12.8** | **9.01** | **6.59** | **5.52** |
| 285 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 286 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 287 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 288 | **75.3** | **60.4** | **49.0** | **40.1** | **32.8** | **27.2** | **23.4** | **19.6** | **16.8** | **14.7** | **12.8** | **11.7** |
| 289 | **68.1** | **53.5** | **42.1** | **33.2** | **25.9** | **20.3** | **16.5** | **13.2** | **10.1** | **7.35** | **5.89** | **5.52** |
| 290 | **68.1** | **53.5** | **42.1** | **33.2** | **25.9** | **20.3** | **16.5** | **13.2** | **10.1** | **7.35** | **5.89** | **5.52** |
| 291 | **98.3** | **77.2** | **57.7** | **39.9** | **30.0** | **23.2** | **16.3** | **11.2** | **8.93** | **7.08** | **5.77** | **5.32** |
| 292 | 95.5 | **75.9** | **57.2** | **40.2** | **30.3** | **23.2** | **16.2** | **11.4** | **8.97** | **7.08** | **5.89** | **5.52** |
| 293 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 294 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 295 | 18Cr–8Ni | Castings | A351 | CF3A | J92500 | ... | ... | 8 |
| 296 | 18Cr–8Ni | Castings | A351 | CF8A | J92600 | ... | ... | 8 |
| 297 | 25Cr–8Ni–N | Castings | A351 | CE20N | J92802 | ... | ... | 8 |
| 298 | 12Cr | Castings | A217 | CA15 | J91150 | ... | ... | 6 |
| 299 | 24Cr–10Ni–4Mo–N | Castings | A995 | 2A | J93345 | ... | ... | 10H |
| 300 | 25Cr–8Ni–3Mo–W–Cu–N | Castings | A995 | 6A | J93380 | ... | ... | 10H |
| 301 | 13Cr–4Ni | Castings | A487 | CA6NM | J91540 | ... | ... | 6 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 295 | (9)(56) | −254 | 531 | 241 | 371 | 161 | 161 | 161 | *160* | *156* | *153* | 151 |
| 296 | (9)(26)(56) | −254 | 531 | 241 | 371 | 161 | 161 | 161 | *160* | *156* | *153* | 151 |
| 297 | (35)(39) | −198 | 552 | 276 | 482 | 184 | 184 | 184 | 184 | 184 | 184 | 184 |
| 298 | (35) | −29 | 621 | 448 | 649 | *207* | *207* | *207* | *205* | *203* | *201* | *199* |
| 299 | (9) | −51 | 655 | 448 | 316 | *218* | *218* | *216* | *208* | *201* | *197* | *195* |
| 300 | (9)(25) | −51 | 689 | 448 | 316 | *230* | *230* | *227* | *221* | *216* | *212* | *209* |
| 301 | (9)(35) | −29 | 758 | 552 | 371 | *253* | *253* | *253* | *251* | *248* | *245* | *244* |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 295 | 146 | 142 | 138 | 135 | 132 | 130 | 127 | ... | ... | ... | ... | ... | ... |
| 296 | 146 | 142 | 138 | 135 | 132 | 130 | 127 | ... | ... | ... | ... | ... | ... |
| 297 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | ... |
| 298 | *198* | *197* | *195* | *193* | *190* | *187* | *182* | **120** | **116** | **105** | **82.1** | **59.9** | **41.8** |
| 299 | *194* | *194* | *194* | *194* | *194* | ... | ... | ... | ... | ... | ... | ... | ... |
| 300 | *207* | *206* | *205* | *204* | *204* | ... | ... | ... | ... | ... | ... | ... | ... |
| 301 | *242* | *240* | *238* | *236* | *232* | *228* | *224* | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 295 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 296 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 297 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 298 | **28.7** | **20.1** | **14.3** | **9.77** | **6.89** | ... | ... | ... | ... | ... | ... | ... |
| 299 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 300 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 301 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5)(7) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 99.95Cu–P | Pipe | B42 | C10200 | O61 | ... | 31 | ... | −269 | 207 | 62 |
| 2 | 99.9Cu–P | Pipe | B42 | C12000 | O61 | ... | 31 | ... | −269 | 207 | 62 |
| 3 | 99.9Cu–P | Pipe | B42 | C12200 | O61 | ... | 31 | ... | −269 | 207 | 62 |
| 4 | 99.95Cu–P | Tube | B75 | C10200 | O50 | ... | 31 | ... | −269 | 207 | 62 |
| 5 | 99.95Cu–P | Tube | B75 | C10200 | O60 | ... | 31 | ... | −269 | 207 | 62 |
| 6 | 99.9Cu–P | Tube | B75 | C12000 | O50 | ... | 31 | ... | −269 | 207 | 62 |
| 7 | 99.9Cu–P | Tube | B75 | C12000 | O60 | ... | 31 | ... | −269 | 207 | 62 |
| 8 | 99.9Cu–P | Tube | B75 | C12200 | O50 | ... | 31 | ... | −269 | 207 | 62 |
| 9 | 99.9Cu–P | Tube | B75 | C12200 | O60 | ... | 31 | ... | −269 | 207 | 62 |
| 10 | 99.9Cu–P | Tube | B68 | C12200 | O50 | ... | 31 | (24) | −269 | 207 | 62 |
| 11 | 99.9Cu–P | Tube | B68 | C12200 | O60 | ... | 31 | (24) | −269 | 207 | 62 |
| 12 | 99.9Cu–P | Tube | B88 | C12200 | O50 | ... | 31 | (24) | −269 | 207 | 62 |
| 13 | 99.9Cu–P | Tube | B88 | C12200 | O60 | ... | 31 | (24) | −269 | 207 | 62 |
| 14 | 99.9Cu–P | Tube | B280 | C12200 | O60 | ... | 31 | (24) | −269 | 207 | 62 |
| 15 | 85Cu–15Zn | Pipe | B43 | C23000 | O61 | ... | 32 | ... | −269 | 276 | 83 |
| 16 | 90Cu–10Ni | Pipe & tube | B467 | C70600 | WO50 | >114 O.D. | 34 | (14) | −269 | 262 | 90 |
| 17 | 90Cu–10Ni | Pipe & tube | B467 | C70600 | WO61 | >114 O.D. | 34 | (14) | −269 | 262 | 90 |
| 18 | 90Cu–10Ni | Pipe & tube | B466 | C70600 | Annealed | ... | 34 | (14) | −269 | 262 | 90 |
| 19 | 90Cu–10Ni | Pipe & tube | B467 | C70600 | WO50 | ≤114 O.D. | 34 | (14) | −269 | 276 | 103 |
| 20 | 90Cu–10Ni | Pipe & tube | B467 | C70600 | WO61 | ≤114 O.D. | 34 | (14) | −269 | 276 | 103 |
| 21 | 70Cu–30Ni | Pipe & tube | B467 | C71500 | WO50 | >114 O.D. | 34 | (14) | −269 | 310 | 103 |
| 22 | 70Cu–30Ni | Pipe & tube | B467 | C71500 | WO61 | >114 O.D. | 34 | (14) | −269 | 310 | 103 |
| 23 | 80Cu–20Ni | Pipe & tube | B466 | C71000 | Annealed | ≤114 O.D. | 34 | (14) | −269 | 310 | 110 |
| 24 | 99.95Cu–P | Pipe | B42 | C10200 | H55 | DN 64 thru 300 | 31 | (14)(34) | −269 | 248 | 207 |
| 25 | 99.9Cu–P | Pipe | B42 | C12000 | H55 | DN 64 thru 300 | 31 | (14)(34) | −269 | 248 | 207 |
| 26 | 99.9Cu–P | Pipe | B42 | C12200 | H55 | DN 64 thru 300 | 31 | (14)(34) | −269 | 248 | 207 |
| 27 | 99.95Cu–P | Tube | B75 | C10200 | H58 | ... | 31 | (14)(34) | −269 | 248 | 207 |
| 28 | 99.9Cu–P | Tube | B75 | C12000 | H58 | ... | 31 | (14)(34) | −269 | 248 | 207 |
| 29 | 99.9Cu–P | Tube | B75 | C12200 | H58 | ... | 31 | (14)(34) | −269 | 248 | 207 |
| 30 | 99.9Cu–P | Tube | B88 | C12200 | H58 | ... | 31 | (14)(24)(34) | −269 | 248 | 207 |
| 31 | 70Cu–30Ni | Pipe & tube | B466 | C71500 | O60 | ... | 34 | (14) | −269 | 359 | 124 |
| 32 | 70Cu–30Ni | Pipe & tube | B467 | C71500 | WO50 | ≤114 O.D. | 34 | (14) | −269 | 345 | 138 |
| 33 | 70Cu–30Ni | Pipe & tube | B467 | C71500 | WO61 | ≤114 O.D. | 34 | (14) | −269 | 345 | 138 |
| 34 | 99.95Cu–P | Pipe | B42 | C10200 | H80 | DN 6 thru 50 | 31 | (14)(34) | −269 | 310 | 276 |
| 35 | 99.9Cu–P | Pipe | B42 | C12000 | H80 | DN 6 thru 50 | 31 | (14)(34) | −269 | 310 | 276 |
| 36 | 99.9Cu–P | Pipe | B42 | C12200 | H80 | DN 6 thru 50 | 31 | (14)(34) | −269 | 310 | 276 |
| 37 | 99.95Cu–P | Tube | B75 | C10200 | H80 | ... | 31 | (14)(34) | −269 | 310 | 276 |
| 38 | 99.9Cu–P | Tube | B75 | C12000 | H80 | ... | 31 | (14)(34) | −269 | 310 | 276 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Max. Use Temp., °C | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 2 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 3 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 4 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 5 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 6 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 7 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 8 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 9 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 10 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 11 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 12 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 13 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 14 | 260 | 41.4 | 34.9 | 33.5 | 32.9 | 32.2 | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 15 | 232 | 55.2 | 54.7 | 54.7 | 54.7 | 54.7 | 54.7 | **36.4** | **17.5** | **13.8** | ... | ... | ... | ... | ... |
| 16 | 316 | 59.8 | 58.0 | 56.1 | 54.9 | 53.8 | 52.9 | 52.0 | 51.2 | 50.4 | 49.7 | **45.1** | **39.3** | ... | ... |
| 17 | 316 | 59.8 | 58.0 | 56.1 | 54.9 | 53.8 | 52.9 | 52.0 | 51.2 | 50.4 | 49.7 | **45.1** | **39.3** | ... | ... |
| 18 | 316 | 59.8 | 58.0 | 56.1 | 54.9 | 53.8 | 52.9 | 52.0 | 51.2 | 50.4 | 49.7 | **45.1** | **39.3** | ... | ... |
| 19 | 316 | 68.9 | 67.0 | 65.1 | 63.7 | 62.4 | 61.1 | 60.0 | 59.1 | 58.3 | **51.3** | **45.1** | **39.3** | ... | ... |
| 20 | 316 | 68.9 | 67.0 | 65.1 | 63.7 | 62.4 | 61.1 | 60.0 | 59.1 | 58.3 | **51.3** | **45.1** | **39.3** | ... | ... |
| 21 | 371 | 68.9 | 66.6 | 64.6 | 63.2 | 61.9 | 60.7 | 59.5 | 58.4 | 57.4 | **56.2** | **55.5** | **54.9** | **54.3** | **53.8** |
| 22 | 371 | 68.9 | 66.6 | 64.6 | 63.2 | 61.9 | 60.7 | 59.5 | 58.4 | 57.4 | **56.2** | **55.5** | **54.9** | **54.3** | **53.8** |
| 23 | 371 | 73.5 | 72.8 | 72.1 | 71.4 | 70.6 | 69.6 | 68.3 | 66.6 | 64.7 | 62.4 | 60.0 | **56.2** | **51.9** | **48.3** |
| 24 | 204 | *82.7* | *80.0* | *74.1* | *71.3* | *69.2* | *67.4* | *65.7* | *65.3* | ... | ... | ... | ... | ... | ... |
| 25 | 204 | *82.7* | *80.0* | *74.1* | *71.3* | *69.2* | *67.4* | *65.7* | *65.3* | ... | ... | ... | ... | ... | ... |
| 26 | 204 | *82.7* | *80.0* | *74.1* | *71.3* | *69.2* | *67.4* | *65.7* | *65.3* | ... | ... | ... | ... | ... | ... |
| 27 | 204 | *82.7* | *80.0* | *74.1* | *71.3* | *69.2* | *67.4* | *65.7* | *65.3* | ... | ... | ... | ... | ... | ... |
| 28 | 204 | *82.7* | *80.0* | *74.1* | *71.3* | *69.2* | *67.4* | *65.7* | *65.3* | ... | ... | ... | ... | ... | ... |
| 29 | 204 | *82.7* | *80.0* | *74.1* | *71.3* | *69.2* | *67.4* | *65.7* | *65.3* | ... | ... | ... | ... | ... | ... |
| 30 | 204 | *82.7* | *80.0* | *74.1* | *71.3* | *69.2* | *67.4* | *65.7* | *65.3* | ... | ... | ... | ... | ... | ... |
| 31 | 371 | 82.7 | 79.8 | 77.5 | 75.9 | 74.3 | 72.9 | 71.5 | 70.2 | 68.9 | 67.8 | 66.8 | 65.9 | 65.3 | 64.8 |
| 32 | 371 | 91.9 | 88.7 | 86.1 | 84.3 | 82.6 | 81.0 | 79.4 | 78.0 | 76.6 | 75.3 | 74.2 | 73.2 | 72.5 | 71.7 |
| 33 | 371 | 91.9 | 88.7 | 86.1 | 84.3 | 82.6 | 81.0 | 79.4 | 78.0 | 76.6 | 75.3 | 74.2 | 73.2 | 72.5 | 71.7 |
| 34 | 204 | *103* | *100* | *92.6* | *89.1* | *86.5* | *84.3* | **35.8** | **29.6** | ... | ... | ... | ... | ... | ... |
| 35 | 204 | *103* | *100* | *92.6* | *89.1* | *86.5* | *84.3* | **35.8** | **29.6** | ... | ... | ... | ... | ... | ... |
| 36 | 204 | *103* | *100* | *92.6* | *89.1* | *86.5* | *84.3* | **35.8** | **29.6** | ... | ... | ... | ... | ... | ... |
| 37 | 204 | *103* | *100* | *92.6* | *89.1* | *86.5* | *84.3* | **35.8** | **29.6** | ... | ... | ... | ... | ... | ... |
| 38 | 204 | *103* | *100* | *92.6* | *89.1* | *86.5* | *84.3* | **35.8** | **29.6** | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5)(7) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 39 | 99.9Cu–P | Tube | B75 | C12200 | H80 | ... | 31 | (14)(34) | −269 | 310 | 276 |
| 40 | 99.95Cu–P | Plate & sheet | B152 | C10200 | O25 | ... | 31 | (14)(24) | −269 | 207 | 69 |
| 41 | 99.95Cu–Ag | Plate & sheet | B152 | C10400 | O25 | ... | 31 | (14)(24) | −269 | 207 | 69 |
| 42 | 99.95Cu–Ag | Plate & sheet | B152 | C10500 | O25 | ... | 31 | (14)(24) | −269 | 207 | 69 |
| 43 | 99.95Cu–Ag | Plate & sheet | B152 | C10700 | O25 | ... | 31 | (14)(24) | −269 | 207 | 69 |
| 44 | 99.9Cu–P | Plate & sheet | B152 | C12200 | O25 | ... | 31 | (14)(24) | −269 | 207 | 69 |
| 45 | 99.9Cu–P | Plate & sheet | B152 | C12300 | O25 | ... | 31 | (14)(24) | −269 | 207 | 69 |
| 46 | 90Cu–10Ni | Plate & sheet | B171 | C70600 | ... | ≤64 thk. | 34 | (14) | −269 | 276 | 103 |
| 47 | 97Cu–3Si | Plate & sheet | B96 | C65500 | O61 | ... | 33 | ... | −269 | 345 | 124 |
| 48 | 70Cu–30Ni | Plate & sheet | B171 | C71500 | ... | ≤64 thk. | 34 | (14) | −269 | 345 | 138 |
| 49 | 90Cu–7Al–3Fe | Plate & sheet | B169 | C61400 | O25 | ≤50 thk. | 35 | (13) | −269 | 483 | 207 |
| 50 | 90Cu–7Al–3Fe | Plate & sheet | B169 | C61400 | O60 | ≤50 thk. | 35 | (13) | −269 | 483 | 207 |
| 51 | 99.9Cu | Forgings | B283 | C11000 | ... | ... | 31 | (14) | −269 | 228 | 76 |
| 52 | 97Cu–3Si | Forgings | B283 | C65500 | ... | ... | 33 | (14) | −269 | 359 | 124 |
| 53 | 60Cu–38Zn–2Pb | Forgings | B283 | C37700 | ... | ... | a | (14) | −198 | 400 | 159 |
| 54 | 60Cu–37Zn–2Pb–Sn | Forgings | B283 | C48500 | ... | ... | a | (14) | −198 | 427 | 165 |
| 55 | 60Cu–39Zn–Sn | Forgings | B283 | C46400 | ... | ... | 32 | (14) | −254 | 441 | 179 |
| 56 | 59Cu–39Zn–Fe–Sn | Forgings | B283 | C67500 | ... | ... | 32 | (14) | −198 | 496 | 234 |
| 57 | 85Cu–5Sn–5Zn–5Pb | Castings | B62 | C83600 | ... | ... | a | (9) | −198 | 207 | 97 |
| 58 | 57Cu–20Zn–12Ni–9Pb–2Sn | Castings | B584 | C97300 | ... | ... | a | ... | −198 | 207 | 103 |
| 59 | 64Cu–20Ni–8Zn–4Sn–4Pb | Castings | B584 | C97600 | ... | ... | a | ... | −198 | 276 | 117 |
| 60 | 87Cu–8Sn–4Zn–1Pb | Castings | B584 | C92300 | ... | ... | a | ... | −198 | 248 | 110 |
| 61 | 88Cu–Sn–Zn–Pb | Castings | B584 | C92200 | ... | ... | a | ... | −198 | 234 | 110 |
| 62 | 88Cu–Sn–Zn–Pb | Castings | B61 | C92200 | ... | ... | a | (9) | −198 | 234 | 110 |
| 63 | 88Cu–8Sn–4Zn | Castings | B584 | C90300 | ... | ... | b | ... | −198 | 276 | 124 |
| 64 | 88Cu–10Sn–2Zn | Castings | B584 | C90500 | ... | ... | b | ... | −198 | 276 | 124 |
| 65 | 58Cu–38Zn–1Sn–1Pb–1Fe | Castings | B584 | C86400 | ... | ... | a | (9) | −198 | 414 | 138 |
| 66 | 66Cu–25Ni–5Sn–2Pb–2Zn | Castings | B584 | C97800 | ... | ... | a | ... | −198 | 345 | 152 |
| 67 | 58Cu–39Zn–1Fe–1Al–1Mn | Castings | B584 | C86500 | ... | ... | b | ... | −198 | 448 | 172 |
| 68 | 88Cu–9Al–3Fe | Castings | B148 | C95200 | ... | ... | 35 | (9) | −254 | 448 | 172 |
| 69 | 89Cu–10Al–1Fe | Castings | B148 | C95300 | ... | ... | 35 | (9) | −254 | 448 | 172 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Max. Use Temp., °C | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39 | 204 | *103* | *100* | *92.6* | *89.1* | *86.5* | *84.3* | **35.8** | **29.6** | ... | ... | ... | ... | ... | ... |
| 40 | 260 | 46.0 | 39.1 | 37.1 | 36.5 | **34.2** | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 41 | 260 | 46.0 | 39.1 | 37.1 | 36.5 | **34.2** | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 42 | 260 | 46.0 | 39.1 | 37.1 | 36.5 | **34.2** | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 43 | 260 | 46.0 | 39.1 | 37.1 | 36.5 | **34.2** | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 44 | 260 | 46.0 | 39.1 | 37.1 | 36.5 | **34.2** | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 45 | 260 | 46.0 | 39.1 | 37.1 | 36.5 | **34.2** | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 46 | 316 | 68.9 | 67.0 | 65.1 | 63.7 | 62.4 | 61.1 | 60.0 | 59.1 | 58.3 | **51.3** | **45.1** | **39.3** | ... | ... |
| 47 | 204 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | **75.4** | **50.8** | **31.9** | ... | ... | ... | ... | ... | ... |
| 48 | 371 | 91.9 | 88.7 | 86.1 | 84.3 | 82.6 | 81.0 | 79.4 | 78.0 | 76.6 | 75.3 | 74.2 | 73.2 | 72.5 | 71.7 |
| 49 | 260 | 138 | 137 | 136 | 135 | 135 | 134 | 133 | 131 | 130 | 130 | ... | ... | ... | ... |
| 50 | 260 | 138 | 137 | 136 | 135 | 135 | 134 | 133 | 131 | 130 | 130 | ... | ... | ... | ... |
| 51 | 260 | 50.6 | 42.8 | 40.8 | 40.2 | **34.2** | **28.0** | **21.7** | **16.7** | **12.9** | **11.6** | ... | ... | ... | ... |
| 52 | 204 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | **75.4** | **50.8** | **31.9** | ... | ... | ... | ... | ... | ... |
| 53 | 204 | 106 | 99.8 | 94.5 | 91.1 | **71.4** | **52.8** | **17.0** | **13.8** | ... | ... | ... | ... | ... | ... |
| 54 | 204 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | ... | ... | ... | ... | ... | ... |
| 55 | 204 | 120 | 120 | 120 | 120 | *118* | *118* | **20.0** | **17.2** | ... | ... | ... | ... | ... | ... |
| 56 | 204 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | ... | ... | ... | ... | ... | ... |
| 57 | 232 | 64.4 | 64.4 | 62.6 | 59.1 | 55.7 | 53.0 | 51.2 | 50.3 | 50.1 | ... | ... | ... | ... | ... |
| 58 | 40 | 68.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 59 | 149 | 78.1 | 69.6 | 64.9 | 62.5 | 60.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 60 | 204 | 73.5 | 73.5 | 73.5 | 73.5 | 73.5 | 73.5 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |
| 61 | 204 | 73.5 | 66.4 | 65.3 | 64.6 | 63.3 | 61.5 | 59.6 | 58.1 | ... | ... | ... | ... | ... | ... |
| 62 | 288 | 73.5 | 66.4 | 65.3 | 64.6 | 63.3 | 61.5 | 59.6 | 58.1 | 57.5 | 57.5 | 57.3 | ... | ... | ... |
| 63 | 204 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | ... | ... | ... | ... | ... | ... |
| 64 | 204 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | ... | ... | ... | ... | ... | ... |
| 65 | 177 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | ... | ... | ... | ... | ... | ... | ... |
| 66 | 177 | 101 | 101 | 101 | 101 | 101 | 101 | 101 | ... | ... | ... | ... | ... | ... | ... |
| 67 | 177 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | ... | ... | ... | ... | ... | ... | ... |
| 68 | 316 | 115 | 108 | 104 | 102 | 99.8 | 98.6 | 97.8 | 97.5 | 97.4 | 97.4 | **65.9** | **43.7** | ... | ... |
| 69 | 316 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5)(7) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | 90Cu–7Al–3Si | Castings | B148 | C95600 | ... | ... | 35 | ... | −198 | 414 | 193 |
| 71 | 85Cu–11Al–4Fe | Castings | B148 | C95400 | ... | ... | 35 | ... | −198 | 517 | 207 |
| 72 | 58Cu–34Zn–2Fe–2Al–2Mn | Castings | B584 | C86700 | ... | ... | a | ... | −198 | 552 | 221 |
| 73 | 82Cu–11Al–4Fe–3Mn | Castings | B148 | C95500 | ... | ... | 35 | ... | −269 | 621 | 276 |
| 74 | 63Cu–27Zn–4Al–3Fe–3Mn | Castings | B584 | C86200 | ... | ... | b | ... | −198 | 621 | 310 |
| 75 | 61Cu–27Zn–6Al–3Fe–3Mn | Castings | B584 | C86300 | ... | ... | b | ... | −198 | 758 | 414 |
| 76 | 75Cu–21.5Zn–3Si | Rod | B371 | C69300 | H02 | ≤12 | a | ... | −198 | 585 | 310 |
| 77 | 75Cu–21.5Zn–3Si | Rod | B371 | C69300 | H02 | >12, ≤25 | a | ... | −198 | 515 | 240 |
| 78 | 75Cu–21.5Zn–3Si | Rod | B371 | C69300 | H02 | >25, ≤50 | a | ... | −198 | 480 | 205 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Max. Use Temp., °C | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 |
| 70 | 40 | 129 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 71 | 260 | 138 | 131 | 128 | 128 | 128 | 128 | 128 | 128 | **101** | **95.8** | ... | ... | ... | ... |
| 72 | 177 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | ... | ... | ... | ... | ... | ... | ... |
| 73 | 260 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | ... | ... | ... | ... |
| 74 | 177 | *207* | *207* | *207* | *207* | *207* | *207* | *207* | ... | ... | ... | ... | ... | ... | ... |
| 75 | 177 | *253* | *253* | *253* | *253* | *253* | *253* | *253* | ... | ... | ... | ... | ... | ... | ... |
| 76 | 149 | 195 | 179 | 176 | 176 | 176 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 77 | 149 | 161 | 139 | 137 | 137 | 137 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 78 | 149 | 138 | 119 | 117 | 117 | 117 | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 1 | 99.0Ni–Low C | Pipe & tube | B161 | ... | N02201 | Annealed | >125 | 41 |
| 2 | 99.0Ni–Low C | Pipe & tube | B725 | ... | N02201 | Annealed | >125 | 41 |
| 3 | 99.0Ni | Pipe & tube | B161 | ... | N02200 | Annealed | >125 | 41 |
| 4 | 99.0Ni | Pipe & tube | B725 | ... | N02200 | Annealed | >125 | 41 |
| 5 | 99.0Ni–Low C | Pipe & tube | B161 | ... | N02201 | Annealed | ≤125 | 41 |
| 6 | 99.0Ni–Low C | Pipe & tube | B725 | ... | N02201 | Annealed | ≤125 | 41 |
| 7 | 99.0Ni | Pipe & tube | B161 | ... | N02200 | Annealed | ≤125 | 41 |
| 8 | 99.0Ni | Pipe & tube | B725 | ... | N02200 | Annealed | ≤125 | 41 |
| 9 | 67Ni–30Cu | Pipe & tube | B165 | ... | N04400 | Annealed | >125 | 42 |
| 10 | 67Ni–30Cu | Pipe & tube | B725 | ... | N04400 | Annealed | >125 | 42 |
| 11 | 33Ni–42Fe–21Cr | Pipe & tube | B407 | ... | N08800 | H.F. or H.F. ann. | ... | 45 |
| 12 | 72Ni–15Cr–8Fe | Pipe & tube | B167 | ... | N06600 | H.F. or H.F. ann. | >125 | 43 |
| 13 | 33Ni–42Fe–21Cr | Pipe & tube | B407 | ... | N08810 | C.D. sol. ann. or H.F. ann. | ... | 45 |
| 14 | 33Ni–42Fe–21Cr | Pipe & tube | B514 | ... | N08810 | Annealed | ... | 45 |
| 15 | 33Ni–42Fe–21Cr–Al–Ti | Pipe & tube | B407 | ... | N08811 | C.D. sol. ann. or H.F. ann. | ... | 45 |
| 16 | 67Ni–30Cu | Pipe & tube | B165 | ... | N04400 | Annealed | ≤125 | 42 |
| 17 | 67Ni–30Cu | Pipe & tube | B725 | ... | N04400 | Annealed | ≤125 | 42 |
| 18 | 26Ni–22Cr–5Mo–Ti | Pipe & tube | B619 | ... | N08320 | Sol. ann. | ... | 45 |
| 19 | 26Ni–22Cr–5Mo–Ti | Pipe & tube | B622 | ... | N08320 | Sol. ann. | ... | 45 |
| 20 | 99.0Ni–Low C | Pipe & tube | B161 | ... | N02201 | Str. rel. | ... | 41 |
| 21 | 99.0Ni–Low C | Pipe & tube | B725 | ... | N02201 | Str. rel. | ... | 41 |
| 22 | 33Ni–42Fe–21Cr | Pipe & tube | B514 | ... | N08800 | Annealed | ... | 45 |
| 23 | 72Ni–15Cr–8Fe | Pipe & tube | B167 | ... | N06600 | H.F. or H.F. ann. | ≤125 | 43 |
| 24 | 72Ni–15Cr–8Fe | Pipe & tube | B167 | ... | N06600 | C.D. ann. | >125 | 43 |
| 25 | 33Ni–42Fe–21Cr | Pipe & tube | B407 | ... | N08800 | C.D. ann. | ... | 45 |
| 26 | 31Ni–31Fe–29Cr–Mo | Pipe & tube | B668 | ... | N08028 | Sol. ann. | ... | 45 |
| 27 | 99.0Ni | Pipe & tube | B161 | ... | N02200 | Str. rel. | ... | 41 |
| 28 | 99.0Ni | Pipe & tube | B725 | ... | N02200 | Str. rel. | ... | 41 |
| 29 | 35Ni–35Fe–20Cr–Cb | Pipe & tube | B464 | ... | N08020 | Annealed | ... | 45 |
| 30 | 35Ni–35Fe–20Cr–Cb | Pipe & tube | B474 | ... | N08020 | Annealed | ... | 45 |
| 31 | 35Ni–35Fe–20Cr–Cb | Pipe & tube | B729 | ... | N08020 | Annealed | ... | 45 |
| 32 | 42Ni–21.5Cr–3Mo–2.3Cu | Smls. tube | B163 | ... | N08825 | Annealed | ... | 45 |
| 33 | 42Ni–21.5Cr–3Mo–2.3Cu | Pipe & tube | B423 | ... | N08825 | C.D. ann. | ... | 45 |
| 34 | 42Ni–21.5Cr–3Mo–2.3Cu | Pipe & tube | B474 | ... | N08825 | Annealed | ... | 45 |
| 35 | 42Ni–21.5Cr–3Mo–2.3Cu | Wld. tube | B704 | ... | N08825 | Annealed | ... | 45 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]: Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ... | −198 | 345 | 69 | 649 | 46.0 | 44.7 | 43.9 | 43.6 | 43.3 | 43.2 | 43.2 | 43.2 | 43.2 |
| 2 | ... | −198 | 345 | 69 | 649 | 46.0 | 44.7 | 43.9 | 43.6 | 43.3 | 43.2 | 43.2 | 43.2 | 43.2 |
| 3 | ... | −198 | 379 | 83 | 316 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 |
| 4 | ... | −198 | 379 | 83 | 316 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 |
| 5 | ... | −198 | 345 | 83 | 649 | 55.2 | 53.8 | 52.8 | 52.3 | 51.9 | 51.7 | 51.6 | 51.6 | 51.6 |
| 6 | ... | −198 | 345 | 83 | 649 | 55.2 | 53.8 | 52.8 | 52.3 | 51.9 | 51.7 | 51.6 | 51.6 | 51.6 |
| 7 | ... | −198 | 379 | 103 | 316 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 8 | ... | −198 | 379 | 103 | 316 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 9 | ... | −198 | 483 | 172 | 482 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 | 90.4 |
| 10 | ... | −198 | 483 | 172 | 482 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 | 90.4 |
| 11 | ... | −198 | 448 | 172 | 816 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 12 | ... | −198 | 517 | 172 | 649 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 13 | (62) | −198 | 448 | 172 | 899 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 14 | (62) | −198 | 448 | 172 | 899 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 15 | (62) | −198 | 448 | 172 | 899 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 16 | ... | −198 | 483 | 193 | 482 | 129 | 119 | 112 | 108 | 105 | 103 | 102 | 101 | 101 |
| 17 | ... | −198 | 483 | 193 | 482 | 129 | 119 | 112 | 108 | 105 | 103 | 102 | 101 | 101 |
| 18 | ... | −198 | 517 | 193 | 427 | 129 | 129 | 129 | 129 | 129 | 129 | 129 | 129 | 129 |
| 19 | ... | −198 | 517 | 193 | 427 | 129 | 129 | 129 | 129 | 129 | 129 | 129 | 129 | 129 |
| 20 | ... | −198 | 414 | 207 | 316 | *138* | *138* | *138* | *137* | *137* | *137* | *137* | *137* | *136* |
| 21 | ... | −198 | 414 | 207 | 316 | *138* | *138* | *138* | *137* | *137* | *137* | *137* | *137* | *136* |
| 22 | ... | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 23 | ... | −198 | 552 | 207 | 649 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 24 | ... | −198 | 552 | 207 | 649 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 25 | (61) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 26 | ... | −198 | 505 | 215 | 454 | 143 | *143* | *143* | *143* | *143* | *143* | *143* | *143* | *143* |
| 27 | ... | −198 | 448 | 276 | 316 | *149* | *149* | *149* | *149* | *149* | *149* | *149* | *149* | *148* |
| 28 | ... | −198 | 448 | 276 | 316 | *149* | *149* | *149* | *149* | *149* | *149* | *149* | *149* | *148* |
| 29 | ... | −198 | 552 | 241 | 427 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 30 | ... | −198 | 552 | 241 | 427 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 31 | ... | −198 | 552 | 241 | 427 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 32 | ... | −198 | 585 | 240 | 538 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 33 | ... | −198 | 585 | 240 | 538 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 34 | ... | −198 | 585 | 240 | 538 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 35 | ... | −198 | 585 | 240 | 538 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Line No.** | **275** | **300** | **325** | **350** | **375** | **400** | **425** | **450** | **475** | **500** | **525** | **550** | **575** |
| 1 | 43.2 | 43.2 | 43.1 | 42.9 | 42.6 | 42.1 | 41.5 | 40.7 | **33.1** | **27.4** | **22.8** | **18.7** | **15.6** |
| 2 | 43.2 | 43.2 | 43.1 | 42.9 | 42.6 | 42.1 | 41.5 | 40.7 | **33.1** | **27.4** | **22.8** | **18.7** | **15.6** |
| 3 | 55.2 | 55.2 | 55.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 4 | 55.2 | 55.2 | 55.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 5 | 51.6 | 51.6 | 51.6 | 51.5 | 51.2 | 50.7 | 49.9 | **41.4** | **33.1** | **27.4** | **22.8** | **18.7** | **15.6** |
| 6 | 51.6 | 51.6 | 51.6 | 51.5 | 51.2 | 50.7 | 49.9 | **41.4** | **33.1** | **27.4** | **22.8** | **18.7** | **15.6** |
| 7 | 68.9 | 68.9 | 68.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 8 | 68.9 | 68.9 | 68.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 9 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | **79.7** | **59.9** | **55.2** | ... | ... | ... |
| 10 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | **79.7** | **59.9** | **55.2** | ... | ... | ... |
| 11 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 113 | **107** |
| 12 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | **84.8** | **58.4** | **39.7** | **27.0** |
| 13 | 115 | 115 | 113 | 110 | 108 | 106 | 104 | 102 | 100 | 98.6 | 97.1 | 95.7 | **91.8** |
| 14 | 115 | 115 | 113 | 110 | 108 | 106 | 104 | 102 | 100 | 98.6 | 97.1 | 95.7 | **91.8** |
| 15 | 115 | 115 | 113 | 110 | 108 | 106 | 104 | 102 | 100 | 98.6 | 97.1 | 95.7 | **92.5** |
| 16 | 101 | 101 | 101 | 101 | 100 | 99.6 | 98.6 | **79.7** | **59.9** | **55.2** | ... | ... | ... |
| 17 | 101 | 101 | 101 | 101 | 100 | 99.6 | 98.6 | **79.7** | **59.9** | **55.2** | ... | ... | ... |
| 18 | 129 | 129 | 127 | 125 | 122 | 121 | 119 | 119 | ... | ... | ... | ... | ... |
| 19 | 129 | 129 | 127 | 125 | 122 | 121 | 119 | 119 | ... | ... | ... | ... | ... |
| 20 | *135* | *133* | *130* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 21 | *135* | *133* | *130* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 22 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 136 | **107** |
| 23 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | **84.8** | **58.4** | **39.7** | **27.0** |
| 24 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | **84.8** | **58.4** | **39.7** | **27.0** |
| 25 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 136 | **107** |
| 26 | **140** | **137** | **133** | **130** | **125** | **122** | **119** | **116** | **113** | ... | ... | ... | ... |
| 27 | *146* | *144* | *141* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 28 | *146* | *144* | *141* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 29 | 161 | 161 | 161 | 161 | 161 | 160 | 157 | 156 | ... | ... | ... | ... | ... |
| 30 | 161 | 161 | 161 | 161 | 161 | 160 | 157 | 156 | ... | ... | ... | ... | ... |
| 31 | 161 | 161 | 161 | 161 | 161 | 160 | 157 | 156 | ... | ... | ... | ... | ... |
| 32 | 161 | 161 | 161 | 161 | 161 | 160 | 159 | 158 | 157 | 156 | 155 | 153 | ... |
| 33 | 161 | 161 | 161 | 161 | 161 | 160 | 159 | 158 | 157 | 156 | 155 | 153 | ... |
| 34 | 161 | 161 | 161 | 161 | 161 | 160 | 159 | 158 | 157 | 156 | 155 | 153 | ... |
| 35 | 161 | 161 | 161 | 161 | 161 | 160 | 159 | 158 | 157 | 156 | 155 | 153 | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 | 850 | 875 | 900 |
| 1 | 12.9 | 10.0 | 8.27 | … | … | … | … | … | … | … | … | … | … |
| 2 | 12.9 | 10.0 | 8.27 | … | … | … | … | … | … | … | … | … | … |
| 3 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 4 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 5 | 12.9 | 10.0 | 8.27 | … | … | … | … | … | … | … | … | … | … |
| 6 | 12.9 | 10.0 | 8.27 | … | … | … | … | … | … | … | … | … | … |
| 7 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 8 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 9 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 10 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 11 | 83.8 | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | … | … | … |
| 12 | 19.2 | 15.0 | 13.8 | … | … | … | … | … | … | … | … | … | … |
| 13 | 75.7 | 62.6 | 50.6 | 41.2 | 33.6 | 27.7 | 22.6 | 18.3 | 15.0 | 11.9 | 9.03 | 7.35 | 5.86 |
| 14 | 75.7 | 62.6 | 50.6 | 41.2 | 33.6 | 27.7 | 22.6 | 18.3 | 15.0 | 11.9 | 9.03 | 7.35 | 5.86 |
| 15 | 84.5 | 69.5 | 56.7 | 46.8 | 38.5 | 31.5 | 25.5 | 20.7 | 17.0 | 13.9 | 11.2 | 9.33 | 7.58 |
| 16 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 17 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 18 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 19 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 20 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 21 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 22 | 83.8 | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | … | … | … |
| 23 | 19.2 | 15.0 | 13.8 | … | … | … | … | … | … | … | … | … | … |
| 24 | 19.2 | 15.0 | 13.8 | … | … | … | … | … | … | … | … | … | … |
| 25 | 83.8 | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | … | … | … |
| 26 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 27 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 28 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 29 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 30 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 31 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 32 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 33 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 34 | … | … | … | … | … | … | … | … | … | … | … | … | … |
| 35 | … | … | … | … | … | … | … | … | … | … | … | … | … |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 36 | 42Ni–21.5Cr–3Mo–2.3Cu | Pipe & tube | B705 | ... | N08825 | Annealed | ... | 45 |
| 37 | 47Ni–22Cr–19Fe–6Mo | Pipe & tube | B619 | ... | N06007 | Sol. ann. | ... | 45 |
| 38 | 47Ni–22Cr–19Fe–6Mo | Pipe & tube | B622 | ... | N06007 | Sol. ann. | ... | 45 |
| 39 | 40Ni–29Cr–15Fe–5Mo | Pipe & tube | B619 | ... | N06030 | Sol. ann. | ... | 45 |
| 40 | 40Ni–29Cr–15Fe–5Mo | Pipe & tube | B622 | ... | N06030 | Sol. ann. | ... | 45 |
| 41 | 40Ni–29Cr–15Fe–5Mo | Pipe & tube | B626 | ... | N06030 | Sol. ann. | ... | 45 |
| 42 | 72Ni–15Cr–8Fe | Pipe & tube | B167 | ... | N06600 | C.D. ann. | ≤125 | 43 |
| 43 | 72Ni–15Cr–8Fe | Pipe & tube | B517 | ... | N06600 | C.D. ann. | ... | 43 |
| 44 | 58Ni–29Cr–9Fe | Tube | B163 | ... | N06690 | Annealed | ≤75 | 43 |
| 45 | 58Ni–29Cr–9Fe | Pipe & tube | B167 | ... | N06690 | C.D. ann. | ≤125 | 43 |
| 46 | 37Ni–33Fe–25Cr | Pipe & tube | B163 | ... | N08120 | Sol. ann. | ... | 45 |
| 47 | 37Ni–33Fe–25Cr | Pipe & tube | B407 | ... | N08120 | Sol. ann. | ... | 45 |
| 48 | 37Ni–33Fe–25Cr | Pipe & tube | B514 | ... | N08120 | Sol. ann. | ... | 45 |
| 49 | 37Ni–33Fe–25Cr | Pipe & tube | B515 | ... | N08120 | Sol. ann. | ... | 45 |
| 50 | 61Ni–16Mo–16Cr | Pipe & tube | B619 | ... | N06455 | Sol. ann. | ... | 43 |
| 51 | 47Ni–22Cr–9Mo–18Fe | Pipe & tube | B619 | ... | N06002 | Sol. ann. | ... | 43 |
| 52 | 47Ni–22Cr–9Mo–18Fe | Pipe & tube | B622 | ... | N06002 | Sol. ann. | ... | 43 |
| 53 | 31Ni–33Fe–27Cr–6.5Mo–Cu–N | Pipe & tube | B619 | ... | N08031 | Annealed | ... | 45 |
| 54 | 31Ni–33Fe–27Cr–6.5Mo–Cu–N | Pipe & tube | B622 | ... | N08031 | Annealed | ... | 45 |
| 55 | 61Ni–16Mo–16Cr | Pipe & tube | B622 | ... | N06455 | Sol. ann. | ... | 43 |
| 56 | 54Ni–16Mo–15Cr | Pipe & tube | B619 | ... | N10276 | Sol. ann. | ... | 43 |
| 57 | 54Ni–16Mo–15Cr | Pipe & tube | B622 | ... | N10276 | Sol. ann. | ... | 43 |
| 58 | 54Ni–16Mo–15Cr | Pipe & tube | B626 | ... | N10276 | Sol. ann. | ... | 43 |
| 59 | 67Ni–30Cu | Pipe & tube | B165 | ... | N04400 | Str. rel. | ... | 42 |
| 60 | 67Ni–30Cu | Pipe & tube | B725 | ... | N04400 | Str. rel. | ... | 42 |
| 61 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Pipe & tube | B675 | ... | N08367 | Annealed | >5 | 45 |
| 62 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Pipe & tube | B690 | ... | N08367 | Annealed | >5 | 45 |
| 63 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Pipe & tube | B804 | ... | N08367 | Annealed | >5 | 45 |
| 64 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Pipe & tube | B675 | ... | N08367 | Annealed | ≤5 | 45 |
| 65 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Pipe & tube | B690 | ... | N08367 | Annealed | ≤5 | 45 |
| 66 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Pipe & tube | B804 | ... | N08367 | Annealed | ≤5 | 45 |
| 67 | 55Ni–21Cr–13.5Mo | Pipe & tube | B619 | ... | N06022 | Sol. ann. | ... | 43 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | | | | | | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 |
| 36 | ... | −198 | 585 | 240 | 538 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 37 | ... | −198 | 621 | 241 | 538 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 38 | ... | −198 | 621 | 241 | 427 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 39 | ... | −198 | 586 | 241 | 427 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 157 | 154 |
| 40 | ... | −198 | 586 | 241 | 427 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 157 | 154 |
| 41 | ... | −198 | 586 | 241 | 427 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 157 | 154 |
| 42 | ... | −198 | 552 | 241 | 649 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 43 | ... | −198 | 552 | 241 | 649 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 44 | ... | −198 | 586 | 241 | 482 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| 45 | ... | −198 | 586 | 240 | 482 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| 46 | ... | −198 | 621 | 276 | 899 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 47 | ... | −198 | 621 | 276 | 899 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 48 | ... | −198 | 621 | 276 | 899 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 49 | ... | −198 | 621 | 276 | 899 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 50 | ... | −198 | 689 | 276 | 427 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 |
| 51 | ... | −198 | 689 | 276 | 816 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 178 |
| 52 | ... | −198 | 689 | 276 | 816 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 178 |
| 53 | ... | −198 | 648 | 276 | 427 | 184 | 184 | 184 | 184 | 184 | 177 | 171 | 166 | 162 |
| 54 | ... | −198 | 648 | 276 | 427 | 184 | 184 | 184 | 184 | 184 | 177 | 171 | 166 | 162 |
| 55 | ... | −198 | 689 | 276 | 427 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 |
| 56 | ... | −198 | 689 | 283 | 677 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 187 |
| 57 | ... | −198 | 689 | 283 | 677 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 187 |
| 58 | ... | −198 | 689 | 283 | 677 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 187 |
| 59 | (54) | −198 | 586 | 379 | 260 | *195* | *195* | *195* | *195* | *195* | *195* | *195* | *195* | *195* |
| 60 | (54) | −198 | 586 | 379 | 260 | *195* | *195* | *195* | *195* | *195* | *195* | *195* | *195* | *195* |
| 61 | ... | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | *206* | *202* | *198* | *195* | *192* |
| 62 | ... | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | *206* | *202* | *198* | *195* | *192* |
| 63 | ... | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | *206* | *202* | *198* | *195* | *192* |
| 64 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | *206* | *202* | *198* | *195* | *192* |
| 65 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | *206* | *202* | *198* | *195* | *192* |
| 66 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | *206* | *202* | *198* | *195* | *192* |
| 67 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 |
| 36 | 161 | 161 | 161 | 161 | 161 | 160 | 159 | 158 | 157 | 156 | 155 | 153 | ... |
| 37 | 160 | 158 | 156 | 154 | 153 | 152 | 151 | 150 | 149 | **136** | **132** | **130** | ... |
| 38 | 160 | 158 | 156 | 154 | 153 | 152 | 151 | 150 | ... | ... | ... | ... | ... |
| 39 | 151 | 148 | 146 | 143 | 141 | 138 | 136 | 136 | ... | ... | ... | ... | ... |
| 40 | 151 | 148 | 146 | 143 | 141 | 138 | 136 | 136 | ... | ... | ... | ... | ... |
| 41 | 151 | 148 | 146 | 143 | 141 | 138 | 136 | 136 | ... | ... | ... | ... | ... |
| 42 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | **84.8** | **58.4** | **39.7** | **27.0** |
| 43 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | **84.8** | **58.4** | **39.7** | **27.0** |
| 44 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | ... | ... | ... |
| 45 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | ... | ... | ... |
| 46 | 170 | 166 | 163 | 160 | 158 | 156 | 154 | 153 | 153 | 152 | 151 | 151 | 151 |
| 47 | 170 | 166 | 163 | 160 | 158 | 156 | 154 | 153 | 153 | 152 | 151 | 151 | 151 |
| 48 | 170 | 166 | 163 | 160 | 158 | 156 | 154 | 153 | 153 | 152 | 151 | 151 | 151 |
| 49 | 170 | 166 | 163 | 160 | 158 | 156 | 154 | 153 | 153 | 152 | 151 | 151 | 151 |
| 50 | 184 | 184 | 184 | 184 | 183 | 180 | 178 | 178 | ... | ... | ... | ... | ... |
| 51 | 173 | 169 | 165 | 162 | 160 | 158 | 157 | 155 | 154 | **135** | **134** | **133** | **129** |
| 52 | 173 | 169 | 165 | 162 | 160 | 158 | 157 | 155 | 154 | **135** | **134** | **133** | **129** |
| 53 | 158 | 155 | 152 | 149 | **74.2** | **61.1** | **50.3** | **49.6** | ... | ... | ... | ... | ... |
| 54 | 158 | 155 | 152 | 149 | **74.2** | **61.1** | **50.3** | **49.6** | ... | ... | ... | ... | ... |
| 55 | 184 | 184 | 184 | 184 | 182 | 180 | 178 | 178 | ... | ... | ... | ... | ... |
| 56 | 183 | 177 | 172 | 169 | 165 | 162 | 159 | 157 | 156 | 155 | 154 | **143** | **118** |
| 57 | 183 | 177 | 172 | 169 | 165 | 162 | 159 | 157 | 156 | 155 | 154 | **143** | **118** |
| 58 | 183 | 177 | 172 | 169 | 165 | 162 | 159 | 157 | 156 | 155 | 154 | **143** | **118** |
| 59 | *195* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 60 | *195* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 61 | 188 | 183 | 179 | 176 | 173 | 170 | 168 | 167 | ... | ... | ... | ... | ... |
| 62 | 188 | 183 | 179 | 176 | 173 | 170 | 168 | 167 | ... | ... | ... | ... | ... |
| 63 | 188 | 183 | 179 | 176 | 173 | 170 | 168 | 167 | ... | ... | ... | ... | ... |
| 64 | 188 | 183 | 179 | 176 | 173 | 170 | 168 | 167 | ... | ... | ... | ... | ... |
| 65 | 188 | 183 | 179 | 176 | 173 | 170 | 168 | 167 | ... | ... | ... | ... | ... |
| 66 | 188 | 183 | 179 | 176 | 173 | 170 | 168 | 167 | ... | ... | ... | ... | ... |
| 67 | 197 | 193 | 189 | 185 | 182 | 180 | 177 | 177 | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 | 850 | 875 | 900 |
| 36 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 37 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 38 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 39 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 40 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 41 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 42 | 19.2 | 15.0 | 13.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 43 | 19.2 | 15.0 | 13.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 44 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 45 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 46 | 117 | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8 |
| 47 | 117 | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8 |
| 48 | 117 | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8 |
| 49 | 117 | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8 |
| 50 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 51 | 115 | 94.2 | 77.3 | 64.9 | 54.7 | 44.7 | 36.1 | 29.2 | 23.6 | 20.7 | ... | ... | ... |
| 52 | 115 | 94.2 | 77.3 | 64.9 | 54.7 | 44.7 | 36.1 | 29.2 | 23.6 | 20.7 | ... | ... | ... |
| 53 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 54 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 55 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 56 | 99.1 | 81.6 | 67.0 | 54.6 | 42.2 | ... | ... | ... | ... | ... | ... | ... | ... |
| 57 | 99.1 | 81.6 | 67.0 | 54.6 | 42.2 | ... | ... | ... | ... | ... | ... | ... | ... |
| 58 | 99.1 | 81.6 | 67.0 | 54.6 | 42.2 | ... | ... | ... | ... | ... | ... | ... | ... |
| 59 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 60 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 61 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 62 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 63 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 64 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 65 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 66 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 67 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 68 | 55Ni–21Cr–13.5Mo | Pipe & tube | B622 | ... | N06022 | Sol. ann. | ... | 43 |
| 69 | 58Ni–33Cr–8Mo | Pipe & tube | B619 | ... | N06035 | Sol. ann. | ... | 43 |
| 70 | 58Ni–33Cr–8Mo | Pipe & tube | B622 | ... | N06035 | Sol. ann. | ... | 43 |
| 71 | 58Ni–33Cr–8Mo | Pipe & tube | B626 | ... | N06035 | Sol. ann. | ... | 43 |
| 72 | 59Ni–23Cr–16Mo | Pipe & tube | B619 | ... | N06059 | Sol. ann. | ... | 43 |
| 73 | 59Ni–23Cr–16Mo | Pipe & tube | B622 | ... | N06059 | Sol. ann. | ... | 43 |
| 74 | 59Ni–23Cr–16Mo–1.6Cu | Pipe & tube | B619 | ... | N06200 | Sol. ann. | All | 43 |
| 75 | 59Ni–23Cr–16Mo–1.6Cu | Pipe & tube | B622 | ... | N06200 | Sol. ann. | All | 43 |
| 76 | 59Ni–23Cr–16Mo–1.6Cu | Pipe & tube | B626 | ... | N06200 | Sol. ann. | All | 43 |
| 77 | 62Ni–22Mo–15Cr | Pipe & tube | B619 | ... | N10362 | Sol. ann. | All | 43 |
| 78 | 62Ni–22Mo–15Cr | Pipe & tube | B622 | ... | N10362 | Sol. ann. | All | 43 |
| 79 | 62Ni–22Mo–15Cr | Pipe & tube | B626 | ... | N10362 | Sol. ann. | All | 43 |
| 80 | 62Ni–28Mo–5Fe | Pipe & tube | B619 | ... | N10001 | Sol. ann. | ... | 44 |
| 81 | 62Ni–28Mo–5Fe | Pipe & tube | B622 | ... | N10001 | Sol. ann. | ... | 44 |
| 82 | 65Ni–28Mo–2Fe | Pipe & tube | B619 | ... | N10665 | Sol. ann. | ... | 44 |
| 83 | 65Ni–28Mo–2Fe | Pipe & tube | B622 | ... | N10665 | Sol. ann. | ... | 44 |
| 84 | 65Ni–29.5Mo–2Fe–2Cr | Pipe & tube | B619 | ... | N10675 | Sol. ann. | ... | 44 |
| 85 | 65Ni–29.5Mo–2Fe–2Cr | Pipe & tube | B622 | ... | N10675 | Sol. ann. | ... | 44 |
| 86 | 65Ni–29.5Mo–2Fe–2Cr | Pipe & tube | B626 | ... | N10675 | Sol. ann. | ... | 44 |
| 87 | 60Ni–22Cr–9Mo–3.5Cb | Pipe & tube | B444 | 1 | N06625 | Annealed | ... | 43 |
| 88 | 60Ni–22Cr–9Mo–3.5Cb | Pipe & tube | B705 | 1 | N06625 | Annealed | ... | 43 |
| 89 | 57Ni–22Cr–14W–2Mo–La | Pipe & tube | B619 | ... | N06230 | Sol. ann. | ... | 43 |
| 90 | 57Ni–22Cr–14W–2Mo–La | Pipe & tube | B622 | ... | N06230 | Sol. ann. | ... | 43 |
| 91 | 57Ni–22Cr–14W–2Mo–La | Pipe & tube | B626 | ... | N06230 | Sol. ann. | ... | 43 |
| 92 | 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | Pipe | B619 | ... | R20033 | Sol. ann. | ... | 45 |
| 93 | 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | Pipe & tube | B622 | ... | R20033 | Sol. ann. | ... | 45 |
| 94 | 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | Tube | B626 | ... | R20033 | Sol. ann. | ... | 45 |
| 95 | 99.0Ni–Low C | Plate | B162 | ... | N02201 | H.R. ann. | ... | 41 |
| 96 | 99.0Ni–Low C | Plate | B162 | ... | N02201 | H.R. as R. | ... | 41 |
| 97 | 99.0Ni | Plate | B162 | ... | N02200 | H.R. ann. | ... | 41 |
| 98 | 99.0Ni | Plate | B162 | ... | N02200 | H.R. as R. | ... | 41 |
| 99 | 33Ni–42Fe–21Cr | Pl. & sht. | B409 | ... | N08810 | Annealed | All | 45 |
| 100 | 33Ni–42Fe–21Cr–Al–Ti | Pl. & sht. | B409 | ... | N08811 | Annealed | All | 45 |
| 101 | 26Ni–22Cr–5Mo–Ti | Pl. & sht. | B620 | ... | N08320 | Sol. ann. | All | 45 |
| 102 | 67Ni–30Cu | Plate | B127 | ... | N04400 | H.R. ann. | ... | 42 |
| 103 | 47Ni–22Cr–19Fe–6Mo | Pl. & sht. | B582 | ... | N06007 | Sol. ann. | >19 | 45 |
| 104 | 33Ni–42Fe–21Cr | Pl. & sht. | B409 | ... | N08800 | Annealed | All | 45 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | | | | | | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 |
| 68 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 |
| 69 | ... | −198 | 586 | 241 | 427 | 161 | 161 | 161 | *161* | *161* | *161* | **154** | **149** | **144** |
| 70 | ... | −198 | 586 | 241 | 427 | 161 | 161 | 161 | *161* | *161* | *161* | **154** | **149** | **144** |
| 71 | ... | −198 | 586 | 241 | 427 | 161 | 161 | 161 | *161* | *161* | *161* | **154** | **149** | **144** |
| 72 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 206 |
| 73 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 206 |
| 74 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | **207** | **200** |
| 75 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | **207** | **200** |
| 76 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | **207** | **200** |
| 77 | ... | −198 | 725 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 | 199 |
| 78 | ... | −198 | 725 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 | 199 |
| 79 | ... | −198 | 725 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 | 199 |
| 80 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 81 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 82 | ... | −198 | 758 | 352 | 427 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 |
| 83 | ... | −198 | 758 | 352 | 427 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 |
| 84 | ... | −198 | 758 | 352 | 427 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 |
| 85 | ... | −198 | 758 | 352 | 427 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 |
| 86 | ... | −198 | 758 | 352 | 427 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 |
| 87 | (64)(70) | −198 | 827 | 414 | 649 | 276 | 276 | 276 | *274* | *273* | *272* | *270* | *269* | *267* |
| 88 | (64)(70) | −198 | 827 | 414 | 649 | 276 | 276 | 276 | *274* | *273* | *272* | *270* | *269* | *267* |
| 89 | ... | −198 | 758 | 310 | 899 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 90 | ... | −198 | 758 | 310 | 899 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 91 | ... | −198 | 758 | 310 | 899 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 92 | ... | −198 | 750 | 380 | 427 | 250 | 231 | 209 | 200 | 193 | 187 | 181 | 176 | 172 |
| 93 | ... | −198 | 750 | 380 | 427 | 250 | 231 | 209 | 200 | 193 | 187 | 181 | 176 | 172 |
| 94 | ... | −198 | 750 | 380 | 427 | 250 | 231 | 209 | 200 | 193 | 187 | 181 | 176 | 172 |
| 95 | ... | −198 | 345 | 83 | 649 | 55.2 | 53.8 | 52.8 | 52.3 | 51.9 | 51.7 | 51.6 | 51.6 | 51.6 |
| 96 | ... | −198 | 345 | 83 | 649 | 55.2 | 53.8 | 52.8 | 52.3 | 51.9 | 51.7 | 51.6 | 51.6 | 51.6 |
| 97 | ... | −198 | 379 | 103 | 316 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 98 | ... | −198 | 379 | 138 | 316 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 |
| 99 | ... | −198 | 448 | 172 | 899 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 100 | ... | −198 | 448 | 172 | 899 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 101 | ... | −198 | 517 | 193 | 427 | 129 | 129 | 129 | 129 | 129 | 129 | 129 | 129 | 129 |
| 102 | ... | −198 | 483 | 193 | 482 | 129 | 119 | 112 | 108 | 105 | 103 | 102 | 101 | 101 |
| 103 | ... | −198 | 586 | 207 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 104 | ... | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **275** | **300** | **325** | **350** | **375** | **400** | **425** | **450** | **475** | **500** | **525** | **550** | **575** |
| 68 | 197 | 193 | 189 | 185 | 182 | 180 | 177 | 177 | ... | ... | ... | ... | ... |
| 69 | **140** | **137** | **135** | **133** | **132** | **131** | **129** | **128** | ... | ... | ... | ... | ... |
| 70 | **140** | **137** | **135** | **133** | **132** | **131** | **129** | **128** | ... | ... | ... | ... | ... |
| 71 | **140** | **137** | **135** | **133** | **132** | **131** | **129** | **128** | ... | ... | ... | ... | ... |
| 72 | 202 | 197 | 192 | 188 | 184 | 180 | 176 | 176 | ... | ... | ... | ... | ... |
| 73 | 202 | 197 | 192 | 188 | 184 | 180 | 176 | 176 | ... | ... | ... | ... | ... |
| 74 | **194** | **188** | **184** | **180** | **177** | **175** | **174** | **173** | ... | ... | ... | ... | ... |
| 75 | **194** | **188** | **184** | **180** | **177** | **175** | **174** | **173** | ... | ... | ... | ... | ... |
| 76 | **194** | **188** | **184** | **180** | **177** | **175** | **174** | **173** | ... | ... | ... | ... | ... |
| 77 | 197 | 193 | 190 | 188 | 186 | 184 | 182 | 180 | ... | ... | ... | ... | ... |
| 78 | 197 | 193 | 190 | 188 | 186 | 184 | 182 | 180 | ... | ... | ... | ... | ... |
| 79 | 197 | 193 | 190 | 188 | 186 | 184 | 182 | 180 | ... | ... | ... | ... | ... |
| 80 | 207 | 207 | 207 | 207 | 207 | 207 | 206 | 206 | ... | ... | ... | ... | ... |
| 81 | 207 | 207 | 207 | 207 | 207 | 207 | 206 | 206 | ... | ... | ... | ... | ... |
| 82 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | ... | ... | ... | ... | ... |
| 83 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | ... | ... | ... | ... | ... |
| 84 | 234 | 234 | 234 | 234 | 234 | **233** | **231** | **230** | ... | ... | ... | ... | ... |
| 85 | 234 | 234 | 234 | 234 | 234 | **233** | **231** | **230** | ... | ... | ... | ... | ... |
| 86 | 234 | 234 | 234 | 234 | 234 | **233** | **231** | **230** | ... | ... | ... | ... | ... |
| 87 | *265* | *262* | *260* | *257* | *255* | *252* | *251* | *249* | *247* | *245* | *242* | **215** | **194** |
| 88 | *265* | *262* | *260* | *257* | *255* | *252* | *251* | *249* | *247* | *245* | *242* | **215** | **194** |
| 89 | 207 | 207 | 203 | 199 | 197 | 196 | 195 | 195 | 195 | 195 | 195 | 195 | 183 |
| 90 | 207 | 207 | 203 | 199 | 197 | 196 | 195 | 195 | 195 | 195 | 195 | 195 | 183 |
| 91 | 207 | 207 | 203 | 199 | 197 | 196 | 195 | 195 | 195 | 195 | 195 | 195 | 183 |
| 92 | 169 | 165 | 163 | 161 | 159 | 157 | 156 | 155 | ... | ... | ... | ... | ... |
| 93 | 169 | 165 | 163 | 161 | 159 | 157 | 156 | 155 | ... | ... | ... | ... | ... |
| 94 | 169 | 165 | 163 | 161 | 159 | 157 | 156 | 155 | ... | ... | ... | ... | ... |
| 95 | 51.6 | 51.6 | 51.6 | 51.5 | 51.2 | 50.7 | 49.9 | **41.4** | **33.1** | **27.4** | **22.8** | **18.7** | **15.6** |
| 96 | 51.6 | 51.6 | 51.6 | 51.5 | 51.2 | 50.7 | 49.9 | **41.4** | **33.1** | **27.4** | **22.8** | **18.7** | **15.6** |
| 97 | 68.9 | 68.9 | 68.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 98 | 91.9 | 91.9 | 91.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 99 | 115 | 115 | 113 | 110 | 108 | 105 | 104 | 102 | 100 | 98.6 | 97.1 | 95.9 | **91.8** |
| 100 | 115 | 115 | 113 | 110 | 108 | 105 | 104 | 102 | 100 | 98.6 | 97.1 | 96.1 | **94.1** |
| 101 | 129 | 129 | 127 | 125 | 122 | 121 | 119 | 119 | ... | ... | ... | ... | ... |
| 102 | 101 | 101 | 101 | 101 | 100 | 99.6 | 98.6 | **79.7** | **59.9** | **55.2** | ... | ... | ... |
| 103 | 138 | 135 | 134 | 132 | 131 | 130 | 129 | 128 | 128 | 127 | 127 | 126 | ... |
| 104 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 136 | **107** |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 | 850 | 875 | 900 |
| 68 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 69 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 70 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 71 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 72 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 73 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 74 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 75 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 76 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 77 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 78 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 79 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 80 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 81 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 82 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 83 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 84 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 85 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 86 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 87 | 156 | 136 | 91.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 88 | 156 | 136 | 91.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 89 | 153 | 128 | 107 | 89.7 | 74.7 | 61.9 | 50.8 | 41.1 | 32.6 | 25.2 | 18.9 | 13.8 | 10.2 |
| 90 | 153 | 128 | 107 | 89.7 | 74.7 | 61.9 | 50.8 | 41.1 | 32.6 | 25.2 | 18.9 | 13.8 | 10.2 |
| 91 | 153 | 128 | 107 | 89.7 | 74.7 | 61.9 | 50.8 | 41.1 | 32.6 | 25.2 | 18.9 | 13.8 | 10.2 |
| 92 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 93 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 94 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 95 | 12.9 | 10.0 | 8.27 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 96 | 12.9 | 10.0 | 8.27 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 97 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 98 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 99 | 75.7 | 62.6 | 50.6 | 41.2 | 33.6 | 27.7 | 22.6 | 18.3 | 15.0 | 11.9 | 9.03 | 7.35 | 5.86 |
| 100 | 85.5 | 69.3 | 56.8 | 46.8 | 38.6 | 31.5 | 25.5 | 20.6 | 17.1 | 13.8 | 10.7 | 7.98 | 6.20 |
| 101 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 102 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 103 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 104 | 83.8 | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 105 | 31Ni–31Fe–29Cr–Mo | Pl. & sht. | B709 | ... | N08028 | Sol. ann. | All | 45 |
| 106 | 42Ni–21.5Cr–3Mo–2.3Cu | Plate | B424 | ... | N08825 | Annealed | ... | 45 |
| 107 | 35Ni–35Fe–20Cr–Cb | Pl. & sht. | B463 | ... | N08020 | Annealed | All | 45 |
| 108 | 40Ni–29Cr–15Fe–5Mo | Pl. & sht. | B582 | ... | N06030 | Sol. ann. | All | 45 |
| 109 | 47Ni–22Cr–19Fe–6Mo | Pl. & sht. | B582 | ... | N06007 | Sol. ann. | ≤19 | 45 |
| 110 | 47Ni–22Cr–9Mo–18Fe | Pl. & sht. | B435 | ... | N06002 | H.R sol. ann. | All | 43 |
| 111 | 72Ni–15Cr–8Fe | Plate | B168 | ... | N06600 | H.R. ann. | ... | 43 |
| 112 | 72Ni–15Cr–8Fe | Plate | B168 | ... | N06600 | H.R. as R. | ... | 43 |
| 113 | 58Ni–29Cr–9Fe | Plate | B168 | ... | N06690 | Annealed | ≥5 | 43 |
| 114 | 58Ni–29Cr–9Fe | Sheet | B168 | ... | N06690 | H.R. ann. or C.R. ann. | 0.5 to 6 | 43 |
| 115 | 67Ni–30Cu | Plate | B127 | ... | N04400 | H.R. as R. | ... | 42 |
| 116 | 37Ni–33Fe–25Cr | Pl. & sht. | B409 | ... | N08120 | Sol. ann. | All | 45 |
| 117 | 31Ni–33Fe–27Cr–6.5Mo–Cu–N | Pl. & sht. | B625 | ... | N08031 | Annealed | All | 45 |
| 118 | 61Ni–16Mo–16Cr | Pl. & sht. | B575 | ... | N06455 | Sol. ann. | All | 43 |
| 119 | 54Ni–16Mo–15Cr | Pl. & sht. | B575 | ... | N10276 | Sol. ann. | All | 43 |
| 120 | 60Ni–22Cr–9Mo–3.5Cb | Plate | B443 | 1 | N06625 | Annealed | All | 43 |
| 121 | 57Ni–22Cr–14W–2Mo–La | Pl. & sht. | B435 | ... | N06230 | Sol. ann. | All | 43 |
| 122 | 55Ni–21Cr–13.5Mo | Sheet | B575 | ... | N06022 | Sol. ann. | <5 | 43 |
| 123 | 58Ni–33Cr–8Mo | Pl. & sht. | B575 | ... | N06035 | Sol. ann. | All | 43 |
| 124 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Pl. & sht. | B688 | ... | N08367 | Annealed | >5 | 45 |
| 125 | 46Fe–24Ni–21Cr–6Mo–Cu–N | Pl. & sht. | B688 | ... | N08367 | Annealed | ≤5 | 45 |
| 126 | 59Ni–23Cr–16Mo | Pl. & sht. | B575 | ... | N06059 | Sol. ann. | All | 43 |
| 127 | 59Ni–23Cr–16Mo–1.6Cu | Pl. & sht. | B575 | ... | N06200 | Sol. ann. | All | 43 |
| 128 | 62Ni–22Mo–15Cr | Pl. & sht. | B575 | ... | N10362 | Sol. ann. | All | 43 |
| 129 | 62Ni–28Mo–5Fe | Plate | B333 | ... | N10001 | Sol. ann. | ≥5, ≤64 | 44 |
| 130 | 62Ni–28Mo–5Fe | Sheet | B333 | ... | N10001 | Sol. ann. | ≤5 | 44 |
| 131 | 65Ni–28Mo–2Fe | Pl. & sht. | B333 | ... | N10665 | Sol. ann. | All | 44 |
| 132 | 65Ni–29.5Mo–2Fe–2Cr | Pl. & sht. | B333 | ... | N10675 | Sol. ann. | All | 44 |
| 133 | 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | Pl. & sht. | B625 | ... | R20033 | Sol. ann. | ... | 45 |
| 134 | 99.0Ni–Low C | Forg. & ftg. | B160 | ... | N02201 | Annealed | All | 41 |
| 135 | 99.0Ni–Low C | Forg. & ftg. | B366 | ... | N02201 | Annealed | All | 41 |
| 136 | 99.0Ni | Forg. & ftg. | B366 | ... | N02200 | Annealed | All | 41 |
| 137 | 99.0Ni | Forg. & ftg. | B564 | ... | N02200 | Annealed | All | 41 |
| 138 | 33Ni–42Fe–21Cr | Forg. & ftg. | B564 | ... | N08810 | Annealed | ... | 45 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 105 | ... | −198 | 505 | 215 | 454 | 143 | *143* | *143* | *143* | *143* | *143* | *143* | *143* | *143* |
| 106 | (9) | −198 | 585 | 240 | 538 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 107 | ... | −198 | 552 | 241 | 427 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 108 | ... | −198 | 586 | 241 | 427 | 161 | *161* | *161* | *161* | *161* | *161* | *161* | **157** | **154** |
| 109 | ... | −198 | 621 | 241 | 538 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 110 | ... | −198 | 655 | 241 | 427 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 156 |
| 111 | ... | −198 | 552 | 241 | 649 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 112 | ... | −198 | 586 | 241 | 649 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 113 | ... | −198 | 586 | 240 | 482 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| 114 | ... | −198 | 586 | 240 | 482 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| 115 | ... | −198 | 517 | 276 | 482 | *172* | *172* | *172* | *171* | *170* | 168 | 165 | 164 | 162 |
| 116 | ... | −198 | 621 | 276 | 899 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 117 | ... | −198 | 648 | 276 | 427 | 184 | 184 | 184 | 184 | 184 | 177 | 171 | 166 | 162 |
| 118 | ... | −198 | 689 | 276 | 427 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 |
| 119 | ... | −198 | 689 | 283 | 677 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 187 |
| 120 | (64)(70) | −198 | 758 | 379 | 649 | 253 | 253 | 253 | *251* | *250* | *249* | *248* | *247* | *245* |
| 121 | ... | −198 | 758 | 310 | 899 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 122 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 |
| 123 | ... | −198 | 586 | 241 | 427 | 161 | 161 | 161 | *161* | *161* | *161* | **154** | **149** | **144** |
| 124 | ... | −198 | 655 | 310 | 427 | 207 | 207 | 207 | 207 | *206* | *202* | *198* | *195* | *192* |
| 125 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 206 | 199 | 193 |
| 126 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 206 |
| 127 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | **207** | **200** |
| 128 | ... | −198 | 725 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 | 199 |
| 129 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 130 | ... | −198 | 793 | 345 | 427 | 230 | 230 | 230 | 230 | 230 | 230 | 230 | 230 | 230 |
| 131 | ... | −198 | 758 | 352 | 427 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 |
| 132 | ... | −198 | 758 | 352 | 427 | 234 | *234* | *234* | *234* | *234* | *234* | *234* | *234* | *234* |
| 133 | ... | −198 | 750 | 380 | 427 | 250 | 231 | 209 | 200 | 193 | 187 | 181 | 176 | 172 |
| 134 | (9)(9a) | −198 | 345 | 69 | 649 | 46.0 | 44.7 | 43.9 | 43.6 | 43.3 | 43.2 | 43.2 | 43.2 | 43.2 |
| 135 | (32)(74) | −198 | 345 | 69 | 649 | 46.0 | 44.7 | 43.9 | 43.6 | 43.3 | 43.2 | 43.2 | 43.2 | 43.2 |
| 136 | (32)(74) | −198 | 380 | 105 | 260 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 |
| 137 | (9) | −198 | 379 | 103 | 316 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 138 | (9) | −198 | 448 | 172 | 899 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 |
| 105 | **140** | **137** | **133** | **130** | **125** | **122** | **119** | **116** | **113** | ... | ... | ... | ... |
| 106 | 161 | 161 | 161 | 161 | 161 | 160 | 159 | 158 | 157 | 156 | 155 | 153 | ... |
| 107 | 161 | 161 | 161 | 161 | 161 | 160 | 157 | 156 | ... | ... | ... | ... | ... |
| 108 | **151** | **148** | **146** | **143** | **141** | **138** | **136** | **136** | ... | ... | ... | ... | ... |
| 109 | 160 | 158 | 156 | 154 | 153 | 152 | 151 | 150 | 149 | **136** | **132** | **130** | ... |
| 110 | 152 | 148 | 145 | 142 | 140 | 138 | 137 | 137 | ... | ... | ... | ... | ... |
| 111 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | **84.8** | **58.4** | **39.7** | **27.0** |
| 112 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | **84.8** | **58.4** | **39.7** | **27.0** |
| 113 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | ... | ... | ... |
| 114 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | ... | ... | ... |
| 115 | 161 | 160 | 159 | 158 | 156 | **136** | **102** | **63.8** | **33.5** | **27.6** | ... | ... | ... |
| 116 | 170 | 166 | 163 | 160 | 158 | 156 | 154 | 153 | 153 | 152 | 151 | 151 | 151 |
| 117 | 158 | 155 | 152 | 149 | 146 | 144 | 141 | 140 | ... | ... | ... | ... | ... |
| 118 | 184 | 184 | 184 | 184 | 182 | 180 | 178 | 176 | ... | ... | ... | ... | ... |
| 119 | 183 | 177 | 172 | 169 | 165 | 162 | 159 | 157 | 156 | 155 | 154 | **143** | **118** |
| 120 | *243* | *241* | *238* | *236* | *233* | *231* | *230* | *228* | *227* | *225* | *222* | **215** | **194** |
| 121 | 207 | 207 | 203 | 199 | 197 | 196 | 195 | 195 | 195 | 195 | 195 | 195 | 183 |
| 122 | 197 | 193 | 189 | 185 | 182 | 180 | 177 | 177 | ... | ... | ... | ... | ... |
| 123 | **140** | **137** | **135** | **133** | **132** | **131** | **129** | **128** | ... | ... | ... | ... | ... |
| 124 | 188 | 183 | 179 | 176 | 173 | 170 | 168 | 167 | ... | ... | ... | ... | ... |
| 125 | 188 | 183 | 179 | 176 | 173 | 170 | 168 | 167 | ... | ... | ... | ... | ... |
| 126 | 202 | 197 | 192 | 188 | 184 | 180 | 176 | 176 | ... | ... | ... | ... | ... |
| 127 | **194** | **188** | **184** | **180** | **177** | **175** | **174** | **173** | ... | ... | ... | ... | ... |
| 128 | 197 | 193 | 190 | 188 | 186 | 184 | 182 | 180 | ... | ... | ... | ... | ... |
| 129 | 207 | 207 | 207 | 207 | 207 | 207 | 206 | 206 | ... | ... | ... | ... | ... |
| 130 | 230 | 230 | 230 | 230 | 230 | 230 | 229 | 229 | ... | ... | ... | ... | ... |
| 131 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | ... | ... | ... | ... | ... |
| 132 | *234* | *234* | *234* | *234* | *234* | **233** | **231** | **230** | ... | ... | ... | ... | ... |
| 133 | 169 | 165 | 163 | 161 | 159 | 157 | 156 | 155 | ... | ... | ... | ... | ... |
| 134 | 43.2 | 43.2 | 43.1 | 42.9 | 42.6 | 42.1 | 41.5 | 40.7 | **33.1** | **27.4** | **22.8** | **18.7** | **15.6** |
| 135 | 43.2 | 43.2 | 43.1 | 42.9 | 42.6 | 42.1 | 41.5 | 40.7 | **33.1** | **27.4** | **22.8** | **18.7** | **15.6** |
| 136 | 70.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 137 | 68.9 | 68.9 | 68.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 138 | 115 | 115 | 113 | 110 | 108 | 105 | 104 | 102 | 100 | 98.6 | 97.1 | 95.9 | 91.8 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 | 850 | 875 | 900 |
| 105 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 106 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 107 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 108 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 109 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 110 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 111 | 19.2 | 15.0 | 13.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 112 | 19.2 | 15.0 | 13.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 113 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 114 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 115 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 116 | 117 | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8 |
| 117 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 118 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 119 | 99.1 | 81.6 | 67.0 | 54.6 | 42.2 | ... | ... | ... | ... | ... | ... | ... | ... |
| 120 | 156 | 136 | 91.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 121 | 153 | 128 | 107 | 89.7 | 74.7 | 61.9 | 50.8 | 41.1 | 32.6 | 25.2 | 18.9 | 13.8 | 10.2 |
| 122 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 123 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 124 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 125 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 126 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 127 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 128 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 129 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 130 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 131 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 132 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 133 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 134 | 12.9 | 10.0 | 8.27 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 135 | 12.9 | 10.0 | 8.27 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 136 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 137 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 138 | 75.7 | 62.6 | 50.6 | 41.2 | 33.6 | 27.7 | 22.6 | 18.3 | 15.0 | 11.9 | 9.03 | 7.35 | 5.86 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 139 | 33Ni–42Fe–21Cr–Al–Ti | Forg. & ftg. | B564 | ... | N08811 | Annealed | ... | 45 |
| 140 | 33Ni–42Fe–21Cr | Fittings | B366 | ... | N08810 | Annealed | All | 45 |
| 141 | 33Ni–42Fe–21Cr–Al–Ti | Fittings | B366 | ... | N08811 | Annealed | All | 45 |
| 142 | 67Ni–30Cu | Forg. & ftg. | B564 | ... | N04400 | Annealed | ... | 42 |
| 143 | 67Ni–30Cu | Forg. & ftg. | B366 | ... | N04400 | Annealed | All | 42 |
| 144 | 72Ni–15Cr–8Fe | Forg. & ftg. | B366 | ... | N06600 | Annealed | All | 43 |
| 145 | 40Ni–29Cr–15Fe–5Mo | Forg. & ftg. | B366 | ... | N06030 | Sol. ann. | All | 45 |
| 146 | 40Ni–29Cr–15Fe–5Mo | Forg. & ftg. | B462 | ... | N06030 | Sol. ann. | All | 45 |
| 147 | 33Ni–42Fe–21Cr | Forg. & ftg. | B366 | ... | N08800 | C.D. ann. | All | 45 |
| 148 | 33Ni–42Fe–21Cr | Forg. & ftg. | B564 | ... | N08800 | Annealed | ... | 45 |
| 149 | 35Ni–35Fe–20Cr–Cb | Forg. & ftg. | B366 | ... | N08020 | Annealed | All | 45 |
| 150 | 35Ni–35Fe–20Cr–Cb | Forg. & ftg. | B462 | ... | N08020 | Annealed | ... | 45 |
| 151 | 72Ni–15Cr–8Fe | Forg. & ftg. | B564 | ... | N06600 | Annealed | All | 43 |
| 152 | 42Ni–21.5Cr–3Mo–2.3Cu | Fittings | B366 | ... | N08825 | C.D. ann. | All | 45 |
| 153 | 42Ni–21.5Cr–3Mo–2.3Cu | Forgings | B564 | ... | N08825 | Annealed | ... | 45 |
| 154 | 58Ni–29Cr–9Fe | Forgings | B564 | ... | N06690 | Annealed | All | 43 |
| 155 | 37Ni–33Fe–25Cr | Fittings | B366 | ... | N08120 | Sol. ann. | All | 45 |
| 156 | 37Ni–33Fe–25Cr | Forgings | B564 | ... | N08120 | Sol. ann. | All | 45 |
| 157 | 47Ni–22Cr–9Mo–18Fe | Forg. & ftg. | B366 | ... | N06002 | Sol. ann. | All | 43 |
| 158 | 31Ni–33Fe–27Cr–6.5Mo–Cu–N | Forg. & ftg. | B366 | ... | N08031 | Sol. ann. | All | 45 |
| 159 | 31Ni–33Fe–27Cr–6.5Mo–Cu–N | Forg. & ftg. | B564 | ... | N08031 | Annealed H.W. | All | 45 |
| 160 | 54Ni–16Mo–15Cr | Forg. & ftg. | B366 | ... | N10276 | Sol. ann. | All | 43 |
| 161 | 54Ni–16Mo–15Cr | Forg. & ftg. | B462 | ... | N10276 | Sol. ann. | All | 43 |
| 162 | 54Ni–16Mo–15Cr | Forg. & ftg. | B564 | ... | N10276 | Sol. ann. | All | 43 |
| 163 | 62Ni–28Mo–5Fe | Forg. & ftg. | B366 | ... | N10001 | Sol. ann. | All | 44 |
| 164 | 55Ni–21Cr–13.5Mo | Forg. & ftg. | B366 | ... | N06022 | Sol. ann. | All | 43 |
| 165 | 55Ni–21Cr–13.5Mo | Forg. & ftg. | B462 | ... | N06022 | Sol. ann. | All | 43 |
| 166 | 55Ni–21Cr–13.5Mo | Forg. & ftg. | B564 | ... | N06022 | Sol. ann. | All | 43 |
| 167 | 58Ni–33Cr–8Mo | Forg. & ftg. | B366 | ... | N06035 | Sol. ann. | All | 43 |
| 168 | 58Ni–33Cr–8Mo | Forg. & ftg. | B462 | ... | N06035 | Sol. ann. | All | 43 |
| 169 | 58Ni–33Cr–8Mo | Forg. & ftg. | B564 | ... | N06035 | Sol. ann. | All | 43 |
| 170 | 59Ni–23Cr–16Mo | Forg. & ftg. | B366 | ... | N06059 | Sol. ann. | All | 43 |
| 171 | 59Ni–23Cr–16Mo | Forg. & ftg. | B564 | ... | N06059 | H.W. sol. ann. | All | 43 |
| 172 | 59Ni–23Cr–16Mo–1.6Cu | Forg. & ftg. | B366 | ... | N06200 | Sol. ann. | All | 43 |
| 173 | 59Ni–23Cr–16Mo–1.6Cu | Forg. & ftg. | B462 | ... | N06200 | Sol. ann. | All | 43 |
| 174 | 59Ni–23Cr–16Mo–1.6Cu | Forg. & ftg. | B564 | ... | N06200 | Sol. ann. | All | 43 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 |
| 139 | (9) | −198 | 448 | 172 | 899 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 140 | (9)(74) | −198 | 450 | 170 | 899 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 141 | (9)(74) | −198 | 450 | 170 | 899 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 142 | (9) | −198 | 483 | 172 | 482 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 | 90.4 |
| 143 | (32)(74) | −198 | 483 | 172 | 482 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 | 90.4 |
| 144 | (32)(74) | −198 | 517 | 172 | 649 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 145 | (74) | −198 | 586 | 241 | 427 | 161 | *161* | *161* | *161* | *161* | *161* | *161* | **157** | **154** |
| 146 | ... | −198 | 586 | 241 | 427 | 161 | *161* | *161* | *161* | *161* | *161* | *161* | **157** | **154** |
| 147 | (74) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 148 | (9) | −198 | 517 | 207 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 149 | (74) | −198 | 552 | 241 | 427 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 150 | (9) | −198 | 552 | 241 | 427 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 151 | (9) | −198 | 552 | 241 | 649 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 152 | (9)(74) | −198 | 585 | 240 | 538 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 153 | (9) | −198 | 585 | 240 | 538 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| 154 | (9) | −198 | 586 | 241 | 482 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| 155 | ... | −198 | 621 | 276 | 899 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 156 | ... | −198 | 621 | 276 | 899 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 157 | (32) | −198 | 689 | 276 | 816 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 178 |
| 158 | (74) | −198 | 648 | 276 | 427 | 184 | 184 | 184 | 184 | 184 | 177 | 171 | 166 | 162 |
| 159 | ... | −198 | 648 | 276 | 427 | 184 | 184 | 184 | 184 | 184 | 177 | 171 | 166 | 162 |
| 160 | (74) | −198 | 689 | 283 | 677 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 187 |
| 161 | (9) | −198 | 689 | 283 | 677 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 187 |
| 162 | (9) | −198 | 689 | 283 | 677 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 187 |
| 163 | (32) | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 164 | (32)(74) | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 |
| 165 | (9) | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 |
| 166 | (9) | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 |
| 167 | (32)(74) | −198 | 586 | 241 | 427 | 161 | 161 | 161 | *161* | *161* | *161* | **154** | **149** | **144** |
| 168 | (9) | −198 | 586 | 241 | 427 | 161 | 161 | 161 | *161* | *161* | *161* | **154** | **149** | **144** |
| 169 | (9) | −198 | 586 | 241 | 427 | 161 | 161 | 161 | *161* | *161* | *161* | **154** | **149** | **144** |
| 170 | (74) | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 206 |
| 171 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 206 |
| 172 | (74) | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | **207** | **200** |
| 173 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | **207** | **200** |
| 174 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | **207** | **200** |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 |
| 139 | 115 | 115 | 113 | 110 | 108 | 105 | 104 | 102 | 100 | 98.7 | 97.1 | 96.1 | 94.1 |
| 140 | 115 | 115 | 113 | 110 | 108 | 105 | 104 | 102 | 100 | 98.6 | 97.1 | 95.9 | 91.8 |
| 141 | 115 | 115 | 113 | 110 | 108 | 105 | 104 | 102 | 100 | 98.7 | 97.1 | 96.1 | 94.1 |
| 142 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | **79.7** | **59.9** | **55.2** | ... | ... | ... |
| 143 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | **79.7** | **59.9** | **55.2** | ... | ... | ... |
| 144 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | **84.8** | **58.4** | **39.7** | **27.0** |
| 145 | **151** | **148** | **146** | **143** | **141** | **138** | **136** | **136** | ... | ... | ... | ... | ... |
| 146 | **151** | **148** | **146** | **143** | **141** | **138** | **136** | **136** | ... | ... | ... | ... | ... |
| 147 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 136 | **107** |
| 148 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 136 | **107** |
| 149 | 161 | 161 | 161 | 161 | 161 | 160 | 157 | 156 | ... | ... | ... | ... | ... |
| 150 | 161 | 161 | 161 | 161 | 161 | 160 | 157 | 156 | ... | ... | ... | ... | ... |
| 151 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | **84.8** | **58.4** | **39.7** | **27.0** |
| 152 | 161 | 161 | 161 | 161 | 161 | 160 | 159 | 158 | 157 | 156 | 155 | 153 | ... |
| 153 | 160 | 160 | 160 | 160 | 160 | 159 | 158 | 157 | 156 | 156 | 154 | 151 | ... |
| 154 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | ... | ... | ... |
| 155 | 170 | 166 | 163 | 160 | 158 | 156 | 154 | 153 | 153 | 152 | 151 | 151 | 151 |
| 156 | 170 | 166 | 163 | 160 | 158 | 156 | 154 | 153 | 153 | 152 | 151 | 151 | 151 |
| 157 | 173 | 169 | 165 | 162 | 160 | 158 | 157 | 155 | 154 | **135** | **134** | **133** | **129** |
| 158 | 158 | 155 | 152 | 149 | 146 | 144 | 141 | 141 | ... | ... | ... | ... | ... |
| 159 | 158 | 155 | 152 | 149 | 146 | 144 | 141 | 141 | ... | ... | ... | ... | ... |
| 160 | 183 | 177 | 172 | 169 | 165 | 162 | 159 | 157 | 156 | 155 | 154 | **143** | **118** |
| 161 | 183 | 177 | 172 | 169 | 165 | 162 | 159 | 157 | 156 | 155 | 154 | **143** | **118** |
| 162 | 183 | 177 | 172 | 169 | 165 | 162 | 159 | 157 | 156 | 155 | 154 | **143** | **118** |
| 163 | 207 | 207 | 207 | 207 | 207 | 207 | 206 | 206 | ... | ... | ... | ... | ... |
| 164 | 197 | 193 | 189 | 185 | 182 | 180 | 177 | 177 | ... | ... | ... | ... | ... |
| 165 | 197 | 193 | 189 | 185 | 182 | 180 | 177 | 177 | ... | ... | ... | ... | ... |
| 166 | 197 | 193 | 189 | 185 | 182 | 180 | 177 | 177 | ... | ... | ... | ... | ... |
| 167 | **140** | **137** | **135** | **133** | **132** | **131** | **129** | **128** | ... | ... | ... | ... | ... |
| 168 | **140** | **137** | **135** | **133** | **132** | **131** | **129** | **128** | ... | ... | ... | ... | ... |
| 169 | **140** | **137** | **135** | **133** | **132** | **131** | **129** | **128** | ... | ... | ... | ... | ... |
| 170 | 202 | 197 | 192 | 188 | 184 | 180 | 176 | 176 | ... | ... | ... | ... | ... |
| 171 | 202 | 197 | 192 | 188 | 184 | 180 | 176 | 176 | ... | ... | ... | ... | ... |
| 172 | **194** | **188** | **184** | **180** | **177** | **175** | **174** | **173** | ... | ... | ... | ... | ... |
| 173 | **194** | **188** | **184** | **180** | **177** | **175** | **174** | **173** | ... | ... | ... | ... | ... |
| 174 | **194** | **188** | **184** | **180** | **177** | **175** | **174** | **173** | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 | 850 | 875 | 900 |
| 139 | 85.5 | 69.3 | 56.8 | 46.8 | 38.6 | 31.5 | 25.5 | 20.6 | 17.1 | 13.8 | 10.2 | 7.98 | 6.20 |
| 140 | 75.7 | 62.6 | 50.6 | 41.2 | 33.6 | 27.7 | 22.6 | 18.3 | 15.0 | 11.9 | 9.03 | 7.35 | 5.86 |
| 141 | 85.5 | 69.3 | 56.8 | 46.8 | 38.6 | 31.5 | 25.5 | 20.6 | 17.1 | 13.8 | 10.2 | 7.98 | 6.20 |
| 142 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 143 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 144 | 19.2 | 15.0 | 13.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 145 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 146 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 147 | 83.8 | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | ... | ... | ... |
| 148 | 83.8 | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | ... | ... | ... |
| 149 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 150 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 151 | 19.2 | 15.0 | 13.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 152 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 153 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 154 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 155 | 117 | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8 |
| 156 | 117 | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8 |
| 157 | 115 | 94.2 | 77.3 | 64.9 | 54.7 | 44.7 | 36.1 | 29.2 | 23.6 | 19.1 | ... | ... | ... |
| 158 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 159 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 160 | 99.1 | 81.6 | 67.0 | 54.6 | 42.2 | ... | ... | ... | ... | ... | ... | ... | ... |
| 161 | 99.1 | 81.6 | 67.0 | 54.6 | 42.2 | ... | ... | ... | ... | ... | ... | ... | ... |
| 162 | 99.1 | 81.6 | 67.0 | 54.6 | 42.2 | ... | ... | ... | ... | ... | ... | ... | ... |
| 163 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 164 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 165 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 166 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 167 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 168 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 169 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 170 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 171 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 172 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 173 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 174 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 175 | 62Ni–22Mo–15Cr | Fittings | B366 | ... | N10362 | Sol. ann. | All | 43 |
| 176 | 62Ni–22Mo–15Cr | Forgings | B462 | ... | N10362 | Sol. ann. | All | 43 |
| 177 | 62Ni–22Mo–15Cr | Forgings | B564 | ... | N10362 | Sol. ann. | All | 43 |
| 178 | 60Ni–22Cr–9Mo–3.5Cb | Forg. & ftg. | B564 | ... | N06625 | Annealed | ≤100 | 43 |
| 179 | 65Ni–28Mo–2Fe | Forg. & ftg. | B366 | ... | N10665 | Sol. ann. | All | 44 |
| 180 | 65Ni–29.5Mo–2Fe–2Cr | Forg. & ftg. | B366 | ... | N10675 | Sol. ann. | All | 44 |
| 181 | 65Ni–29.5Mo–2Fe–2Cr | Forg. & ftg. | B462 | ... | N10675 | Sol. ann. | All | 44 |
| 182 | 65Ni–29.5Mo–2Fe–2Cr | Forg. & ftg. | B564 | ... | N10675 | Sol. ann. | All | 44 |
| 183 | 57Ni–22Cr–14W–2Mo–La | Forg. & ftg. | B564 | ... | N06230 | Sol. ann. | All | 43 |
| 184 | 57Ni–22Cr–14W–2Mo–La | Forg. & ftg. | B366 | ... | N06230 | Sol. ann. | All | 43 |
| 185 | 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | Fittings | B366 | ... | R20033 | Sol. ann. | ... | 45 |
| 186 | 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | Fittings | B462 | ... | R20033 | Sol. ann. | ... | 45 |
| 187 | 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | Forgings | B564 | ... | R20033 | Sol. ann. | ... | 45 |
| 188 | 99.0Ni | Rod & bar | B160 | ... | N02200 | H.W. | All | 41 |
| 189 | 99.0Ni | Rod & bar | B160 | ... | N02200 | Annealed | All | 41 |
| 190 | 67Ni–30Cu | Rod & bar | B164 | ... | N04400 | Ann. forg. | All | 42 |
| 191 | 33Ni–42Fe–21Cr | Rod & bar | B408 | ... | N08810 | Sol. trt. or ann. | ... | 45 |
| 192 | 33Ni–42Fe–21Cr–Al–Ti | Rod & bar | B408 | ... | N08811 | Annealed | ... | 45 |
| 193 | 33Ni–42Fe–21Cr | Rod & bar | B408 | ... | N08800 | Annealed | ... | 45 |
| 194 | 26Ni–22Cr–5Mo–Ti | Rod & bar | B621 | ... | N08320 | Sol. ann. | All | 45 |
| 195 | 47Ni–22Cr–19Fe–6Mo | Rod & bar | B581 | ... | N06007 | Sol. ann. | >19 | 45 |
| 196 | 42Ni–21.5Cr–3Mo–2.3Cu | Rod & bar | B425 | ... | N08825 | Annealed | ... | 45 |
| 197 | 58Ni–29Cr–9Fe | Rod & bar | B166 | ... | N06690 | H.R. | >75 | 43 |
| 198 | 58Ni–29Cr–9Fe | Rod & bar | B166 | ... | N06690 | H.R. ann. or C.D. ann. | All | 43 |
| 199 | 47Ni–22Cr–19Fe–6Mo | Rod & bar | B581 | ... | N06007 | Sol. ann. | ≤19 | 45 |
| 200 | 40Ni–29Cr–15Fe–5Mo | Rod & bar | B581 | ... | N06030 | Sol. ann. | All | 45 |
| 201 | 31Ni–33Fe–27Cr–6.5Mo–Cu–N | Rod & bar | B649 | ... | N08031 | Annealed | All | 45 |
| 202 | 67Ni–30Cu | Rod & bar | B164 | ... | N04400 | H.W. | All except hex >54 | 42 |
| 203 | 58Ni–33Cr–8Mo | Rod & bar | B574 | ... | N06035 | Sol. ann. | All | 43 |
| 204 | 37Ni–33Fe–25Cr | Rod & bar | B408 | ... | N08120 | Sol. ann. | All | 45 |
| 205 | 61Ni–16Mo–16Cr | Rod & bar | B574 | ... | N06455 | Sol. ann. | All | 43 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | | | | | | Basic Allowable Stress, $S$, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 |
| 175 | ... | −198 | 725 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 | 199 |
| 176 | ... | −198 | 725 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 | 199 |
| 177 | ... | −198 | 725 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 | 199 |
| 178 | (9)(64) | −198 | 827 | 414 | 649 | 276 | 276 | 276 | *274* | *273* | *272* | *270* | *269* | *267* |
| 179 | (74) | −198 | 758 | 352 | 427 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 |
| 180 | (74) | −198 | 758 | 352 | 427 | 234 | *234* | *234* | *234* | *234* | *234* | *234* | *234* | *234* |
| 181 | ... | −198 | 758 | 352 | 427 | 234 | *234* | *234* | *234* | *234* | *234* | *234* | *234* | *234* |
| 182 | ... | −198 | 758 | 352 | 427 | 234 | *234* | *234* | *234* | *234* | *234* | *234* | *234* | *234* |
| 183 | ... | −198 | 758 | 310 | 899 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 184 | (74) | −198 | 758 | 310 | 899 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 185 | ... | −198 | 750 | 380 | 427 | 250 | 231 | 209 | 200 | 193 | 187 | 181 | 176 | 172 |
| 186 | ... | −198 | 750 | 380 | 427 | 250 | 231 | 209 | 200 | 193 | 187 | 181 | 176 | 172 |
| 187 | ... | −198 | 750 | 380 | 427 | 250 | 231 | 209 | 200 | 193 | 187 | 181 | 176 | 172 |
| 188 | (9) | −198 | 414 | 103 | 316 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 189 | (9) | −198 | 379 | 103 | 316 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 190 | (13) | −198 | 483 | 172 | 482 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 | 90.4 |
| 191 | (9) | −198 | 450 | 170 | 899 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 192 | (9) | −198 | 450 | 170 | 899 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| 193 | (9) | −198 | 515 | 205 | 816 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 194 | ... | −198 | 517 | 193 | 427 | 129 | 129 | 129 | 129 | 129 | 129 | 129 | 129 | 129 |
| 195 | ... | −198 | 586 | 207 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 196 | (9) | −198 | 585 | 240 | 538 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 197 | ... | −198 | 585 | 240 | 482 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| 198 | ... | −198 | 586 | 240 | 482 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| 199 | ... | −198 | 621 | 241 | 538 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 200 | ... | −198 | 586 | 241 | 427 | 161 | *161* | *161* | *161* | *161* | *161* | *161* | **157** | **154** |
| 201 | ... | −198 | 648 | 276 | 427 | 184 | 184 | 184 | 184 | 184 | 177 | 171 | 166 | 162 |
| 202 | ... | −198 | 552 | 276 | 510 | 184 | 182 | 177 | 174 | 171 | 168 | 165 | 164 | 162 |
| 203 | (9) | −198 | 586 | 241 | 427 | 161 | 161 | 161 | *161* | *161* | *161* | **154** | **149** | **144** |
| 204 | ... | −198 | 621 | 276 | 899 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 205 | (9) | −198 | 689 | 276 | 427 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 |
| 175 | 197 | 193 | 190 | 188 | 186 | 184 | 182 | 180 | … | … | … | … | … |
| 176 | 197 | 193 | 190 | 188 | 186 | 184 | 182 | 180 | … | … | … | … | … |
| 177 | 197 | 193 | 190 | 188 | 186 | 184 | 182 | 180 | … | … | … | … | … |
| 178 | *265* | *262* | *260* | *257* | *255* | *252* | *251* | *249* | *247* | *245* | *242* | **215** | **194** |
| 179 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | 234 | … | … | … | … | … |
| 180 | *234* | *234* | *234* | *234* | *234* | **233** | **231** | **230** | … | … | … | … | … |
| 181 | *234* | *234* | *234* | *234* | *234* | **233** | **231** | **230** | … | … | … | … | … |
| 182 | *234* | *234* | *234* | *234* | *234* | **233** | **231** | **230** | … | … | … | … | … |
| 183 | 207 | 207 | 203 | 199 | 197 | 196 | 195 | 195 | 195 | 195 | 195 | 195 | 183 |
| 184 | 207 | 207 | 203 | 199 | 197 | 196 | 195 | 195 | 195 | 195 | 195 | 195 | 183 |
| 185 | 169 | 165 | 163 | 161 | 159 | 157 | 156 | 155 | … | … | … | … | … |
| 186 | 169 | 165 | 163 | 161 | 159 | 157 | 156 | 155 | … | … | … | … | … |
| 187 | 169 | 165 | 163 | 161 | 159 | 157 | 156 | 155 | … | … | … | … | … |
| 188 | 68.9 | 68.9 | 68.9 | … | … | … | … | … | … | … | … | … | … |
| 189 | 68.9 | 68.9 | 68.9 | … | … | … | … | … | … | … | … | … | … |
| 190 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | **79.7** | **59.9** | **55.2** | … | … | … |
| 191 | 115 | 115 | 113 | 110 | 108 | 105 | 104 | 102 | 100 | 98.6 | 97.1 | 95.9 | 91.8 |
| 192 | 115 | 115 | 113 | 110 | 108 | 105 | 104 | 102 | 100 | 98.7 | 97.1 | 96.1 | 94.1 |
| 193 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 137 | 131 | **108** |
| 194 | 129 | 129 | 127 | 125 | 122 | 121 | 119 | 119 | … | … | … | … | … |
| 195 | 138 | 135 | 134 | 132 | 131 | 130 | 129 | 128 | 128 | 127 | 127 | 126 | … |
| 196 | 161 | 161 | 161 | 161 | 161 | 160 | 159 | 158 | 157 | 156 | 155 | 153 | … |
| 197 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | … | … | … |
| 198 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | … | … | … |
| 199 | 160 | 158 | 156 | 154 | 153 | 152 | 151 | 150 | 149 | **136** | **132** | **130** | … |
| 200 | **151** | **148** | **146** | **143** | **141** | **138** | **136** | **136** | … | … | … | … | … |
| 201 | 158 | 155 | 152 | 149 | 146 | 144 | 141 | 141 | … | … | … | … | … |
| 202 | 161 | 160 | 159 | 158 | 156 | **136** | **102** | **63.8** | **33.5** | **17.0** | **13.0** | … | … |
| 203 | **140** | **137** | **135** | **133** | **132** | **131** | **129** | **128** | … | … | … | … | … |
| 204 | 170 | 166 | 163 | 160 | 158 | 156 | 154 | 153 | 153 | 152 | 151 | 151 | 151 |
| 205 | 184 | 184 | 184 | 184 | 182 | 180 | 178 | 178 | … | … | … | … | … |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 | 850 | 875 | 900 |
| 175 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 176 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 177 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 178 | **156** | **136** | **91.0** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 179 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 180 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 181 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 182 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 183 | **153** | **128** | **107** | **89.7** | **74.7** | **61.9** | **50.8** | **41.1** | **32.6** | **25.2** | **18.9** | **13.8** | **10.2** |
| 184 | **153** | **128** | **107** | **89.7** | **74.7** | **61.9** | **50.8** | **41.1** | **32.6** | **25.2** | **18.9** | **13.8** | **10.2** |
| 185 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 186 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 187 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 188 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 189 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 190 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 191 | **75.7** | **62.6** | **50.6** | **41.2** | **33.6** | **27.7** | **22.6** | **18.3** | **15.0** | **11.9** | **9.03** | **7.35** | **5.86** |
| 192 | **85.5** | **69.3** | **56.8** | **46.8** | **38.6** | **31.5** | **25.5** | **20.6** | **17.1** | **13.8** | **10.2** | **7.98** | **6.20** |
| 193 | **85.0** | **64.4** | **44.8** | **30.0** | **15.5** | **11.3** | **8.82** | **6.98** | **6.43** | **5.00** | ... | ... | ... |
| 194 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 195 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 196 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 197 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 198 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 199 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 200 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 201 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 202 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 203 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 204 | **117** | **96.2** | **79.3** | **65.6** | **54.4** | **45.0** | **37.2** | **30.6** | **25.1** | **20.5** | **16.5** | **13.0** | **9.8** |
| 205 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 206 | 54Ni–16Mo–15Cr | Rod & bar | B574 | ... | N10276 | Sol. ann. | All | 43 |
| 207 | 62Ni–22Mo–15Cr | Rod & bar | B574 | ... | N10362 | Sol. ann. | All | 43 |
| 208 | 60Ni–22Cr–9Mo–3.5Cb | Rod & bar | B446 | 1 | N06625 | Annealed | >100, ≤250 | 43 |
| 209 | 60Ni–22Cr–9Mo–3.5Cb | Rod & bar | B446 | 1 | N06625 | Annealed | ≤100 | 43 |
| 210 | 57Ni–22Cr–14W–2Mo–La | Rod & bar | B572 | ... | N06230 | Sol. ann. | All | 43 |
| 211 | 59Ni–23Cr–16Mo | Rod & bar | B574 | ... | N06059 | Sol. ann. | All | 43 |
| 212 | 59Ni–23Cr–16Mo–1.6Cu | Rod & bar | B574 | ... | N06200 | Sol. ann. | All | 43 |
| 213 | 65Ni–29.5Mo–2Fe–2Cr | Rod & bar | B335 | ... | N10675 | Sol. ann. | All | 44 |
| 214 | 33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N | Rod | B649 | ... | R20033 | Sol. ann. | ... | 45 |
| 215 | 53Ni–17Mo–16Cr–6Fe–5W | Castings | A494 | CW12MW | N30002 | ... | ... | ... |
| 216 | 56Ni–19Mo–18Cr–2Fe | Castings | A494 | CW6M | N30107 | ... | ... | ... |
| 217 | 59Ni–22Cr–14Mo–4Fe–3W | Castings | A494 | CX2MW | N26022 | Sol. ann. | ... | 43 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | | | | | | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 |
| 206 | ... | −198 | 689 | 283 | 677 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 187 |
| 207 | ... | −198 | 725 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 | 199 |
| 208 | (9)(64)(70) | −198 | 758 | 345 | 649 | 230 | 230 | 230 | 230 | 230 | 230 | 230 | 230 | 230 |
| 209 | (9)(64)(70) | −198 | 827 | 414 | 649 | 276 | 276 | 276 | *274* | *273* | *272* | *270* | *269* | *267* |
| 210 | ... | −198 | 758 | 310 | 899 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 211 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 206 |
| 212 | ... | −198 | 689 | 310 | 427 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | **207** | **200** |
| 213 | ... | −198 | 758 | 352 | 427 | 234 | *234* | *234* | *234* | *234* | *234* | *234* | *234* | *234* |
| 214 | ... | −198 | 750 | 380 | 427 | 250 | 231 | 209 | 200 | 193 | 187 | 181 | 176 | 172 |
| 215 | (9)(44) | −198 | 496 | 276 | 538 | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* |
| 216 | (9) | −198 | 496 | 276 | 538 | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* |
| 217 | (9) | −198 | 552 | 310 | 260 | *184* | *184* | *184* | *184* | *184* | *184* | *184* | *184* | *184* |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Line No.** | **275** | **300** | **325** | **350** | **375** | **400** | **425** | **450** | **475** | **500** | **525** | **550** | **575** |
| 206 | 183 | 177 | 172 | 169 | 165 | 162 | 159 | 157 | 156 | 155 | 154 | **143** | **118** |
| 207 | 197 | 193 | 190 | 188 | 186 | 184 | 182 | 180 | ... | ... | ... | ... | ... |
| 208 | 230 | 230 | 230 | 230 | 230 | 230 | *230* | *228* | *227* | *225* | *222* | **215** | **194** |
| 209 | *265* | *262* | *260* | *257* | *255* | *252* | *251* | *249* | *247* | *245* | *242* | **215** | **194** |
| 210 | 207 | 207 | 203 | 199 | 197 | 196 | 195 | 195 | 195 | 195 | 195 | 195 | 183 |
| 211 | 202 | 197 | 192 | 188 | 184 | 180 | 176 | 176 | ... | ... | ... | ... | ... |
| 212 | **194** | **188** | **184** | **180** | **177** | **175** | **174** | **173** | ... | ... | ... | ... | ... |
| 213 | *234* | *234* | *234* | *234* | *234* | **233** | **231** | **230** | ... | ... | ... | ... | ... |
| 214 | 169 | 165 | 163 | 161 | 159 | 157 | 156 | 155 | ... | ... | ... | ... | ... |
| 215 | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *157* | ... |
| 216 | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *165* | *157* | ... |
| 217 | *184* | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 | 850 | 875 | 900 |
| 206 | **99.1** | **81.6** | **67.0** | **54.6** | **42.2** | ... | ... | ... | ... | ... | ... | ... | ... |
| 207 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 208 | **156** | **136** | **91.0** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 209 | **156** | **136** | **91.0** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 210 | **153** | **128** | **107** | **89.7** | **74.7** | **61.9** | **50.8** | **41.1** | **32.6** | **25.2** | **18.9** | **13.8** | **10.2** |
| 211 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 212 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 213 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 214 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 215 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 216 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 217 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Ti | Smls. & wld. tube | B338 | 1 | R50250 | Annealed | 51 | ... | −59 | 240 | 138 |
| 2 | Ti | Smls. pipe | B861 | 1 | R50250 | Annealed | 51 | ... | −59 | 240 | 138 |
| 3 | Ti | Wld. pipe | B862 | 1 | R50250 | Annealed | 51 | ... | −59 | 240 | 138 |
| 4 | Ti | Smls. & wld. tube | B338 | 2 | R50400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 5 | Ti | Smls. pipe | B861 | 2 | R50400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 6 | Ti | Wld. pipe | B862 | 2 | R50400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 7 | Ti | Smls. & wld. tube | B338 | 3 | R50550 | Annealed | 52 | ... | −59 | 450 | 380 |
| 8 | Ti | Smls. pipe | B861 | 3 | R50550 | Annealed | 52 | ... | −59 | 450 | 380 |
| 9 | Ti | Wld. pipe | B862 | 3 | R50550 | Annealed | 52 | ... | −59 | 450 | 380 |
| 10 | Ti–Pd | Smls. & wld. tube | B338 | 7 | R52400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 11 | Ti–Pd | Smls. pipe | B861 | 7 | R52400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 12 | Ti–Pd | Wld. pipe | B862 | 7 | R52400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 13 | Ti–0.3Mo–0.8Ni | Smls. & wld. tube | B338 | 12 | R53400 | Annealed | 52 | ... | −59 | 485 | 345 |
| 14 | Ti–0.3Mo–0.8Ni | Smls. pipe | B861 | 12 | R53400 | Annealed | 52 | ... | −59 | 485 | 345 |
| 15 | Ti–0.3Mo–0.8Ni | Wld. pipe | B862 | 12 | R53400 | Annealed | 52 | ... | −59 | 485 | 345 |
| 16 | Ti | Plate, sheet, strip | B265 | 1 | R50250 | Annealed | 51 | ... | −59 | 240 | 138 |
| 17 | Ti | Plate, sheet, strip | B265 | 2 | R50400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 18 | Ti | Plate, sheet, strip | B265 | 3 | R50550 | Annealed | 52 | ... | −59 | 450 | 380 |
| 19 | Ti–Pd | Plate, sheet, strip | B265 | 7 | R52400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 20 | Ti–0.3Mo–0.8Ni | Plate, sheet, strip | B265 | 12 | R53400 | Annealed | 52 | ... | −59 | 485 | 345 |
| 21 | Ti | Fittings | B363 | WPT1 | R50250 | Annealed | 51 | ... | −59 | 240 | 138 |
| 22 | Ti | Forgings | B381 | F-1 | R50250 | Annealed | 51 | ... | −59 | 240 | 138 |
| 23 | Ti | Fittings | B363 | WPT2 | R50400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 24 | Ti | Forgings | B381 | F-2 | R50400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 25 | Ti | Fittings | B363 | WPT3 | R50550 | Annealed | 52 | ... | −59 | 450 | 380 |
| 26 | Ti | Forgings | B381 | F-3 | R50550 | Annealed | 52 | ... | −59 | 450 | 380 |
| 27 | Ti–Pd | Fittings | B363 | WPT7 | R52400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 28 | Ti–Pd | Forgings | B381 | F-7 | R52400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 29 | Ti–0.3Mo–0.8Ni | Fittings | B363 | WPT12 | R53400 | Annealed | 52 | ... | −59 | 485 | 345 |
| 30 | Ti–0.3Mo–0.8Ni | Forgings | B381 | F-12 | R53400 | Annealed | 52 | ... | −59 | 485 | 345 |
| 31 | Ti | Bar | B348 | 1 | R50250 | Annealed | 51 | ... | −59 | 240 | 138 |
| 32 | Ti | Bar | B348 | 2 | R50400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 33 | Ti | Bar | B348 | 3 | R50550 | Annealed | 52 | ... | −59 | 450 | 380 |
| 34 | Ti–Pd | Bar | B348 | 7 | R52400 | Annealed | 51 | ... | −59 | 345 | 275 |
| 35 | Ti–0.3Mo–0.8Ni | Bar | B348 | 12 | R53400 | Annealed | 52 | ... | −59 | 485 | 345 |
| 36 | Ti | Castings | B367 | C-2 | R52550 | ... | 51 | (14)(44) | −59 | 345 | 275 |
| 37 | Ti | Castings | B367 | C-3 | R52550 | ... | 52 | (14)(44) | −59 | 450 | 380 |
| 38 | Ti–Pd | Castings | B367 | C-7 | R52700 | ... | 51 | (14)(44) | −59 | 345 | 275 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Max. Use Temp., °C | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 |
| 1 | 316 | *80.3* | *73.8* | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 2 | 316 | *80.3* | *73.8* | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 3 | 316 | *80.3* | *73.8* | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 4 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 5 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 6 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 7 | 316 | *149* | *139* | *124* | *113* | *102* | *93.3* | *84.7* | *77.7* | *70.7* | *66.2* | *61.7* | *57.7* |
| 8 | 316 | *149* | *139* | *124* | *113* | *102* | *93.3* | *84.7* | *77.7* | *70.7* | *66.2* | *61.7* | *57.7* |
| 9 | 316 | *149* | *139* | *124* | *113* | *102* | *93.3* | *84.7* | *77.7* | *70.7* | *66.2* | *61.7* | *57.7* |
| 10 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 11 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 12 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 13 | 316 | *161* | *156* | *148* | *139* | *130* | *123* | *116* | *111* | *106* | *104* | *101* | *98.3* |
| 14 | 316 | *161* | *156* | *148* | *139* | *130* | *123* | *116* | *111* | *106* | *104* | *101* | *98.3* |
| 15 | 316 | *161* | *156* | *148* | *139* | *130* | *123* | *116* | *111* | *106* | *104* | *101* | *98.3* |
| 16 | 316 | *80.3* | *73.8* | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 17 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 18 | 316 | *149* | *139* | *124* | *113* | *102* | *93.3* | *84.7* | *77.7* | *70.7* | *66.2* | *61.7* | *57.7* |
| 19 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 20 | 316 | *161* | *156* | *148* | *139* | *130* | *123* | *116* | *111* | *106* | *104* | *101* | *98.3* |
| 21 | 316 | *80.3* | *73.8* | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 22 | 316 | *80.3* | *73.8* | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 23 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 24 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 25 | 316 | *149* | *139* | *124* | *113* | *102* | *93.3* | *84.7* | *77.7* | *70.7* | *66.2* | *61.7* | *57.7* |
| 26 | 316 | *149* | *139* | *124* | *113* | *102* | *93.3* | *84.7* | *77.7* | *70.7* | *66.2* | *61.7* | *57.7* |
| 27 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 28 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 29 | 316 | *161* | *156* | *148* | *139* | *130* | *123* | *116* | *111* | *106* | *104* | *101* | *98.3* |
| 30 | 316 | *161* | *156* | *148* | *139* | *130* | *123* | *116* | *111* | *106* | *104* | *101* | *98.3* |
| 31 | 316 | *80.3* | *73.8* | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 32 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 33 | 316 | *149* | *139* | *124* | *113* | *102* | *93.3* | *84.7* | *77.7* | *70.7* | *66.2* | *61.7* | *57.7* |
| 34 | 316 | *115* | *108* | *98.3* | *90.7* | *83.0* | *77.5* | *72.0* | *67.3* | *62.7* | *58.7* | *54.7* | 50.7 |
| 35 | 316 | *161* | *156* | *148* | *139* | *130* | *123* | *116* | *111* | *106* | *104* | *101* | *98.3* |
| 36 | 260 | *115* | *106* | *92.7* | *85.3* | *78.0* | *72.2* | *66.3* | *61.5* | *56.7* | *52.0* | ... | ... |
| 37 | 260 | *149* | *139* | *124* | *113* | *102* | *93.3* | *84.7* | *77.7* | *70.7* | *65.3* | ... | ... |
| 38 | 260 | *115* | *106* | *92.7* | *85.3* | *78.0* | *72.2* | *66.3* | *61.5* | *56.7* | *52.0* | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | UNS No. | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 99.2Zr | Pipe & tube | B523 | R60702 | 61 | ... | −59 | 379 | 207 | 371 |
| 2 | 99.2Zr | Pipe & tube | B658 | R60702 | 61 | ... | −59 | 379 | 207 | 371 |
| 3 | 95.5Zr + 2.5Cb | Pipe & tube | B523 | R60705 | 62 | (73) | −59 | 552 | 379 | 371 |
| 4 | 95.5Zr + 2.5Cb | Pipe & tube | B658 | R60705 | 62 | (73) | −59 | 552 | 379 | 371 |
| 5 | 99.2Zr | Plate & sheet | B551 | R60702 | 61 | ... | −59 | 379 | 207 | 371 |
| 6 | 95.5Zr + 2.5Cb | Plate & sheet | B551 | R60705 | 62 | (73) | −59 | 552 | 379 | 371 |
| 7 | 99.2Zr | Forgings & bar | B493 | R60702 | 61 | ... | −59 | 379 | 207 | 371 |
| 8 | 99.2Zr | Forgings & bar | B550 | R60702 | 61 | ... | −59 | 379 | 207 | 371 |
| 9 | 95.5Zr + 2.5Cb | Forgings & bar | B493 | R60705 | 62 | (73) | −59 | 483 | 379 | 371 |
| 10 | 95.5Zr + 2.5Cb | Forgings & bar | B550 | R60705 | 62 | (73) | −59 | 552 | 379 | 371 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *126* | 119 | 103 | 92.4 | 82.5 | 73.6 | 65.7 | 58.8 | 52.8 | 47.8 | 43.7 | 40.4 | 37.8 | 36.1 |
| 2 | *126* | 119 | 103 | 92.4 | 82.5 | 73.6 | 65.7 | 58.8 | 52.8 | 47.8 | 43.7 | 40.4 | 37.8 | 36.1 |
| 3 | *184* | *169* | *149* | *139* | *130* | *123* | *116* | *111* | *106* | *101* | *97.6* | *94.6* | *92.4* | *91.0* |
| 4 | *184* | *169* | *149* | *139* | *130* | *123* | *116* | *111* | *106* | *101* | *97.6* | *94.6* | *92.4* | *91.0* |
| 5 | *126* | 119 | 103 | 92.4 | 82.5 | 73.6 | 65.7 | 58.8 | 52.8 | 47.8 | 43.7 | 40.4 | 37.8 | 36.1 |
| 6 | *184* | *169* | *149* | *139* | *130* | *123* | *116* | *111* | *106* | *101* | *97.6* | *94.6* | *92.4* | *91.0* |
| 7 | *126* | 119 | 103 | 92.4 | 82.5 | 73.6 | 65.7 | 58.8 | 52.8 | 47.8 | 43.7 | 40.4 | 37.8 | 36.1 |
| 8 | *126* | 119 | 103 | 92.4 | 82.5 | 73.6 | 65.7 | 58.8 | 52.8 | 47.8 | 43.7 | 40.4 | 37.8 | 36.1 |
| 9 | *184* | *169* | *149* | *139* | *130* | *123* | *116* | *111* | *106* | *101* | *97.6* | *94.6* | *92.4* | *91.0* |
| 10 | *184* | *169* | *149* | *139* | *130* | *123* | *116* | *111* | *106* | *101* | *97.6* | *94.6* | *92.4* | *91.0* |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 1 | Al–Mn–Cu | Smls. pipe & tube | B210 | Alclad 3003 | A83003 | O | ... | 21 |
| 2 | Al–Mn–Cu | Smls. pipe & tube | B210 | Alclad 3003 | A83003 | H112 | ... | 21 |
| 3 | Al–Mn–Cu | Smls. pipe & tube | B241 | Alclad 3003 | A83003 | O | ... | 21 |
| 4 | Al–Mn–Cu | Smls. pipe & tube | B241 | Alclad 3003 | A83003 | H112 | ... | 21 |
| 5 | Al–Mn–Cu | Smls. pipe & tube | B210 | Alclad 3003 | A83003 | H14 | ... | 21 |
| 6 | Al–Mn–Cu | Smls. pipe & tube | B210 | Alclad 3003 | A83003 | H18 | ... | 21 |
| 7 | 99.60Al | Smls. pipe & tube | B210 | 1060 | A91060 | O | ... | 21 |
| 8 | 99.60Al | Smls. pipe & tube | B210 | 1060 | A91060 | H112 | ... | 21 |
| 9 | 99.60Al | Smls. pipe & tube | B210 | 1060 | A91060 | H113 | ... | 21 |
| 10 | 99.60Al | Smls. pipe & tube | B241 | 1060 | A91060 | O | ... | 21 |
| 11 | 99.60Al | Smls. pipe & tube | B241 | 1060 | A91060 | H112 | ... | 21 |
| 12 | 99.60Al | Smls. pipe & tube | B241 | 1060 | A91060 | H113 | ... | 21 |
| 13 | 99.60Al | Smls. pipe & tube | B210 | 1060 | A91060 | H14 | ... | 21 |
| 14 | 99.0Al–Cu | Smls. pipe & tube | B241 | 1100 | A91100 | O | ... | 21 |
| 15 | 99.0Al–Cu | Smls. pipe & tube | B241 | 1100 | A91100 | H112 | ... | 21 |
| 16 | 99.0Al–Cu | Smls. pipe & tube | B210 | 1100 | A91100 | H113 | ... | 21 |
| 17 | 99.0Al–Cu | Smls. pipe & tube | B210 | 1100 | A91100 | H14 | ... | 21 |
| 18 | Al–Mn–Cu | Smls. pipe & tube | B210 | 3003 | A93003 | O | ... | 21 |
| 19 | Al–Mn–Cu | Smls. pipe & tube | B210 | 3003 | A93003 | H112 | ... | 21 |
| 20 | Al–Mn–Cu | Smls. pipe & tube | B241 | 3003 | A93003 | O | ... | 21 |
| 21 | Al–Mn–Cu | Smls. pipe & tube | B241 | 3003 | A93003 | H112 | ... | 21 |
| 22 | Al–Mn–Cu | Smls. pipe & tube | B491 | 3003 | A93003 | O | ... | 21 |
| 23 | Al–Mn–Cu | Smls. pipe & tube | B491 | 3003 | A93003 | H112 | ... | 21 |
| 24 | Al–Mn–Cu | Smls. pipe & tube | B210 | 3003 | A93003 | H14 | ... | 21 |
| 25 | Al–Mn–Cu | Smls. pipe & tube | B210 | 3003 | A93003 | H18 | ... | 21 |
| 26 | Al–Mn–Cu | Smls. pipe & tube | B241 | 3003 | A93003 | H18 | ... | 21 |
| 27 | Al–2.5Mg | Smls. pipe & tube | B210 | 5052 | A95052 | O | ... | 22 |
| 28 | Al–2.5Mg | Smls. pipe & tube | B241 | 5052 | A95052 | O | ... | 22 |
| 29 | Al–2.5Mg | Smls. pipe & tube | B210 | 5052 | A95052 | H32 | ... | 22 |
| 30 | Al–2.5Mg | Smls. pipe & tube | B210 | 5052 | A95052 | H34 | ... | 22 |
| 31 | Al–4.4Mg–Mn | Smls. pipe & tube | B210 | 5083 | A95083 | O | ... | 25 |
| 32 | Al–4.4Mg–Mn | Smls. pipe & tube | B210 | 5083 | A95083 | H112 | ... | 25 |
| 33 | Al–4.4Mg–Mn | Smls. pipe & tube | B241 | 5083 | A95083 | O | ... | 25 |
| 34 | Al–4.4Mg–Mn | Smls. pipe & tube | B241 | 5083 | A95083 | H112 | ... | 25 |
| 35 | Al–4.0Mg–Mn | Smls. pipe & tube | B210 | 5086 | A95086 | O | ... | 25 |
| 36 | Al–4.0Mg–Mn | Smls. pipe & tube | B210 | 5086 | A95086 | H112 | ... | 25 |
| 37 | Al–4.0Mg–Mn | Smls. pipe & tube | B241 | 5086 | A95086 | O | ... | 25 |
| 38 | Al–4.0Mg–Mn | Smls. pipe & tube | B241 | 5086 | A95086 | H112 | ... | 25 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 |
| 1 | (14)(33) | −269 | 90 | 31 | 204 | 20.7 | 19.9 | 19.3 | 18.4 | 17.3 | **13.6** | **10.9** | **10.5** |
| 2 | (14)(33) | −269 | 90 | 31 | 204 | 20.7 | 19.9 | 19.3 | 18.4 | 17.3 | **13.6** | **10.9** | **10.5** |
| 3 | (14)(33) | −269 | 90 | 31 | 204 | 20.7 | 19.9 | 19.3 | 18.4 | 17.3 | **13.6** | **10.9** | **10.5** |
| 4 | (14)(33) | −269 | 90 | 31 | 204 | 20.7 | 19.9 | 19.3 | 18.4 | 17.3 | **13.6** | **10.9** | **10.5** |
| 5 | (14)(33) | −269 | 131 | 110 | 204 | *43.7* | *43.7* | *43.7* | *41.7* | **29.0** | **21.1** | **16.7** | **16.1** |
| 6 | (14)(33) | −269 | 179 | 159 | 204 | *59.8* | *59.8* | *59.8* | *57.0* | **29.0** | **21.1** | **16.7** | **16.1** |
| 7 | (14)(33) | −269 | 59 | 17 | 204 | 11.5 | 11.5 | 10.9 | 9.8 | 8.8 | **7.5** | **5.8** | **5.5** |
| 8 | (14)(33) | −269 | 59 | 17 | 204 | 11.5 | 11.5 | 10.9 | 9.8 | 8.8 | **7.5** | **5.8** | **5.5** |
| 9 | (14)(33) | −269 | 59 | 17 | 204 | 11.5 | 11.5 | 10.9 | 9.8 | 8.8 | **7.5** | **5.8** | **5.5** |
| 10 | (14)(33) | −269 | 59 | 17 | 204 | 11.5 | 11.5 | 10.9 | 9.8 | 8.8 | **7.5** | **5.8** | **5.5** |
| 11 | (14)(33) | −269 | 59 | 17 | 204 | 11.5 | 11.5 | 10.9 | 9.8 | 8.8 | **7.5** | **5.8** | **5.5** |
| 12 | (14)(33) | −269 | 59 | 17 | 204 | 11.5 | 11.5 | 10.9 | 9.8 | 8.8 | **7.5** | **5.8** | **5.5** |
| 13 | (14)(33) | −269 | 83 | 69 | 204 | *27.6* | *27.6* | *27.6* | *26.6* | **18.1** | **12.7** | **8.4** | **7.8** |
| 14 | (14)(33) | −269 | 76 | 21 | 204 | 13.8 | 13.8 | 13.7 | 13.2 | **11.8** | **9.3** | **7.2** | **6.9** |
| 15 | (14)(33) | −269 | 76 | 21 | 204 | 13.8 | 13.8 | 13.7 | 13.2 | **11.8** | **9.3** | **7.2** | **6.9** |
| 16 | (14)(33) | −269 | 76 | 24 | 204 | 16.1 | 16.1 | 16.0 | 15.6 | **11.8** | **9.3** | **7.2** | **6.9** |
| 17 | (14)(33) | −269 | 110 | 97 | 204 | *36.8* | *36.8* | *36.1* | *33.1* | **19.0** | **13.6** | **8.5** | **7.8** |
| 18 | (14)(33) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 19 | (14)(33) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 20 | (14)(33) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 21 | (14)(33) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 22 | (14)(33) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 23 | (14)(33) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 24 | (14)(33) | −269 | 138 | 117 | 204 | *46.0* | *46.0* | *46.0* | *43.9* | **29.0** | **21.1** | **16.7** | **16.1** |
| 25 | (14)(33) | −269 | 186 | 165 | 204 | *62.1* | *62.1* | *60.3* | **52.1** | **36.1** | **24.5** | **18.0** | **17.0** |
| 26 | (14)(33) | −269 | 186 | 165 | 204 | *62.1* | *62.1* | *60.3* | **52.1** | **36.1** | **24.5** | **18.0** | **17.0** |
| 27 | (14) | −269 | 172 | 69 | 204 | 46.0 | 46.0 | 46.0 | 45.9 | **41.6** | **28.8** | **17.6** | **16.1** |
| 28 | (14) | −269 | 172 | 69 | 204 | 46.0 | 46.0 | 46.0 | 45.9 | **41.6** | **28.8** | **17.6** | **16.1** |
| 29 | (14)(33) | −269 | 214 | 159 | 204 | *71.2* | *71.2* | *71.2* | *71.0* | **41.6** | **28.8** | **17.6** | **16.1** |
| 30 | (14)(33) | −269 | 234 | 179 | 204 | *78.1* | *78.1* | *78.1* | *78.1* | **41.6** | **28.8** | **17.6** | **16.1** |
| 31 | (33) | −269 | 269 | 110 | 65 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |
| 32 | (33) | −269 | 269 | 110 | 65 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |
| 33 | (33) | −269 | 269 | 110 | 65 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |
| 34 | (33) | −269 | 269 | 110 | 65 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |
| 35 | (33) | −269 | 241 | 97 | 65 | 64.4 | 64.4 | ... | ... | ... | ... | ... | ... |
| 36 | (33) | −269 | 241 | 97 | 65 | 64.4 | 64.4 | ... | ... | ... | ... | ... | ... |
| 37 | (33) | −269 | 241 | 97 | 65 | 64.4 | 64.4 | ... | ... | ... | ... | ... | ... |
| 38 | (33) | −269 | 241 | 97 | 65 | 64.4 | 64.4 | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 39 | Al–4.0Mg–Mn | Smls. pipe & tube | B210 | 5086 | A95086 | H32 | ... | 25 |
| 40 | Al–4.0Mg–Mn | Smls. pipe & tube | B210 | 5086 | A95086 | H34 | ... | 25 |
| 41 | Al–3.5Mg | Smls. pipe & tube | B210 | 5154 | A95154 | O | ... | 22 |
| 42 | Al–3.5Mg | Smls. pipe & tube | B210 | 5154 | A95154 | H34 | ... | 22 |
| 43 | Al–2.7Mg–Mn | Smls. pipe & tube | B241 | 5454 | A95454 | O | ... | 22 |
| 44 | Al–2.7Mg–Mn | Smls. pipe & tube | B241 | 5454 | A95454 | H112 | ... | 22 |
| 45 | Al–5.1Mg–Mn | Smls. pipe & tube | B210 | 5456 | A95456 | O | ... | 25 |
| 46 | Al–5.1Mg–Mn | Smls. pipe & tube | B210 | 5456 | A95456 | H112 | ... | 25 |
| 47 | Al–5.1Mg–Mn | Smls. pipe & tube | B241 | 5456 | A95456 | O | ... | 25 |
| 48 | Al–5.1Mg–Mn | Smls. pipe & tube | B241 | 5456 | A95456 | H112 | ... | 25 |
| 49 | Al–Mg–Si–Cu | Smls. pipe & tube | B210 | 6061 | A96061 | T4 wld. | ... | 23 |
| 50 | Al–Mg–Si–Cu | Smls. pipe & tube | B210 | 6061 | A96061 | T6 wld. | ... | 23 |
| 51 | Al–Mg–Si–Cu | Smls. pipe & tube | B241 | 6061 | A96061 | T4 wld. | ... | 23 |
| 52 | Al–Mg–Si–Cu | Smls. pipe & tube | B241 | 6061 | A96061 | T6 wld. | ... | 23 |
| 53 | Al–Mg–Si–Cu | Smls. pipe & tube | B241 | 6061 | A96061 | T4 | ... | 23 |
| 54 | Al–Mg–Si–Cu | Smls. pipe & tube | B210 | 6061 | A96061 | T4 | ... | 23 |
| 55 | Al–Mg–Si–Cu | Smls. pipe & tube | B241 | 6061 | A96061 | T6 | ... | 23 |
| 56 | Al–Mg–Si–Cu | Smls. pipe & tube | B210 | 6061 | A96061 | T6 | ... | 23 |
| 57 | Al–Mg–Si | Smls. pipe & tube | B210 | 6063 | A96063 | T4 wld. | ... | 23 |
| 58 | Al–Mg–Si | Smls. pipe & tube | B210 | 6063 | A96063 | T5 wld. | ... | 23 |
| 59 | Al–Mg–Si | Smls. pipe & tube | B210 | 6063 | A96063 | T6 wld. | ... | 23 |
| 60 | Al–Mg–Si | Smls. pipe & tube | B241 | 6063 | A96063 | T4 wld. | ... | 23 |
| 61 | Al–Mg–Si | Smls. pipe & tube | B241 | 6063 | A96063 | T5 wld. | ... | 23 |
| 62 | Al–Mg–Si | Smls. pipe & tube | B241 | 6063 | A96063 | T6 wld. | ... | 23 |
| 63 | Al–Mg–Si | Smls. pipe & tube | B241 | 6063 | A96063 | T4 | ≤13 | 23 |
| 64 | Al–Mg–Si | Smls. pipe & tube | B210 | 6063 | A96063 | T4 | ... | 23 |
| 65 | Al–Mg–Si | Smls. pipe & tube | B241 | 6063 | A96063 | T5 | ≤13 | 23 |
| 66 | Al–Mg–Si | Smls. pipe & tube | B241 | 6063 | A96063 | T6 | ... | 23 |
| 67 | Al–Mg–Si | Smls. pipe & tube | B210 | 6063 | A96063 | T6 | ... | 23 |
| 68 | Al–4.4Mg–Mn | Wld. pipe & tube | B547 | 5083 | A95083 | O | ... | 25 |
| 69 | Al–Mn–Cu | Structural tube | B221 | Alclad 3003 | A83003 | O | ... | 21 |
| 70 | Al–Mn–Cu | Structural tube | B221 | Alclad 3003 | A83003 | H112 | ... | 21 |
| 71 | 99.0Al | Structural tube | B221 | 1060 | A91060 | O | ... | 21 |
| 72 | 99.0Al | Structural tube | B221 | 1060 | A91060 | H112 | ... | 21 |
| 73 | 99.0Al–Cu | Structural tube | B221 | 1100 | A91100 | O | ... | 21 |
| 74 | 99.0Al–Cu | Structural tube | B221 | 1100 | A91100 | H112 | ... | 21 |
| 75 | Al–Mn–Cu | Structural tube | B221 | 3003 | A93003 | O | ... | 21 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39 | (33) | −269 | 276 | 193 | 65 | *91.9* | *91.9* | ... | ... | ... | ... | ... | ... |
| 40 | (33) | −269 | 303 | 234 | 65 | *101.1* | *101.1* | ... | ... | ... | ... | ... | ... |
| 41 | ... | −269 | 207 | 76 | 65 | 50.6 | 50.6 | ... | ... | ... | ... | ... | ... |
| 42 | (33) | −269 | 269 | 200 | 65 | *89.6* | *89.6* | ... | ... | ... | ... | ... | ... |
| 43 | (33) | −269 | 214 | 83 | 204 | 55.2 | 55.2 | 55.2 | **48.9** | **37.5** | **28.6** | **21.7** | **20.7** |
| 44 | (33) | −269 | 214 | 83 | 204 | 55.2 | 55.2 | 55.2 | **48.9** | **37.5** | **28.6** | **21.7** | **20.7** |
| 45 | (33) | −269 | 283 | 131 | 65 | 87.3 | 87.3 | ... | ... | ... | ... | ... | ... |
| 46 | (33) | −269 | 283 | 131 | 65 | 87.3 | 87.3 | ... | ... | ... | ... | ... | ... |
| 47 | (33) | −269 | 283 | 131 | 65 | 87.3 | 87.3 | ... | ... | ... | ... | ... | ... |
| 48 | (33) | −269 | 283 | 131 | 65 | 87.3 | 87.3 | ... | ... | ... | ... | ... | ... |
| 49 | (22)(63) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 50 | (22)(63) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 51 | (22)(63) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 52 | (22)(63) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 53 | (33)(63) | −269 | 179 | 110 | 204 | *59.8* | *59.8* | *59.8* | *58.9* | *56.3* | *50.2* | *38.3* | *35.9* |
| 54 | (33) | −269 | 207 | 110 | 204 | *68.9* | *68.9* | *68.9* | *67.8* | *64.8* | *57.9* | **40.2** | **35.9** |
| 55 | (33)(63) | −269 | 262 | 241 | 204 | *87.3* | *87.3* | *87.3* | *83.6* | *72.3* | *57.2* | **40.2** | **35.9** |
| 56 | (33) | −269 | 290 | 241 | 204 | *96.5* | *96.5* | *96.5* | *92.5* | *79.9* | *63.1* | **40.2** | **35.9** |
| 57 | ... | −269 | 117 | ... | 204 | *39.1* | *39.1* | *37.9* | *35.9* | *32.1* | *25.7* | *17.6* | *13.8* |
| 58 | ... | −269 | 117 | ... | 204 | *39.1* | *39.1* | *37.9* | *35.9* | *32.1* | *25.7* | *17.6* | *13.8* |
| 59 | ... | −269 | 117 | ... | 204 | *39.1* | *39.1* | *37.9* | *35.9* | *32.1* | *25.7* | *17.6* | *13.8* |
| 60 | ... | −269 | 117 | ... | 204 | *39.1* | *39.1* | *37.9* | *35.9* | *32.1* | *25.7* | *17.6* | *13.8* |
| 61 | ... | −269 | 117 | ... | 204 | *39.1* | *39.1* | *37.9* | *35.9* | *32.1* | *25.7* | *17.6* | *13.8* |
| 62 | ... | −269 | 117 | ... | 204 | *39.1* | *39.1* | *37.9* | *35.9* | *32.1* | *25.7* | *17.6* | *13.8* |
| 63 | (33) | −269 | 131 | 69 | 204 | *43.7* | *43.7* | *43.7* | *43.7* | *43.7* | *35.8* | *23.9* | *10.3* |
| 64 | (33) | −269 | 152 | 69 | 204 | 46.0 | 45.8 | 45.8 | 45.5 | 45.5 | *41.5* | *27.7* | *12.0* |
| 65 | (33) | −269 | 152 | 110 | 204 | *50.6* | *50.6* | *48.7* | *46.6* | *41.4* | **27.5** | **15.3** | **13.8** |
| 66 | (33) | −269 | 207 | 172 | 204 | *68.9* | *68.9* | *67.7* | *59.0* | *45.9* | **27.5** | **15.3** | **49.3** |
| 67 | (33) | −269 | 228 | 193 | 204 | *75.8* | *75.8* | *74.8* | **64.0** | **49.2** | **27.5** | **15.3** | **13.8** |
| 68 | ... | −269 | 276 | 124 | 65 | *82.7* | *82.7* | ... | ... | ... | ... | ... | ... |
| 69 | (33)(69) | −269 | 90 | 31 | 204 | 20.7 | 19.9 | 19.3 | 18.4 | 17.3 | **13.6** | **10.9** | **10.5** |
| 70 | (33)(69) | −269 | 90 | 31 | 204 | 20.7 | 19.9 | 19.3 | 18.4 | 17.3 | **13.6** | **10.9** | **10.5** |
| 71 | (33)(69) | −269 | 59 | 17 | 204 | 11.5 | 11.5 | 10.9 | 9.8 | 8.8 | **7.5** | **5.8** | **5.5** |
| 72 | (33)(69) | −269 | 59 | 17 | 204 | 11.5 | 11.5 | 10.9 | 9.8 | 8.8 | **7.5** | **5.8** | **5.5** |
| 73 | (33)(69) | −269 | 76 | 21 | 204 | 13.8 | 13.8 | 13.7 | 13.2 | **11.8** | **9.3** | **7.2** | **6.9** |
| 74 | (33)(69) | −269 | 76 | 21 | 204 | 13.8 | 13.8 | 13.7 | 13.2 | **11.8** | **9.3** | **7.2** | **6.9** |
| 75 | (33)(69) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 76 | Al–Mn–Cu | Structural tube | B221 | 3003 | A93003 | H112 | ... | 21 |
| 77 | Al–2.5Mg | Structural tube | B221 | 5052 | A95052 | O | ... | 22 |
| 78 | Al–4.4Mg–Mn | Structural tube | B221 | 5083 | A95083 | O | ... | 25 |
| 79 | Al–4.0Mg–Mn | Structural tube | B221 | 5086 | A95086 | O | ... | 25 |
| 80 | Al–3.5Mg | Structural tube | B221 | 5154 | A95154 | O | ... | 22 |
| 81 | Al–2.7Mg–Mn | Structural tube | B221 | 5454 | A95454 | O | ... | 22 |
| 82 | Al–5.1Mg–Mn | Structural tube | B221 | 5456 | A95456 | O | ... | 25 |
| 83 | Al–Mg–Si–Cu | Structural tube | B221 | 6061 | A96061 | T4 wld. | ... | 23 |
| 84 | Al–Mg–Si–Cu | Structural tube | B221 | 6061 | A96061 | T6 wld. | ... | 23 |
| 85 | Al–Mg–Si–Cu | Structural tube | B221 | 6061 | A96061 | T4 | ... | 23 |
| 86 | Al–Mg–Si–Cu | Structural tube | B221 | 6061 | A96061 | T6 | ... | 23 |
| 87 | Al–Mg–Si | Structural tube | B221 | 6063 | A96063 | T4 wld. | ... | 23 |
| 88 | Al–Mg–Si | Structural tube | B221 | 6063 | A96063 | T5 wld. | ... | 23 |
| 89 | Al–Mg–Si | Structural tube | B221 | 6063 | A96063 | T6 wld. | ... | 23 |
| 90 | Al–Mg–Si | Structural tube | B221 | 6063 | A96063 | T4 | ≤13 | 23 |
| 91 | Al–Mg–Si | Structural tube | B221 | 6063 | A96063 | T5 | ≤13 | 23 |
| 92 | Al–Mg–Si | Structural tube | B221 | 6063 | A96063 | T6 | ... | 23 |
| 93 | Al–Mn–Cu | Plate & sheet | B209 | Alclad 3003 | A83003 | O | ≥0.15, <13 | 21 |
| 94 | Al–Mn–Cu | Plate & sheet | B209 | Alclad 3003 | A83003 | O | ≥13, ≤75 | 21 |
| 95 | Al–Mn–Cu | Plate & sheet | B209 | Alclad 3003 | A83003 | H112 | ≥13, ≤50 | 21 |
| 96 | Al–Mn–Cu | Plate & sheet | B209 | Alclad 3003 | A83003 | H12 | ≥0.43, <13 | 21 |
| 97 | Al–Mn–Cu | Plate & sheet | B209 | Alclad 3003 | A83003 | H12 | ≥13, ≤50 | 21 |
| 98 | Al–Mn–Cu | Plate & sheet | B209 | Alclad 3003 | A83003 | H14 | ≥0.23, <13 | 21 |
| 99 | Al–Mn–Cu | Plate & sheet | B209 | Alclad 3003 | A83003 | H14 | ≥13, ≤25 | 21 |
| 100 | Al–Mn–Mg | Plate & sheet | B209 | Alclad 3004 | A83004 | O | ≥0.15, <13 | 22 |
| 101 | Al–Mn–Mg | Plate & sheet | B209 | Alclad 3004 | A83004 | O | ≥13, ≤75 | 22 |
| 102 | Al–Mn–Mg | Plate & sheet | B209 | Alclad 3004 | A83004 | H112 | ≥6, <13 | 22 |
| 103 | Al–Mn–Mg | Plate & sheet | B209 | Alclad 3004 | A83004 | H112 | ≥13, ≤75 | 22 |
| 104 | Al–Mn–Mg | Plate & sheet | B209 | Alclad 3004 | A83004 | H32 | ≥0.43, <13 | 22 |
| 105 | Al–Mn–Mg | Plate & sheet | B209 | Alclad 3004 | A83004 | H32 | ≥13, ≤50 | 22 |
| 106 | Al–Mn–Mg | Plate & sheet | B209 | Alclad 3004 | A83004 | H34 | ≥0.23, <13 | 22 |
| 107 | Al–Mn–Mg | Plate & sheet | B209 | Alclad 3004 | A83004 | H34 | ≥13, ≤25 | 22 |
| 108 | Al–Mg–Si–Cu | Plate & sheet | B209 | Alclad 6061 | A86061 | T4 wld. | ... | 23 |
| 109 | Al–Mg–Si–Cu | Plate & sheet | B209 | Alclad 6061 | A86061 | T6 wld. | ... | 23 |
| 110 | Al–Mg–Si–Cu | Plate & sheet | B209 | Alclad 6061 | A86061 | T4 | ... | 23 |
| 111 | Al–Mg–Si–Cu | Plate & sheet | B209 | Alclad 6061 | A86061 | T451 | ≥6, <13 | 23 |
| 112 | Al–Mg–Si–Cu | Plate & sheet | B209 | Alclad 6061 | A86061 | T451 | ≥13, ≤75 | 23 |
| 113 | Al–Mg–Si–Cu | Plate & sheet | B209 | Alclad 6061 | A86061 | T6 | ... | 23 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| | | | | | | Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 |
| 76 | (33)(69) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 77 | (69) | −269 | 172 | 69 | 204 | 46.0 | 46.0 | 46.0 | 45.9 | **41.6** | **28.8** | **17.6** | **16.1** |
| 78 | (69) | −269 | 269 | 110 | 65 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |
| 79 | (69) | −269 | 241 | 97 | 65 | 64.4 | 64.4 | ... | ... | ... | ... | ... | ... |
| 80 | (69) | −269 | 207 | 76 | 65 | 50.6 | 50.6 | ... | ... | ... | ... | ... | ... |
| 81 | (69) | −269 | 214 | 83 | 204 | 55.2 | 55.2 | 55.2 | **48.9** | **37.5** | **28.6** | **21.7** | **20.7** |
| 82 | (69) | −269 | 283 | 131 | 65 | 87.3 | 87.3 | ... | ... | ... | ... | ... | ... |
| 83 | (22)(63)(69) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 84 | (22)(63)(69) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 85 | (33)(63)(69) | −269 | 179 | 110 | 204 | *59.8* | *59.8* | *59.8* | *58.9* | *56.3* | *50.2* | *38.3* | *35.9* |
| 86 | (33)(63)(69) | −269 | 262 | 241 | 204 | *87.3* | *87.3* | *87.3* | *83.6* | *72.3* | *57.2* | **40.2** | **35.9** |
| 87 | (69) | −269 | 117 | ... | 204 | *39.1* | *39.1* | *37.9* | *35.9* | *32.1* | *25.7* | *17.6* | *13.8* |
| 88 | (69) | −269 | 117 | ... | 204 | *39.1* | *39.1* | *37.9* | *35.9* | *32.1* | *25.7* | *17.6* | *13.8* |
| 89 | (69) | −269 | 117 | ... | 204 | *39.1* | *39.1* | *37.9* | *35.9* | *32.1* | *25.7* | *17.6* | *13.8* |
| 90 | (13)(33)(69) | −269 | 131 | 69 | 204 | *43.7* | *43.7* | *43.7* | *43.7* | *43.7* | *35.8* | *23.9* | *10.3* |
| 91 | (13)(33)(69) | −269 | 152 | 110 | 204 | *50.6* | *50.6* | *48.7* | *46.6* | *41.4* | **27.5** | **15.3** | **13.8** |
| 92 | (33)(69) | −269 | 207 | 172 | 204 | *68.9* | *68.9* | *67.7* | *59.0* | *45.9* | **27.5** | **15.3** | **49.3** |
| 93 | (66) | −269 | 90 | 31 | 204 | 20.7 | 19.9 | 19.3 | 18.4 | 17.3 | **13.6** | **10.9** | **10.5** |
| 94 | (68) | −269 | 97 | 34 | 204 | 23.0 | 22.2 | 21.3 | 20.4 | ***18.2*** | **13.6** | **10.9** | **10.5** |
| 95 | (33)(66) | −269 | 103 | 41 | 204 | 27.6 | 26.6 | 25.6 | 24.4 | ***18.2*** | **13.6** | **10.9** | **10.5** |
| 96 | (33)(66) | −269 | 110 | 76 | 204 | *36.8* | *36.8* | *35.9* | *33.7* | ***29.0*** | **21.1** | **16.7** | **16.1** |
| 97 | (33)(68) | −269 | 117 | 83 | 204 | *39.1* | *39.1* | *39.1* | *39.1* | ***29.0*** | **21.1** | **16.7** | **16.1** |
| 98 | (33)(66) | −269 | 131 | 110 | 204 | *43.7* | *43.7* | *43.7* | *41.7* | ***29.0*** | **21.1** | **16.7** | **16.1** |
| 99 | (33)(68) | −269 | 138 | 117 | 204 | *46.0* | *46.0* | *46.0* | *43.9* | ***29.0*** | **21.1** | **16.7** | **16.1** |
| 100 | (66) | −269 | 145 | 55 | 204 | 36.8 | 36.8 | 36.8 | 36.8 | 36.8 | **26.9** | **17.4** | **16.1** |
| 101 | (68) | −269 | 152 | 59 | 204 | 39.1 | 39.1 | 39.1 | 39.1 | **38.9** | **26.9** | **17.4** | **16.1** |
| 102 | (33)(66) | −269 | 152 | 59 | 204 | 39.1 | 39.1 | 39.1 | 39.1 | **38.9** | **26.9** | **17.4** | **16.1** |
| 103 | (33)(68) | −269 | 159 | 62 | 204 | 41.4 | 41.4 | 41.4 | 41.4 | **38.9** | **26.9** | **17.4** | **16.1** |
| 104 | (33)(66) | −269 | 186 | 138 | 204 | *62.1* | *62.1* | *62.1* | **60.4** | **38.9** | **26.9** | **17.4** | **16.1** |
| 105 | (33)(68) | −269 | 193 | 145 | 204 | *64.4* | *64.4* | *64.4* | **60.4** | **38.9** | **26.9** | **17.4** | **16.1** |
| 106 | (33)(66) | −269 | 214 | 165 | 204 | *71.2* | *71.2* | *71.2* | *71.2* | **38.9** | **26.9** | **17.4** | **16.1** |
| 107 | (33)(68) | −269 | 221 | 172 | 204 | *73.5* | *73.5* | *73.5* | *73.5* | **38.9** | **26.9** | **17.4** | **16.1** |
| 108 | (22)(63) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 109 | (22)(63) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 110 | (33)(66) | −269 | 186 | 97 | 204 | *62.1* | *62.1* | *62.1* | *61.0* | *58.3* | *52.1* | *39.7* | *35.9* |
| 111 | (33)(66) | −269 | 186 | 97 | 204 | *62.1* | *62.1* | *62.1* | *61.0* | *58.3* | *52.1* | *39.7* | *35.9* |
| 112 | (33)(68) | −269 | 207 | 110 | 204 | *68.9* | *68.9* | *68.9* | *67.8* | *64.8* | *57.9* | **40.2** | **35.9** |
| 113 | (33)(66) | −269 | 262 | 221 | 204 | *87.3* | *87.3* | *87.3* | *83.8* | *72.3* | *57.2* | **40.2** | **35.9** |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 114 | Al–Mg–Si–Cu | Plate & sheet | B209 | Alclad 6061 | A86061 | T651 | ≥6, <13 | 23 |
| 115 | Al–Mg–Si–Cu | Plate & sheet | B209 | Alclad 6061 | A86061 | T651 | ≥13, ≤100 | 23 |
| 116 | 99.60Al | Plate & sheet | B209 | 1060 | A91060 | O | ... | 21 |
| 117 | 99.60Al | Plate & sheet | B209 | 1060 | A91060 | H112 | ≥13, ≤25 | 21 |
| 118 | 99.60Al | Plate & sheet | B209 | 1060 | A91060 | H12 | ... | 21 |
| 119 | 99.60Al | Plate & sheet | B209 | 1060 | A91060 | H14 | ... | 21 |
| 120 | 99.0Al–Cu | Plate & sheet | B209 | 1100 | A91100 | O | ... | 21 |
| 121 | 99.0Al–Cu | Plate & sheet | B209 | 1100 | A91100 | H112 | ≥13, ≤50 | 21 |
| 122 | 99.0Al–Cu | Plate & sheet | B209 | 1100 | A91100 | H12 | ... | 21 |
| 123 | 99.0Al–Cu | Plate & sheet | B209 | 1100 | A91100 | H14 | ... | 21 |
| 124 | Al–Mn–Cu | Plate & sheet | B209 | 3003 | A93003 | O | ... | 21 |
| 125 | Al–Mn–Cu | Plate & sheet | B209 | 3003 | A93003 | H112 | ≥13, ≤50 | 21 |
| 126 | Al–Mn–Cu | Plate & sheet | B209 | 3003 | A93003 | H12 | ... | 21 |
| 127 | Al–Mn–Cu | Plate & sheet | B209 | 3003 | A93003 | H14 | ... | 21 |
| 128 | Al–Mn–Mg | Plate & sheet | B209 | 3004 | A93004 | O | ... | 22 |
| 129 | Al–Mn–Mg | Plate & sheet | B209 | 3004 | A93004 | H112 | ... | 22 |
| 130 | Al–Mn–Mg | Plate & sheet | B209 | 3004 | A93004 | H32 | ... | 22 |
| 131 | Al–Mn–Mg | Plate & sheet | B209 | 3004 | A93004 | H34 | ... | 22 |
| 132 | Al–1.5Mg | Plate & sheet | B209 | 5050 | A95050 | O | ... | 21 |
| 133 | Al–1.5Mg | Plate & sheet | B209 | 5050 | A95050 | H112 | ... | 21 |
| 134 | Al–1.5Mg | Plate & sheet | B209 | 5050 | A95050 | H32 | ... | 21 |
| 135 | Al–1.5Mg | Plate & sheet | B209 | 5050 | A95050 | H34 | ... | 21 |
| 136 | Al–2.5Mg | Plate & sheet | B209 | 5052 | A95052 | O | ... | 22 |
| 137 | Al–2.5Mg | Plate & sheet | B209 | 5052 | A95052 | H112 | ≥13, ≤75 | 22 |
| 138 | Al–2.5Mg | Plate & sheet | B209 | 5052 | A95052 | H32 | ... | 22 |
| 139 | Al–2.5Mg | Plate & sheet | B209 | 5052 | A95052 | H34 | ... | 22 |
| 140 | Al–4.4Mg–Mn | Plate & sheet | B209 | 5083 | A95083 | O | ≥1.3, ≤38 | 25 |
| 141 | Al–4.4Mg–Mn | Plate & sheet | B209 | 5083 | A95083 | H32 | ≥5, ≤38 | 25 |
| 142 | Al–4.0Mg–Mn | Plate & sheet | B209 | 5086 | A95086 | O | ... | 25 |
| 143 | Al–4.0Mg–Mn | Plate & sheet | B209 | 5086 | A95086 | H112 | ≥13, ≤25 | 25 |
| 144 | Al–4.0Mg–Mn | Plate & sheet | B209 | 5086 | A95086 | H32 | ... | 25 |
| 145 | Al–4.0Mg–Mn | Plate & sheet | B209 | 5086 | A95086 | H34 | ... | 25 |
| 146 | Al–3.5Mg | Plate & sheet | B209 | 5154 | A95154 | O | ... | 22 |
| 147 | Al–3.5Mg | Plate & sheet | B209 | 5154 | A95154 | H112 | ≥13, ≤75 | 22 |
| 148 | Al–3.5Mg | Plate & sheet | B209 | 5154 | A95154 | H32 | ... | 22 |
| 149 | Al–3.5Mg | Plate & sheet | B209 | 5154 | A95154 | H34 | ... | 22 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 114 | (33)(66) | −269 | 262 | 221 | 204 | *87.3* | *87.3* | *87.3* | *83.8* | *72.3* | *57.2* | **40.2** | **35.9** |
| 115 | (33)(68) | −269 | 290 | 241 | 204 | *96.5* | *96.5* | *96.5* | *92.5* | *79.9* | *63.1* | **40.2** | **35.9** |
| 116 | ... | −269 | 55 | 17 | 204 | 11.5 | 11.5 | 10.9 | 9.8 | 8.8 | **7.5** | **5.8** | **5.5** |
| 117 | (13)(33) | −269 | 69 | 34 | 204 | *23.0* | *21.8* | *19.1* | *17.0* | *15.0* | **11.8** | **7.5** | **5.9** |
| 118 | (33) | −269 | 76 | 62 | 204 | *25.3* | *25.3* | *23.1* | *21.0* | **18.1** | **12.7** | **8.4** | **7.8** |
| 119 | (33) | −269 | 83 | 69 | 204 | *27.6* | *27.6* | *27.6* | *26.6* | **18.1** | **12.7** | **8.4** | **7.8** |
| 120 | ... | −269 | 76 | 24 | 204 | 16.1 | 16.1 | 16.0 | 15.6 | **11.8** | **9.3** | **7.2** | **6.9** |
| 121 | (13)(33) | −269 | 83 | 34 | 204 | 23.0 | 23.0 | 22.7 | **21.6** | **16.3** | **11.8** | **7.5** | **6.9** |
| 122 | (33) | −269 | 97 | 76 | 204 | *32.2* | *32.2* | *31.3* | **25.2** | **19.0** | **13.6** | **8.5** | **7.8** |
| 123 | (33) | −269 | 110 | 97 | 204 | *36.8* | *36.8* | *36.1* | *33.1* | **19.0** | **13.6** | **8.5** | **7.8** |
| 124 | ... | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 125 | (13)(33) | −269 | 103 | 41 | 204 | 27.6 | 26.6 | 25.6 | 24.4 | **18.2** | **13.6** | **10.9** | **10.5** |
| 126 | (33) | −269 | 117 | 83 | 204 | *39.1* | *39.1* | *38.1* | *35.8* | **29.0** | **21.1** | **16.7** | **16.1** |
| 127 | (33) | −269 | 138 | 117 | 204 | *46.0* | *46.0* | *46.0* | *43.9* | **29.0** | **21.1** | **16.7** | **16.1** |
| 128 | ... | −269 | 152 | 59 | 204 | 39.1 | 39.1 | 39.1 | 39.0 | ***38.9*** | **26.9** | **17.4** | **16.1** |
| 129 | (33) | −269 | 159 | 62 | 204 | 41.4 | 41.4 | 41.4 | 41.4 | ***38.9*** | **26.9** | **17.4** | **16.1** |
| 130 | (33) | −269 | 193 | 145 | 204 | *64.4* | *64.4* | *64.4* | **60.4** | **38.9** | **26.9** | **17.4** | **16.1** |
| 131 | (33) | −269 | 221 | 172 | 204 | *73.5* | *73.5* | *73.5* | *73.5* | **38.9** | **26.9** | **17.4** | **16.1** |
| 132 | ... | −269 | 124 | 41 | 204 | 27.6 | 27.6 | 27.5 | 27.5 | 27.5 | **20.1** | **10.8** | **9.7** |
| 133 | (33) | −269 | 138 | 55 | 204 | 36.8 | 36.7 | 36.7 | 36.6 | **35.8** | **20.1** | **10.8** | **9.7** |
| 134 | (33) | −269 | 152 | 110 | 204 | *50.6* | *50.6* | *50.6* | *50.6* | **35.8** | **20.1** | **10.8** | **9.7** |
| 135 | (33) | −269 | 172 | 138 | 204 | *57.5* | *57.5* | *57.5* | *57.5* | **35.8** | **20.1** | **10.8** | **9.7** |
| 136 | ... | −269 | 172 | 65 | 204 | 43.7 | 43.7 | 43.7 | 43.6 | **41.6** | **28.8** | **17.6** | **16.1** |
| 137 | (13)(33) | −269 | 172 | 65 | 204 | 43.7 | 43.7 | 43.7 | 43.6 | **41.6** | **28.8** | **17.6** | **16.1** |
| 138 | (33) | −269 | 214 | 159 | 204 | *71.2* | *71.2* | *71.2* | *71.0* | **41.6** | **28.8** | **17.6** | **16.1** |
| 139 | (33) | −269 | 234 | 179 | 204 | *78.1* | *78.1* | *78.1* | *78.1* | **41.6** | **28.8** | **17.6** | **16.1** |
| 140 | (13) | −269 | 276 | 124 | 65 | 82.7 | 82.7 | ... | ... | ... | ... | ... | ... |
| 141 | (13)(33) | −269 | 303 | 214 | 65 | *101.1* | *101.1* | ... | ... | ... | ... | ... | ... |
| 142 | ... | −269 | 241 | 97 | 65 | 64.4 | 64.4 | ... | ... | ... | ... | ... | ... |
| 143 | (13)(33) | −269 | 241 | 110 | 65 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |
| 144 | (33) | −269 | 276 | 193 | 65 | *91.9* | *91.9* | ... | ... | ... | ... | ... | ... |
| 145 | (33) | −269 | 303 | 234 | 65 | *101.1* | *101.1* | ... | ... | ... | ... | ... | ... |
| 146 | ... | −269 | 207 | 76 | 65 | 50.6 | 50.4 | ... | ... | ... | ... | ... | ... |
| 147 | (13)(33) | −269 | 207 | 76 | 65 | 50.6 | 50.4 | ... | ... | ... | ... | ... | ... |
| 148 | (33) | −269 | 248 | 179 | 65 | *82.7* | *82.7* | ... | ... | ... | ... | ... | ... |
| 149 | (33) | −269 | 269 | 200 | 65 | *89.6* | *89.6* | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 150 | Al–3.5Mg | Plate & sheet | B209 | 5254 | A95254 | O | ... | 22 |
| 151 | Al–3.5Mg | Plate & sheet | B209 | 5254 | A95254 | H112 | ≥13, ≤75 | 22 |
| 152 | Al–3.5Mg | Plate & sheet | B209 | 5254 | A95254 | H32 | ... | 22 |
| 153 | Al–3.5Mg | Plate & sheet | B209 | 5254 | A95254 | H34 | ... | 22 |
| 154 | Al–2.7Mg–Mn | Plate & sheet | B209 | 5454 | A95454 | O | ... | 22 |
| 155 | Al–2.7Mg–Mn | Plate & sheet | B209 | 5454 | A95454 | H112 | ≥13, ≤75 | 22 |
| 156 | Al–2.7Mg–Mn | Plate & sheet | B209 | 5454 | A95454 | H32 | ... | 22 |
| 157 | Al–2.7Mg–Mn | Plate & sheet | B209 | 5454 | A95454 | H34 | ... | 22 |
| 158 | Al–5.1Mg–Mn | Plate & sheet | B209 | 5456 | A95456 | O | ≥1.3, ≤38 | 25 |
| 159 | Al–5.1Mg–Mn | Plate & sheet | B209 | 5456 | A95456 | H32 | ≥5, <13 | 25 |
| 160 | Al–2.5Mg | Plate & sheet | B209 | 5652 | A95652 | O | ... | 22 |
| 161 | Al–2.5Mg | Plate & sheet | B209 | 5652 | A95652 | H112 | ≥13, ≤75 | 22 |
| 162 | Al–2.5Mg | Plate & sheet | B209 | 5652 | A95652 | H32 | ... | 22 |
| 163 | Al–2.5Mg | Plate & sheet | B209 | 5652 | A95652 | H34 | ... | 22 |
| 164 | Al–Mg–Si–Cu | Plate & sheet | B209 | 6061 | A96061 | T4 wld. | ... | 23 |
| 165 | Al–Mg–Si–Cu | Plate & sheet | B209 | 6061 | A96061 | T6 wld. | ... | 23 |
| 166 | Al–Mg–Si–Cu | Plate & sheet | B209 | 6061 | A96061 | T4 | ... | 23 |
| 167 | Al–Mg–Si–Cu | Plate & sheet | B209 | 6061 | A96061 | T6 | ... | 23 |
| 168 | Al–Mg–Si–Cu | Plate & sheet | B209 | 6061 | A96061 | T651 | ≥6, ≤100 | 23 |
| 169 | Al–Mn–Cu | Forgings & fittings | B361 | WP Alclad 3003 | A83003 | O | ... | 21 |
| 170 | Al–Mn–Cu | Forgings & fittings | B361 | WP Alclad 3003 | A83003 | H112 | ... | 21 |
| 171 | 99.60Al | Forgings & fittings | B361 | WP1060 | A91060 | O | ... | 21 |
| 172 | 99.60Al | Forgings & fittings | B361 | WP1060 | A91060 | H112 | ... | 21 |
| 173 | 99.0Al–Cu | Forgings & fittings | B361 | WP1100 | A91100 | O | ... | 21 |
| 174 | 99.0Al–Cu | Forgings & fittings | B361 | WP1100 | A91100 | H112 | ... | 21 |
| 175 | Al–Mn–Cu | Forgings & fittings | B247 | 3003 | A93003 | H112 | ... | 21 |
| 176 | Al–Mn–Cu | Forgings & fittings | B247 | 3003 | A93003 | H112 wld. | ... | 21 |
| 177 | Al–Mn–Cu | Forgings & fittings | B361 | WP3003 | A93003 | O | ... | 21 |
| 178 | Al–Mn–Cu | Forgings & fittings | B361 | WP3003 | A93003 | H112 | ... | 21 |
| 179 | Al–Mn–Cu | Forgings & fittings | B247 | 5083 | A95083 | O | ... | 25 |
| 180 | Al–Mn–Cu | Forgings & fittings | B247 | 5083 | A95083 | H112 | ... | 25 |
| 181 | Al–Mn–Cu | Forgings & fittings | B247 | 5083 | A95083 | H112 wld. | ... | 25 |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150 | ... | −269 | 207 | 76 | 65 | 50.6 | 50.4 | ... | ... | ... | ... | ... | ... |
| 151 | (13)(33) | −269 | 207 | 76 | 65 | 50.6 | 50.4 | ... | ... | ... | ... | ... | ... |
| 152 | (33) | −269 | 248 | 179 | 65 | *82.7* | *82.7* | ... | ... | ... | ... | ... | ... |
| 153 | (33) | −269 | 269 | 200 | 65 | *89.6* | *89.6* | ... | ... | ... | ... | ... | ... |
| 154 | ... | −269 | 214 | 83 | 204 | 55.2 | 55.2 | 55.2 | **48.9** | **37.5** | **28.6** | **21.7** | **20.7** |
| 155 | (13)(33) | −269 | 214 | 83 | 204 | 55.2 | 55.2 | 55.2 | **48.9** | **37.5** | **28.6** | **21.7** | **20.7** |
| 156 | (33) | −269 | 248 | 179 | 204 | *82.7* | *82.7* | *82.7* | **49.5** | **37.5** | **28.6** | **21.7** | **20.7** |
| 157 | (33) | −269 | 269 | 200 | 204 | *89.6* | *89.6* | *89.6* | **49.5** | **37.5** | **28.6** | **21.7** | **20.7** |
| 158 | (13) | −269 | 290 | 131 | 65 | 87.3 | 87.3 | ... | ... | ... | ... | ... | ... |
| 159 | (13)(33) | −269 | 317 | 228 | 65 | *105.7* | *105.7* | ... | ... | ... | ... | ... | ... |
| 160 | ... | −269 | 172 | 65 | 204 | 43.7 | 43.7 | 43.7 | 43.6 | **41.6** | **28.8** | **17.6** | **16.1** |
| 161 | (13)(33) | −269 | 172 | 65 | 204 | 43.7 | 43.7 | 43.7 | 43.6 | **41.6** | **28.8** | **17.6** | **16.1** |
| 162 | (33) | −269 | 214 | 159 | 204 | *71.2* | *71.2* | *71.2* | *71.0* | **41.6** | **28.8** | **17.6** | **16.1** |
| 163 | (33) | −269 | 234 | 179 | 204 | *78.1* | *78.1* | *78.1* | *78.1* | **41.6** | **28.8** | **17.6** | **16.1** |
| 164 | (22)(63) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 165 | (22)(63) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 166 | (33)(63) | −269 | 207 | 110 | 204 | *68.9* | *68.9* | *68.9* | *67.8* | *64.8* | *57.9* | **40.2** | **35.9** |
| 167 | (33) | −269 | 290 | 241 | 204 | *96.5* | *96.5* | *96.5* | *92.5* | *79.9* | *63.1* | **40.2** | **35.9** |
| 168 | (13)(33) | −269 | 290 | 241 | 204 | *96.5* | *96.5* | *96.5* | *92.5* | *79.9* | *63.1* | **40.2** | **35.9** |
| 169 | (13)(14)(32)(33)(66) | −269 | 90 | 31 | 204 | 20.7 | 19.9 | 19.3 | 18.4 | 17.3 | **13.6** | **10.9** | **10.5** |
| 170 | (13)(14)(32)(33)(66) | −269 | 90 | 31 | 204 | 20.7 | 19.9 | 19.3 | 18.4 | 17.3 | **13.6** | **10.9** | **10.5** |
| 171 | (13)(14)(32)(33) | −269 | 55 | 17 | 204 | 11.5 | 11.5 | 10.9 | 9.8 | 8.8 | **7.5** | **5.8** | **5.5** |
| 172 | (13)(14)(32)(33) | −269 | 55 | 17 | 204 | 11.5 | 11.5 | 10.9 | 9.8 | 8.8 | **7.5** | **5.8** | **5.5** |
| 173 | (13)(14)(32)(33) | −269 | 76 | 21 | 204 | 13.8 | 13.8 | 13.7 | 13.2 | **11.8** | **9.3** | **7.2** | **6.9** |
| 174 | (13)(14)(32)(33) | −269 | 76 | 21 | 204 | 13.8 | 13.8 | 13.7 | 13.2 | **11.8** | **9.3** | **7.2** | **6.9** |
| 175 | (9)(45) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 176 | (9)(45) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 177 | (13)(14)(32)(33) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 178 | (13)(14)(32)(33) | −269 | 97 | 34 | 204 | 23.0 | 22.1 | 21.4 | 20.5 | **18.2** | **13.6** | **10.9** | **10.5** |
| 179 | (9)(32)(33) | −269 | 268 | 110 | 65 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |
| 180 | (9)(32)(33) | −269 | 268 | 110 | 65 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |
| 181 | (9)(32)(33) | −269 | 268 | 110 | 65 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|---|---|---|---|---|---|---|---|---|
| 182 | Al–4.4Mg–Mn | Forgings & fittings | B361 | WP5083 | A95083 | O | ... | 25 |
| 183 | Al–4.4Mg–Mn | Forgings & fittings | B361 | WP5083 | A95083 | H112 | ... | 25 |
| 184 | Al–3.5Mg | Forgings & fittings | B361 | WP5154 | A95154 | O | ... | 22 |
| 185 | Al–3.5Mg | Forgings & fittings | B361 | WP5154 | A95154 | H112 | ... | 22 |
| 186 | Al–Mg–Si–Cu | Forgings & fittings | B247 | 6061 | A96061 | T6 wld. | ... | 23 |
| 187 | Al–Mg–Si–Cu | Forgings & fittings | B361 | WP6061 | A96061 | T4 wld. | ... | 23 |
| 188 | Al–Mg–Si–Cu | Forgings & fittings | B361 | WP6061 | A96061 | T6 wld. | ... | 23 |
| 189 | Al–Mg–Si–Cu | Forgings & fittings | B361 | WP6061 | A96061 | T4 | ... | 23 |
| 190 | Al–Mg–Si–Cu | Forgings & fittings | B247 | 6061 | A96061 | T6 | ... | 23 |
| 191 | Al–Mg–Si–Cu | Forgings & fittings | B361 | WP6061 | A96061 | T6 | ... | 23 |
| 192 | Al–Mg–Si | Forgings & fittings | B361 | WP6063 | A96063 | T4 wld. | ... | 23 |
| 193 | Al–Mg–Si | Forgings & fittings | B361 | WP6063 | A96063 | T6 wld. | ... | 23 |
| 194 | Al–Mg–Si | Forgings & fittings | B361 | WP6063 | A96063 | T4 | ... | 23 |
| 195 | Al–Mg–Si | Forgings & fittings | B361 | WP6063 | A96063 | T6 | ... | 23 |
| 196 | Al–Si–Mg | Castings | B26 | 356.0 | A03560 | T71 | ... | 26 |
| 197 | Al–Si–Mg | Castings | B26 | 356.0 | A03560 | T6 | ... | 26 |
| 198 | Al–Si | Castings | B26 | 443.0 | A04430 | F | ... | ... |

## Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 182 | (13)(32)(33) | −269 | 269 | 110 | 65 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |
| 183 | (13)(32)(33) | −269 | 269 | 110 | 65 | 73.5 | 73.5 | ... | ... | ... | ... | ... | ... |
| 184 | (32)(33) | −269 | 207 | 76 | 65 | 50.6 | 50.6 | ... | ... | ... | ... | ... | ... |
| 185 | (32)(33) | −269 | 207 | 76 | 65 | 50.6 | 50.6 | ... | ... | ... | ... | ... | ... |
| 186 | (9)(22) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 187 | (22)(32)(63) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 188 | (22)(32)(63) | −269 | 165 | ... | 204 | *55.2* | *55.2* | *55.2* | *54.3* | *52.0* | *46.3* | *35.3* | *34.8* |
| 189 | (13)(32)(33)(63) | −269 | 179 | 110 | 204 | *59.8* | *59.8* | *59.8* | *58.9* | *56.3* | *50.2* | *38.3* | *35.9* |
| 190 | (9)(33) | −269 | 262 | 241 | 204 | *87.3* | *87.3* | *87.3* | *83.6* | *72.3* | *57.2* | **40.2** | **35.9** |
| 191 | (13)(32)(33)(63) | −269 | 262 | 241 | 204 | *87.3* | *87.3* | *87.3* | *83.6* | *72.3* | *57.2* | **40.2** | **35.9** |
| 192 | (32) | −269 | 117 | ... | 204 | *39.1* | *39.1* | *37.6* | *36.0* | *32.0* | *24.7* | **15.3** | **13.8** |
| 193 | (32) | −269 | 117 | ... | 204 | *39.1* | *39.1* | *37.6* | *36.0* | *32.0* | *24.7* | **15.3** | **13.8** |
| 194 | (13)(32)(33) | −269 | 124 | 62 | 204 | *41.4* | 41.3 | *41.3* | 41.0 | *41.0* | *33.9* | *22.6* | *9.8* |
| 195 | (13)(32)(33) | −269 | 207 | 172 | 204 | *68.9* | *68.9* | *67.7* | *59.0* | *45.9* | **27.5** | **15.3** | **13.8** |
| 196 | (9)(43) | −269 | 172 | 124 | 204 | *57.5* | *57.5* | *57.5* | **55.0** | **49.8** | **38.6** | **18.9** | **16.5** |
| 197 | (9)(43) | −269 | 207 | 138 | 121 | *68.9* | *68.9* | *68.9* | *57.9* | ... | ... | ... | ... |
| 198 | (9)(43) | −269 | 117 | 48 | 204 | 32.0 | 32.0 | 32.0 | 32.0 | 32.0 | 32.0 | 32.0 | 24.1 |

(18)

## Table A-1A Basic Casting Quality Factors, $E_c$

**These quality factors are determined in accordance with para. 302.3.3(b). See also para. 302.3.3(c) and Table 302.3.3C for increased quality factors applicable in special cases. Specifications are ASTM.**

| Spec. No. | Description | $E_c$ [Note (2)] | Appendix A Notes |
|---|---|---|---|
| **Iron** | | | |
| A47 | Malleable iron castings | 1.00 | (9) |
| A48 | Gray iron castings | 1.00 | (9) |
| A126 | Gray iron castings | 1.00 | (9) |
| A197 | Cupola malleable iron castings | 1.00 | (9) |
| A278 | Gray iron castings | 1.00 | (9) |
| A395 | Ductile and ferritic ductile iron castings | 0.80 | (9), (40) |
| A536 | Ductile iron castings | 0.80 | (9), (40) |
| A571 | Austenitic ductile iron castings | 0.80 | (9), (40) |
| **Carbon Steel** | | | |
| A216 | Carbon steel castings | 0.80 | (9), (40) |
| A352 | Ferritic steel castings | 0.80 | (9), (40) |
| **Low and Intermediate Alloy Steel** | | | |
| A217 | Martensitic stainless and alloy castings | 0.80 | (9), (40) |
| A352 | Ferritic steel castings | 0.80 | (9), (40) |
| A426 | Centrifugally cast pipe | 1.00 | (10) |
| **Stainless Steel** | | | |
| A351 | Austenitic steel castings | 0.80 | (9), (40) |
| A451 | Centrifugally cast pipe | 0.90 | (10), (40) |
| A487 | Steel castings | 0.80 | (9), (40) |
| **Copper and Copper Alloy** | | | |
| B61 | Steam bronze castings | 0.80 | (9), (40) |
| B62 | Composition bronze castings | 0.80 | (9), (40) |
| B148 | Al–bronze and Si–Al–bronze castings | 0.80 | (9), (40) |
| B584 | Copper alloy castings | 0.80 | (9), (40) |
| **Nickel and Nickel Alloy** | | | |
| A494 | Nickel and nickel alloy castings | 0.80 | (9), (40) |
| **Aluminum Alloy** | | | |
| B26, Temper F | Aluminum alloy castings | 1.00 | (9), (10) |
| B26, Temper T6, T71 | Aluminum alloy castings | 0.80 | (9), (40) |
| **Titanium and Titanium Alloy** | | | |
| B367 | Titanium and titanium alloy castings | 0.80 | (9), (40) |

(18) **Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes, $E_j$**

**These quality factors are determined in accordance with para. 302.3.4(a). See also para. 302.3.4(b) and Table 302.3.4 for increased quality factors applicable in special cases. Specifications, except API, are ASTM.**

| Spec. No. | Class (or Type) | Description | $E_j$ [Note (2)] | Appendix A Notes |
|---|---|---|---|---|
| **Carbon Steel** | | | | |
| API 5L | ... | Seamless pipe | 1.00 | ... |
| | | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | | Electric resistance welded pipe | 0.85 | ... |
| | | Electric fusion welded pipe, double butt seam | 0.95 | ... |
| | | Continuous welded (furnace butt welded) pipe | 0.60 | ... |
| A53 | Type S | Seamless pipe | 1.00 | ... |
| | Type E | Electric resistance welded pipe | 0.85 | ... |
| | Type F | Furnace butt welded pipe | 0.60 | ... |
| A106 | ... | Seamless pipe | 1.00 | ... |
| A134 | ... | Electric fusion welded pipe, single butt, straight or spiral (helical) seam | 0.80 | ... |
| A135 | ... | Electric resistance welded pipe | 0.85 | ... |
| A139 | ... | Electric fusion welded pipe, straight or spiral (helical) seam | 0.80 | ... |
| A179 | ... | Seamless tube | 1.00 | ... |
| A333 | ... | Seamless pipe | 1.00 | ... |
| | | Electric resistance welded pipe | 0.85 | ... |
| A334 | ... | Seamless tube | 1.00 | ... |
| A369 | ... | Seamless pipe | 1.00 | ... |
| A381 | ... | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | | Electric fusion welded pipe, spot radiographed | 0.90 | (19) |
| | | Electric fusion welded pipe, as manufactured | 0.85 | ... |
| A524 | ... | Seamless pipe | 1.00 | ... |
| A587 | ... | Electric resistance welded pipe | 0.85 | ... |
| A671 | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| A672 | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| A691 | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| **Low and Intermediate Alloy Steel** | | | | |
| A333 | ... | Seamless pipe | 1.00 | ... |
| | | Electric resistance welded pipe | 0.85 | (78) |
| A334 | ... | Seamless tube | 1.00 | ... |
| A335 | ... | Seamless pipe | 1.00 | ... |
| A369 | ... | Seamless pipe | 1.00 | ... |
| A671 | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam | 0.85 | (78) |
| A672 | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam | 0.85 | (78) |
| A691 | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam | 0.85 | (78) |

## Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes, $E_j$ (Cont'd)

**These quality factors are determined in accordance with para. 302.3.4(a). See also para. 302.3.4(b) and Table 302.3.4 for increased quality factors applicable in special cases. Specifications, except API, are ASTM.**

| Spec. No. | Class (or Type) | Description | $E_j$ [Note (2)] | Appendix A Notes |
|---|---|---|---|---|
| **Stainless Steel** | | | | |
| A249 | ... | Electric fusion welded tube, single butt seam | 0.80 | ... |
| A268 | ... | Seamless tube | 1.00 | ... |
| | | Electric fusion welded tube, double butt seam | 0.85 | ... |
| | | Electric fusion welded tube, single butt seam | 0.80 | ... |
| A269 | ... | Seamless tube | 1.00 | ... |
| | | Electric fusion welded tube, double butt seam | 0.85 | ... |
| | | Electric fusion welded tube, single butt seam | 0.80 | ... |
| A270 | ... | Seamless tube | 1.00 | ... |
| | | Electric fusion welded tube, double butt seam | 0.85 | ... |
| | | Electric fusion welded tube, single butt seam | 0.80 | ... |
| A312 | ... | Seamless pipe | 1.00 | ... |
| | | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| | | Electric fusion welded pipe, single butt seam | 0.80 | ... |
| | | Electric fusion welded pipe, 100% radiographed | 1.00 | (46) |
| A358 | 1, 3, 4 | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | 5 | Electric fusion welded pipe, spot radiographed | 0.90 | ... |
| | 2 | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| A376 | ... | Seamless pipe | 1.00 | ... |
| A409 | ... | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| | | Electric fusion welded pipe, single butt seam | 0.80 | ... |
| A789 | ... | Seamless tube | 1.00 | ... |
| | | Electric fusion welded tube, 100% radiographed | 1.00 | ... |
| | | Electric fusion welded tube, double butt | 0.85 | ... |
| | | Electric fusion welded tube, single butt | 0.80 | ... |
| A790 | ... | Seamless pipe | 1.00 | ... |
| | | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | | Electric fusion welded pipe, double butt | 0.85 | ... |
| | | Electric fusion welded pipe, single butt | 0.80 | ... |
| A813 | DW | Electric fusion welded pipe, double butt | 0.85 | ... |
| | SW | Electric fusion welded pipe, single butt | 0.80 | ... |
| A814 | DW | Electric fusion welded pipe, double butt | 0.85 | ... |
| | SW | Electric fusion welded pipe, single butt | 0.80 | ... |
| A928 | 1, 3, 4 | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | 5 | Electric fusion welded pipe, spot radiographed | 0.90 | ... |
| | 2 | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| **Copper and Copper Alloy** | | | | |
| B42 | ... | Seamless pipe | 1.00 | ... |
| B43 | ... | Seamless pipe | 1.00 | ... |
| B68 | ... | Seamless tube | 1.00 | ... |
| B75 | ... | Seamless tube | 1.00 | ... |

## Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes, $E_j$ (Cont'd)

**These quality factors are determined in accordance with para. 302.3.4(a). See also para. 302.3.4(b) and Table 302.3.4 for increased quality factors applicable in special cases. Specifications, except API, are ASTM.**

| Spec. No. | Class (or Type) | Description | $E_j$ [Note (2)] | Appendix A Notes |
|---|---|---|---|---|
| **Copper and Copper Alloy (Cont'd)** | | | | |
| B88 | ... | Seamless water tube | 1.00 | ... |
| B280 | ... | Seamless tube | 1.00 | ... |
| B466 | ... | Seamless pipe and tube | 1.00 | ... |
| B467 | ... | Electric resistance welded pipe | 0.85 | ... |
| | | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| | | Electric fusion welded pipe, single butt seam | 0.80 | ... |
| **Nickel and Nickel Alloy** | | | | |
| B161 | ... | Seamless pipe and tube | 1.00 | ... |
| B163 | ... | Seamless tube | 1.00 | ... |
| B165 | ... | Seamless pipe and tube | 1.00 | ... |
| B167 | ... | Seamless pipe and tube | 1.00 | ... |
| B407 | ... | Seamless pipe and tube | 1.00 | ... |
| B444 | ... | Seamless pipe and tube | 1.00 | ... |
| B464 | ... | Welded pipe | 0.80 | ... |
| B474 | 1, 3, 4 | Welded pipe, 100% radiographed | 1.00 | ... |
| | 2 | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| B514 | ... | Welded pipe | 0.80 | ... |
| B515 | ... | Welded tube | 0.80 | ... |
| B619 | ... | Electric resistance welded pipe | 0.85 | ... |
| | | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| | | Electric fusion welded pipe, single butt seam | 0.80 | ... |
| B622 | ... | Seamless pipe and tube | 1.00 | ... |
| B626 | All | Electric resistance welded tube | 0.85 | ... |
| | | Electric fusion welded tube, double butt seam | 0.85 | ... |
| | | Electric fusion welded tube, single butt seam | 0.80 | ... |
| B668 | All | Seamless pipe and tube | 1.00 | ... |
| B675 | All | Welded pipe | 0.80 | ... |
| B690 | ... | Seamless pipe and tube | 1.00 | ... |
| B704 | ... | Welded tube | 0.80 | ... |
| B705 | ... | Welded pipe | 0.80 | ... |
| B725 | ... | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| | | Electric fusion welded pipe, single butt seam | 0.80 | ... |
| B729 | ... | Seamless pipe and tube | 1.00 | ... |
| B804 | 1, 3, 5 | Welded pipe, 100% radiographed | 1.00 | ... |
| | 2, 4 | Welded pipe, double fusion welded | 0.85 | ... |
| | 6 | Welded pipe, single fusion welded | 0.80 | ... |

## Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes, $E_j$ (Cont'd)

**These quality factors are determined in accordance with para. 302.3.4(a). See also para. 302.3.4(b) and Table 302.3.4 for increased quality factors applicable in special cases. Specifications, except API, are ASTM.**

| Spec. No. | Class (or Type) | Description | $E_j$ [Note (2)] | Appendix A Notes |
|---|---|---|---|---|
| **Titanium and Titanium Alloy** | | | | |
| B338 | ... | Seamless tube | 1.00 | ... |
| | | Electric fusion welded tube, 100% radiographed | 1.00 | ... |
| | | Electric fusion welded tube, double butt seam | 0.85 | ... |
| | | Electric fusion welded tube, single butt seam | 0.80 | ... |
| B861 | ... | Seamless pipe | 1.00 | ... |
| B862 | ... | Electric fusion welded pipe, 100% radiographed | 1.00 | ... |
| | | Electric fusion welded pipe, double butt seam | 0.85 | ... |
| | | Electric fusion welded pipe, single butt seam | 0.80 | ... |
| **Zirconium and Zirconium Alloy** | | | | |
| B523 | ... | Seamless tube | 1.00 | ... |
| | | Electric fusion welded tube | 0.80 | ... |
| B658 | ... | Seamless pipe | 1.00 | ... |
| | | Electric fusion welded pipe | 0.80 | ... |
| **Aluminum Alloy** | | | | |
| B210 | ... | Seamless tube | 1.00 | ... |
| B241 | ... | Seamless pipe and tube | 1.00 | ... |
| B547 | ... | Welded pipe and tube, 100% radiographed | 1.00 | ... |
| | | Welded pipe, double butt seam | 0.85 | ... |
| | | Welded pipe, single butt seam | 0.80 | ... |

TABLE STARTS ON NEXT PAGE

(18)

## Table A-2 Design Stress Values for Bolting Materials

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| | | | | | | | | | Specified Min. Strength, ksi | | Design Stress, ksi, at Metal Temperature, °F [Note (1)] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, Dia., in. | Notes | Min. Temp., °F (6) | Tensile | Yield | Min. Temp. to 100 | 200 | 300 | 400 | 500 |
| ... | Bolts | A675 | 45 | D40450 | ... | ... | (8f)(8g) | −20 | 45 | 22.5 | 11.3 | 11.3 | 11.3 | 11.3 | 11.3 |
| ... | Bolts | A675 | 50 | D40500 | ... | ... | (8f)(8g) | −20 | 50 | 25 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 |
| ... | Bolts | A675 | 55 | D40550 | ... | ... | (8f)(8g) | −20 | 55 | 27.5 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 |
| ... | Bolts | A307 | B | ... | ... | ... | (8f)(8g) | −20 | 60 | ... | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 |
| ... | Bolts | A675 | 60 | D40600 | ... | ... | (8f)(8g) | −20 | 60 | 30 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 |
| ... | Bolts | A675 | 65 | D40650 | ... | ... | (8g) | −20 | 65 | 32.5 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 |
| ... | Bolts | A675 | 70 | D40700 | ... | ... | (8g) | −20 | 70 | 35 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 |
| ... | Bolts | A675 | 80 | D40800 | ... | ... | (8g) | −20 | 80 | 40 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| ... | Bolts | F3125 | A325 | K02706 | ... | ... | (8g) | −20 | 120 | 92 | 23.0 | 23.0 | 23.0 | 23.0 | 23.0 |
| ... | Nuts | A194 | 1 | K01503 | ... | ... | (42) | −20 | ... | ... | ... | ... | ... | ... | ... |
| ... | Nuts | A194 | 2 | K04002 | ... | ... | (42) | −55 | ... | ... | ... | ... | ... | ... | ... |
| ... | Nuts | A194 | 2H | K04002 | ... | ... | (42) | −55 | ... | ... | ... | ... | ... | ... | ... |
| ... | Nuts | A194 | 2HM | K04002 | ... | ... | (42) | −55 | ... | ... | ... | ... | ... | ... | ... |
| ... | Nuts, hvy. hex | A563 | A | K05802 | ... | ... | (42b) | −20 | ... | ... | ... | ... | ... | ... | ... |
| **Alloy Steel** | | | | | | | | | | | | | | | |
| Cr–⅕Mo | Bolts | A193 | B7M | G41400 | ... | ≤4 | ... | −55 | 100 | 80 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| Cr–⅕Mo | Bolts | A320 | L7M | G41400 | ... | ≤2½ | ... | −100 | 100 | 80 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 5Cr | Bolts | A193 | B5 | S50100 | ... | ≤4 | (15) | −20 | 100 | 80 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| Cr–Mo–V | Bolts | A193 | B16 | K14072 | ... | >2½, ≤4 | (15) | −20 | 110 | 95 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 |
| Alloy steel | Bolts | A354 | BC | K04100 | ... | >2½, ≤4 | (15) | 0 | 115 | 99 | 23.0 | 23.0 | 23.0 | 23.0 | 23.0 |
| Cr–Mo | Bolts | A193 | B7 | G41400 | ... | >2½, ≤4 | (15) | −40 | 115 | 95 | 23.0 | 23.0 | 23.0 | 23.0 | 23.0 |
| Ni–Cr–Mo | Bolts | A320 | L43 | G43400 | ... | ≤4 | (15) | −150 | 125 | 105 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Cr–Mo | Bolts | A320 | L7 | G41400 | ... | ≤2½ | (15) | −150 | 125 | 105 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Cr–Mo | Bolts | A320 | L7A | G40370 | ... | ≤2½ | (15) | −150 | 125 | 105 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Cr–Mo | Bolts | A320 | L7B | G41370 | ... | ≤2½ | (15) | −150 | 125 | 105 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Cr–Mo | Bolts | A320 | L7C | G87400 | ... | ≤2½ | (15) | −150 | 125 | 105 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Cr–Mo | Bolts | A193 | B7 | G41400 | ... | ≤2½ | ... | −55 | 125 | 105 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Cr–Mo–V | Bolts | A193 | B16 | K14072 | ... | ≤2½ | (15) | −20 | 125 | 105 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Alloy steel | Bolts | A354 | BC | K04100 | ... | ≤2½ | (15) | 0 | 125 | 109 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Alloy steel | Bolts | A354 | BD | K04100 | ... | ≤4 | (15) | −20 | 150 | 130 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |
| 5Cr | Nuts | A194 | 3 | S50100 | ... | ... | (42) | −20 | ... | ... | ... | ... | ... | ... | ... |
| C–Mo | Nuts | A194 | 4 | K14510 | ... | ... | (42) | −55 | ... | ... | ... | ... | ... | ... | ... |
| C–Mo | Nuts | A194 | 4L | K14510 | ... | ... | (42) | −150 | ... | ... | ... | ... | ... | ... | ... |
| Cr–Mo | Nuts | A194 | 7 | G41400 | ... | ... | (42) | −55 | ... | ... | ... | ... | ... | ... | ... |
| Cr–Mo | Nuts | A194 | 7L | G41400 | ... | ... | (42) | −150 | ... | ... | ... | ... | ... | ... | ... |
| Cr–Mo | Nuts | A194 | 7M | G41400 | ... | ... | (42) | −55 | ... | ... | ... | ... | ... | ... | ... |
| Cr–Mo | Nuts | A194 | 7ML | G41400 | ... | ... | (42) | −100 | ... | ... | ... | ... | ... | ... | ... |

## Table A-2 Design Stress Values for Bolting Materials

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM**

| Design Stress, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| 11.3 | 11.1 | 10.7 | 10.4 | 9.2 | 7.9 | 5.9 | 4.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 45 | A675 |
| 12.5 | 12.4 | 11.9 | 10.7 | 9.2 | 7.9 | 5.9 | 4.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 50 | A675 |
| 13.8 | 13.6 | 13.1 | 12.7 | 10.8 | 8.7 | 5.9 | 4.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 55 | A675 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | B | A307 |
| 15.0 | 14.8 | 14.3 | 13.8 | 11.4 | 8.7 | 5.9 | 4.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 60 | A675 |
| 16.3 | 16.1 | 15.5 | 13.9 | 11.4 | 9.0 | 6.3 | 4.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 65 | A675 |
| 17.5 | 17.3 | 16.7 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 70 | A675 |
| 20.0 | 19.8 | 19.1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 80 | A675 |
| 23.0 | 23.0 | 23.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A325 | F3125 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1 | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2 | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2H | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2HM | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A | A563 |
| | | | | | | | | | | | | | | | | | | | | **Alloy Steel** |
| 20.0 | 20.0 | 20.0 | 20.0 | 18.5 | 16.3 | 12.5 | 8.5 | 4.5 | 2.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B7M | A193 |
| 20.0 | 20.0 | 20.0 | 20.0 | 18.5 | 16.3 | 12.5 | 8.5 | 4.5 | 2.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | L7M | A320 |
| 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 14.3 | 10.9 | 8.0 | 5.8 | 4.2 | 2.9 | 1.8 | 1.0 | 0.6 | ... | ... | ... | ... | ... | B5 | A193 |
| 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 21.0 | 18.5 | 15.3 | 11.0 | 6.3 | 2.8 | 1.2 | ... | ... | ... | ... | ... | ... | ... | B16 | A193 |
| 23.0 | 23.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | BC | A354 |
| 23.0 | 23.0 | 23.0 | 23.0 | 20.0 | 16.3 | 12.5 | 8.5 | 4.5 | 2.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B7 | A193 |
| 25.0 | 25.0 | 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L43 | A320 |
| 25.0 | 25.0 | 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L7 | A320 |
| 25.0 | 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L7A | A320 |
| 25.0 | 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L7B | A320 |
| 25.0 | 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | L7C | A320 |
| 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 21.0 | 17.0 | 12.5 | 8.5 | 4.5 | 2.4 | ... | ... | ... | ... | ... | ... | ... | ... | B7 | A193 |
| 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 23.5 | 20.5 | 16.0 | 11.0 | 6.3 | 2.8 | 1.2 | ... | ... | ... | ... | ... | ... | ... | B16 | A193 |
| 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | BC | A354 |
| 30.0 | 30.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | BD | A354 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 3 | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 4 | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 4L | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 7 | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 7L | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 7M | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 7ML | A194 |

## Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, Dia., in. | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Design Stress, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel** | | | | | | | | | | | | | | | |
| 16Cr–12Ni–2Mo | Bolts | A193 | B8M | S31600 | 2 | >1¼, ≤1½ | (15)(60) | −325 | 90 | 50 | 18.8 | 17.3 | 15.6 | 14.3 | 13.3 |
| 16Cr–12Ni–2Mo | Bolts | A320 | B8M | S31600 | 2 | >1¼, ≤1½ | (15)(60) | −325 | 90 | 50 | 18.8 | 17.3 | 15.6 | 14.3 | 13.3 |
| 18Cr–8Ni | Bolts | A193 | B8 | S30400 | 2 | >1¼, ≤1½ | (15)(60) | −325 | 100 | 50 | 18.8 | 16.7 | 15.0 | 13.8 | 12.9 |
| 18Cr–8Ni | Bolts | A320 | B8 | S30400 | 2 | >1¼, ≤1½ | (15)(60) | −325 | 100 | 50 | 18.8 | 16.7 | 15.0 | 13.8 | 12.9 |
| 18Cr–10Ni–Cb | Bolts | A193 | B8C | ... | 2 | >1¼, ≤1½ | (15)(60) | −325 | 100 | 50 | 18.8 | 17.9 | 16.5 | 15.5 | 15.0 |
| 18Cr–10Ni–Cb | Bolts | A320 | B8C | S34700 | 2 | >1¼, ≤1½ | (15)(60) | −325 | 100 | 50 | 18.8 | 17.9 | 16.5 | 15.5 | 15.0 |
| 18Cr–10Ni–Ti | Bolts | A193 | B8T | S32100 | 2 | >1¼, ≤1½ | (15)(60) | −325 | 100 | 50 | 18.8 | 17.8 | 16.5 | 15.3 | 14.3 |
| 18Cr–10Ni–Ti | Bolts | A320 | B8T | S32100 | 2 | >1¼, ≤1½ | (15)(60) | −325 | 100 | 50 | 18.8 | 17.8 | 16.5 | 15.3 | 14.3 |
| 18Cr–9Ni | Bolts | A320 | B8F | S30300 | 1 | ... | (8f)(15)(39) | −325 | 75 | 30 | 18.8 | 16.7 | 15.0 | 13.8 | 12.9 |
| 19Cr–9Ni | Bolts | A453 | 651B | ... | ... | >3 | (15)(35) | −20 | 95 | 50 | 23.8 | 23.4 | 22.1 | 21.3 | 20.8 |
| 19Cr–9Ni | Bolts | A453 | 651B | ... | ... | ≤3 | (15)(35) | −20 | 95 | 60 | 23.8 | 23.4 | 22.1 | 21.3 | 20.8 |
| 19Cr–9Ni | Bolts | A453 | 651A | ... | ... | >3 | (15)(35) | −20 | 100 | 60 | 23.8 | 23.4 | 22.1 | 21.3 | 20.8 |
| 19Cr–9Ni | Bolts | A453 | 651A | ... | ... | ≤3 | (15)(35) | −20 | 100 | 70 | 23.8 | 23.4 | 22.1 | 21.3 | 20.8 |
| 16Cr–12Ni–2Mo | Bolts | A193 | B8M | S31600 | 2 | >1, ≤1¼ | (15)(60) | −325 | 105 | 65 | 18.8 | 17.3 | 16.3 | 16.3 | 16.3 |
| 16Cr–12Ni–2Mo | Bolts | A320 | B8M | S31600 | 2 | >1, ≤1¼ | (15)(60) | −325 | 105 | 65 | 18.8 | 17.3 | 16.3 | 16.3 | 16.3 |
| 18Cr–10Ni–Cb | Bolts | A193 | B8C | ... | 2 | >1, ≤1¼ | (15)(60) | −325 | 105 | 65 | 18.8 | 17.9 | 16.5 | 16.3 | 16.3 |
| 18Cr–10Ni–Cb | Bolts | A320 | B8C | S34700 | 2 | >1, ≤1¼ | (15)(60) | −325 | 105 | 65 | 18.8 | 17.9 | 16.5 | 16.3 | 16.3 |
| 18Cr–8Ni | Bolts | A193 | B8 | S30400 | 2 | >1, ≤1¼ | (15)(60) | −325 | 105 | 65 | 18.8 | 16.7 | 16.3 | 16.3 | 16.3 |
| 18Cr–8Ni | Bolts | A320 | B8 | S30400 | 2 | >1, ≤1¼ | (15)(60) | −325 | 105 | 65 | 18.8 | 16.7 | 16.3 | 16.3 | 16.3 |
| 18Cr–10Ni–Ti | Bolts | A193 | B8T | S32100 | 2 | >1, ≤1¼ | (15)(60) | −325 | 105 | 65 | 18.8 | 17.8 | 16.5 | 16.3 | 16.3 |
| 18Cr–10Ni–Ti | Bolts | A320 | B8T | S32100 | 2 | >1, ≤1¼ | (15)(60) | −325 | 105 | 65 | 18.8 | 17.8 | 16.5 | 16.3 | 16.3 |
| 18Cr–10Ni–Ti | Bolts | A193 | B8T | S32100 | 1 | ... | (8f)(15)(28) | −325 | 75 | 30 | 18.8 | 17.8 | 16.5 | 15.3 | 14.3 |
| 18Cr–8Ni | Bolts | A320 | B8 | S30400 | 1 | ... | (8f)(15)(28) | −425 | 75 | 30 | 18.8 | 16.7 | 15.0 | 13.8 | 12.9 |
| 18Cr–10Ni–Cb | Bolts | A193 | B8C | ... | 1 | ... | (8f)(15)(28) | −425 | 75 | 30 | 18.8 | 17.9 | 16.5 | 15.5 | 15.0 |
| 16Cr–12Ni–2Mo | Bolts | A193 | B8M | S31600 | 1 | ... | (8f)(15)(28) | −325 | 75 | 30 | 18.8 | 17.3 | 15.6 | 14.3 | 13.3 |
| 16Cr–12Ni–2Mo | Bolts | A193 | B8M | S31600 | 2 | >¾, ≤1 | (15)(60) | −325 | 100 | 80 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 16Cr–12Ni–2Mo | Bolts | A320 | B8M | S31600 | 2 | >¾, ≤1 | (15)(60) | −325 | 100 | 80 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | Bolts | A193 | B8C | ... | 2 | >¾, ≤1 | (15)(60) | −325 | 115 | 80 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb | Bolts | A320 | B8C | S34700 | 2 | >¾, ≤1 | (15)(60) | −325 | 115 | 80 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–8Ni | Bolts | A193 | B8 | S30400 | 2 | >¾, ≤1 | (15)(60) | −325 | 115 | 80 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–8Ni | Bolts | A320 | B8 | S30400 | 2 | >¾, ≤1 | (15)(60) | −325 | 115 | 80 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti | Bolts | A193 | B8T | S32100 | 2 | >¾, ≤1 | (15)(60) | −325 | 115 | 80 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti | Bolts | A320 | B8T | S32100 | 2 | >¾, ≤1 | (15)(60) | −325 | 115 | 80 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 12Cr | Bolts | A437 | B4C | S42200 | ... | ... | (35) | −20 | 115 | 85 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 |
| 13Cr | Bolts | A193 | B6 | S41000 | ... | ≤4 | (15)(35) | −20 | 110 | 85 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 |

## Table A-2 Design Stress Values for Bolting Materials (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM**

| Design Stress, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | | | | | | | | **Stainless Steel** | |
| 12.6 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2 | A193 |
| 12.6 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2 | A320 |
| 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2 | A193 |
| 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2 | A320 |
| 14.3 | 14.0 | 13.8 | 13.7 | 13.6 | 13.5 | 13.4 | 13.4 | 13.4 | 12.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2 | A193 |
| 14.3 | 14.0 | 13.8 | 13.7 | 13.6 | 13.5 | 13.4 | 13.4 | 13.4 | 12.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2 | A320 |
| 13.5 | 13.2 | 13.0 | 12.7 | 12.6 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2 | A193 |
| 13.5 | 13.2 | 13.0 | 12.7 | 12.6 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2 | A320 |
| 12.3 | 12.0 | 11.7 | 11.5 | 11.2 | 11.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8F Cl. 1 | A320 |
| 20.5 | 20.4 | 20.3 | 20.2 | 20.0 | 19.7 | 19.3 | 18.9 | 18.2 | 17.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 651B | A453 |
| 20.5 | 20.4 | 20.3 | 20.2 | 20.0 | 19.7 | 19.3 | 18.9 | 18.2 | 17.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 651B | A453 |
| 20.5 | 20.4 | 20.3 | 20.2 | 20.0 | 19.7 | 19.3 | 18.9 | 18.2 | 17.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 651A | A453 |
| 20.5 | 20.4 | 20.3 | 20.2 | 20.0 | 19.7 | 19.3 | 18.9 | 18.2 | 17.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 651A | A453 |
| 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2 | A193 |
| 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2 | A320 |
| 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2 | A193 |
| 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2 | A320 |
| 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2 | A193 |
| 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2 | A320 |
| 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2 | A193 |
| 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2 | A320 |
| 13.5 | 13.2 | 13.0 | 12.7 | 12.6 | 12.4 | 12.3 | 12.1 | 12.0 | 9.6 | 6.9 | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | B8T Cl. 1 | A193 |
| 12.3 | 12.0 | 11.7 | 11.5 | 11.2 | 11.0 | 10.8 | 10.6 | 10.4 | 10.1 | 9.8 | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | B8 Cl. 1 | A320 |
| 14.3 | 14.0 | 13.8 | 13.7 | 13.6 | 13.5 | 13.4 | 13.4 | 13.4 | 12.1 | 9.1 | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | B8C Cl. 1 | A193 |
| 12.6 | 12.3 | 12.1 | 11.9 | 11.8 | 11.6 | 11.5 | 11.4 | 11.3 | 11.2 | 11.1 | 9.8 | 7.4 | 5.6 | 4.2 | 3.2 | 2.4 | 1.8 | 1.4 | B8M Cl. 1 | A193 |
| 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2 | A193 |
| 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2 | A320 |
| 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2 | A193 |
| 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2 | A320 |
| 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2 | A193 |
| 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2 | A320 |
| 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2 | A193 |
| 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2 | A320 |
| 21.3 | 21.3 | 21.3 | 21.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | B4C | A437 |
| 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 20.2 | 18.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | B6 | A193 |

## Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, Dia., in. | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Design Stress, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel** | | | | | | | | | | | | | | | |
| 14Cr–24Ni | Bolts | A453 | 660 | S66286 | A | ... | (15)(35) | −325 | 130 | 85 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 |
| 14Cr–24Ni | Bolts | A453 | 660 | S66286 | B | ... | (15)(35) | −325 | 130 | 85 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 |
| 16Cr–12Ni–2Mo | Bolts | A193 | B8M | S31600 | 2 | ≤$^3/_4$ | (15)(60) | −325 | 110 | 95 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 |
| 16Cr–12Ni–2Mo | Bolts | A320 | B8M | S31600 | 2 | ≤$^3/_4$ | (15)(60) | −325 | 110 | 95 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 |
| 18Cr–10Ni–Cb | Bolts | A193 | B8C | ... | 2 | ≤$^3/_4$ | (15)(60) | −325 | 125 | 100 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| 18Cr–10Ni–Cb | Bolts | A320 | B8C | S34700 | 2 | ≤$^3/_4$ | (15)(60) | −325 | 125 | 100 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| 18Cr–8Ni | Bolts | A193 | B8 | S30400 | 2 | ≤$^3/_4$ | (15)(60) | −325 | 125 | 100 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| 18Cr–8Ni | Bolts | A320 | B8 | S30400 | 2 | ≤$^3/_4$ | (15)(60) | −325 | 125 | 100 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| 18Cr–10Ni–Ti | Bolts | A193 | B8T | S32100 | 2 | ≤$^3/_4$ | (15)(60) | −325 | 125 | 100 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| 18Cr–10Ni–Ti | Bolts | A320 | B8T | S32100 | 2 | ≤$^3/_4$ | (15)(60) | −325 | 125 | 100 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| 12Cr | Bolts | A437 | B4B | S42225 | ... | ... | (35) | −20 | 145 | 105 | 26.3 | 26.3 | 26.3 | 26.3 | 26.3 |
| 12Cr | Nuts | A194 | 6 | S41000 | ... | ... | (35)(42) | −20 | ... | ... | ... | ... | ... | ... | ... |
| 18Cr–9Ni | Nuts | A194 | 8FA | S30300 | ... | ... | (42) | −20 | ... | ... | ... | ... | ... | ... | ... |
| 16Cr–12Ni–2Mo | Nuts | A194 | 8MA | S31600 | ... | ... | (42) | −325 | ... | ... | ... | ... | ... | ... | ... |
| 18Cr–10Ni–Ti | Nuts | A194 | 8TA | S32100 | ... | ... | (42) | −325 | ... | ... | ... | ... | ... | ... | ... |
| 18Cr–8Ni | Nuts | A194 | 8 | S30400 | ... | ... | (42) | −425 | ... | ... | ... | ... | ... | ... | ... |
| 18Cr–8Ni | Nuts | A194 | 8A | S30400 | ... | ... | (42) | −425 | ... | ... | ... | ... | ... | ... | ... |
| 18Cr–10Ni–Cb | Nuts | A194 | 8CA | S34700 | ... | ... | (42) | −425 | ... | ... | ... | ... | ... | ... | ... |

## Table A-2 Design Stress Values for Bolting Materials (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM**

| Design Stress, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/ Grade | Spec. No. |
| | | | | | | | | | | | | | | | | | | | **Stainless Steel** | **(Cont'd)** |
| 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 660 Cl. A | A453 |
| 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 660 Cl. B | A453 |
| 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2 | A193 |
| 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2 | A320 |
| 24.6 | 24.5 | 24.5 | 24.5 | 24.5 | 24.5 | 24.4 | 24.2 | 23.9 | 23.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2 | A193 |
| 24.6 | 24.5 | 24.5 | 24.5 | 24.5 | 24.5 | 24.4 | 24.2 | 23.9 | 23.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2 | A320 |
| 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 24.7 | 23.9 | 22.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2 | A193 |
| 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 24.7 | 23.9 | 22.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2 | A320 |
| 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2 | A193 |
| 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2 | A320 |
| 26.3 | 26.3 | 26.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | B4B | A437 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 6 | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8FA | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8MA | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8TA | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8 | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8A | A194 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8CA | A194 |

## Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, Dia., in. | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Design Stress, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Copper and Copper Alloy** | | | | | | | | | | | | | |
| Naval brass | Bolts | B21 | ... | C46400 | O60 | ... | (8f) | −325 | 50 | 20 | 12.5 | 12.5 | 12.5 |
| Naval brass | Bolts | B21 | ... | C48200 | O60 | ... | (8f) | −325 | 50 | 20 | 12.5 | 12.5 | 12.5 |
| Naval brass | Bolts | B21 | ... | C48500 | O60 | ... | (8f) | −325 | 50 | 20 | 12.5 | 12.5 | 12.5 |
| Cu | Bolts | B187 | ... | C10200 | O60 | ... | (8f) | −325 | 30 | 10 | 6.7 | 5.4 | 5.0 |
| Cu | Bolts | B187 | ... | C11000 | O60 | ... | (8f) | −325 | 30 | 10 | 6.7 | 5.4 | 5.0 |
| Cu | Bolts | B187 | ... | C12000 | O60 | ... | (8f) | −325 | 30 | 10 | 6.7 | 5.4 | 5.0 |
| Cu | Bolts | B187 | ... | C12200 | O60 | ... | (8f) | −325 | 30 | 10 | 6.7 | 5.4 | 5.0 |
| Cu–Si | Bolts | B98 | ... | C65100 | O60 | ... | (8f)(52) | −325 | 40 | 12 | 8.0 | 8.0 | 7.1 |
| Cu–Si | Bolts | B98 | ... | C65500 | O60 | ... | (8f)(52) | −325 | 52 | 15 | 10.0 | 10.0 | 10.0 |
| Cu–Si | Bolts | B98 | ... | C66100 | O60 | ... | (8f)(52) | −325 | 52 | 15 | 10.0 | 10.0 | 10.0 |
| Cu–Si | Bolts | B98 | ... | C65500 | H01 | ... | (8f) | −325 | 55 | 24 | 10.0 | 10.0 | 10.0 |
| Cu–Si | Bolts | B98 | ... | C66100 | H01 | ... | (8f) | −325 | 55 | 24 | 10.0 | 10.0 | 10.0 |
| Cu–Si | Bolts | B98 | ... | C65500 | H02 | <2 | ... | −325 | 70 | 38 | 10.0 | 10.0 | 10.0 |
| Cu–Si | Bolts | B98 | ... | C66100 | H02 | <2 | ... | −325 | 70 | 38 | 10.0 | 10.0 | 10.0 |
| Cu–Si | Bolts | B98 | ... | C65100 | H06 | >1, <1½ | ... | −325 | 75 | 40 | 10.0 | 10.0 | 10.0 |
| Cu–Si | Bolts | B98 | ... | C65100 | H06 | >½, ≤1 | ... | −325 | 75 | 45 | 11.3 | 11.3 | 11.3 |
| Cu–Si | Bolts | B98 | ... | C65100 | H06 | ≤½ | ... | −325 | 85 | 55 | 13.8 | 13.8 | 13.8 |
| Al–Si–bronze | Bolts | B150 | ... | C64200 | HR50 | >1, ≤2 | ... | −325 | 80 | 42 | 16.7 | 13.9 | 13.4 |
| Al–Si–bronze | Bolts | B150 | ... | C64200 | HR50 | >½, ≤1 | ... | −325 | 85 | 42 | 16.7 | 13.9 | 13.4 |
| Al–Si–bronze | Bolts | B150 | ... | C64200 | HR50 | ≤½ | ... | −325 | 90 | 42 | 16.7 | 13.9 | 13.4 |
| Al–bronze | Bolts | B150 | ... | C61400 | HR50 | >1, ≤2 | ... | −325 | 70 | 32 | 17.5 | 17.5 | 17.5 |
| Al–bronze | Bolts | B150 | ... | C61400 | HR50 | >½, ≤1 | ... | −325 | 75 | 35 | 17.5 | 17.5 | 17.5 |
| Al–bronze | Bolts | B150 | ... | C61400 | HR50 | ≤½ | ... | −325 | 80 | 40 | 18.0 | 18.0 | 18.0 |
| Al–bronze | Bolts | B150 | ... | C63000 | HR50 | >2, ≤3 | ... | −325 | 85 | 42.5 | 21.3 | 21.3 | 21.0 |
| Al–bronze | Bolts | B150 | ... | C63000 | M20 | >3, ≤4 | ... | −325 | 85 | 42.5 | 20.0 | 19.6 | 19.1 |
| Al–bronze | Bolts | B150 | ... | C63000 | HR50 | >1, ≤2 | ... | −325 | 90 | 45 | 22.5 | 22.5 | 22.5 |
| Al–bronze | Bolts | B150 | ... | C63000 | HR50 | ≥½, ≤1 | ... | −325 | 100 | 50 | 22.5 | 22.5 | 22.5 |
| **Nickel and Nickel Alloy** | | | | | | | | | | | | | |
| Low C–Ni | Bolts | B160 | ... | N02201 | Hot fin./ann. | ... | (8f) | −325 | 50 | 10 | 6.7 | 6.4 | 6.3 |
| Ni | Bolts | B160 | ... | N02200 | Hot fin. | ... | (8f) | −325 | 60 | 15 | 10.0 | 10.0 | 10.0 |
| Ni | Bolts | B160 | ... | N02200 | Annealed | ... | (8f) | −325 | 55 | 15 | 10.0 | 10.0 | 10.0 |
| Ni | Bolts | B160 | ... | N02200 | Cold drawn | ... | ... | −325 | 65 | 40 | 10.0 | 10.0 | 10.0 |
| Ni–Cu | Bolts | B164 | ... | N04400 | C.D./str. rel. | ... | (54) | −325 | 84 | 50 | 16.7 | 14.6 | 13.6 |
| Ni–Cu | Bolts | B164 | ... | N04405 | Cold drawn | ... | (54) | −325 | 85 | 50 | 16.7 | 14.6 | 13.6 |
| Ni–Cu | Bolts | B164 | ... | N04400 | Cold drawn | ... | (54) | −325 | 85 | 55 | 16.7 | 14.6 | 13.8 |
| Ni–Cu | Bolts | B164 | ... | N04400 | Annealed | ... | (8f) | −325 | 70 | 25 | 16.7 | 14.6 | 13.6 |
| Ni–Cu | Bolts | B164 | ... | N04405 | Annealed | ... | (8f) | −325 | 70 | 25 | 16.7 | 14.6 | 13.6 |

## Table A-2 Design Stress Values for Bolting Materials (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM**

| Design Stress, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | UNS No. | Spec. No. |
| **Copper and Copper Alloy** | | | | | | | | | | | | | | | | | | |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C46400 | B21 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C48200 | B21 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C48500 | B21 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C10200 | B187 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C11000 | B187 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C12000 | B187 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C12200 | B187 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65100 | B98 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65500 | B98 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C66100 | B98 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65500 | B98 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C66100 | B98 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65500 | B98 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C66100 | B98 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65100 | B98 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65100 | B98 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65100 | B98 |
| 10.8 | 5.2 | 1.7 | 1.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C64200 | B150 |
| 10.8 | 5.2 | 1.7 | 1.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C64200 | B150 |
| 10.8 | 5.2 | 1.7 | 1.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C64200 | B150 |
| 17.2 | 16.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C61400 | B150 |
| 17.2 | 16.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C61400 | B150 |
| 17.7 | 16.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C61400 | B150 |
| 20.7 | 19.4 | 12.0 | 8.6 | 6.0 | 4.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C63000 | B150 |
| 18.8 | 17.6 | 12.0 | 8.6 | 6.0 | 4.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C63000 | B150 |
| 22.5 | 21.1 | 12.0 | 8.6 | 6.0 | 4.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C63000 | B150 |
| 22.5 | 21.1 | 12.0 | 8.6 | 6.0 | 4.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | C63000 | B150 |
| **Nickel and Nickel Alloy** | | | | | | | | | | | | | | | | | | |
| 6.2 | 6.2 | 6.2 | 6.2 | 6.2 | 6.1 | 6.0 | 5.8 | 4.5 | 3.7 | 3.0 | 2.4 | 2.0 | 1.5 | 1.2 | 1.0 | ... | N02201 | B160 |
| 10.0 | 10.0 | 10.0 | 10.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B160 |
| 10.0 | 10.0 | 10.0 | 10.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B160 |
| 10.0 | 10.0 | 10.0 | 10.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200 | B160 |
| 13.2 | 13.1 | 13.1 | 13.1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B164 |
| 13.2 | 13.1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04405 | B164 |
| 13.8 | 13.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400 | B164 |
| 13.2 | 13.1 | 13.1 | 13.1 | 13.0 | 12.9 | 12.7 | 12.6 | 12.5 | 9.2 | ... | ... | ... | ... | ... | ... | ... | N04400 | B164 |
| 13.2 | 13.1 | 13.1 | 13.1 | 13.0 | 12.9 | 12.7 | 12.6 | 12.5 | 9.2 | ... | ... | ... | ... | ... | ... | ... | N04405 | B164 |

## Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, Dia., in. | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi: Tensile | Specified Min. Strength, ksi: Yield | Design Stress, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100 | 200 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nickel and Nickel Alloy** | | | | | | | | | | | | | |
| Ni–Cu | Rod | B164 | ... | N04405 | Hot fin. | ≤3 | ... | −325 | 75 | 35 | 16.7 | 14.6 | 13.6 |
| Ni–Cu | Hex | B164 | ... | N04400 | Hot fin. | ≥2⅛, ≤4 | (8f) | −325 | 75 | 30 | 16.7 | 14.6 | 13.6 |
| Ni–Cu | All except hex | B164 | ... | N04400 | Hot fin. | >2⅛ | ... | −325 | 80 | 40 | 16.7 | 14.6 | 13.6 |
| Ni–Cr–Fe | Rod | B166 | ... | N06600 | Cold drawn | ≤3 | (41)(54) | −325 | 105 | 80 | 20.0 | 20.0 | 20.0 |
| Ni–Cr–Fe | Rod | B166 | ... | N06600 | Hot fin. | ≤3 | ... | −325 | 90 | 40 | 16.7 | 15.9 | 15.2 |
| Ni–Cr–Fe | Bolts | B166 | ... | N06600 | Annealed | ... | ... | −325 | 80 | 35 | 16.7 | 15.9 | 15.2 |
| Ni–Cr–Fe | Rod | B166 | ... | N06600 | Hot fin. | >3 | ... | −325 | 85 | 35 | 16.7 | 15.9 | 15.2 |
| Ni–Mo | Bolts | B335 | ... | N10001 | Annealed | ... | ... | −325 | 100 | 46 | 25.0 | 25.0 | 25.0 |
| Ni–Mo–Cr | Bolts | B574 | ... | N10276 | Sol. ann. | ... | ... | −325 | 100 | 41 | 25.0 | 24.9 | 23.0 |
| **Aluminum Alloy** | | | | | | | | | | | | | |
| ... | Bolts | B211 | 6061 | 6061 | T6, T651 wld. | ≥⅛, ≤8 | (8f)(43)(63) | −452 | 24 | ... | 4.8 | 4.8 | 4.8 |
| ... | Bolts | B211 | 6061 | 6061 | T6, T651 | ≥⅛, ≤8 | (43)(63) | −452 | 42 | 35 | 8.4 | 8.4 | 8.4 |
| ... | Bolts | B211 | 2024 | 2024 | T4 | >6½, ≤8 | (43)(63) | −452 | 58 | 38 | 9.5 | 9.5 | 9.5 |
| ... | Bolts | B211 | 2024 | 2024 | T4 | >4½, ≤6½ | (43)(63) | −452 | 62 | 40 | 10.0 | 10.0 | 10.0 |
| ... | Bolts | B211 | 2024 | 2024 | T4 | ≥½, ≤4½ | (43)(63) | −452 | 62 | 42 | 10.5 | 10.5 | 10.3 |
| ... | Bolts | B211 | 2024 | 2024 | T4 | ≥⅛, <½ | (43)(63) | −452 | 62 | 45 | 11.3 | 11.3 | 10.3 |
| ... | Bolts | B211 | 2014 | 2014 | T6, T651 | ≥⅛, ≤8 | (43)(63) | −452 | 65 | 55 | 13.0 | 13.0 | 12.4 |

## Table A-2 Design Stress Values for Bolting Materials (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM**

| Design Stress, ksi, at Metal Temperature, °F [Note (1)] | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **400** | **500** | **600** | **650** | **700** | **750** | **800** | **850** | **900** | **950** | **1,000** | **1,050** | **1,100** | **1,150** | **1,200** | **1,250** | **1,300** | **UNS No.** | **Spec. No.** |
| | | | | | | | | | | | | | | | **Nickel and Nickel Alloy** | | | **(Cont'd)** |
| 13.2 | 13.1 | 13.1 | 13.1 | 13.0 | 12.9 | 12.7 | 12.6 | 12.5 | 9.2 | ... | ... | ... | ... | ... | ... | ... | N04405 | B164 |
| 13.2 | 13.1 | 13.1 | 13.1 | 13.0 | 12.9 | 12.7 | 12.6 | 12.5 | 9.2 | ... | ... | ... | ... | ... | ... | ... | N04400 | B164 |
| 13.2 | 13.1 | 13.1 | 13.1 | 13.0 | 12.9 | 12.7 | 12.6 | 12.5 | 9.2 | ... | ... | ... | ... | ... | ... | ... | N04400 | B164 |
| 20.0 | 20.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | N06600 | B166 |
| 14.6 | 14.0 | 13.5 | 13.3 | 13.1 | 12.9 | 12.7 | 12.5 | 12.4 | 10.0 | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | 1.8 | ... | N06600 | B166 |
| 14.6 | 14.0 | 13.5 | 13.3 | 13.1 | 12.9 | 12.7 | 12.5 | 12.4 | 9.2 | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | 1.8 | ... | N06600 | B166 |
| 14.6 | 14.0 | 13.5 | 13.3 | 13.1 | 12.9 | 12.7 | 12.5 | 12.4 | 9.2 | 7.0 | 4.5 | 3.0 | 2.2 | 2.0 | 1.8 | ... | N06600 | B166 |
| 24.6 | 24.3 | 23.6 | 23.3 | 23.0 | 22.8 | 22.6 | 22.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | N10001 | B335 |
| 21.3 | 19.9 | 18.7 | 18.2 | 17.8 | 17.4 | 17.1 | 16.9 | 16.7 | 16.6 | 16.5 | 16.5 | ... | ... | ... | ... | ... | N10276 | B574 |
| | | | | | | | | | | | | | | | | | | **Aluminum Alloy** |
| 3.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A96061 | B211 |
| 4.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A96061 | B211 |
| 4.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A92024 | B211 |
| 4.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A92024 | B211 |
| 4.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A92024 | B211 |
| 4.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A92024 | B211 |
| 4.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | A92014 | B211 |

(18)

## Table A-2M Design Stress Values for Bolting Materials (SI Units)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, Dia., mm | Notes |
|---|---|---|---|---|---|---|---|---|
| 1 | Carbon steel | Bolts | A675 | 45 | D40450 | ... | ... | (8f)(8g) |
| 2 | Carbon steel | Bolts | A675 | 50 | D40500 | ... | ... | (8f)(8g) |
| 3 | Carbon steel | Bolts | A675 | 55 | D40550 | ... | ... | (8f)(8g) |
| 4 | Carbon steel | Bolts | A307 | B | ... | ... | ... | (8f)(8g) |
| 5 | Carbon steel | Bolts | A675 | 60 | D40600 | ... | ... | (8f)(8g) |
| 6 | Carbon steel | Bolts | A675 | 65 | D40650 | ... | ... | (8g) |
| 7 | Carbon steel | Bolts | A675 | 70 | D40700 | ... | ... | (8g) |
| 8 | Carbon steel | Bolts | A675 | 80 | D40800 | ... | ... | (8g) |
| 9 | Carbon steel | Bolts | F3125 | A325 | K02706 | ... | ... | (8g) |
| 10 | Carbon steel | Nuts | A194 | 1 | K01503 | ... | ... | (42) |
| 11 | Carbon steel | Nuts | A194 | 2, 2H | K04002 | ... | ... | (42) |
| 12 | Carbon steel | Nuts | A194 | 2HM | K04002 | ... | ... | (42) |
| 13 | Carbon steel | Nuts | A563 | A, hvy. hex | K05802 | ... | ... | (42b) |
| 14 | Cr–0.2Mo | Bolts | A193 | B7M | G41400 | ... | ≤100 | ... |
| 15 | Cr–0.2Mo | Bolts | A320 | L7M | G41400 | ... | ≤64 | ... |
| 16 | 5Cr | Bolts | A193 | B5 | S50100 | ... | ≤100 | (15) |
| 17 | Cr–Mo–V | Bolts | A193 | B16 | K14072 | ... | >64, ≤100 | (15) |
| 18 | Alloy steel | Bolts | A354 | BC | ... | ... | >64, ≤100 | (15) |
| 19 | Cr–Mo | Bolts | A193 | B7 | G41400 | ... | >64, ≤100 | (15) |
| 20 | Ni–Cr–Mo | Bolts | A320 | L43 | G43400 | ... | ≤100 | (15) |
| 21 | Cr–Mo | Bolts | A320 | L7 | G41400 | ... | ≤64 | (15) |
| 22 | Cr–Mo | Bolts | A320 | L7A | G40370 | ... | ≤64 | (15) |
| 23 | Cr–Mo | Bolts | A320 | L7B | G41370 | ... | ≤64 | (15) |
| 24 | Cr–Mo | Bolts | A320 | L7C | G87400 | ... | ≤64 | (15) |
| 25 | Cr–Mo | Bolts | A193 | B7 | G41400 | ... | ≤64 | ... |
| 26 | Cr–Mo–V | Bolts | A193 | B16 | K14072 | ... | ≤64 | (15) |
| 27 | Alloy steel | Bolts | A354 | BC | ... | ... | ≤64 | (15) |
| 28 | Alloy steel | Bolts | A354 | BD | ... | ... | ≤100 | (15) |
| 29 | 5Cr | Nuts | A194 | 3 | S50100 | ... | ... | (42) |
| 30 | C–Mo | Nuts | A194 | 4 | K14510 | ... | ... | (42) |
| 31 | C–Mo | Nuts | A194 | 4L | K14510 | ... | ... | (42) |
| 32 | Cr–Mo | Nuts | A194 | 7 | G41400 | ... | ... | (42) |
| 33 | Cr–Mo | Nuts | A194 | 7L | G41400 | ... | ... | (42) |
| 34 | Cr–Mo | Nuts | A194 | 7M | G41400 | ... | ... | (42) |
| 35 | Cr–Mo | Nuts | A194 | 7ML | G41400 | ... | ... | (42) |
| 36 | 16Cr–12Ni–2Mo | Bolts | A193 | B8M | S31600 | 2 | >32, ≤38 | (15)(60) |
| 37 | 16Cr–12Ni–2Mo | Bolts | A320 | B8M | S31600 | 2 | >32, ≤38 | (15)(60) |
| 38 | 18Cr–8Ni | Bolts | A193 | B8 | S30400 | 2 | >32, ≤38 | (15)(60) |
| 39 | 18Cr–8Ni | Bolts | A320 | B8 | S30400 | 2 | >32, ≤38 | (15)(60) |

## Table A-2M Design Stress Values for Bolting Materials (SI Units)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Design Stress, MPa, at Metal Temperature, °C [Note (1)] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 |
| 1 | −29 | 310 | 155 | 482 | 77.6 | 77.6 | 77.6 | 77.6 | 77.6 | 77.6 | 77.6 | 77.6 |
| 2 | −29 | 345 | 172 | 482 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 |
| 3 | −29 | 379 | 190 | 482 | 94.8 | 94.8 | 94.8 | 94.8 | 94.8 | 94.8 | 94.8 | 94.8 |
| 4 | −29 | 414 | ... | 260 | 103 | 103 | 103 | 103 | 103 | 103 | 103 | 103 |
| 5 | −29 | 414 | 207 | 482 | 103 | 103 | 103 | 103 | 103 | 103 | 103 | 103 |
| 6 | −29 | 448 | 224 | 538 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 |
| 7 | −29 | 483 | 241 | 538 | 121 | 121 | 121 | 121 | 121 | 121 | 121 | 121 |
| 8 | −29 | 552 | 276 | 343 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 9 | −29 | 825 | 635 | 343 | 159 | 159 | 159 | 159 | 159 | 159 | 159 | 159 |
| 10 | −29 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 11 | −48 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 12 | −48 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 13 | −29 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 14 | −48 | 689 | 552 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 15 | −73 | 689 | 552 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 16 | −29 | 689 | 552 | 649 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 17 | −29 | 758 | 655 | 593 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 |
| 18 | −18 | 793 | 683 | 343 | 159 | 159 | 159 | 159 | 159 | 159 | 159 | 159 |
| 19 | −40 | 793 | 655 | 538 | 159 | 159 | 159 | 159 | 159 | 159 | 159 | 159 |
| 20 | −101 | 862 | 724 | 371 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 21 | −101 | 862 | 724 | 371 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 22 | −101 | 862 | 724 | 343 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 23 | −101 | 862 | 724 | 343 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 24 | −101 | 862 | 724 | 343 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 25 | −48 | 862 | 724 | 538 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 26 | −29 | 862 | 724 | 593 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 27 | −18 | 862 | 752 | 343 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 28 | −29 | 1034 | 896 | 343 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| 29 | −29 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 30 | −48 | ... | ... | 593 | ... | ... | ... | ... | ... | ... | ... | ... |
| 31 | −101 | ... | ... | 593 | ... | ... | ... | ... | ... | ... | ... | ... |
| 32 | −48 | ... | ... | 593 | ... | ... | ... | ... | ... | ... | ... | ... |
| 33 | −101 | ... | ... | 593 | ... | ... | ... | ... | ... | ... | ... | ... |
| 34 | −48 | ... | ... | 593 | ... | ... | ... | ... | ... | ... | ... | ... |
| 35 | −73 | ... | ... | 593 | ... | ... | ... | ... | ... | ... | ... | ... |
| 36 | −198 | 621 | 345 | 538 | 129 | 126 | 118 | 112 | 107 | 103 | 99.1 | 95.8 |
| 37 | −198 | 621 | 345 | 538 | 129 | 126 | 118 | 112 | 107 | 103 | 99.1 | 95.8 |
| 38 | −198 | 689 | 345 | 538 | 129 | 123 | 113 | 108 | 103 | 99.0 | 95.6 | 92.7 |
| 39 | −198 | 689 | 345 | 538 | 129 | 123 | 113 | 108 | 103 | 99.0 | 95.6 | 92.7 |

## Table A-2M Design Stress Values for Bolting Materials (SI Units)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM**

| Line No. | Design Stress, MPa, at Metal Temperature, °C [Note (1)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 1 | 77.6 | 77.6 | 77.6 | 77.6 | 76.0 | 73.7 | 71.5 | 64.0 | 55.8 | 43.9 | 31.7 | ... |
| 2 | 86.2 | 86.2 | 86.2 | 86.2 | 84.5 | 81.9 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | ... |
| 3 | 94.8 | 94.8 | 94.8 | 94.8 | 92.9 | 90.1 | 87.4 | 75.3 | 62.1 | 45.0 | 31.7 | ... |
| 4 | 103 | 103 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 5 | 103 | 103 | 103 | 103 | 101 | 98.3 | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | ... |
| 6 | 112 | 112 | 112 | 112 | 110 | 106 | 95.1 | 79.5 | 64.4 | 47.7 | 32.5 | 21.4 |
| 7 | 121 | 121 | 121 | 121 | 118 | 115 | 101 | 83.8 | 66.8 | 50.3 | 33.2 | 21.4 |
| 8 | 138 | 138 | 138 | 138 | 135 | ... | ... | ... | ... | ... | ... | ... |
| 9 | 159 | 159 | 159 | 159 | 159 | ... | ... | ... | ... | ... | ... | ... |
| 10 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 11 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 13 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 14 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 115 | 92.3 | 67.3 | 41.6 |
| 15 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 115 | 92.3 | 67.3 | 41.6 |
| 16 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 80.6 | 61.7 | 46.4 |
| 17 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 148 | 132 | 113 | 88.3 |
| 18 | 159 | 159 | 159 | 159 | 159 | ... | ... | ... | ... | ... | ... | ... |
| 19 | 159 | 159 | 159 | 159 | 159 | 159 | 159 | 159 | 116 | 92.3 | 67.3 | 41.6 |
| 20 | 172 | 172 | 172 | 172 | 172 | 172 | ... | ... | ... | ... | ... | ... |
| 21 | 172 | 172 | 172 | 172 | 172 | 172 | ... | ... | ... | ... | ... | ... |
| 22 | 172 | 172 | 172 | 172 | 172 | ... | ... | ... | ... | ... | ... | ... |
| 23 | 172 | 172 | 172 | 172 | 172 | ... | ... | ... | ... | ... | ... | ... |
| 24 | 172 | 172 | 172 | 172 | 172 | ... | ... | ... | ... | ... | ... | ... |
| 25 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 121 | 93.4 | 67.3 | 41.6 |
| 26 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 166 | 146 | 121 | 90.1 |
| 27 | 172 | 172 | 172 | 172 | 172 | ... | ... | ... | ... | ... | ... | ... |
| 28 | 207 | 207 | 207 | 207 | 207 | ... | ... | ... | ... | ... | ... | ... |
| 29 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 30 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 31 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 32 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 33 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 34 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 35 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 36 | 92.8 | 90.3 | 88.1 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 |
| 37 | 92.8 | 90.3 | 88.1 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 |
| 38 | 90.1 | 87.9 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 |
| 39 | 90.1 | 87.9 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 |

## Table A-2M Design Stress Values for Bolting Materials (SI Units)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| | Design Stress, MPa, at Metal Temperature, °C [Note (1)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 6 | 14.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 7 | 14.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 10 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 11 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 13 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 14 | 23.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 15 | 23.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 16 | 34.7 | 25.5 | 17.8 | 11.4 | 6.7 | ... | ... | ... | ... | ... | ... | ... |
| 17 | 59.3 | 33.0 | 15.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 18 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 19 | 23.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 20 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 21 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 22 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 23 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 24 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 25 | 23.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 26 | 59.3 | 33.0 | 15.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 27 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 29 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 30 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 31 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 32 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 33 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 34 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 35 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 36 | 86.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 37 | 86.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 38 | 86.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 39 | 86.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, Dia., mm | Notes |
|---|---|---|---|---|---|---|---|---|
| 40 | 18Cr–10Ni–Cb | Bolts | A193 | B8C | ... | 2 | >32, ≤38 | (15)(60) |
| 41 | 18Cr–10Ni–Cb | Bolts | A320 | B8C | S34700 | 2 | >32, ≤38 | (15)(60) |
| 42 | 18Cr–10Ni–Ti | Bolts | A193 | B8T | S32100 | 2 | >32, ≤38 | (15)(60) |
| 43 | 18Cr–10Ni–Ti | Bolts | A320 | B8T | S32100 | 2 | >32, ≤38 | (15)(60) |
| 44 | 18Cr–9Ni | Bolts | A320 | B8F | S30300 | 1 | ... | (8f)(15)(39) |
| 45 | 19Cr–9Ni | Bolts | A453 | 651B | ... | ... | >75 | (15)(35) |
| 46 | 19Cr–9Ni | Bolts | A453 | 651B | ... | ... | ≤75 | (15)(35) |
| 47 | 19Cr–9Ni | Bolts | A453 | 651A | ... | ... | >75 | (15)(35) |
| 48 | 19Cr–9Ni | Bolts | A453 | 651A | ... | ... | ≤75 | (15)(35) |
| 49 | 16Cr–12Ni–2Mo | Bolts | A193 | B8M | S31600 | 2 | >25, ≤32 | (15)(60) |
| 50 | 16Cr–12Ni–2Mo | Bolts | A320 | B8M | S31600 | 2 | >25, ≤32 | (15)(60) |
| 51 | 18Cr–10Ni–Cb | Bolts | A193 | B8C | ... | 2 | >25, ≤32 | (15)(60) |
| 52 | 18Cr–10Ni–Cb | Bolts | A320 | B8C | S34700 | 2 | >25, ≤32 | (15)(60) |
| 53 | 18Cr–8Ni | Bolts | A193 | B8 | S30400 | 2 | >25, ≤32 | (15)(60) |
| 54 | 18Cr–8Ni | Bolts | A320 | B8 | S30400 | 2 | >25, ≤32 | (15)(60) |
| 55 | 18Cr–10Ni–Ti | Bolts | A193 | B8T | S32100 | 2 | >25, ≤32 | (15)(60) |
| 56 | 18Cr–10Ni–Ti | Bolts | A320 | B8T | S32100 | 2 | >25, ≤32 | (15)(60) |
| 57 | 18Cr–10Ni–Ti | Bolts | A193 | B8T | S32100 | 1 | ... | (8f)(15)(28) |
| 58 | 18Cr–8Ni | Bolts | A320 | B8 | S30400 | 1 | ... | (8f)(15)(28) |
| 59 | 18Cr–10Ni–Cb | Bolts | A193 | B8C | ... | 1 | ... | (8f)(15)(28) |
| 60 | 16Cr–12Ni–2Mo | Bolts | A193 | B8M | S31600 | 1 | ... | (8f)(15)(28) |
| 61 | 16Cr–12Ni–2Mo | Bolts | A193 | B8M | S31600 | 2 | >19, ≤25 | (15)(60) |
| 62 | 16Cr–12Ni–2Mo | Bolts | A320 | B8M | S31600 | 2 | >19, ≤25 | (15)(60) |
| 63 | 18Cr–10Ni–Cb | Bolts | A193 | B8C | ... | 2 | >19, ≤25 | (15)(60) |
| 64 | 18Cr–10Ni–Cb | Bolts | A320 | B8C | S34700 | 2 | >19, ≤25 | (15)(60) |
| 65 | 18Cr–8Ni | Bolts | A193 | B8 | S30400 | 2 | >19, ≤25 | (15)(60) |
| 66 | 18Cr–8Ni | Bolts | A320 | B8 | S30400 | 2 | >19, ≤25 | (15)(60) |
| 67 | 18Cr–10Ni–Ti | Bolts | A193 | B8T | S32100 | 2 | >19, ≤25 | (15)(60) |
| 68 | 18Cr–10Ni–Ti | Bolts | A320 | B8T | S32100 | 2 | >19, ≤25 | (15)(60) |
| 69 | 12Cr | Bolts | A437 | B4C | S42200 | ... | ... | (35) |
| 70 | 13Cr | Bolts | A193 | B6 | S41000 | ... | ≤100 | (15)(35) |
| 71 | 14Cr–24Ni | Bolts | A453 | 660 | S66286 | A | ... | (15)(35) |
| 72 | 14Cr–24Ni | Bolts | A453 | 660 | S66286 | B | ... | (15)(35) |
| 73 | 16Cr–12Ni–2Mo | Bolts | A193 | B8M | S31600 | 2 | ≤19 | (15)(60) |
| 74 | 16Cr–12Ni–2Mo | Bolts | A320 | B8M | S31600 | 2 | ≤19 | (15)(60) |
| 75 | 18Cr–10Ni–Cb | Bolts | A193 | B8C | ... | 2 | ≤19 | (15)(60) |
| 76 | 18Cr–10Ni–Cb | Bolts | A320 | B8C | S34700 | 2 | ≤19 | (15)(60) |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Design Stress, MPa, at Metal Temperature, °C [Note (1)] Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | −198 | 689 | 345 | 538 | 129 | 129 | 122 | 117 | 113 | 110 | 108 | 105 |
| 41 | −198 | 689 | 345 | 538 | 129 | 129 | 122 | 117 | 113 | 110 | 108 | 105 |
| 42 | −198 | 689 | 345 | 538 | 129 | 129 | 121 | 118 | 114 | 110 | 106 | 103 |
| 43 | −198 | 689 | 345 | 538 | 129 | 129 | 121 | 118 | 114 | 110 | 106 | 103 |
| 44 | −198 | 517 | 207 | 427 | 129 | 123 | 113 | 108 | 103 | 99.0 | 95.6 | 92.7 |
| 45 | −29 | 655 | 345 | 538 | 164 | 164 | 160 | 156 | 152 | 149 | 147 | 145 |
| 46 | −29 | 655 | 414 | 538 | 164 | 164 | 160 | 156 | 152 | 149 | 147 | 145 |
| 47 | −29 | 689 | 414 | 538 | 164 | 164 | 160 | 156 | 152 | 149 | 147 | 145 |
| 48 | −29 | 689 | 483 | 538 | 164 | 164 | 160 | 156 | 152 | 149 | 147 | 145 |
| 49 | −198 | 724 | 448 | 538 | 129 | 126 | 118 | 112 | 112 | 112 | 112 | 112 |
| 50 | −198 | 724 | 448 | 538 | 129 | 126 | 118 | 112 | 112 | 112 | 112 | 112 |
| 51 | −198 | 724 | 448 | 538 | 129 | 129 | 122 | 117 | 113 | 112 | 112 | 112 |
| 52 | −198 | 724 | 448 | 538 | 129 | 129 | 122 | 117 | 113 | 112 | 112 | 112 |
| 53 | −198 | 724 | 448 | 538 | 129 | 123 | 113 | 112 | 112 | 112 | 112 | 112 |
| 54 | −198 | 724 | 448 | 538 | 129 | 123 | 113 | 112 | 112 | 112 | 112 | 112 |
| 55 | −198 | 724 | 448 | 538 | 129 | 129 | 121 | 118 | 114 | 112 | 112 | 112 |
| 56 | −198 | 724 | 448 | 538 | 129 | 129 | 121 | 118 | 114 | 112 | 112 | 112 |
| 57 | −198 | 517 | 207 | 816 | 129 | 129 | 121 | 118 | 114 | 110 | 106 | 103 |
| 58 | −254 | 517 | 207 | 816 | 129 | 123 | 113 | 108 | 103 | 99.0 | 95.6 | 92.7 |
| 59 | −254 | 517 | 207 | 816 | 129 | 129 | 122 | 117 | 113 | 110 | 108 | 105 |
| 60 | −198 | 517 | 207 | 816 | 129 | 126 | 118 | 112 | 107 | 103 | 99.1 | 95.8 |
| 61 | −198 | 689 | 552 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 62 | −198 | 689 | 552 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 63 | −198 | 793 | 552 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 64 | −198 | 793 | 552 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 65 | −198 | 793 | 552 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 66 | −198 | 793 | 552 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 67 | −198 | 793 | 552 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 68 | −198 | 793 | 552 | 538 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 69 | −29 | 793 | 586 | 371 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 70 | −29 | 758 | 586 | 482 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 71 | −198 | 896 | 586 | 538 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 72 | −198 | 896 | 586 | 538 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 73 | −198 | 758 | 655 | 538 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 |
| 74 | −198 | 758 | 655 | 538 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 |
| 75 | −198 | 862 | 689 | 538 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 76 | −198 | 862 | 689 | 538 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Design Stress, MPa, at Metal Temperature, °C [Note (1)] 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 104 | 102 | 99.9 | 98.0 | 96.4 | 95.2 | 94.2 | 93.5 | 93.0 | 92.7 | 92.6 | 92.4 |
| 41 | 104 | 102 | 99.9 | 98.0 | 96.4 | 95.2 | 94.2 | 93.5 | 93.0 | 92.7 | 92.6 | 92.4 |
| 42 | 100 | 97.2 | 94.7 | 92.6 | 90.8 | 89.2 | 87.8 | 86.6 | 86.2 | 86.2 | 86.2 | 86.2 |
| 43 | 100 | 97.2 | 94.7 | 92.6 | 90.8 | 89.2 | 87.8 | 86.6 | 86.2 | 86.2 | 86.2 | 86.2 |
| 44 | 90.1 | 87.9 | 85.8 | 84.0 | 82.3 | 80.6 | 79.1 | 77.6 | 76.2 | ... | ... | ... |
| 45 | 144 | 143 | 142 | 141 | 141 | 140 | 139 | 138 | 136 | 134 | 131 | 128 |
| 46 | 144 | 143 | 142 | 141 | 141 | 140 | 139 | 138 | 136 | 134 | 131 | 128 |
| 47 | 144 | 143 | 142 | 141 | 141 | 140 | 139 | 138 | 136 | 134 | 131 | 128 |
| 48 | 144 | 143 | 142 | 141 | 141 | 140 | 139 | 138 | 136 | 134 | 131 | 128 |
| 49 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 |
| 50 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 |
| 51 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 |
| 52 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 |
| 53 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 |
| 54 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 |
| 55 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 |
| 56 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 |
| 57 | 99.9 | 97.2 | 94.7 | 92.6 | 90.8 | 89.2 | 87.8 | 86.6 | 85.6 | 84.7 | 84.0 | 83.2 |
| 58 | 90.1 | 87.9 | 85.8 | 84.0 | 82.3 | 80.6 | 79.1 | 77.6 | 76.2 | 74.8 | 73.4 | 72.1 |
| 59 | 104 | 102 | 99.9 | 98.0 | 96.4 | 95.2 | 94.2 | 93.5 | 93.0 | 92.7 | 92.6 | 92.4 |
| 60 | 92.8 | 90.3 | 88.1 | 86.2 | 84.6 | 83.3 | 82.2 | 81.2 | 80.4 | 79.7 | 79.0 | 78.4 |
| 61 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 62 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 63 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 64 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 65 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 66 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 67 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 68 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 69 | 147 | 147 | 147 | 147 | 147 | 147 | ... | ... | ... | ... | ... | ... |
| 70 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 141 | 133 | ... |
| 71 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 72 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 73 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 |
| 74 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 |
| 75 | 172 | 171 | 170 | 170 | 169 | 169 | 169 | 169 | 169 | 168 | 167 | 166 |
| 76 | 172 | 171 | 170 | 170 | 169 | 169 | 169 | 169 | 169 | 168 | 167 | 166 |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Design Stress, MPa, at Metal Temperature, °C [Note (1)] 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 92.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 41 | 92.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 42 | 86.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 43 | 86.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 44 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 45 | 124 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 46 | 124 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 47 | 124 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 48 | 124 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 49 | 112 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 50 | 112 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 51 | 112 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 52 | 112 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 53 | 112 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 54 | 112 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 55 | 112 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 56 | 112 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 57 | 82.4 | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.5 | 6.2 | 4.3 | 2.8 | 1.7 |
| 58 | 70.7 | 69.4 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 8.8 |
| 59 | 92.2 | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 9.0 | 7.1 | 5.9 | 5.3 |
| 60 | 77.7 | 76.9 | 75.9 | 65.0 | 50.5 | 39.2 | 30.4 | 23.6 | 18.4 | 14.3 | 11.1 | 8.6 |
| 61 | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 62 | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 63 | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 64 | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 65 | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 66 | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 67 | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 68 | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 69 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 70 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 71 | 147 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 72 | 147 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 73 | 152 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 74 | 152 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 75 | 164 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 76 | 164 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, Dia., mm | Notes |
|---|---|---|---|---|---|---|---|---|
| 77 | 18Cr–8Ni | Bolts | A193 | B8 | S30400 | 2 | ≤19 | (15)(60) |
| 78 | 18Cr–8Ni | Bolts | A320 | B8 | S30400 | 2 | ≤19 | (15)(60) |
| 79 | 18Cr–10Ni–Ti | Bolts | A193 | B8T | S32100 | 2 | ≤19 | (15)(60) |
| 80 | 18Cr–10Ni–Ti | Bolts | A320 | B8T | S32100 | 2 | ≤19 | (15)(60) |
| 81 | 12Cr | Bolts | A437 | B4B | S42225 | ... | ... | (35) |
| 82 | 12Cr | Nuts | A194 | 6 | S41000 | ... | ... | (35)(42) |
| 83 | 18Cr–9Ni | Nuts | A194 | 8FA | S30300 | ... | ... | (42) |
| 84 | 16Cr–12Ni–2Mo | Nuts | A194 | 8MA | S31600 | ... | ... | (42) |
| 85 | 18Cr–10Ni–Ti | Nuts | A194 | 8TA | S32100 | ... | ... | (42) |
| 86 | 18Cr–8Ni | Nuts | A194 | 8 | S30400 | ... | ... | (42) |
| 87 | 18Cr–8Ni | Nuts | A194 | 8A | S30400 | ... | ... | (42) |
| 88 | 18Cr–10Ni–Cb | Nuts | A194 | 8CA | S34700 | ... | ... | (42) |
| 89 | Naval brass | Bolts | B21 | ... | C46400 | O60 | ... | (8f) |
| 90 | Naval brass | Bolts | B21 | ... | C48200 | O60 | ... | (8f) |
| 91 | Naval brass | Bolts | B21 | ... | C48500 | O60 | ... | (8f) |
| 92 | Cu | Bolts | B187 | ... | C10200 | O60 | ... | (8f) |
| 93 | Cu | Bolts | B187 | ... | C11000 | O60 | ... | (8f) |
| 94 | Cu | Bolts | B187 | ... | C12000 | O60 | ... | (8f) |
| 95 | Cu | Bolts | B187 | ... | C12200 | O60 | ... | (8f) |
| 96 | Cu–Si | Bolts | B98 | ... | C65100 | O60 | ... | (8f)(52) |
| 97 | Cu–Si | Bolts | B98 | ... | C65500 | O60 | ... | (8f)(52) |
| 98 | Cu–Si | Bolts | B98 | ... | C66100 | O60 | ... | (8f)(52) |
| 99 | Cu–Si | Bolts | B98 | ... | C65500 | H01 | ... | (8f) |
| 100 | Cu–Si | Bolts | B98 | ... | C66100 | H01 | ... | (8f) |
| 101 | Cu–Si | Bolts | B98 | ... | C65500 | H02 | ≤50 | ... |
| 102 | Cu–Si | Bolts | B98 | ... | C66100 | H02 | ≤50 | ... |
| 103 | Cu–Si | Bolts | B98 | ... | C65100 | H06 | >25, ≤38 | ... |
| 104 | Cu–Si | Bolts | B98 | ... | C65100 | H06 | >13, ≤25 | ... |
| 105 | Cu–Si | Bolts | B98 | ... | C65100 | H06 | ≤13 | ... |
| 106 | Al–Si–bronze | Bolts | B150 | ... | C64200 | HR50 | >25, ≤50 | ... |
| 107 | Al–Si–bronze | Bolts | B150 | ... | C64200 | HR50 | >13, ≤25 | ... |
| 108 | Al–Si–bronze | Bolts | B150 | ... | C64200 | HR50 | ≤13 | ... |
| 109 | Al–bronze | Bolts | B150 | ... | C61400 | HR50 | >25, ≤50 | ... |
| 110 | Al–bronze | Bolts | B150 | ... | C61400 | HR50 | >13, ≤25 | ... |
| 111 | Al–bronze | Bolts | B150 | ... | C61400 | HR50 | ≤13 | ... |
| 112 | Al–bronze | Bolts | B150 | ... | C63000 | HR50 | >50, ≤75 | ... |
| 113 | Al–bronze | Bolts | B150 | ... | C63000 | M20 | >75, ≤100 | ... |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Design Stress, MPa, at Metal Temperature, °C [Note (1)] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 |
| 77 | −198 | 862 | 689 | 538 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 78 | −198 | 862 | 689 | 538 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 79 | −198 | 862 | 689 | 538 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 80 | −198 | 862 | 689 | 538 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 81 | −29 | 1000 | 724 | 343 | 181 | 181 | 181 | 181 | 181 | 181 | 181 | 181 |
| 82 | −29 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 83 | −29 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 84 | −198 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 85 | −198 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 86 | −254 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 87 | −254 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 88 | −254 | ... | ... | 40 | ... | ... | ... | ... | ... | ... | ... | ... |
| 89 | −198 | 345 | 138 | 149 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | ... | ... | ... |
| 90 | −198 | 345 | 138 | 149 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | ... | ... | ... |
| 91 | −198 | 345 | 138 | 149 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | ... | ... | ... |
| 92 | −198 | 207 | 69 | 149 | 46.0 | 38.8 | 37.2 | 36.5 | 34.2 | ... | ... | ... |
| 93 | −198 | 207 | 69 | 149 | 46.0 | 38.8 | 37.2 | 36.5 | 34.2 | ... | ... | ... |
| 94 | −198 | 207 | 69 | 149 | 46.0 | 38.8 | 37.2 | 36.5 | 34.2 | ... | ... | ... |
| 95 | −198 | 207 | 69 | 149 | 46.0 | 38.8 | 37.2 | 36.5 | 34.2 | ... | ... | ... |
| 96 | −198 | 276 | 83 | 149 | 55.2 | 55.2 | 55.2 | 54.0 | 48.3 | ... | ... | ... |
| 97 | −198 | 359 | 103 | 149 | 68.9 | 68.9 | 68.9 | 68.9 | 68.8 | ... | ... | ... |
| 98 | −198 | 359 | 103 | 149 | 68.9 | 68.9 | 68.9 | 68.9 | 68.8 | ... | ... | ... |
| 99 | −198 | 379 | 165 | 149 | 68.9 | 68.9 | 68.9 | 68.9 | 68.8 | ... | ... | ... |
| 100 | −198 | 379 | 165 | 149 | 68.9 | 68.9 | 68.9 | 68.9 | 68.8 | ... | ... | ... |
| 101 | −198 | 483 | 262 | 149 | 68.9 | 68.9 | 68.9 | 68.9 | 68.8 | ... | ... | ... |
| 102 | −198 | 483 | 262 | 149 | 68.9 | 68.9 | 68.9 | 68.9 | 68.8 | ... | ... | ... |
| 103 | −198 | 517 | 276 | 149 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | ... | ... | ... |
| 104 | −198 | 517 | 310 | 149 | 77.6 | 77.6 | 77.6 | 77.6 | 77.6 | ... | ... | ... |
| 105 | −198 | 586 | 379 | 149 | 94.8 | 94.8 | 94.8 | 94.8 | 94.8 | ... | ... | ... |
| 106 | −198 | 552 | 290 | 316 | 115 | 100 | 95.2 | 93.6 | 92.1 | 89.1 | 76.9 | 57.7 |
| 107 | −198 | 586 | 290 | 316 | 115 | 100 | 95.2 | 93.6 | 92.1 | 89.1 | 76.9 | 57.7 |
| 108 | −198 | 621 | 290 | 316 | 115 | 100 | 95.2 | 93.6 | 92.1 | 89.1 | 76.9 | 57.7 |
| 109 | −198 | 483 | 221 | 260 | 121 | 121 | 121 | 121 | 121 | 121 | 119 | 115 |
| 110 | −198 | 517 | 241 | 260 | 121 | 121 | 121 | 121 | 121 | 121 | 119 | 115 |
| 111 | −198 | 552 | 276 | 260 | 124 | 124 | 124 | 124 | 124 | 124 | 122 | 118 |
| 112 | −198 | 586 | 293 | 371 | 147 | 147 | 147 | 146 | 145 | 144 | 143 | 140 |
| 113 | −198 | 586 | 293 | 371 | 138 | 137 | 134 | 133 | 132 | 131 | 130 | 128 |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| | Design Stress, MPa, at Metal Temperature, °C [Note (1)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 77 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 168 |
| 78 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 168 |
| 79 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 80 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 81 | 181 | 181 | 181 | 181 | 181 | ... | ... | ... | ... | ... | ... | ... |
| 82 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 83 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 84 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 85 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 86 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 87 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 88 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 89 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 90 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 91 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 92 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 93 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 94 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 95 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 96 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 97 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 98 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 99 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 100 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 101 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 102 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 103 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 104 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 105 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 106 | 40.9 | 24.1 | 14.5 | 10.3 | ... | ... | ... | ... | ... | ... | ... | ... |
| 107 | 40.9 | 24.1 | 14.5 | 10.3 | ... | ... | ... | ... | ... | ... | ... | ... |
| 108 | 40.9 | 24.1 | 14.5 | 10.3 | ... | ... | ... | ... | ... | ... | ... | ... |
| 109 | 111 | 109 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 110 | 111 | 109 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 111 | 115 | 112 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 112 | 136 | 126 | 97.2 | 73.9 | 54.4 | 39.3 | ... | ... | ... | ... | ... | ... |
| 113 | 124 | 117 | 97.2 | 73.9 | 54.4 | 39.3 | ... | ... | ... | ... | ... | ... |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Design Stress, MPa, at Metal Temperature, °C [Note (1)] 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 77 | 162 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 78 | 162 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 79 | 172 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 80 | 172 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 81 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 82 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 83 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 84 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 85 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 86 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 87 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 88 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 89 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 90 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 91 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 92 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 93 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 94 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 95 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 96 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 97 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 98 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 99 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 100 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 101 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 102 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 103 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 104 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 105 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 106 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 107 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 108 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 109 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 110 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 111 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 112 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 113 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

**Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, Dia., mm | Notes |
|---|---|---|---|---|---|---|---|---|
| 114 | Al–bronze | Bolts | B150 | ... | C63000 | HR50 | >25, ≤50 | ... |
| 115 | Al–bronze | Bolts | B150 | ... | C63000 | HR50 | ≥13, ≤25 | ... |
| 116 | Low C–Ni | Bolts | B160 | ... | N02201 | Hot fin./ ann. | ... | (8f) |
| 117 | Ni | Bolts | B160 | ... | N02200 | Hot fin. | ... | (8f) |
| 118 | Ni | Bolts | B160 | ... | N02200 | Annealed | ... | (8f) |
| 119 | Ni | Bolts | B160 | ... | N02200 | Cold drawn | ... | ... |
| 120 | Ni–Cu | Bolts | B164 | ... | N04400 | C.D./str. rel. | ... | (54) |
| 121 | Ni–Cu | Bolts | B164 | ... | N04405 | Cold drawn | ... | (54) |
| 122 | Ni–Cu | Bolts | B164 | ... | N04400 | Cold drawn | ... | (54) |
| 123 | Ni–Cu | Bolts | B164 | ... | N04400 | Annealed | ... | (8f) |
| 124 | Ni–Cu | Bolts | B164 | ... | N04405 | Annealed | ... | (8f) |
| 125 | Ni–Cu | Rod | B164 | ... | N04405 | Hot fin. | ≤75 | ... |
| 126 | Ni–Cu | Hex | B164 | ... | N04400 | Hot fin. | ≥54, ≤100 | (8f) |
| 127 | Ni–Cu | All except hex | B164 | ... | N04400 | Hot fin. | >54 | ... |
| 128 | Ni–Cr–Fe | Rod | B166 | ... | N06600 | Cold drawn | ≤75 | (41)(54) |
| 129 | Ni–Cr–Fe | Rod | B166 | ... | N06600 | Hot fin. | ≤75 | ... |
| 130 | Ni–Cr–Fe | Bolts | B166 | ... | N06600 | Annealed | ... | ... |
| 131 | Ni–Cr–Fe | Rod | B166 | ... | N06600 | Hot fin. | >75 | ... |
| 132 | Ni–Mo | Bolts | B335 | ... | N10001 | Annealed | ... | ... |
| 133 | Ni–Mo–Cr | Bolts | B574 | ... | N10276 | Sol. ann. | ... | ... |
| 134 | Aluminum alloy | Bolts | B211 | 6061 | A96061 | T6, T651 wld. | ≥3, ≤200 | (8f)(43) (63) |
| 135 | Aluminum alloy | Bolts | B211 | 6061 | A96061 | T6, T651 | ≥3, ≤200 | (43)(63) |
| 136 | Aluminum alloy | Bolts | B211 | 2024 | A92024 | T4 | >165, ≤200 | (43)(63) |
| 137 | Aluminum alloy | Bolts | B211 | 2024 | A92024 | T4 | >114, ≤165 | (43)(63) |
| 138 | Aluminum alloy | Bolts | B211 | 2024 | A92024 | T4 | >13, ≤114 | (43)(63) |
| 139 | Aluminum alloy | Bolts | B211 | 2024 | A92024 | T4 | ≥3, <13 | (43)(63) |
| 140 | Aluminum alloy | Bolts | B211 | 2014 | A92014 | T6, T651 | ≥3, ≤200 | (43)(63) |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Design Stress, MPa, at Metal Temperature, °C [Note (1)] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Min. Temp. to 40 | 65 | 100 | 125 | 150 | 175 | 200 | 225 |
| 114 | −198 | 621 | 310 | 371 | 155 | 155 | 155 | 155 | 155 | 155 | 155 | 153 |
| 115 | −198 | 689 | 345 | 371 | 155 | 155 | 155 | 155 | 155 | 155 | 155 | 153 |
| 116 | −198 | 345 | 69 | 649 | 46.0 | 44.8 | 44.0 | 43.6 | 43.3 | 43.1 | 43.0 | 43.0 |
| 117 | −198 | 414 | 103 | 316 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 118 | −198 | 379 | 103 | 316 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 119 | −198 | 448 | 276 | 316 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 120 | −198 | 579 | 345 | 316 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 121 | −198 | 586 | 345 | 260 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 122 | −198 | 586 | 379 | 260 | 115 | 106 | 99.7 | 96.2 | 94.8 | 94.8 | 94.8 | 94.8 |
| 123 | −198 | 483 | 172 | 482 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 124 | −198 | 483 | 172 | 482 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 125 | −198 | 517 | 241 | 482 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 126 | −198 | 517 | 207 | 482 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 127 | −198 | 552 | 276 | 482 | 115 | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 128 | −198 | 724 | 552 | 260 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 129 | −198 | 621 | 276 | 649 | 115 | 112 | 109 | 107 | 105 | 103 | 101 | 99.0 |
| 130 | −198 | 552 | 241 | 649 | 115 | 112 | 109 | 107 | 105 | 103 | 101 | 99.0 |
| 131 | −198 | 586 | 241 | 649 | 115 | 112 | 109 | 107 | 105 | 103 | 101 | 99.0 |
| 132 | −198 | 689 | 317 | 427 | 172 | 172 | 172 | 172 | 172 | 171 | 170 | 169 |
| 133 | −198 | 689 | 283 | 538 | 172 | 172 | 170 | 164 | 158 | 153 | 148 | 143 |
| 134 | −269 | 165 | ... | 204 | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 | 26.4 | 16.1 |
| 135 | −269 | 290 | 241 | 204 | 57.9 | 57.9 | 57.9 | 57.9 | 57.9 | 47.3 | 34.9 | 21.1 |
| 136 | −269 | 400 | 262 | 204 | 65.5 | 65.5 | 65.5 | 65.5 | 65.5 | 43.1 | 29.3 | 29.3 |
| 137 | −269 | 427 | 276 | 204 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 46.1 | 31.3 | 31.3 |
| 138 | −269 | 427 | 290 | 204 | 72.4 | 72.4 | 72.4 | 72.4 | 70.2 | 46.2 | 31.2 | 31.2 |
| 139 | −269 | 427 | 310 | 204 | 77.6 | 77.6 | 77.6 | 77.6 | 70.2 | 46.2 | 31.2 | 31.2 |
| 140 | −269 | 448 | 379 | 204 | 89.6 | 89.6 | 89.6 | 89.6 | 84.2 | 46.9 | 26.2 | 20.2 |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Design Stress, MPa, at Metal Temperature, °C [Note (1)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 114 | 148 | 126 | 97.2 | 73.9 | 54.4 | 39.3 | ... | ... | ... | ... | ... | ... |
| 115 | 148 | 126 | 97.2 | 73.9 | 54.4 | 39.3 | ... | ... | ... | ... | ... | ... |
| 116 | 43.0 | 43.0 | 43.0 | 43.0 | 42.9 | 42.7 | 42.2 | 41.6 | 40.7 | 33.1 | 27.4 | 22.8 |
| 117 | 68.9 | 68.9 | 68.9 | 68.9 | ... | ... | ... | ... | ... | ... | ... | ... |
| 118 | 68.9 | 68.9 | 68.9 | 68.9 | ... | ... | ... | ... | ... | ... | ... | ... |
| 119 | 68.9 | 68.9 | 68.9 | 68.9 | ... | ... | ... | ... | ... | ... | ... | ... |
| 120 | 90.4 | 90.4 | 90.4 | 90.4 | ... | ... | ... | ... | ... | ... | ... | ... |
| 121 | 90.4 | 90.4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 122 | 94.8 | 94.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 123 | 90.4 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 87.0 | 86.4 | 75.6 | ... |
| 124 | 90.4 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 87.0 | 86.4 | 75.6 | ... |
| 125 | 90.4 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 87.0 | 86.4 | 75.6 | ... |
| 126 | 90.4 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 87.0 | 86.4 | 75.6 | ... |
| 127 | 90.4 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 87.0 | 86.4 | 75.6 | ... |
| 128 | 138 | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 129 | 97.3 | 95.6 | 94.0 | 92.6 | 91.2 | 89.9 | 88.7 | 87.7 | 86.7 | 85.8 | 75.6 | 58.4 |
| 130 | 97.3 | 95.6 | 94.0 | 92.6 | 91.2 | 89.9 | 88.7 | 87.7 | 86.7 | 85.8 | 75.6 | 58.4 |
| 131 | 97.3 | 95.6 | 94.0 | 92.6 | 91.2 | 89.9 | 88.7 | 87.7 | 86.7 | 85.8 | 75.6 | 58.4 |
| 132 | 168 | 166 | 164 | 162 | 160 | 158 | 157 | 156 | 155 | ... | ... | ... |
| 133 | 139 | 135 | 131 | 128 | 125 | 122 | 120 | 118 | 117 | 115 | 115 | 114 |
| 134 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 135 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 136 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 137 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 139 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 140 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

## Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| | Design Stress, MPa, at Metal Temperature, °C [Note (1)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 114 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 115 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 116 | 18.7 | 15.6 | 12.9 | 10.0 | 8.2 | ... | ... | ... | ... | ... | ... | ... |
| 117 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 118 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 119 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 120 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 121 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 122 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 123 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 124 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 125 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 126 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 127 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 128 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 129 | 39.7 | 27.0 | 19.2 | 15.0 | 13.7 | ... | ... | ... | ... | ... | ... | ... |
| 130 | 39.7 | 27.0 | 19.2 | 15.0 | 13.7 | ... | ... | ... | ... | ... | ... | ... |
| 131 | 39.7 | 27.0 | 19.2 | 15.0 | 13.7 | ... | ... | ... | ... | ... | ... | ... |
| 132 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 133 | 114 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 134 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 135 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 136 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 137 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 139 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 140 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

# APPENDIX B
# STRESS TABLES AND ALLOWABLE PRESSURE TABLES FOR NONMETALS

The data and Notes in Appendix B are requirements of this Code.

## Specification Index for Appendix B

| Spec. No. | Title [Note (1)] |
|---|---|
| **ASTM** | |
| C361 | Reinforced Concrete Low-Head Pressure Pipe |
| C582 | Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion Resistant Equipment |
| C599 | Process Glass Pipe and Fittings |
| D1785 | PVC Plastic Pipe, Schedules 40, 80, and 120 |
| D2239 | PE Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter |
| D2241 | PVC Plastic Pressure-Rated Pipe (SDR Series) |
| D2447 | PE Plastic Pipe, Schedules 40 and 80, Based on Outside Diameter |
| D2513 | Thermoplastic Gas Pressure Pipe, Tubing and Fittings |
| D2517 | Reinforced Epoxy Resin Gas Pressure Pipe and Fittings |
| D2662 | PB Plastic Pipe (SDR-PR) |
| D2666 | PB Plastic Tubing |
| D2672 | Joints for IPS PVC Pipe Using Solvent Cement |
| D2737 | PE Plastic Tubing |
| D2846 | CPVC Plastic Hot- and Cold-Water Distribution Systems |
| D2996 | Filament-Wound Fiberglass RTR Pipe [Note (2)] |
| D2997 | Centrifugally Cast RTR Pipe [Note (2)] |
| D3000 | PB Plastic Pipe (SDR-PR) Based on Outside Diameter |
| D3035 | PE Plastic Pipe (DR-PR) Based on Controlled Outside Diameter |
| D3309 | PB Plastic Hot- and Cold-Water Distribution Systems |
| D3517 | Fiberglass RTR Pressure Pipe [Note (2)] |
| D3754 | Fiberglass RTR Sewer and Industrial Pressure Pipe [Note (2)] |
| F441 | CPVC Plastic Pipe, Schedules 40 and 80 |
| F442 | CPVC Plastic Pipe (SDR-PR) |
| F2389 | Pressure-Rated Polypropylene (PP) Piping Systems |
| F2788/F2788M | Metric and Inch-sized Crosslinked Polyethylene (PEX) Pipe |
| **AWWA** | |
| C300 | Reinforced Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids |
| C301 | Prestressed Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids |
| C302 | Reinforced Concrete Pressure Pipe, Noncylinder Type |
| C950 | Fiberglass Pressure Pipe |

GENERAL NOTE: It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in Appendix E.

NOTES:
(1) For names of plastics identified only by abbreviation, see para. A326.4.
(2) The term *fiberglass RTR* takes the place of the ASTM designation *"fiberglass" (glass-fiber-reinforced thermosetting resin)*.

## Table B-1 Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe

| ASTM Spec. No. | Pipe Designation | Material Designation | Cell Class | Recommended Temperature Limits, °F [Notes (1), (2)] Minimum | Maximum | Hydrostatic Design Stress, ksi, at 73°F [Note (3)] | 100°F | 180°F | 200°F |
|---|---|---|---|---|---|---|---|---|---|
| ... | PR | ABS | 43232 | -40 | 176 | ... | ... | ... | ... |
| D2846 | SDR11 | CPVC4120 | 23447 | ... | 180 | 2.0 | ... | 0.5 | ... |
| F441 | Sch. 40 | CPVC4120 | 23447 | 73 | 200 | 2.0 | ... | 0.5 | ... |
| F441 | Sch. 80 | CPVC4120 | 23447 | 73 | 200 | 2.0 | ... | 0.5 | ... |
| F442 | SDR-PR | CPVC4120 | 23447 | 73 | 200 | 2.0 | 1.64 | 0.5 | ... |
| D3309 | SDR11 | PB2110 | ... | 73 | 200 | 1.0 | ... | 0.5 | ... |
| D2239 | SIDR-PR | PE1404 | ... | 73 | ... | 0.40 | ... | ... | ... |
| D2239 | SIDR-PR | PE2305 | ... | 73 | ... | 0.50 | ... | ... | ... |
| D2239 | SIDR-PR | PE2306 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2239 | SIDR-PR | PE2406 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2239 | SIDR-PR | PE3306 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2239 | SIDR-PR | PE3406 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2239 | SIDR-PR | PE3408 | ... | 73 | ... | 0.80 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE1404 | ... | 73 | ... | 0.40 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE2305 | ... | 73 | ... | 0.50 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE2306 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE2406 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE3306 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE3406 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE2305 | ... | 73 | ... | 0.50 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE2306 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE2406 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE3306 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE3406 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE3408 | ... | 73 | ... | 0.80 | ... | ... | ... |
| D3035 | DR-PR | PE1404 | ... | 73 | ... | 0.40 | ... | ... | ... |
| D3035 | DR-PR | PE2606 | ... | 73 | ... | 0.63 | ... | ... | ... |
| D3035 | DR-PR | PE2708 | ... | 73 | ... | 0.80 | ... | ... | ... |
| D3035 | DR-PR | PE3608 | ... | 73 | ... | 0.80 | ... | ... | ... |
| D3035 | DR-PR | PE3708 | ... | 73 | ... | 0.80 | ... | ... | ... |
| D3035 | DR-PR | PE3710 | ... | 73 | ... | 1.00 | ... | ... | ... |
| D3035 | DR-PR | PE4608 | ... | 73 | ... | 0.80 | ... | ... | ... |
| D3035 | DR-PR | PE4708 | ... | 73 | ... | 0.80 | ... | ... | ... |
| D3035 | DR-PR | PE4710 | ... | 73 | ... | 1.00 | ... | ... | ... |
| F714 | SDR-PR | PE1404 | ... | 73 | ... | 0.40 | ... | ... | ... |
| F714 | SDR-PR | PE2606 | ... | 73 | ... | 0.63 | ... | ... | ... |
| F714 | SDR-PR | PE2708 | ... | 73 | ... | 0.80 | ... | ... | ... |
| F714 | SDR-PR | PE3608 | ... | 73 | ... | 0.80 | ... | ... | ... |

## Table B-1 Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe (Cont'd)

| ASTM Spec. No. | Pipe Designation | Material Designation | Cell Class | Recommended Temperature Limits, °F [Notes (1), (2)] Minimum | Maximum | Hydrostatic Design Stress, ksi, at 73°F [Note (3)] | 100°F | 180°F | 200°F |
|---|---|---|---|---|---|---|---|---|---|
| F714 | SDR-PR | PE3708 | ... | 73 | ... | 0.80 | ... | ... | ... |
| F714 | SDR-PR | PE3710 | ... | 73 | ... | 1.00 | ... | ... | ... |
| F714 | SDR-PR | PE4608 | ... | 73 | ... | 0.80 | ... | ... | ... |
| F714 | SDR-PR | PE4708 | ... | 73 | ... | 0.80 | ... | ... | ... |
| F714 | SDR-PR | PE4710 | ... | 73 | ... | 1.00 | ... | ... | ... |
| F2788/ F2788M | SDR/DR-PR | PEX0006 | ... | −58 | 230 | 0.63 | ... | 0.40 | 0.31 |
| F2788/ F2788M | SDR/DR-PR | PEX0008 | ... | −58 | 230 | 0.80 | ... | 0.40 | 0.31 |
| F2389 | SDR6, SDR7.3, SDR11 | PP | ... | 0 | 210 | 0.63 | 0.50 | 0.20 | ... |
| D1785 | Sch. 40, 80, 120 | PVC1120 | 12454 | 73 | ... | 2.00 | ... | ... | ... |
| D1785 | Sch. 40, 80, 120 | PVC1220 | 12454 | 73 | ... | 2.00 | ... | ... | ... |
| D1785 | Sch. 40, 80, 120 | PVC2120 | 14333 | 73 | ... | 2.00 | ... | ... | ... |
| D1785 | Sch. 40, 80, 120 | PVC2116 | 14333 | 73 | ... | 1.60 | ... | ... | ... |
| D1785 | Sch. 40, 80, 120 | PVC2112 | 14333 | 73 | ... | 1.25 | ... | ... | ... |
| D1785 | Sch. 40, 80, 120 | PVC2110 | 14333 | 73 | ... | 1.00 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC1120 | 12454 | 73 | ... | 2.00 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC1220 | 12454 | 73 | ... | 2.00 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC2120 | 14333 | 73 | ... | 2.00 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC2116 | 14333 | 73 | ... | 1.60 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC2112 | 14333 | 73 | ... | 1.25 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC2110 | 14333 | 73 | ... | 1.00 | ... | ... | ... |

NOTES:
(1) These recommended limits are for low pressure applications with water and other fluids that do not significantly affect the properties of the thermoplastic. The upper temperature limits are reduced at higher pressures, depending on the combination of fluid and expected service life. Lower temperature limits are affected more by the environment, safeguarding, and installation conditions than by strength.
(2) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.
(3) Use these hydrostatic design stress (HDS) values at all lower temperatures.

## Table B-1M Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe (SI Units)

| ASTM Spec. No. | Pipe Designation | Material Designation | Cell Class | Recommended Temperature Limits, °C [Notes (1), (2)] Minimum | Recommended Temperature Limits, °C [Notes (1), (2)] Maximum | Hydrostatic Design Stress, MPa, at 23°C [Note (3)] | 38°C | 82°C | 93°C |
|---|---|---|---|---|---|---|---|---|---|
| ... | PR | ABS | 43232 | −40 | 80 | ... | ... | ... | ... |
| D2846 | SDR11 | CPVC4120 | 23447 | ... | 82 | 13.8 | ... | 3.45 | ... |
| F441 | Sch. 40 | CPVC4120 | 23447 | 23 | 93.3 | 13.8 | ... | 3.45 | ... |
| F441 | Sch. 80 | CPVC4120 | 23447 | 23 | 93.3 | 13.8 | ... | 3.45 | ... |
| F442 | SDR-PR | CPVC4120 | 23447 | 23 | 93.3 | 13.8 | 11.3 | 3.45 | ... |
| D3309 | SDR11 | PB2110 | ... | 23 | 93.3 | 6.9 | ... | 3.45 | ... |
| D2239 | SIDR-PR | PE1404 | ... | 23 | ... | 2.76 | ... | ... | ... |
| D2239 | SIDR-PR | PE2305 | ... | 23 | ... | 3.45 | ... | ... | ... |
| D2239 | SIDR-PR | PE2306 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2239 | SIDR-PR | PE2406 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2239 | SIDR-PR | PE3306 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2239 | SIDR-PR | PE3406 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2239 | SIDR-PR | PE3408 | ... | 23 | ... | 5.51 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE1404 | ... | 23 | ... | 2.76 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE2305 | ... | 23 | ... | 3.45 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE2306 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE2406 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE3306 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2447 | Sch. 40 and 80 | PE3406 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE2305 | ... | 23 | ... | 3.45 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE2306 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE2406 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE3306 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE3406 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D2737 | SDR7.3, SDR9, SDR11 | PE3408 | ... | 23 | ... | 5.51 | ... | ... | ... |
| D3035 | DR-PR | PE1404 | ... | 23 | ... | 2.76 | ... | ... | ... |
| D3035 | DR-PR | PE2606 | ... | 23 | ... | 4.34 | ... | ... | ... |
| D3035 | DR-PR | PE2708 | ... | 23 | ... | 5.51 | ... | ... | ... |
| D3035 | DR-PR | PE3608 | ... | 23 | ... | 5.51 | ... | ... | ... |
| D3035 | DR-PR | PE3708 | ... | 23 | ... | 5.51 | ... | ... | ... |
| D3035 | DR-PR | PE3710 | ... | 23 | ... | 6.89 | ... | ... | ... |
| D3035 | DR-PR | PE4608 | ... | 23 | ... | 5.51 | ... | ... | ... |
| D3035 | DR-PR | PE4708 | ... | 23 | ... | 5.51 | ... | ... | ... |
| D3035 | DR-PR | PE4710 | ... | 23 | ... | 6.89 | ... | ... | ... |
| F714 | SDR-PR | PE1404 | ... | 23 | ... | 2.76 | ... | ... | ... |
| F714 | SDR-PR | PE2606 | ... | 23 | ... | 4.34 | ... | ... | ... |
| F714 | SDR-PR | PE2708 | ... | 23 | ... | 5.51 | ... | ... | ... |
| F714 | SDR-PR | PE3608 | ... | 23 | ... | 5.51 | ... | ... | ... |

## Table B-1M Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe (SI Units) (Cont'd)

| ASTM Spec. No. | Pipe Designation | Material Designation | Cell Class | Recommended Temperature Limits, °C [Notes (1), (2)] Minimum | Maximum | Hydrostatic Design Stress, MPa, at 23°C [Note (3)] | 38°C | 82°C | 93°C |
|---|---|---|---|---|---|---|---|---|---|
| F714 | SDR-PR | PE3708 | ... | 23 | ... | 5.51 | ... | ... | ... |
| F714 | SDR-PR | PE3710 | ... | 23 | ... | 6.89 | ... | ... | ... |
| F714 | SDR-PR | PE4608 | ... | 23 | ... | 5.51 | ... | ... | ... |
| F714 | SDR-PR | PE4708 | ... | 23 | ... | 5.51 | ... | ... | ... |
| F714 | SDR-PR | PE4710 | ... | 23 | ... | 6.89 | ... | ... | ... |
| F2788/ F2788M | SDR/DR-PR | PEX0006 | ... | −50 | 110 | 4.34 | ... | 2.76 | 2.17 |
| F2788/ F2788M | SDR/DR-PR | PEX0008 | ... | −50 | 110 | 5.51 | ... | 2.76 | 2.17 |
| F2389 | SDR6, SDR7.3, SDR11 | PP | ... | −18 | 99 | 4.34 | 3.45 | 1.38 | ... |
| D1785 | Sch. 40, 80, 120 | PVC1120 | 12454 | 23 | ... | 13.8 | ... | ... | ... |
| D1785 | Sch. 40, 80, 120 | PVC1220 | 12454 | 23 | ... | 13.8 | ... | ... | ... |
| D1785 | Sch. 40, 80, 120 | PVC2120 | 14333 | 23 | ... | 13.8 | ... | ... | ... |
| D1785 | Sch. 40, 80, 120 | PVC2116 | 14333 | 23 | ... | 11.0 | ... | ... | ... |
| D1785 | Sch. 40, 80, 120 | PVC2112 | 14333 | 23 | ... | 8.6 | ... | ... | ... |
| D1785 | Sch. 40, 80, 120 | PVC2110 | 14333 | 23 | ... | 6.9 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC1120 | 12454 | 23 | ... | 13.8 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC1220 | 12454 | 23 | ... | 13.8 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC2120 | 14333 | 23 | ... | 13.8 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC2116 | 14333 | 23 | ... | 11.0 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC2112 | 14333 | 23 | ... | 8.6 | ... | ... | ... |
| D2241 | PR (SDR series) | PVC2110 | 14333 | 23 | ... | 6.9 | ... | ... | ... |

NOTES:

(1) These recommended limits are for low pressure applications with water and other fluids that do not significantly affect the properties of the thermoplastic. The upper temperature limits are reduced at higher pressures, depending on the combination of fluid and expected service life. Lower temperature limits are affected more by the environment, safeguarding, and installation conditions than by strength.

(2) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

(3) Use these hydrostatic design stress (HDS) values at all lower temperatures.

### Table B-2 Listed Specifications for Laminated Reinforced Thermosetting Resin Pipe

| Spec. No. |
|---|
| ASTM C582 |

GENERAL NOTE: The intent of listing in this Table is to include all the types, grades, classes, and hydrostatic design bases in the listed specifications.

### Table B-3 Listed Specifications for Filament Wound and Centrifugally Cast Reinforced Thermosetting Resin and Reinforced Plastic Mortar Pipe

| Spec. Nos. (ASTM Except as Noted) | | |
|---|---|---|
| D2517 | D2997 | D3754 |
| D2996 | D3517 | AWWA C950 |

GENERAL NOTE: The intent of listing in this Table is to include all the types, grades, classes, and hydrostatic design bases in the listed specifications.

## Table B-4 Allowable Pressures and Recommended Temperature Limits for Concrete Pipe

| | | | Allowable Gage Pressure | | Recommended Temperature Limits [Note (1)] | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Minimum | | Maximum | |
| Spec. No. | Material | Class | kPa | psi | °C | °F | °C | °F |
| ASTM C361 | Reinforced concrete | 25 | 69 | 10 | ... | ... | ... | ... |
| | | 50 | 138 | 20 | ... | ... | ... | ... |
| | | 75 | 205 | 30 | ... | ... | ... | ... |
| | | 100 | 275 | 40 | ... | ... | ... | ... |
| | | 125 | 345 | 50 | ... | ... | ... | ... |
| AWWA C300 | Reinforced concrete | ... | 1 795 | 260 | ... | ... | ... | ... |
| AWWA C301 | Reinforced concrete | Lined cylinder | 1 725 | 250 | ... | ... | ... | ... |
| | | Embedded cylinder | 2 415 | 350 | ... | ... | ... | ... |
| AWWA C302 | Reinforced concrete | ... | 310 | 45 | ... | ... | ... | ... |

NOTE: (1) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

## Table B-5 Allowable Pressures and Recommended Temperature Limits for Borosilicate Glass Pipe

| | | Size Range | | Allowable Gage Pressure | | Recommended Temperature Limits [Note (1)] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Minimum | | Maximum | |
| ASTM Spec. No. | Material | DN | NPS | kPa | psi | °C | °F | °C | °F |
| C599 | Borosilicate glass | 8–15 | $\frac{1}{4}$–$\frac{1}{2}$ | 690 | 100 | ... | ... | 232 | 450 |
| | | 20 | $\frac{3}{4}$ | 515 | 75 | ... | ... | 232 | 450 |
| | | 25–80 | 1–3 | 345 | 50 | ... | ... | 232 | 450 |
| | | 100 | 4 | 240 | 35 | ... | ... | 232 | 450 |
| | | 150 | 6 | 138 | 20 | ... | ... | 232 | 450 |

NOTE: (1) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

## Table B-6 Allowable Pressures and Recommended Temperature Limits for PEX-AL-PEX and PE-AL-PE Pipe

| ASTM Spec. No. | Material | Size Range |  | Allowable Gage Pressure |  | Maximum Temperature Limits [Note (1)] |  |
|---|---|---|---|---|---|---|---|
|  |  | mm | in. | kPa | psi | °C | °F |
| F1281 | PEX-AL-PEX | 9.12–60.75 | $\frac{3}{8}$–$2\frac{1}{2}$ | 1 379 | 200 | 23 | 73.4 |
|  |  |  |  | 1 103 | 160 | 60 | 140 |
|  |  |  |  | 862 | 125 | 82.2 | 180 |
| F1282 | PE-AL-PE | 9.12–60.75 | $\frac{3}{8}$–$2\frac{1}{2}$ | 1 379 | 200 | 23 | 73.4 |
|  |  |  |  | 1 103 | 160 | 60 | 140 |
|  |  |  |  | 862 | 100 | 82.2 | 180 |
| F1974 | Metal insert fittings for PEX-AL-PEX systems | 12.16–25.32 | $\frac{1}{2}$–1 | 862 | 125 | 82 | 180 |
|  | Metal insert fittings for PE-AL-PE systems | 12.16–25.32 | $\frac{1}{2}$–1 | 1 103 | 160 | 60 | 140 |
|  |  |  |  | 862 | 125 | 82 | 180 |

NOTE: (1) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

# APPENDIX C
# PHYSICAL PROPERTIES OF PIPING MATERIALS

Begins on the next page.

# Table C-1 Thermal Expansion Data

$A$ = Mean Coefficient of Thermal Expansion, $10^{-6}$ in./in./°F
$B$ = Linear Thermal Expansion, in./100 ft
} in Going From 70°F to Indicated Temperature [Note (1)]

| Material | Coefficient | Temperature Range 70°F to −325 | −150 | −50 | 70 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group 1 carbon and low alloy steels [Note (2)] | A | 5.5 | 5.9 | 6.2 | 6.4 | 6.7 | 6.9 | 7.1 | 7.3 | 7.4 | 7.6 | 7.8 | 7.9 | 8.1 | 8.2 | 8.3 | 8.4 | 8.4 |
| | B | −2.6 | −1.6 | −0.9 | 0 | 1.0 | 1.9 | 2.8 | 3.7 | 4.7 | 5.7 | 6.8 | 7.9 | 9.0 | 10.1 | 11.3 | 12.4 | 14.7 |
| Group 2 low alloy steels [Note (3)] | A | 6.0 | 6.5 | 6.7 | 7.0 | 7.3 | 7.4 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.4 | 8.5 |
| | B | −2.9 | −1.7 | −1.0 | 0 | 1.1 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.1 | 9.2 | 10.3 | 11.4 | 12.5 | 13.5 |
| 5Cr–1Mo steels | A | 5.6 | 6.0 | 6.2 | 6.4 | 6.7 | 6.9 | 7.0 | 7.1 | 7.2 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.6 | 7.7 | 7.8 |
| | B | −2.7 | −1.6 | −0.9 | 0 | 1.0 | 1.9 | 2.8 | 3.7 | 4.6 | 5.5 | 6.4 | 7.4 | 8.4 | 9.3 | 10.3 | 11.4 | 12.4 |
| 9Cr–1Mo steels | A | 5.0 | 5.4 | 5.6 | 5.8 | 6.0 | 6.2 | 6.3 | 6.4 | 6.5 | 6.6 | 6.7 | 6.8 | 6.9 | 7.0 | 7.1 | 7.2 | 7.2 |
| | B | −2.4 | −1.4 | −0.8 | 0 | 0.9 | 1.7 | 2.5 | 3.3 | 4.1 | 5.0 | 5.9 | 6.8 | 7.7 | 8.7 | 9.7 | 10.6 | 11.6 |
| Straight chromium stainless steels | | | | | | | | | | | | | | | | | | |
| 12Cr to 13Cr steels | A | 5.1 | 5.5 | 5.7 | 5.9 | 6.2 | 6.3 | 6.4 | 6.5 | 6.5 | 6.6 | 6.7 | 6.7 | 6.8 | 6.8 | 6.9 | 6.9 | 7.0 |
| | B | −2.4 | −1.5 | −0.8 | 0 | 1.0 | 1.7 | 2.5 | 3.3 | 4.2 | 5.0 | 5.8 | 6.7 | 7.6 | 8.5 | 9.4 | 10.2 | 11.1 |
| 15Cr to 17Cr steels | A | 4.5 | 4.9 | 5.1 | 5.3 | 5.5 | 5.7 | 5.8 | 5.9 | 6.0 | 6.1 | 6.2 | 6.2 | 6.3 | 6.4 | 6.4 | 6.5 | 6.5 |
| | B | −2.1 | −1.3 | −0.7 | 0 | 0.9 | 1.6 | 2.3 | 3.0 | 3.8 | 4.6 | 5.4 | 6.2 | 7.0 | 7.9 | 8.7 | 9.5 | 10.4 |
| 27Cr steels | A | 4.3 | 4.7 | 4.9 | 5.0 | 5.2 | 5.2 | 5.3 | 5.4 | 5.4 | 5.5 | 5.6 | 5.7 | 5.7 | 5.8 | 5.9 | 5.9 | 6.0 |
| | B | −2.0 | −1.2 | −0.7 | 0 | 0.8 | 1.4 | 2.1 | 2.8 | 3.5 | 4.2 | 4.9 | 5.6 | 6.4 | 7.2 | 8.0 | 8.7 | 9.6 |
| Austenitic stainless steels (304, 305, 316, 317, 321, 347, 348, 19-9DL, XM-15, etc.) | A | 7.5 | 8.0 | 8.2 | 8.5 | 8.9 | 9.2 | 9.5 | 9.7 | 9.9 | 10.0 | 10.1 | 10.2 | 10.3 | 10.4 | 10.6 | 10.7 | 10.8 |
| | B | −3.6 | −2.1 | −1.2 | 0 | 1.4 | 2.5 | 3.8 | 5.0 | 6.3 | 7.5 | 8.8 | 10.2 | 11.5 | 12.9 | 14.3 | 15.8 | 17.2 |
| Other austenitic stainless steels (309, 310, 315, XM-19, etc.) | A | 7.1 | 7.6 | 7.8 | 8.2 | 8.5 | 8.7 | 8.9 | 9.1 | 9.2 | 9.3 | 9.4 | 9.5 | 9.6 | 9.7 | 9.8 | 9.9 | 10.1 |
| | B | −3.4 | −2.0 | −1.1 | 0 | 1.3 | 2.4 | 3.5 | 4.7 | 5.8 | 7.0 | 8.2 | 9.5 | 10.7 | 12.0 | 13.3 | 14.7 | 16.1 |
| Gray iron | A | ... | ... | ... | ... | 5.8 | 5.9 | 6.1 | 6.3 | 6.5 | 6.7 | 6.8 | 7.0 | 7.2 | ... | ... | ... | ... |
| | B | ... | ... | ... | 0 | 0.9 | 1.6 | 2.4 | 3.2 | 4.1 | 5.0 | 6.0 | 7.0 | 8.0 | ... | ... | ... | ... |
| Ductile cast iron | A | ... | 4.9 | 5.3 | 5.7 | 6.0 | 6.3 | 6.6 | 6.8 | 7.0 | 7.1 | 7.3 | 7.4 | 7.5 | ... | ... | ... | ... |
| | B | ... | −1.3 | −0.8 | 0 | 0.9 | 1.7 | 2.6 | 3.5 | 4.5 | 5.4 | 6.4 | 7.3 | 8.4 | ... | ... | ... | ... |

## Table C-1 Thermal Expansion Data (Cont'd)

$A$ = Mean Coefficient of Thermal Expansion, $10^{-6}$ in./in./°F
$B$ = Linear Thermal Expansion, in./100 ft
} in Going From 70°F to Indicated Temperature [Note (1)]

| Material | Coefficient | Temperature Range 70°F to −325 | −150 | −50 | 70 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monel (67Ni–30Cu) N04400 | *A* | 5.8 | 6.8 | 7.2 | 7.7 | 8.1 | 8.3 | 8.5 | 8.7 | 8.8 | 8.9 | 8.9 | 9.0 | 9.1 | 9.1 | 9.2 | 9.2 | 9.3 |
| | *B* | −2.7 | −1.8 | −1.0 | 0 | 1.3 | 2.3 | 3.4 | 4.5 | 5.6 | 6.7 | 7.8 | 9.0 | 10.1 | 11.3 | 12.4 | 13.6 | 14.8 |
| Nickel alloys N02200 and N02201 | *A* | 5.3 | 6.0 | 6.3 | 6.6 | 7.2 | 7.5 | 7.7 | 7.9 | 8.0 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.7 | 8.8 | 8.9 |
| | *B* | −2.7 | −1.7 | −1.0 | 0 | 1.1 | 2.1 | 3.1 | 4.1 | 5.1 | 6.2 | 7.3 | 8.4 | 9.5 | 10.7 | 11.8 | 13.0 | 14.2 |
| Nickel alloy N06022 | *A* | ... | ... | ... | 6.9 | 6.9 | 6.9 | 6.9 | 7.0 | 7.0 | 7.2 | 7.3 | 7.5 | 7.7 | 7.9 | 8.1 | 8.3 | 8.5 |
| | *B* | ... | ... | ... | 0 | 1.1 | 1.9 | 2.7 | 3.6 | 4.5 | 5.4 | 6.4 | 7.5 | 8.6 | 9.8 | 11.0 | 12.2 | 13.6 |
| Nickel alloy N06600 | *A* | 5.5 | 6.1 | 6.4 | 6.8 | 7.1 | 7.3 | 7.5 | 7.6 | 7.8 | 7.9 | 8.0 | 8.2 | 8.3 | 8.4 | 8.6 | 8.7 | 8.9 |
| | *B* | −2.6 | −1.6 | −0.9 | 0 | 1.1 | 2.0 | 3.0 | 3.9 | 5.0 | 6.0 | 7.0 | 8.1 | 9.3 | 10.4 | 11.6 | 12.9 | 14.2 |
| Nickel alloy N06625 | *A* | ... | ... | ... | 6.7 | 7.1 | 7.2 | 7.3 | 7.4 | 7.4 | 7.5 | 7.6 | 7.7 | 7.9 | 8.0 | 8.2 | 8.4 | 8.5 |
| | *B* | ... | ... | ... | 0 | 1.1 | 2.0 | 2.9 | 3.8 | 4.7 | 5.6 | 6.6 | 7.7 | 8.8 | 9.9 | 11.1 | 12.3 | 13.6 |
| Nickel alloys N08800 and N08810 | *A* | 5.9 | 6.9 | 7.4 | 7.9 | 8.4 | 8.6 | 8.8 | 8.9 | 9.0 | 9.1 | 9.2 | 9.3 | 9.4 | 9.5 | 9.6 | 9.7 | 9.8 |
| | *B* | −2.8 | −1.7 | −1.1 | 0 | 1.3 | 2.4 | 3.5 | 4.6 | 5.7 | 6.9 | 8.1 | 9.3 | 10.5 | 11.8 | 13.0 | 14.4 | 15.7 |
| Nickel alloy N08825 | *A* | ... | ... | 7.2 | 7.5 | 7.7 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | ... | ... | ... | ... |
| | *B* | ... | ... | −1.0 | 0 | 1.2 | 2.2 | 3.2 | 4.2 | 5.2 | 6.3 | 7.4 | 8.5 | 9.6 | ... | ... | ... | ... |
| Nickel alloy N10276 | *A* | ... | ... | ... | 6.0 | 6.3 | 6.5 | 6.7 | 6.9 | 7.1 | 7.2 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 |
| | *B* | ... | ... | ... | 0 | 1.0 | 1.8 | 2.7 | 3.6 | 4.5 | 5.5 | 6.4 | 7.5 | 8.5 | 9.5 | 10.6 | 11.7 | 12.8 |
| Copper alloys C1XXXX series | *A* | 7.7 | 8.7 | 9.0 | 9.3 | 9.6 | 9.7 | 9.8 | 9.9 | 10.0 | ... | ... | ... | ... | ... | ... | ... | ... |
| | *B* | −3.7 | −2.3 | −1.3 | 0 | 1.5 | 2.7 | 3.9 | 5.1 | 6.4 | ... | ... | ... | ... | ... | ... | ... | ... |
| Bronze alloys | *A* | 8.4 | 8.8 | 9.2 | 9.6 | 10.0 | 10.1 | 10.2 | 10.3 | 10.4 | 10.5 | 10.6 | 10.7 | 10.8 | 10.9 | 11.0 | ... | ... |
| | *B* | −4.0 | −2.3 | −1.3 | 0 | 1.6 | 2.8 | 4.0 | 5.3 | 6.6 | 8.0 | 9.3 | 10.7 | 12.1 | 13.5 | 14.9 | ... | ... |
| Brass alloys | *A* | 8.2 | 8.5 | 9.0 | 9.3 | 9.8 | 10.0 | 10.2 | 10.5 | 10.7 | 10.9 | 11.2 | 11.4 | 11.6 | 11.9 | 12.1 | ... | ... |
| | *B* | −3.9 | −2.2 | −1.3 | 0 | 1.5 | 2.8 | 4.1 | 5.4 | 6.8 | 8.2 | 9.8 | 11.4 | 13.0 | 14.7 | 16.4 | ... | ... |
| Copper–nickel (70Cu–30Ni) | *A* | 6.7 | 7.4 | 7.8 | 8.1 | 8.5 | 8.7 | 8.9 | 9.1 | 9.2 | 9.2 | ... | ... | ... | ... | ... | ... | ... |
| | *B* | −3.2 | −2.0 | −1.1 | 0 | 1.3 | 2.4 | 3.5 | 4.7 | 5.8 | 7.0 | ... | ... | ... | ... | ... | ... | ... |

## Table C-1 Thermal Expansion Data (Cont'd)

$A$ = Mean Coefficient of Thermal Expansion, $10^{-6}$ in./in./°F
$B$ = Linear Thermal Expansion, in./100 ft
} in Going From 70°F to Indicated Temperature [Note (1)]

| Material | Coefficient | Temperature Range 70°F to −325 | −150 | −50 | 70 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aluminum alloys | *A* | 9.9 | 10.9 | 11.6 | 12.1 | 13.0 | 13.3 | 13.6 | 13.9 | 14.2 | ... | ... | ... | ... | ... | ... | ... | ... |
| | *B* | −4.7 | −2.9 | −1.7 | 0 | 2.0 | 3.7 | 5.4 | 7.2 | 9.0 | ... | ... | ... | ... | ... | ... | ... | ... |
| Titanium alloys (Grades 1, 2, 3, 7, and 12) | *A* | ... | ... | 4.5 | 4.6 | 4.7 | 4.8 | 4.8 | 4.9 | 4.9 | 5.0 | 5.1 | ... | ... | ... | ... | ... | ... |
| | *B* | ... | ... | −0.6 | 0 | 0.7 | 1.3 | 1.9 | 2.5 | 3.1 | 3.8 | 4.5 | ... | ... | ... | ... | ... | ... |

NOTES:
(1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.
(2) Group 1 alloys (by nominal composition):

| | |
|---|---|
| Carbon steels (C, C–Si, C–Mn, and C–Mn–Si) | 3Cr–1Mo |
| C–½Mo | ½Ni–½Mo–V |
| ½Cr–⅕Mo–V | ½Ni–½Cr–¼Mo–V |
| ½Cr–¼Mo–Si | ¾Ni–½Mo–Cr–V |
| ½Cr–½Mo | ¾Ni–½Mo–⅓Cr–V |
| ½Cr–½Ni–¼Mo | ¾Ni–½Cu–Mo |
| ¾Cr–½Ni–Cu | ¾Ni–½Cr–½Mo–V |
| ¾Cr–¾Ni–Cu–Al | ¾Ni–1Mo–¾Cr |
| 1Cr–⅕Mo | 1Ni–½Cr–½Mo |
| 1Cr–⅕Mo–Si | 1¼Ni–1Cr–½Mo |
| 1Cr–½Mo | 1¾Ni–¾Cr–¼Mo |
| 1Cr–½Mo–V | 2Ni–¾Cr–¼Mo |
| 1¼Cr–½Mo | 2Ni–¾Cr–⅓Mo |
| 1¼Cr–½Mo–Si | 2½Ni |
| 1¾Cr–½Mo–Cu | 3½Ni |
| 2Cr–½Mo | 3½Ni–1¾Cr–½Mo–V |
| 2¼Cr–1Mo | |

(3) Group 2 alloys (by nominal composition):

| | |
|---|---|
| Mn–V | Mn–½Mo–¼Ni |
| Mn–¼Mo | Mn–½Mo–½Ni |
| Mn–½Mo | Mn–½Mo–¾Ni |

TABLE STARTS ON NEXT PAGE

(18)

## Table C-1M Thermal Expansion Data (SI Units)

*A* = Mean Coefficient of Thermal Expansion, $10^{-6}$ mm/mm/°C
*B* = Linear Thermal Expansion, mm/m
} in Going From 20°C to Indicated Temperature Note [(1)]

| Material | Coefficient | Temperature Range 20°C to | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | −200 | −100 | −50 | 20 | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 |
| Group 1 carbon and low alloy steels [Note (2)] | *A* | 9.9 | 10.7 | 11.1 | 11.5 | 11.8 | 11.9 | 12.1 | 12.3 | 12.4 | 12.6 | 12.7 | 12.9 | 13.0 | 13.2 |
| | *B* | −2.2 | −1.3 | −0.8 | 0 | 0.4 | 0.7 | 1.0 | 1.3 | 1.6 | 2.0 | 2.3 | 2.6 | 3.0 | 3.4 |
| Group 2 low alloy steels [Note (3)] | *A* | 10.8 | 11.7 | 12.0 | 12.6 | 12.8 | 13.0 | 13.1 | 13.2 | 13.4 | 13.5 | 13.6 | 13.7 | 13.8 | 13.9 |
| | *B* | −2.4 | −1.4 | −0.8 | 0 | 0.4 | 0.7 | 1.0 | 1.4 | 1.7 | 2.1 | 2.4 | 2.8 | 3.2 | 3.6 |
| 5Cr-1Mo steels | *A* | 10.1 | 10.8 | 11.2 | 11.5 | 11.8 | 12.0 | 12.1 | 12.3 | 12.4 | 12.5 | 12.6 | 12.6 | 12.7 | 12.8 |
| | *B* | −2.2 | −1.3 | −0.8 | 0 | 0.4 | 0.7 | 1.0 | 1.3 | 1.6 | 1.9 | 2.3 | 2.6 | 2.9 | 3.3 |
| 9Cr–1Mo steels | *A* | 9.0 | 9.8 | 10.1 | 10.5 | 10.6 | 10.7 | 10.9 | 11.0 | 11.1 | 11.2 | 11.3 | 11.4 | 11.5 | 11.6 |
| | *B* | −2.0 | −1.2 | −0.7 | 0 | 0.3 | 0.6 | 0.9 | 1.2 | 1.4 | 1.7 | 2.0 | 2.3 | 2.6 | 3.0 |
| Straight chromium stainless steels | | | | | | | | | | | | | | | |
| 12Cr to 13Cr steels | *A* | 9.1 | 9.9 | 10.2 | 10.6 | 10.9 | 11.0 | 11.1 | 11.3 | 11.4 | 11.4 | 11.5 | 11.6 | 11.6 | 11.7 |
| | *B* | −2.0 | −1.2 | −0.7 | 0 | 0.3 | 0.6 | 0.9 | 1.2 | 1.5 | 1.8 | 2.1 | 2.4 | 2.7 | 3.0 |
| 15Cr to 17Cr steels | *A* | 8.1 | 8.8 | 9.1 | 9.6 | 9.7 | 9.9 | 10.0 | 10.1 | 10.2 | 10.3 | 10.4 | 10.5 | 10.6 | 10.7 |
| | *B* | −1.8 | −1.1 | −0.6 | 0 | 0.3 | 0.5 | 0.8 | 1.1 | 1.3 | 1.6 | 1.9 | 2.2 | 2.4 | 2.7 |
| 27Cr steels | *A* | 7.7 | 8.5 | 8.7 | 9.0 | 9.2 | 9.2 | 9.3 | 9.4 | 9.4 | 9.5 | 9.5 | 9.6 | 9.6 | 9.7 |
| | *B* | −1.7 | −1.0 | −0.6 | 0 | 0.3 | 0.5 | 0.7 | 1.0 | 1.2 | 1.5 | 1.7 | 2.0 | 2.2 | 2.5 |
| Austenitic stainless steels (304, (305, 316, 317, 321, 347, 348, 19-9DL, XM-15, etc.) | *A* | 13.5 | 14.3 | 14.7 | 15.3 | 15.6 | 15.9 | 16.2 | 16.4 | 16.6 | 16.8 | 17.0 | 17.2 | 17.4 | 17.5 |
| | *B* | −3.0 | −1.7 | −1.0 | 0 | 0.5 | 0.9 | 1.3 | 1.7 | 2.2 | 2.6 | 3.1 | 3.5 | 4.0 | 4.5 |
| Other austenitic stainless steels (309, 310, 315, XM-19, etc.) | *A* | 12.8 | 13.6 | 14.1 | 14.7 | 15.0 | 15.2 | 15.4 | 15.6 | 15.7 | 15.9 | 16.0 | 16.1 | 16.3 | 16.4 |
| | *B* | −2.8 | −1.6 | −1.0 | 0 | 0.4 | 0.8 | 1.2 | 1.6 | 2.0 | 2.5 | 2.9 | 3.3 | 3.7 | 4.2 |
| Gray iron | *A* | ... | ... | ... | 9.8 | 10.1 | 10.2 | 10.4 | 10.5 | 10.7 | 10.8 | 11.0 | 11.1 | 11.2 | 11.4 |
| | *B* | ... | ... | ... | 0 | 0.3 | 0.6 | 0.8 | 1.1 | 1.4 | 1.7 | 2.0 | 2.3 | 2.6 | 2.9 |
| Ductile cast iron | *A* | ... | 8.8 | 9.5 | 10.3 | 10.5 | 10.7 | 10.9 | 11.1 | 11.3 | 11.6 | 11.8 | 12.0 | 12.2 | 12.4 |
| | *B* | ... | −1.1 | −0.7 | 0 | 0.3 | 0.6 | 0.9 | 1.2 | 1.5 | 1.8 | 2.1 | 2.5 | 2.8 | 3.1 |
| Monel (67Ni–30Cu) N04400 | *A* | 10.4 | 12.2 | 13.0 | 13.8 | 14.1 | 14.4 | 14.6 | 14.8 | 15.0 | 15.1 | 15.3 | 15.4 | 15.5 | 15.6 |
| | *B* | −2.3 | −1.5 | −0.9 | 0 | 0.4 | 0.8 | 1.2 | 1.6 | 1.9 | 2.3 | 2.8 | 3.2 | 3.6 | 4.0 |
| Nickel alloys N02200 and N02201 | *A* | 9.6 | 10.8 | 11.4 | 11.9 | 12.4 | 12.7 | 13.0 | 13.3 | 13.5 | 13.7 | 13.9 | 14.0 | 14.2 | 14.3 |
| | *B* | −2.2 | −1.4 | −0.8 | 0 | 0.4 | 0.7 | 1.0 | 1.4 | 1.8 | 2.1 | 2.5 | 2.9 | 3.3 | 3.6 |
| Nickel alloy N06022 | *A* | ... | ... | ... | 12.4 | 12.4 | 12.4 | 12.4 | 12.4 | 12.4 | 12.4 | 12.4 | 12.5 | 12.5 | 12.6 |
| | *B* | ... | ... | ... | 0 | 0.4 | 0.7 | 1.0 | 1.3 | 1.6 | 1.9 | 2.2 | 2.6 | 2.9 | 3.2 |
| Nickel alloy N06600 | *A* | 9.9 | 10.8 | 11.5 | 12.3 | 12.5 | 12.7 | 12.8 | 13.0 | 13.2 | 13.3 | 13.5 | 13.6 | 13.7 | 13.8 |
| | *B* | −2.2 | −1.3 | −0.8 | 0 | 0.4 | 0.7 | 1.0 | 1.4 | 1.7 | 2.1 | 2.4 | 2.8 | 3.2 | 3.5 |
| Nickel alloy N06625 | *A* | ... | ... | ... | 12.0 | 12.4 | 12.6 | 12.8 | 12.9 | 13.0 | 13.1 | 13.2 | 13.2 | 13.2 | 13.3 |
| | *B* | ... | ... | ... | 0 | 0.4 | 0.7 | 1.0 | 1.4 | 1.7 | 2.0 | 2.4 | 2.7 | 3.0 | 3.4 |

## Table C-1M Thermal Expansion Data (SI Units)

**$A$ = Mean Coefficient of Thermal Expansion, $10^{-6}$ mm/mm/°C**
**$B$ = Linear Thermal Expansion, mm/m**
} **in Going From 20°C to Indicated Temperature Note [(1)]**

| Temperature Range 20°C to | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 |
| 13.3 | 13.4 | 13.6 | 13.7 | 13.8 | 14.0 | 14.1 | 14.2 | 14.4 | 14.5 | 14.6 | 14.7 | 14.8 | 14.9 | 15.0 | 15.1 | 15.1 | 15.2 | 15.3 | 15.3 | 15.4 |
| 3.7 | 4.1 | 4.5 | 4.9 | 5.3 | 5.7 | 6.1 | 6.5 | 6.9 | 7.3 | 7.7 | 8.2 | 8.6 | 9.0 | 9.4 | 9.9 | 10.3 | 10.7 | 11.1 | 11.6 | 12.0 |
| 14.0 | 14.1 | 14.2 | 14.3 | 14.4 | 14.5 | 14.6 | 14.6 | 14.7 | 14.8 | 14.8 | 14.9 | 15.0 | 15.0 | 15.1 | 15.1 | 15.2 | 15.2 | 15.3 | 15.3 | 15.3 |
| 3.9 | 4.3 | 4.7 | 5.1 | 5.5 | 5.9 | 6.3 | 6.7 | 7.1 | 7.5 | 7.9 | 8.3 | 8.7 | 9.1 | 9.5 | 9.9 | 10.3 | 10.7 | 11.1 | 11.1 | 11.5 |
| 12.8 | 12.9 | 13.0 | 13.0 | 13.1 | 13.2 | 13.2 | 13.3 | 13.4 | 13.4 | 13.5 | 13.6 | 13.6 | 13.7 | 13.7 | 13.8 | 13.9 | 13.9 | 14.0 | 14.0 | 14.1 |
| 3.6 | 3.9 | 4.3 | 4.6 | 5.0 | 5.3 | 5.7 | 6.1 | 6.4 | 6.8 | 7.2 | 7.5 | 7.9 | 8.3 | 8.7 | 9.0 | 9.4 | 9.8 | 10.2 | 10.6 | 11.0 |
| 11.7 | 11.8 | 11.9 | 11.9 | 12.0 | 12.1 | 12.2 | 12.3 | 12.3 | 12.4 | 12.5 | 12.6 | 12.7 | 12.7 | 12.8 | 12.9 | 13.0 | 13.1 | 13.3 | 13.4 | 13.6 |
| 3.3 | 3.6 | 3.9 | 4.2 | 4.6 | 4.9 | 5.2 | 5.6 | 5.9 | 6.3 | 6.6 | 7.0 | 7.3 | 7.7 | 8.1 | 8.5 | 8.9 | 9.3 | 9.7 | 10.1 | 10.6 |
| 11.7 | 11.8 | 11.8 | 11.9 | 11.9 | 12.0 | 12.0 | 12.1 | 12.1 | 12.2 | 12.2 | 12.3 | 12.3 | 12.4 | 12.4 | 12.5 | 12.5 | 12.5 | 12.5 | 12.6 | 12.6 |
| 3.3 | 3.6 | 3.9 | 4.2 | 4.5 | 4.9 | 5.2 | 5.5 | 5.8 | 6.2 | 6.5 | 6.8 | 7.2 | 7.5 | 7.8 | 8.2 | 8.5 | 8.8 | 9.2 | 9.5 | 9.8 |
| 10.8 | 10.8 | 10.9 | 11.0 | 11.0 | 11.1 | 11.2 | 11.2 | 11.3 | 11.3 | 11.4 | 11.4 | 11.5 | 11.5 | 11.5 | 11.6 | 11.6 | 11.7 | 11.7 | 11.8 | 11.9 |
| 3.0 | 3.3 | 3.6 | 3.9 | 4.2 | 4.5 | 4.8 | 5.1 | 5.4 | 5.7 | 6.0 | 6.3 | 6.6 | 7.0 | 7.3 | 7.6 | 7.9 | 8.2 | 8.6 | 8.9 | 9.3 |
| 9.7 | 9.8 | 9.9 | 9.9 | 10.0 | 10.0 | 10.1 | 10.2 | 10.2 | 10.3 | 10.4 | 10.4 | 10.5 | 10.5 | 10.6 | 10.6 | 10.7 | 10.7 | 10.8 | 10.8 | 10.9 |
| 2.7 | 3.0 | 3.3 | 3.5 | 3.8 | 4.1 | 4.3 | 4.6 | 4.9 | 5.2 | 5.5 | 5.8 | 6.1 | 6.4 | 6.7 | 7.0 | 7.2 | 7.6 | 7.9 | 8.2 | 8.5 |
| 17.7 | 17.8 | 17.9 | 18.0 | 18.1 | 18.2 | 18.3 | 18.4 | 18.4 | 18.5 | 18.6 | 18.7 | 18.8 | 18.9 | 19.0 | 19.1 | 19.2 | 19.3 | 19.4 | 19.4 | 19.4 |
| 4.9 | 5.4 | 5.9 | 6.4 | 6.9 | 7.4 | 7.9 | 8.3 | 8.9 | 9.4 | 9.9 | 10.4 | 10.9 | 11.4 | 12.0 | 12.5 | 13.1 | 13.6 | 14.1 | 14.7 | 15.2 |
| 16.5 | 16.6 | 16.6 | 16.7 | 16.8 | 16.9 | 17.0 | 17.1 | 17.2 | 17.2 | 17.3 | 17.4 | 17.5 | 17.6 | 17.7 | 17.8 | 17.9 | 18.0 | 18.1 | 18.2 | 18.3 |
| 4.6 | 5.0 | 5.5 | 5.9 | 6.4 | 6.8 | 7.3 | 7.8 | 8.2 | 8.7 | 9.2 | 9.7 | 10.2 | 10.6 | 11.1 | 11.7 | 12.2 | 12.7 | 13.2 | 13.7 | 14.3 |
| 11.5 | 11.7 | 11.8 | 12.0 | 12.1 | 12.3 | 12.4 | 12.6 | 12.7 | 12.9 | 13.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 3.2 | 3.6 | 3.9 | 4.2 | 4.6 | 5.0 | 5.3 | 5.7 | 6.1 | 6.5 | 6.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 12.5 | 12.6 | 12.8 | 12.9 | 13.0 | 13.1 | 13.2 | 13.2 | 13.3 | 13.4 | 13.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 3.5 | 3.9 | 4.2 | 4.6 | 4.9 | 5.3 | 5.7 | 6.0 | 6.4 | 6.8 | 7.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 15.7 | 15.8 | 15.9 | 16.0 | 16.0 | 16.1 | 16.1 | 16.2 | 16.2 | 16.3 | 16.3 | 16.4 | 16.4 | 16.5 | 16.5 | 16.5 | 16.6 | 16.6 | 16.7 | 16.7 | 16.8 |
| 4.4 | 4.8 | 5.2 | 5.7 | 6.1 | 6.5 | 6.9 | 7.4 | 7.8 | 8.2 | 8.6 | 9.1 | 9.5 | 10.0 | 10.4 | 10.8 | 11.3 | 11.7 | 12.2 | 12.6 | 13.1 |
| 14.4 | 14.5 | 14.6 | 14.7 | 14.8 | 14.9 | 15.0 | 15.1 | 15.2 | 15.3 | 15.4 | 15.5 | 15.6 | 15.6 | 15.7 | 15.8 | 15.9 | 15.9 | 16.0 | 16.1 | 16.2 |
| 4.0 | 4.4 | 4.8 | 5.2 | 5.6 | 6.0 | 6.5 | 6.9 | 7.3 | 7.7 | 8.2 | 8.6 | 9.0 | 9.5 | 9.9 | 10.3 | 10.8 | 11.2 | 11.7 | 12.2 | 12.6 |
| 12.6 | 12.7 | 12.8 | 12.9 | 13.0 | 13.2 | 13.3 | 13.5 | 13.6 | 13.8 | 13.9 | 14.1 | 14.3 | 14.4 | 14.6 | 14.8 | 14.9 | 15.1 | 15.2 | 15.4 | 15.6 |
| 3.5 | 3.9 | 4.2 | 4.6 | 5.0 | 5.3 | 5.7 | 6.1 | 6.5 | 7.0 | 7.4 | 7.8 | 8.3 | 8.7 | 9.2 | 9.7 | 10.1 | 10.6 | 11.1 | 11.6 | 12.1 |
| 14.0 | 14.1 | 14.2 | 14.3 | 14.4 | 14.5 | 14.6 | 14.7 | 14.8 | 14.9 | 15.0 | 15.1 | 15.2 | 15.3 | 15.4 | 15.6 | 15.7 | 15.8 | 15.9 | 16.1 | 16.2 |
| 3.9 | 4.3 | 4.7 | 5.1 | 5.5 | 5.9 | 6.3 | 6.7 | 7.1 | 7.5 | 7.9 | 8.4 | 8.8 | 9.3 | 9.7 | 10.2 | 10.7 | 11.1 | 11.6 | 12.1 | 12.6 |
| 13.3 | 13.3 | 13.4 | 13.5 | 13.5 | 13.6 | 13.7 | 13.8 | 14.0 | 14.1 | 14.2 | 14.3 | 14.5 | 14.6 | 14.8 | 14.9 | 15.0 | 15.1 | 15.3 | 15.4 | 15.6 |
| 3.7 | 4.1 | 4.4 | 4.8 | 5.1 | 5.5 | 5.9 | 6.3 | 6.7 | 7.1 | 7.5 | 8.0 | 8.4 | 8.8 | 9.3 | 9.8 | 10.2 | 10.7 | 11.2 | 11.6 | 12.1 |

## Table C-1M Thermal Expansion Data (SI Units) (Cont'd)

**$A$ = Mean Coefficient of Thermal Expansion, $10^{-6}$ mm/mm/°C**
**$B$ = Linear Thermal Expansion, mm/m**
} **in Going From 20°C to Indicated Temperature Note [(1)]**

| | | Temperature Range 20°C to | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Material** | **Coefficient** | **−200** | **−100** | **−50** | **20** | **50** | **75** | **100** | **125** | **150** | **175** | **200** | **225** | **250** | **275** |
| Nickel alloys N08800 and N08810 | $A$ | 10.6 | 12.5 | 13.3 | 14.2 | 14.6 | 14.9 | 15.1 | 15.3 | 15.5 | 15.6 | 15.8 | 15.9 | 16.0 | 16.1 |
| | $B$ | −2.3 | −1.5 | −0.9 | 0 | 0.4 | 0.8 | 1.2 | 1.6 | 2.0 | 2.4 | 2.8 | 3.3 | 3.7 | 4.1 |
| Nickel alloy N08825 | $A$ | ... | ... | 12.9 | 13.5 | 13.6 | 13.7 | 13.9 | 14.0 | 14.2 | 14.3 | 14.4 | 14.4 | 14.5 | 14.6 |
| | $B$ | ... | ... | −0.9 | 0 | 0.4 | 0.8 | 1.1 | 1.5 | 1.8 | 2.2 | 2.6 | 3.0 | 3.3 | 3.7 |
| Nickel alloy N10276 | $A$ | ... | ... | ... | 10.8 | 11.0 | 11.2 | 11.4 | 11.6 | 11.7 | 11.9 | 12.0 | 12.2 | 12.4 | 12.5 |
| | $B$ | ... | ... | ... | 0 | 0.3 | 0.6 | 0.9 | 1.2 | 1.5 | 1.8 | 2.2 | 2.5 | 2.8 | 3.2 |
| Copper alloys C1XXXX series | $A$ | 13.9 | 15.7 | 16.2 | 16.7 | 17.0 | 17.2 | 17.3 | 17.4 | 17.5 | 17.6 | 17.7 | 17.8 | 17.8 | 17.9 |
| | $B$ | −3.1 | −1.9 | −1.1 | 0 | 0.5 | 0.9 | 1.4 | 1.8 | 2.3 | 2.7 | 3.2 | 3.6 | 4.1 | 4.6 |
| Bronze alloys | $A$ | 15.1 | 15.8 | 16.4 | 17.2 | 17.6 | 17.9 | 18.0 | 18.2 | 18.2 | 18.3 | 18.4 | 18.5 | 18.5 | 18.6 |
| | $B$ | −3.3 | −1.9 | −1.1 | 0 | 0.5 | 1.0 | 1.4 | 1.9 | 2.4 | 2.8 | 3.3 | 3.8 | 4.3 | 4.7 |
| Brass alloys | $A$ | 14.7 | 15.4 | 16.0 | 16.7 | 17.1 | 17.4 | 17.6 | 17.8 | 18.0 | 18.2 | 18.4 | 18.6 | 18.8 | 19.0 |
| | $B$ | −3.2 | −1.9 | −1.1 | 0 | 0.5 | 1.0 | 1.4 | 1.9 | 2.3 | 2.8 | 3.3 | 3.8 | 4.3 | 4.8 |
| Copper–nickel (70Cu–30Ni) | $A$ | 11.9 | 13.4 | 14.0 | 14.5 | 14.9 | 15.2 | 15.3 | 15.5 | 15.7 | 15.8 | 16.0 | 16.1 | 16.3 | 16.4 |
| | $B$ | −2.6 | −1.6 | −1.0 | 0 | 0.4 | 0.8 | 1.2 | 1.6 | 2.0 | 2.5 | 2.9 | 3.3 | 3.7 | 4.2 |
| Aluminum alloys | $A$ | 18.0 | 19.7 | 20.8 | 21.7 | 22.6 | 23.1 | 23.4 | 23.7 | 23.9 | 24.2 | 24.4 | 24.7 | 25.0 | 25.2 |
| | $B$ | −4.0 | −2.4 | −1.5 | 0 | 0.7 | 1.3 | 1.9 | 2.5 | 3.1 | 3.7 | 4.4 | 5.1 | 5.7 | 6.4 |
| Titanium alloys (Grades 1, 2, 3, 7, and 12) | $A$ | ... | ... | 8.2 | 8.3 | 8.4 | 8.5 | 8.5 | 8.6 | 8.6 | 8.6 | 8.7 | 8.7 | 8.7 | 8.8 |
| | $B$ | ... | ... | −0.6 | 0 | 0.3 | 0.5 | 0.7 | 0.9 | 1.1 | 1.3 | 1.6 | 1.8 | 2.0 | 2.2 |

## Table C-1M Thermal Expansion Data (SI Units) (Cont'd)

$A$ = Mean Coefficient of Thermal Expansion, $10^{-6}$ mm/mm/°C
$B$ = Linear Thermal Expansion, mm/m
} in Going From 20°C to Indicated Temperature Note [(1)]

| Temperature Range 20°C to | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 |
| 16.2 | 16.3 | 16.4 | 16.5 | 16.5 | 16.6 | 16.7 | 16.8 | 16.8 | 16.9 | 17.0 | 17.1 | 17.2 | 17.2 | 17.3 | 17.4 | 17.5 | 17.6 | 17.7 | 17.8 | 17.9 |
| 4.5 | 5.0 | 5.4 | 5.8 | 6.3 | 6.7 | 7.2 | 7.6 | 8.1 | 8.5 | 9.0 | 9.5 | 9.9 | 10.4 | 10.9 | 11.4 | 11.9 | 12.4 | 12.9 | 13.4 | 14.0 |
| 14.7 | 14.8 | 14.9 | 15.0 | 15.1 | 15.1 | 15.2 | 15.3 | 15.4 | 15.5 | 15.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 4.1 | 4.5 | 4.9 | 5.3 | 5.7 | 6.1 | 6.5 | 7.0 | 7.4 | 7.8 | 8.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 12.6 | 12.8 | 12.9 | 13.0 | 13.1 | 13.2 | 13.3 | 13.4 | 13.5 | 13.6 | 13.7 | 13.8 | 13.9 | 14.0 | 14.1 | 14.2 | 14.3 | 14.3 | 14.4 | 14.5 | 14.6 |
| 3.5 | 3.9 | 4.3 | 4.6 | 5.0 | 5.4 | 5.7 | 6.1 | 6.5 | 6.9 | 7.3 | 7.7 | 8.1 | 8.5 | 8.9 | 9.3 | 9.7 | 10.1 | 10.5 | 10.9 | 11.4 |
| 18.0 | 18.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 5.0 | 5.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 18.7 | 18.8 | 18.9 | 19.0 | 19.0 | 19.1 | 19.2 | 19.3 | 19.4 | 19.4 | 19.5 | 19.6 | 19.7 | 19.7 | 19.8 | ... | ... | ... | ... | ... | ... |
| 5.2 | 5.7 | 6.2 | 6.7 | 7.2 | 7.7 | 8.3 | 8.8 | 9.3 | 9.8 | 10.3 | 10.9 | 11.4 | 11.9 | 12.5 | ... | ... | ... | ... | ... | ... |
| 19.2 | 19.3 | 19.5 | 19.6 | 19.8 | 20.1 | 20.3 | 20.5 | 20.7 | 20.8 | 21.0 | 21.2 | 21.4 | 21.6 | 21.8 | ... | ... | ... | ... | ... | ... |
| 5.4 | 5.9 | 6.4 | 7.0 | 7.5 | 8.2 | 8.7 | 9.3 | 9.9 | 10.5 | 11.1 | 11.8 | 12.4 | 13.1 | 13.7 | ... | ... | ... | ... | ... | ... |
| 16.5 | 16.5 | 16.6 | 16.6 | 16.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 4.6 | 5.0 | 5.5 | 5.9 | 6.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 25.5 | 25.6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 7.1 | 7.8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 8.8 | 8.8 | 8.9 | 8.9 | 9.0 | 9.2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 2.5 | 2.7 | 2.9 | 3.2 | 3.4 | 3.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |