
**Petroleum and natural gas industries —
Induction bends, fittings and flanges for
pipeline transportation systems —**

**Part 1:
Induction bends**

*Industries du pétrole et du gaz naturel — Coudes d'induction, raccords et
brides pour systèmes de transport par conduites —*

Partie 1: Coudes d'induction



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 15590 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 15590-1 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum and natural gas industries*, Subcommittee SC 2, *Pipeline transportation systems*.

ISO 15590 consists of the following parts, under the general title *Petroleum and natural gas industries — Induction bends, fittings and flanges for pipeline transportation systems*:

- *Part 1: Induction bends*
- *Part 2: Fittings*
- *Part 3: Flanges*

Introduction

Users of this part of ISO 15590 should be aware that further or differing requirements may be needed for individual applications. This part of ISO 15590 is not intended to inhibit a manufacturer from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application. This can be particularly applicable where there is innovative or developing technology. Where an alternative is offered, the manufacturer should identify any variations from this part of ISO 15590 and provide details.

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Petroleum and natural gas industries — Induction bends, fittings and flanges for pipeline transportation systems —

Part 1: Induction bends

1 Scope

This part of ISO 15590 specifies the technical delivery conditions for bends made by the induction bending process for use in pipeline transportation systems for the petroleum and natural gas industries as defined in ISO 13623.

This part of ISO 15590 is applicable to induction bends made from seamless and welded pipe of unalloyed or low-alloy steels.

This part of ISO 15590 specifies three classes of induction bend corresponding to increasing quality requirements in accordance with the technical delivery conditions of ISO 3183 for pipe as indicated in Table 1 (see also ISO 3183-3:1999, Introduction).

Table 1 — Induction bend class and corresponding pipe standard

Induction bend class	Corresponding pipe standard
Class A	ISO 3183-1
Class B	ISO 3183-2
Class C	ISO 3183-3

This part of ISO 15590 is not applicable to the selection of the induction bend class.

This part of ISO 15590 is not applicable to pipeline bends made by other manufacturing processes.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 15590. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 148, *Steel — Charpy impact test (V-notch)*.

ISO 377, *Steel and steel products — Location and preparation of samples and test pieces for mechanical testing*.

ISO 783, *Metallic materials — Tensile testing at elevated temperature*.

ISO 2566-1, *Steel — Conversion of elongation values — Part 1: Carbon and low alloy steels*.

ISO 3183-1, *Petroleum and natural gas industries — Steel pipe for pipelines — Technical delivery conditions — Part 1: Pipes of requirement class A.*

ISO 3183-2, *Petroleum and natural gas industries — Steel pipe for pipelines — Technical delivery conditions — Part 2: Pipes of requirement class B.*

ISO 3183-3:1999, *Petroleum and natural gas industries — Steel pipe for pipelines — Technical delivery conditions — Part 3: Pipes of requirement class C.*

ISO 6507-1, *Metallic materials — Vickers hardness test — Part 1: Test method.*

ISO 6892, *Metallic materials — Tensile testing at ambient temperature.*

ISO 7438, *Metallic materials — Bend test.*

ISO/TR 7705:1991, *Guidelines for specifying Charpy V-notch impact prescriptions in steel specifications.*

ISO 8501-1, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings.*

ISO 9305, *Seamless steel tubes for pressure purposes — Full peripheral ultrasonic testing for the detection of transverse imperfections.*

ISO 9712, *Non-destructive testing — Qualification and certification of personnel.*

ISO 10124, *Seamless and welded (except submerged arc-welded) steel tubes for pressure purposes — Ultrasonic testing for the detection of laminar imperfections.*

ISO 10474, *Steel and steel products — Inspection documents.*

ISO 11496, *Seamless and welded steel tubes for pressure purposes — Ultrasonic testing of tube ends for the detection of laminar imperfections.*

ISO 12094, *Welded steel tubes for pressure purposes — Ultrasonic testing for the detection of laminar imperfections in strips/plates used in the manufacture of welded tubes.*

ISO 12095, *Seamless and welded steel tubes for pressure purposes — Liquid penetrant testing.*

ISO 13623, *Petroleum and natural gas industries — Pipeline transportation systems.*

ISO 13664, *Seamless and welded steel tubes for pressure purposes — Magnetic particle inspection of the tube ends for the detection of laminar imperfections.*

ISO 13665, *Seamless and welded steel tubes for pressure purposes — Magnetic particle inspection of the tube body for the detection of surface imperfections.*

ASTM E 112, *Standard test methods for determining average grain size.*

ASTM E 340, *Standard test method for macroetching metals and alloys.*

ASTM E 797, *Standard practice for measuring thickness by manual ultrasonic pulse-echo contact method.*

European Federation of Corrosion, Publication No. 16:1995, *Guidelines on materials requirements for carbon and low alloy steels for H₂S containing environments in oil and gas production.*

3 Terms and definitions

For the purposes of this part of ISO 15590, the following terms and definitions apply.

3.1

arc

curved portion of a bend

3.2

bend angle

amount of directional change through the bend

3.3

bend radius

distance from the centre of curvature to the centreline axis of the bent pipe

3.4

by agreement

agreed between manufacturer and purchaser

3.5

extrados

outer curved section of the bend arc

3.6

heat

batch of steel prepared in one steel-making operation

3.7

induction bending

continuous bending process which utilizes induction heating to create a narrow, circumferential, heated band around the material being bent

3.8

intrados

inner curved section of the bend arc

3.9

manufacturing procedure specification

MPS

document which specifies the properties and description of the mother pipe, the bending procedure, the post-bending heat treatment equipment and cycle, the qualification bend testing results, the non-destructive testing procedures and the weld end bevel details used for the manufacture of the bends

3.10

mother pipe

straight section of pipe from which an induction bend is made

3.11

tangent

straight section at the ends of an induction bend

3.12

transition zone

areas at the start and stop points of bending which include material that extends from the unheated mother pipe to the material that has been heated to the full bending temperature

3.13

wall thinning

amount of reduction from the original wall thickness of the pipe to the wall thickness in the extrados after bending

4 Symbols and abbreviated terms

For the purpose of this part of ISO 15590, the following symbols and abbreviations apply.

A	Percentage of elongation of tensile test specimen after fracture
CE	Carbon equivalent
CTOD	Crack tip opening displacement testing
D	Specified diameter (outside or inside)
$D_{\max}$	Maximum measured diameter (outside or inside)
$D_{\min}$	Minimum measured diameter (outside or inside)
DWT	Drop-weight tear testing
HAZ	Heat-affected zone
HIC	Hydrogen-induced cracking
HFV	High-frequency welded
MT	Magnetic particle testing
NDT	Non-destructive testing
PT	Liquid penetrant testing
R	Bend centreline radius
r	Mean radius of the mother pipe
R_m	Ultimate tensile strength
$R_{t0,5}$	Yield strength for 0,5 % total elongation
RT	Radiographic testing
SAW	Submerged arc welding
SAWH	Helical seam SAW pipe
S_0	Initial cross-sectional area of the gauge length of a tensile test specimen
SSC	Sulfide stress-cracking
$T_{d\min}$	Minimum design temperature specified by the purchaser
t_i	Minimum wall thickness at the bend intrados
$t_{\min}$	Minimum wall thickness required in accordance with ISO 13623 for the straight pipe adjacent to the bend
UT	Ultrasonic testing
WPS	Welding procedure specification

5 Designation

Designation of induction bends shall take the form **IB xxx-A** or **B** or **C** or **CS**, where:

- xxx is the specified minimum yield strength, expressed in megapascals;
- the suffix A, B, C identifies the technical delivery conditions class for induction bends in non-sour service;
- the suffix CS identifies class C bends for use in sour-service conditions.

6 Pressure rating and design

The hoop stress in the induction bend due to internal fluid pressure shall not exceed the hoop stress permitted in ISO 13623 for the adjacent straight pipe.

Compliance with this requirement shall be demonstrated either by calculations or by satisfying both of the following requirements.

- a) The wall thickness of the bend extrados shall be at least $t_{\min}$.
- b) The wall thickness at the bend intrados shall be at least:

$$t_i = t_{\min} \cdot \frac{2R - r}{2(R - r)}$$

For pipelines not designed in accordance with ISO 13623, it may be permitted for the wall thickness of the bend extrados to be less than $t_{\min}$.

The requirements in this clause address the design of a bend against internal pressure. Other loads, both static and dynamic, and pipeline test conditions also need to be considered by the designer to demonstrate compliance with the strength requirements of ISO 13623.

7 Information to be supplied by the purchaser

7.1 Principal information

The purchaser shall provide the following information, in the order given below:

- a) bend designation of each bend;
- b) quantity of bends;
- c) supply of mother pipe by the purchaser or the manufacturer;
- d) required bend dimensions, including:
 - 1) diameter (inside or outside),
 - 2) minimum wall thickness,
 - 3) radius,
 - 4) bend angle,
 - 5) tangent lengths;
- e) end preparation if different from square ends.

7.2 Supplementary information

If applicable, the purchaser should specify the following supplementary information:

- a) minimum design temperature;
- b) maximum design temperature;

- c) maximum wall thickness;
- d) special dimensional requirements;
- e) requirements for supplementary inspection and testing;
- f) requirements for gauging and other measurements of dimensions if different from this part of ISO 15590;
- g) pipeline design standard or design factors, if different from ISO 13623;
- h) pipeline operating conditions;
- i) whether post-bending heat treatment is to be applied;
- j) mechanical property requirements at the maximum design temperature;
- k) requirements for proof, burst or hydrostatic testing;
- l) hold-points for witness and approval by purchaser;
- m) surface condition;
- n) coating or painting requirements;
- o) marking requirements if different from this part of ISO 15590;
- p) packaging and shipping instructions;
- q) third-party inspection organization;
- r) standard designation in accordance with ISO 10474 of inspection document required;
- s) requirements for format and additional content of the inspection document.

7.3 Information on the mother pipe

If the mother pipe is supplied by the purchaser, the following information on the mother pipe shall be provided to the manufacturer:

- a) purchasing specification;
- b) pipe diameter (inside or outside);
- c) pipe wall thickness (nominal or minimum);
- d) pipe lengths;
- e) pipe manufacturer;
- f) inspection documents with complete chemical composition, mechanical properties, results of NDT and dimensions;
- g) welding procedure specification and weld metal chemical composition for SAW and SAWH pipe;
- h) weld seam repair welding procedure specification for SAW and SAWH pipe.

8 Manufacturing

8.1 Manufacturing procedure specification

Test bends shall be manufactured in accordance with a preliminary MPS documented before commencement of test bending. The preliminary MPS shall be modified as necessary, based on the parameters recorded during test bending, prior to commencing production bending. If specified by the purchaser, manufacturing shall not proceed until the MPS has been accepted by the purchaser.

The MPS shall specify the following details.

a) Information on the mother pipe:

- 1) name of manufacturer;
- 2) steel class and name;
- 3) pipe forming process;
- 4) pipe dimensions;
- 5) chemical composition;
- 6) mechanical properties;
- 7) welding procedure and weld metal chemical composition for welded pipe;
- 8) inspection technique and reports for weld seam;
- 9) weld seam repair procedures;
- 10) heat treatment conditions.

b) Testing and inspection requirements for:

- 1) qualification test bend;
- 2) production bends.

c) Bending process details:

- 1) pipe cleaning method prior to bending;
- 2) identification of the bending machine;
- 3) method of temperature measurement and control during bending;
- 4) values of bending parameters (see Table 2);
- 5) heating and quenching of tangent ends.

d) Details of post-bending heat treatment:

- 1) type of post-bending heat treatment;
- 2) heating rate, soaking time and temperature, cooling rate;
- 3) type and location of thermocouples.

- e) Sizing and rounding processes.
- f) Additional purchaser requirements (such as end preparation, coating and marking).

8.2 Mother pipe

The mother pipe may be supplied by either the purchaser or the manufacturer.

If the mother pipe is supplied by the purchaser, the manufacturer should be consulted as to the required chemical composition, properties and dimensions of the mother pipe (including seam weld and seam repair weld) regarding suitability for induction bending.

Permissible welding processes for the mother pipe shall be as allowed in the corresponding part of ISO 3183. The mother pipe should not contain weld repairs to the pipe body.

The wall thickness of the mother pipe shall have adequate allowance for wall thinning at the extrados due to induction bending.

The surface of the mother pipe shall be free of contamination by low-melting temperature metals, such as copper, brass and aluminium.

8.3 MPS qualification

Bend manufacture shall be carried out in accordance with an MPS which shall be qualified in accordance with this clause before commencement of production.

A test bend with a sufficient arc length to allow extraction of the necessary test specimens shall be manufactured in accordance with each preliminary MPS. The inspection and testing of the test bend shall include tangents and transition zones if included in the produced bends.

The test bend shall be tested and inspected in accordance with clause 9.

The MPS to be used for production shall, for each of the essential variables in Table 2, specify:

- the values recorded during the manufacturing of the test bend;
- the permissible range during production bending.

The variation in essential variables shall not exceed the permissible limits shown in Table 2.

8.4 Production bending

Induction bending shall be carried out in accordance with a qualified MPS as specified in 8.3.

Interruption of the induction bending operation shall result in rejection of the bend.

8.5 Post-bending heat treatment

Post-bending heat treatment of bends is not mandatory for compliance with this part of ISO 15590.

Post-bending heat treatment may be performed to achieve the required material properties, improve corrosion resistance, remove transition zones at the ends of the bend arc or to relieve residual stresses.

The temperature of each furnace-load of bends shall be monitored by thermocouples connected directly to selected bends and shall be recorded. The type and location of the thermocouples shall be as specified in the MPS.

8.6 Forming and sizing after bending

Hot forming, including spot heating, or hot sizing after bending, shall not be performed unless followed by a subsequent full heat treatment above the upper critical temperature.

Cold forming or sizing without subsequent heat treatment is permitted provided the induced permanent strain does not exceed 1,5 %.

Table 2 — Essential variables and maximum permissible variations

Essential variable	Maximum permissible variations
Heat of steel	None
Mother pipe seam weld WPS and welding consumables	None
Nominal mother pipe diameter	None
Nominal mother pipe wall thickness	± 3 mm
Bend radius	For $R \leq 5D$: $\left(\begin{smallmatrix} 25 \\ 0 \end{smallmatrix} \right) \%$ For $5D < R \leq 10D$: $\left(\begin{smallmatrix} 100 \\ 0 \end{smallmatrix} \right) \%$ For $R > 10D$: $\left(\begin{smallmatrix} \text{unlimited} \\ 0 \end{smallmatrix} \right)$
Forming velocity	± 2,5 mm/min
Forming temperature	± 25 °C
Coil design	None
Coolant	None
Coolant flowrate or pressure	± 10 %
Coolant temperature	± 15 °C
Induction heating frequency	± 20 %
Weld seam location	± 15° from the location in the test bend
Post-bending heat treatment	Method: no change Soaking time: $\left(\begin{smallmatrix} 15 \\ 0 \end{smallmatrix} \right) \text{ min}$ Soaking temperature: ± 15 °C Heating and cooling rates: by agreement
The permissible variations apply to the values as stated in the MPS.	

8.7 Strip/plate end welds

Induction bends shall not contain strip/plate end welds.

8.8 Joints and girth welds

Induction bends shall not contain girth welds.

8.9 End preparation

Bends shall be supplied with square ends unless otherwise specified by the purchaser.

9 Testing and inspection

9.1 General requirements

An MPS shall be approved or production bends accepted only after all testing and inspection required in this clause have been performed and all results meet the specified requirements.

Except where otherwise stated in this clause, the testing and inspection methods and acceptance criteria for induction bends shall be as required by the corresponding part of ISO 3183 for pipe of the same steel grade and type.

Testing and inspection shall be carried out on bends after final heat treatment.

Test results already available for the mother pipe may be used in place of re-testing where indicated in Table 3.

If the pipeline installation techniques require post-weld heat treatment of the bend, the purchaser may require additional testing to demonstrate that the mechanical properties of the bend are also achieved after post-weld heat treatment. The purchaser shall specify the details of the post-weld heat treatment cycle to be used during pipeline installation. The test requirements and acceptance criteria shall be decided by agreement.

9.2 Extent of testing and inspection

9.2.1 MPS qualification test bend

The extent of testing and inspection to be performed for qualification of the MPS shall be as stated in Table 3 for each bend class.

The location and type of tests shall be as specified in Table 4, with the locations for the extraction of samples as shown in Figure 1. For SAWH pipe, the inspection and testing requirements shall be decided by agreement.

9.2.2 Production bends

The extent of testing and inspection to be performed during production shall be as stated in Table 3 for each bend class.

9.3 Chemical composition

The chemical composition of each bend shall comply with the requirements for pipe of the same grade and type as specified in the corresponding part of ISO 3183.

NOTE In some instances, aluminium and/or copper contents within the limits allowed by ISO 3183 can give rise to embrittlement and cracking during bending.

9.4 Physical testing

9.4.1 Test pieces — General

Test pieces shall be prepared in accordance with ISO 377.

If thermal cutting has been used to remove samples, the full extent of the heat-affected region shall be removed during the preparation of the test pieces.

9.4.2 Tensile testing

9.4.2.1 Test pieces

Round bar test pieces machined from unflattened samples may be used by agreement.

Welds shall be ground flush. Local imperfections and mill scale may be removed.

Table 3 — Summary of testing and inspection requirements

Test		Class A	Class B	Class C	Acceptance
Chemical analysis	Chemical composition	M	M	M	ISO 3183
Physical tests	Tensile	T	T	T	ISO 3183
	Impact	O	T	T	9.4.3.3
	Through-thickness hardness	N	T	T	9.4.4.2
	Surface hardness	T and P	T and P	T and P	9.4.5.2
	Metallography	T	T	T	9.4.6.2
	HIC	N	N	O ^a	9.4.7
	SSC	N	N	O ^a	9.4.8
	DWT	N	N	O	By agreement
	CTOD	N	N	O	By agreement
	Guided bend (weld seam)	M	M	M	ISO 3183
	Flattening	M	M	M	ISO 3183
NDT	Visual inspection	T and P	T and P	T and P	ISO 3183 and 9.5.1
	Weld seam (UT or RT)	M	M	T and P	ISO 3183
	Bend ends (laminations)	P	P	P	9.5.3
	Bend body (MT or PT)	T and P	T and P	T and P	9.5.4
	Bend body (UT) transverse defects	N	T and O	T and P	9.5.5
	Bend body (UT) laminations	N	M	M	9.5.5
	Residual magnetism ends	P	P	P	9.5.6
	Repairs	P	P	P	ISO 3183
Dimensions	Wall thickness	T and P	T and P	T and P	9.6
	D bend body	P	P	P	9.6
	D at ends	P	P	P	9.6
	Out-of-roundness ends	P	P	P	9.6
	Out-of-roundness body	P	P	P	9.6
	Linear dimensions	P	P	P	9.6
	Angle	P	P	P	9.6
	Radius	O	O	O	9.6
	End squareness	P	P	P	9.6
	Out of plane	P	P	P	9.6
	End preparation	By agreement			By agreement
Gauging		By agreement			By agreement
Hydrostatic test		By agreement			By agreement

^a Only required for sour-service conditions.

M – Testing of the induction bend shall not be required if acceptable test results are available for the mother pipe. If acceptable test results for the mother pipe are not available then the test shall be performed on either the mother pipe or the bend.

N – Not required.

O – Performance of the test or inspection on a production induction bend may be required by agreement.

P – Required for each production bend.

T – Required for each MPS qualification test bend.

Table 4 — Location of test pieces and type of test for destructive testing of test bends

Location	Test
Tangent base metal ^a	Tensile Impact Through-thickness hardness
Tangent weld ^a	Tensile transverse Impact Flattening Through-thickness hardness Metallography Guided bend
Transition zones base metal	Tensile Impact Through-thickness hardness Metallography
Transition zones weld	Tensile transverse ^c Impact ^c
Bend extrados base metal	Tensile Impact Through-thickness hardness
Bend intrados base metal	Tensile Impact Through-thickness hardness
Bend weld ^b	Tensile transverse Impact Through-thickness hardness Metallography Guided bend
^a Testing after bending is not necessary if test results are available for mother pipe and the tangent is not heat-treated during induction bending or subsequent heat treatment. ^b Additional testing for SAWH pipe shall be by agreement. ^c These tests may be distributed between the two transition zones.	

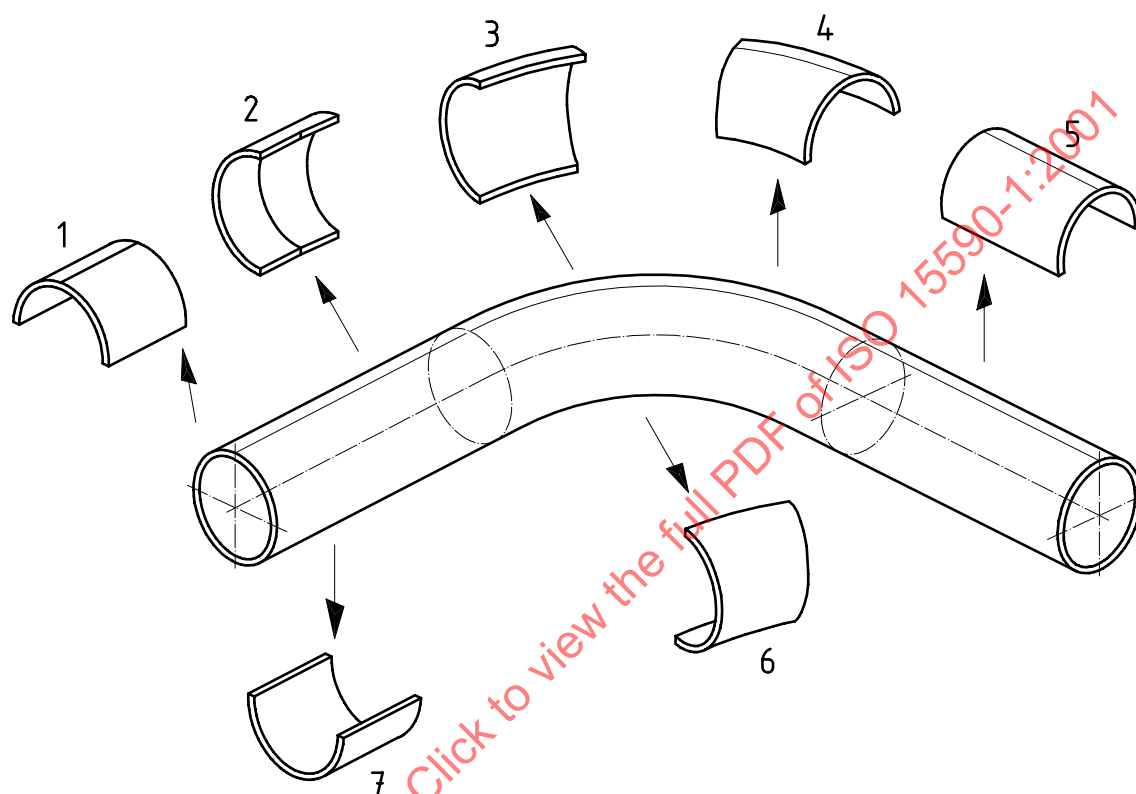
9.4.2.2 Test method

Tensile testing at ambient temperature shall be carried out in accordance with ISO 6892. Additional elevated temperature tensile testing should be performed if the maximum design temperature exceeds 50 °C. Tensile testing at elevated temperatures shall be carried out in accordance with ISO 783 and the acceptance criteria shall be by agreement.

R_m , $R_{t0,5}$ and A shall be determined using test pieces from the base metal in the bend arc and tangent.

The percentage elongation after fracture shall be reported with reference to a gauge length of $5,65\sqrt{S_0}$. If other gauge lengths are used, the elongation referred to a gauge length of $5,65\sqrt{S_0}$ shall be determined in accordance with ISO 2566-1.

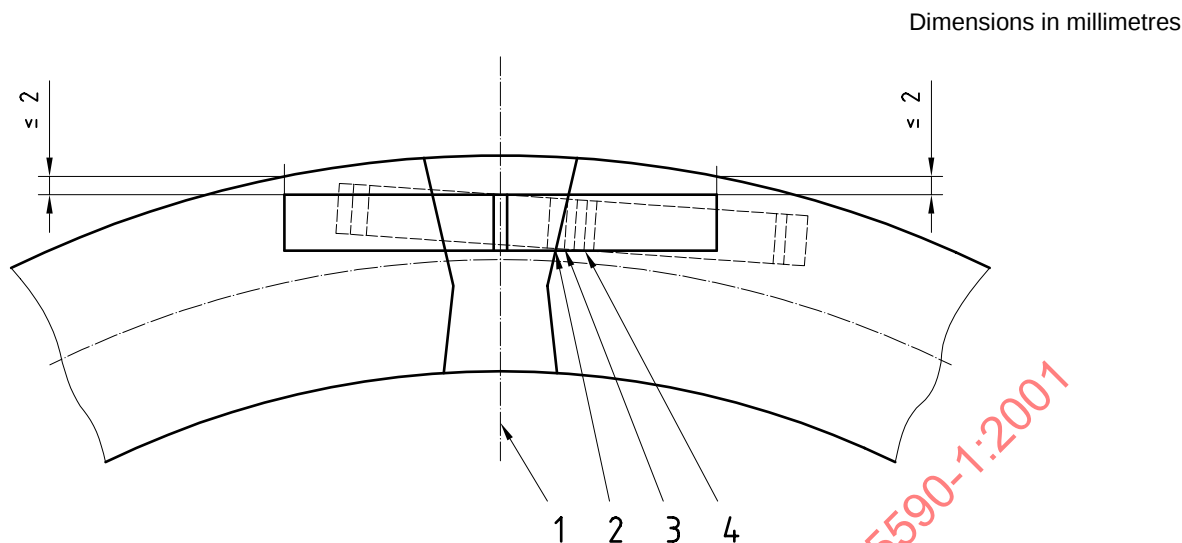
For weld transverse tensile tests, R_m only shall be required.



Key

- 1 Tangent weld
- 2 Transition zone base metal
- 3 Bend extrados base metal
- 4 Bend weld
- 5 Transition zone weld
- 6 Bend intrados base metal
- 7 Tangent base metal

Figure 1 — Location for extraction of samples for testing

**Key**

- 1 Weld centreline
- 2 Fusion line
- 3 Fusion line + 2 mm
- 4 Fusion line + 5 mm

Figure 2 — Location of V-notch test pieces in the weld region of SAW pipe

9.4.3 Charpy V-notch impact testing

9.4.3.1 Test pieces

Charpy V-notch test pieces shall be prepared in accordance with ISO 148 with the axis of the notch perpendicular to the bend surface. Alternative test pieces may be used by agreement (see ISO 3183-3:1999, 8.2.24). The orientation and size of the test pieces shall be transverse with the greatest possible width between 10 mm and 5 mm. If transverse test pieces with a minimum width of 5 mm are not possible, longitudinal test pieces with the greatest possible width between 10 mm and 5 mm shall be used.

Impact testing is not required if the bend dimensions are insufficient to produce longitudinal test pieces with a minimum width of 5 mm.

All Charpy V-notch test pieces shall be taken from the sample at a depth of no more than 2 mm below the outer surface.

Test pieces from welds in SAW pipe with a wall thickness not exceeding 25 mm shall be taken across the weld with the notch at the four locations indicated in Figure 2. The distance of notch location from the fusion line shall be determined with reference to the centreline of the test piece.

Test pieces from welds in HFW pipe shall be taken across the weld: one set with the notch located in the weld centreline and one set with the notch located 2 mm from the weld centreline. The weld centreline shall be located by using metallographic etching techniques.

For bends with a wall thickness greater than 25 mm, the locations of test pieces shall be decided by agreement.

9.4.3.2 Test method

Each set of impact tests shall consist of three adjacent test pieces taken from a single non-flattened sample.

Charpy V-notch impact testing shall be in accordance with ISO 148 with an additional requirement to report shear area of the fracture surface for all test pieces except those for the weld centreline.

The impact test temperature shall be established in accordance with Table 5.

Table 5 — Maximum Charpy V-notch test temperature

Nominal wall thickness mother pipe mm	Test temperature °C		
	Class A	Class B	Class C
$t \leq 20$	By agreement	$T_{d \text{ min.}}$	$T_{d \text{ min.}} - 10$
$20 < t \leq 25$	By agreement	$T_{d \text{ min.}}$	$T_{d \text{ min.}} - 20$
$t > 25$	By agreement	By agreement	By agreement

9.4.3.3 Requirements

For bends from mother pipe with a nominal wall thickness up to and including 25 mm, the results of the Charpy V-notch impact tests shall meet the following requirements.

- a) For each set of tests, the minimum average absorbed energy in joules shall be:

$$\frac{\text{Specified Minimum Yield Strength (MPa)}}{10}, \text{ with a minimum of 27 J, for the transverse direction.}$$

- b) The minimum individual value for any set of tests shall not be less than 75 % of the minimum required average value.
- c) The minimum average and individual values when testing longitudinal test pieces shall be 1,5 times the values specified for transverse test pieces.
- d) The minimum average shear area at the fracture surface shall be 50 % and all individual test pieces shall exhibit at least 40 % fibrous shear.

For subsize test pieces, the minimum required absorbed energy values shall be adjusted in accordance with ISO/TR 7705, clause 6.

Any additional requirements for assessing the resistance to brittle fracture in thicker wall induction bends and for the arrest of shear fracture shall be by agreement.

NOTE Owing to the relatively small percentage of total pipeline length represented by bends, and their dimensional considerations, shear fracture arrest principles are not normally applied to induction bends.

9.4.4 Through-thickness hardness testing

9.4.4.1 Test method

For class B and C bends, through-thickness hardness testing shall be performed using the Vickers method in accordance with ISO 6507-1 with a test force of 98,07 N. Hardness indent locations shall be in accordance with ISO 3183-3.

9.4.4.2 Requirements

Hardness readings shall not exceed

- 300 HV 10 for class B and C bends,
- 250 HV 10 for class C bends intended for sour-service conditions (designation CS).

9.4.5 Surface hardness testing

9.4.5.1 Test method

Three surface hardness readings shall be taken across two circumferential locations in the arc and across one circumferential location in each tangent.

The same type of testing device shall be used for both test and production bends. The selection of the testing device shall be by agreement.

9.4.5.2 Requirements

The average value of the three readings at each location of the test bend fabricated for MPS qualification shall be used as the reference for production test acceptance.

The average value of the three hardness readings at each location of a production bend shall not vary by more than the equivalent of 30 HV 10 hardness points from the average value measured in the same location of the test bend. Single hardness values shall meet the requirements of 9.4.4.2.

9.4.6 Metallographic examination

9.4.6.1 Test method

The test pieces for through-thickness hardness testing (see 9.4.4) shall be examined, prior to hardness testing, at a magnification of not less than 100 ×. Test piece preparation shall be in accordance with ASTM E 340.

Photomicrographs of the microstructures of the test bend arc, transition and tangent materials after completion of all post-bend heat treatment shall be prepared at magnifications of 100 × and 400 ×. The photomicrographs shall be representative of the full wall thickness and shall include the external surface of the extrados of the arc of the bend and the transition zones. Grain-size measurement shall be performed in accordance with ASTM E 112 where appropriate for the microstructure.

9.4.6.2 Requirements

The photomicrographs shall demonstrate that the induction bending and any subsequent heat treatment have produced a consistent microstructure without separations in the base metal and, for welded pipe, in the weld and HAZ. The type of microstructure and actual grain size shall be recorded on the bending procedure qualification test report. The minimum average grain-size number shall be 7.

9.4.7 Hydrogen-induced cracking testing

Unless otherwise specified in the purchase order, the test procedures and acceptance criteria shall be in accordance with European Federation of Corrosion, Publication No. 16, Annex B.

9.4.8 Sulfide stress cracking testing

Unless otherwise specified in the purchase order, the test procedures and acceptance criteria shall be in accordance with European Federation of Corrosion, Publication No. 16.

9.4.9 Drop-weight tear testing

DWT is not mandatory for any bend class.

Test methods, test piece locations and acceptance criteria shall be decided by agreement.

9.4.10 Crack tip opening displacement testing

CTOD testing is not mandatory for any bend class.

Test methods and requirements shall be decided by agreement.

9.4.11 Guided bend testing

9.4.11.1 Test pieces

Test pieces shall be taken in accordance with ISO 7438.

For induction bends with a wall thickness > 20 mm, the test pieces may be machined to provide a rectangular cross section having a thickness of 19 mm. Full thickness curved section test pieces are mandatory for pipe wall thickness ≤ 20 mm. Welds shall be ground flush at both faces.

9.4.11.2 Test method

The mandrel dimensions shall be as defined in the corresponding part of ISO 3183 for pipe of the same grade as the production bend and made by the same process as the mother pipe.

Both test pieces shall be bent through approximately 180°, one with the root of the weld and the other with the face of the weld directly under the mandrel.

9.4.12 Flattening tests

If required, flattening tests shall be as defined in the corresponding part of ISO 3183 for pipe of the same grade and type.

9.5 Non-destructive testing

9.5.1 Visual inspection

Visual inspection for laminations, cracks, notches, gouges and other imperfections shall be performed on the complete outer and, if practical, the inner surface of the bend in accordance with ISO 3183-3:1999, 8.2.3.13. Prior to visual inspection, the entire outside surface of all bends shall be cleaned to a cleanliness grade of ISO 8501-1 Sa 2.

Waving, as shown in Figure 3, is acceptable provided that the following requirements are met:

- wave shapes blend into the pipe surface in a gradual manner with a maximum crest-to-valley depth, *CVD*, of 1 % of the actual outside diameter;
- the ratio of the distance between adjacent crests, *l*, to the *CVD* is a minimum of 25.

CVD shall be determined as follows:

$$CVD = \frac{D_2 + D_4}{2} - D_3$$

where

D_2 and D_4 are the outside diameters of two adjacent crests;

D_3 is the outside diameter of the intervening valley.

9.5.2 Weld seam testing

RT or UT of the weld seam shall be required for

- the complete weld seam in the arc and transition zones;
- the end 250 mm of the tangent, if not examined already on the mother pipe prior to bending.

9.5.3 Inspection of bend ends

After end preparation, the complete end preparation and 100 mm of the weld seam shall be inspected by MT or PT. MT of bend ends shall be performed in accordance with ISO 13664. PT shall be performed in accordance with ISO 12095.

For class B and C bends, a 50 mm wide band at each end shall be inspected for laminar imperfections by UT in accordance with ISO 11496. Laminar imperfections shall not exceed 6 mm in the circumferential direction or have an area in excess of 100 mm².

9.5.4 Magnetic particle testing or liquid penetrant testing on bend body

For all bends, the bend body shall be inspected over an arc of 90° both sides from the extrados by MT in accordance with ISO 13665 or PT in accordance with ISO 12095.

All cracks, laps, laminations, and all rounded indications greater than 3 mm in any direction, shall be classed as defects and shall be repaired in accordance with 9.5.7.

9.5.5 Ultrasonic testing on bend body

If required, ultrasonic testing in accordance with ISO 9305 shall be performed on the bend extrados to verify that the bend is free from transverse defects.

If required, ultrasonic testing in accordance with ISO 12094, or ISO 10124 as appropriate, shall be performed on the bend to detect laminar imperfections. The acceptance criteria shall be as stated in the appropriate part of ISO 3183.

9.5.6 Level of residual magnetism

The level of residual magnetism shall not exceed 2 mT.

9.5.7 Repairs

Unless otherwise agreed by the purchaser, no repair by welding shall be performed on any part of the bend or tangents. If repair by welding is agreed, weld repairs should be examined by UT and/or RT.

Surface defects may be removed by grinding, provided that a smooth curved surface is maintained and the required minimum wall thickness is maintained. Thickness measurement by UT shall be in accordance with ASTM E 797.

All ground repair areas shall be examined by MT in accordance with ISO 13665, or PT in accordance with ISO 12095, to confirm the complete removal of the defects.

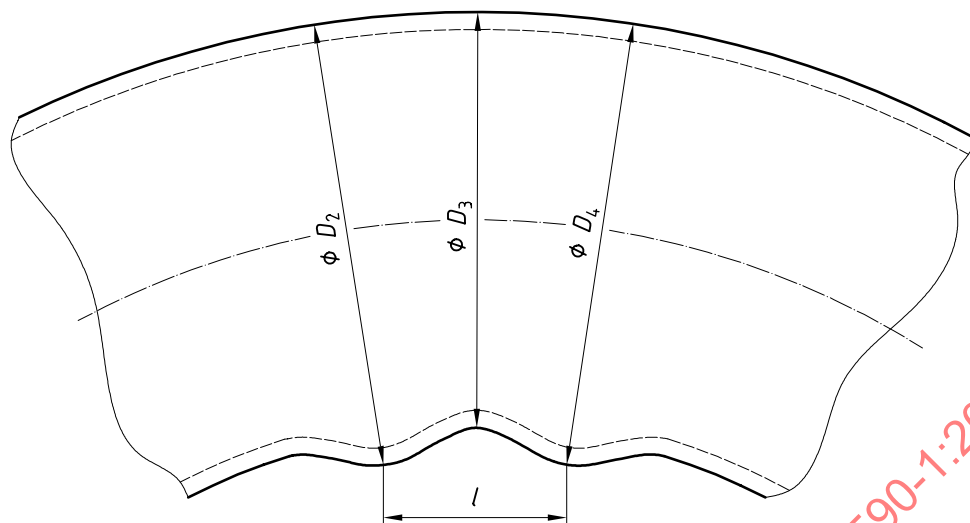


Figure 3 — Schematic diagram for measurement of waving

9.5.8 NDT personnel

All NDT personnel shall be qualified and certified in accordance with ISO 9712 to the appropriate level of competence.

9.6 Dimensions

The dimensions of the bends shall be measured to confirm that the dimensions specified by the purchaser have been achieved within the permissible tolerances of Table 6.

Wall thickness measurements shall be made at sufficient locations by ultrasonic methods in accordance with ASTM E 797.

The bend angle may be determined as follows (see Figure 4).

- Extend the centreline axis of each tangent to the "centre of bend" where the two axes cross.
- Measure and mark the distance from the "centre of bend" to each of the "centre of ends".
- Calculate the bend angle from the two "centre of bend" to "centre of end" dimensions and the chord length.

For angles less than 15°, the angle may be determined by measuring a triangle established by the two centreline axes and the offset at the end of the bend, as shown in Figure 4 b).

End out-of-squareness shall be measured from lines constructed at the specified bend angle and lines perpendicular to the plane of the bend, as shown in Figure 5.

Out-of-planeness is measured by levelling the centrelines of both bend tangents and measuring the difference in height between the two tangent centrelines, as shown in Figure 6.

Out-of-roundness, expressed as a percent, is defined as:
$$\frac{D_{\max} - D_{\min}}{D} \times 100$$