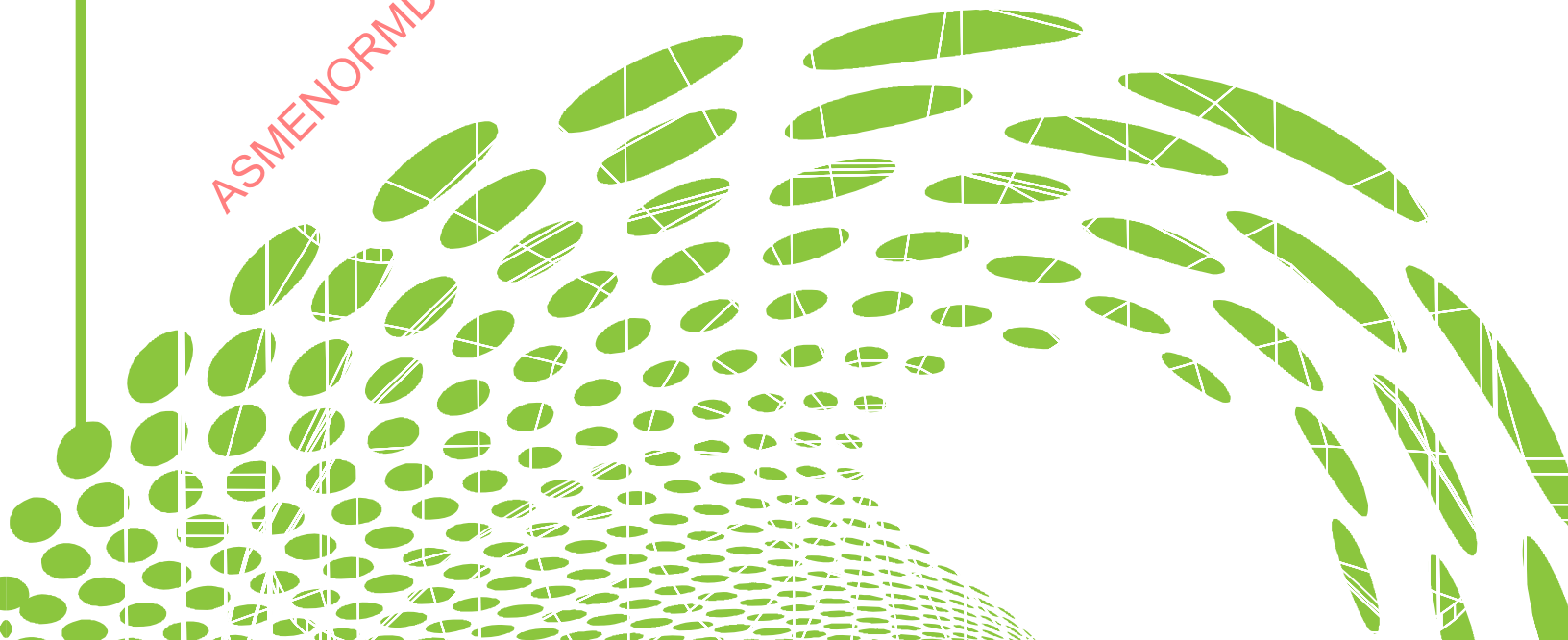
ASME STANDARDS TECHNOLOGY, LLC

STP-PT-087

YIELD STRENGTH VALUES UP TO MAXIMUM TEMPERATURE DESIGN



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YIELD STRENGTH VALUES UP TO MAXIMUM TEMPERATURE DESIGN

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FOREWORD

Table Y-1 of ASME Boiler & Pressure Vessel Code (BPVC) Section II Part D currently provides yield strength values up to 1000°F maximum, with some yield strength values at lower temperatures. The maximum design temperature in Tables 1A and 1B may be higher, therefore yield strength values need to be provided to be able to expand Table Y-1 up to the maximum temperature design of Table 1A-1B-5A and Table 1A-1B-5B for construction pursuant to ASME BPVC Section VIII Division 1 and Division 2.

The author acknowledges, with deep appreciation, the activities of ASME staff and volunteers who have provided valuable technical input, advice and assistance with review of, commenting on, and editing of, this document.

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ABSTRACT

The publication provides yield strength data for different materials (steels, copper, and nickel-base) for temperatures greater than the ones provided in current ASME BPVC IID/Y-1 tables. For this purpose, data from different sources were obtained. The current Y-1 Tables values were not to be affected; therefore, the data had to be fit to those values (customary and metric). This led to bumps in the curves, which were normalized by shifting the data of the current report (in the percent range). Providing smooth curves via a polynomial fit through all data is certainly an alternative, however, this would also affect values in ASME BPVC IID/Y-1 tables. The data provided in this report would allow for such a treatment.

ABBREVIATIONS AND ACRONYMS

AISI	American Iron and Steel Institute
ASM	American Society for Metals
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATI	Allegheny Technologies
BPVC	ASME Boiler & Pressure Vessel Code
DOE	United States Department of Energy
EURO INOX	European Stainless Steel Development Association
JTEVA	Journal of Testing and Evaluation
NIDI	Nickel Development Institute
ORNL	Oak Ridge National Laboratory
VDM	Vereinigte Deutsche Metallwerke AG

1 INTRODUCTION

In ASME BPVC Section VIII Division 1, the yield strength (Sy) is used directly, or indirectly through the allowable primary and secondary stress limit (SPS = max [3S, 2Sy]), and in many of the design rules, such as:

(a) UG-28 and UG-33 – External pressure: Calculation of allowable external pressure on cylinders and heads – Sy [see UG-28(c)(2) Step 3]

(b) Part UHX – Shell-and-tube heat exchangers: Secondary stress limit in tube sheets, channels, shells, and expansion joints – SPS 27 October 2015 Page 2 of 6

(c) Part UHX – Fixed tube sheet heat exchangers: Allowable tube buckling stress at design temperature – Sy

(d) Appendix 1-4 – Design of Head: Yield strength at design temperature – Sy

(e) Appendix 1-5 and 1-8 – Conical Reducers: Discontinuity stress limit and operating metal temperature – SPS

(f) Appendix 5 – Flanged-and-Flued and Flanged-Only Expansion Joints: Thermally induced stress limit at operating metal temperature – SPS

(g) Appendix 13 – Noncircular Vessels: Plate buckling stress at design temperature

(h) Appendix 26 – Bellows Expansion Joints: Calculation of instability due to internal pressure at design temperature – Sy

(i) Non-mandatory Appendix A – Tube-to-Tube sheet Joint Loads: Calculation of tube joint interface pressure at the operating metal temperature – Sy

Because Table Y-1 provides yield strength values up to 1000°F maximum, yield strength values up to the maximum temperature design are needed.

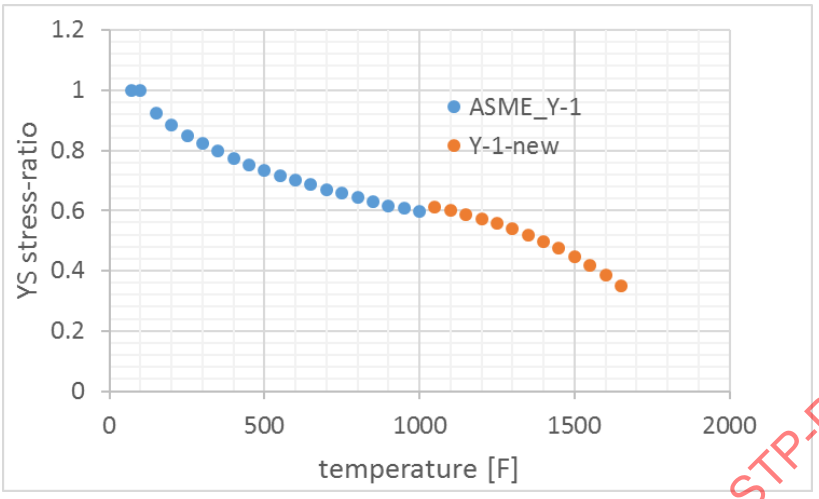
Due to the large number of missing values, the materials investigated will be restricted to the list below, which correspond to the most commonly used materials for heat exchangers.

Figure 1-1: List of steels and required maximum temperatures

MAXIMUM TEMPERATURE (F) FOR TABLE Y-1 VALUES				
Material (UNS)	Material	Table 1A/16 Max Design Temp VIII-1	Table Y-1 Maximum Yield Temp	EP Chart Max Temp
S20910	XM-19	1200	1000	1200
S30400	SS-304	1500	1000	1500
S30403	SS-304L	1200	1000	800
S30908	SS-309S	1500	1000	1500
S31008	SS-310S	1500	1000	1500
S31600	SS-316	1500	1000	1500
S31603	SS-316L	850	1000	800
S31635	SS-316Ti	1500	1000	1500
S31700	SS-317	1500	1000	1500
S31703	SS-317L	850	1000	800
S32100	SS-321	1500	1000	1500
S34700	SS-347	1500	1000	1500
S34800	SS-348	1500	1000	1500
C23000	Cu 230	450	None	150
C28000	Cu 280	400	None	600
C36500	Cu 365	400	None	350
C44300	Cu 443	400	None	350
C44400	Cu 444	400	None	350
C44500	Cu 445	400	None	350
C46400	Cu 464	400	None	350
C46500	Cu 465	400	None	350
C64200	Cu 642	500	100	450
C68700	Cu 687	450	None	350
C70400	Cu 704	150	None	350
C71000	Cu 710	700	None	600
N02201	Ni 201	1200	1000	1000
N06002	Ni X	1650	1000	1000
N06022		1250	1000	1000
N06600	Ni 600	1200	900	1200
N06625	Ni 625 SA	1600	1000	1500
N06625	Ni 625 Ann	1200	1000	1200
N08330	Ni 330	1650	1000	1200
N08800	Ni 800	1500	1000	1100
N08810	Ni 800H	1650	1000	1650
N08811	Ni 811	1650	None	1650
N10003	Ni N	1300	1000	1300
N10276	Ni C276	1250	1000	1000

There are differences between the current ASME Y-1 data and the new Y-1 evaluation. See Figure 1-2 taking N08330 as an example.

Figure 1-2: Current ASME Y-1 data and data from the current new evaluation



There are two possibilities to handle those differences:

1) Anchoring the new data at the 1000°F value by shifting the new data (Figure 1-3)
2) Taking a new polynomial through all data (Figure 1-4)

Figure 1-3: Matching current Y-1 data and new evaluation by shifting the new curve. Using 1.045 instead of 1.07 as constant in the polynomial for the new values

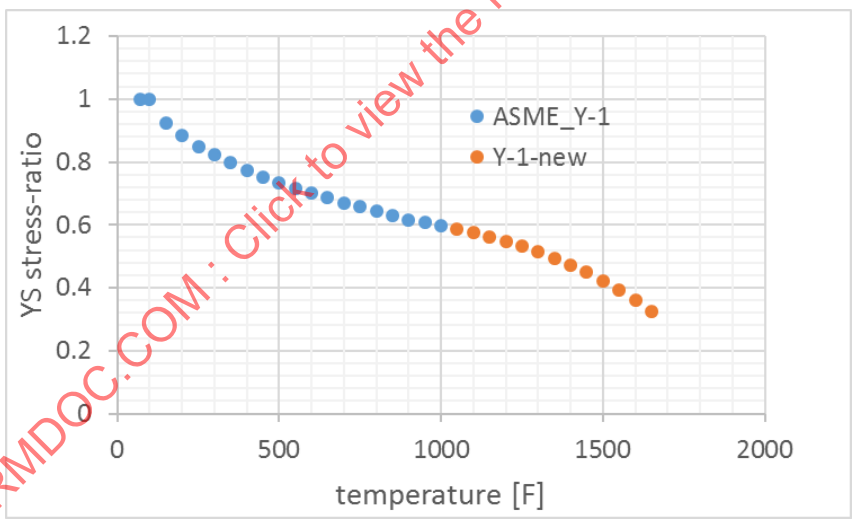
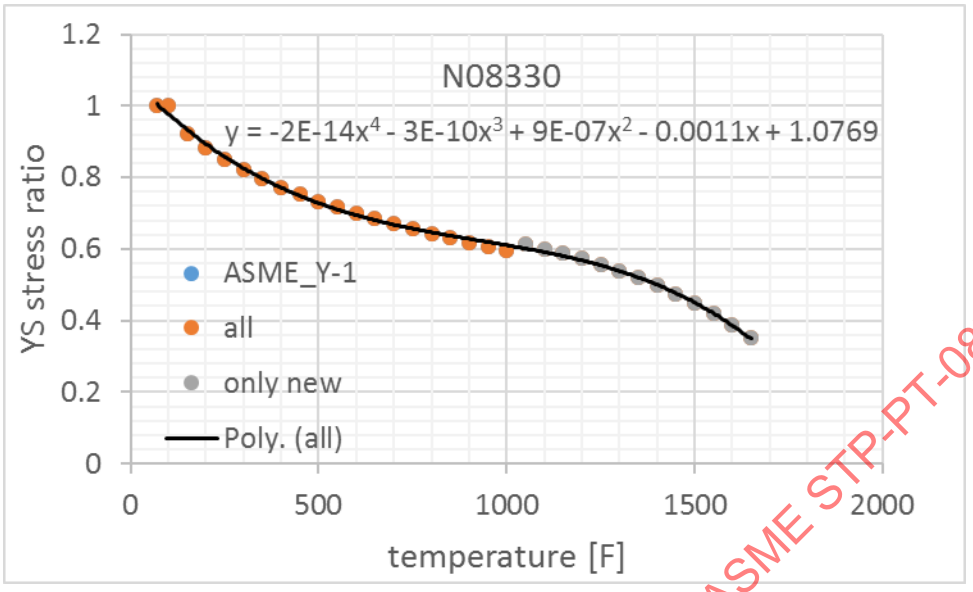


Figure 1-4: Matching current Y-1 data and new evaluation by making a joint polynomial fit



The differences are not too pronounced. Basically, the joint polynomial would make more sense. However, this means that current Y-1 data also had to be changed since one boundary condition for the report was that current Y-1 data remain untouched. To address this requirement, the shift-solution is proposed here.

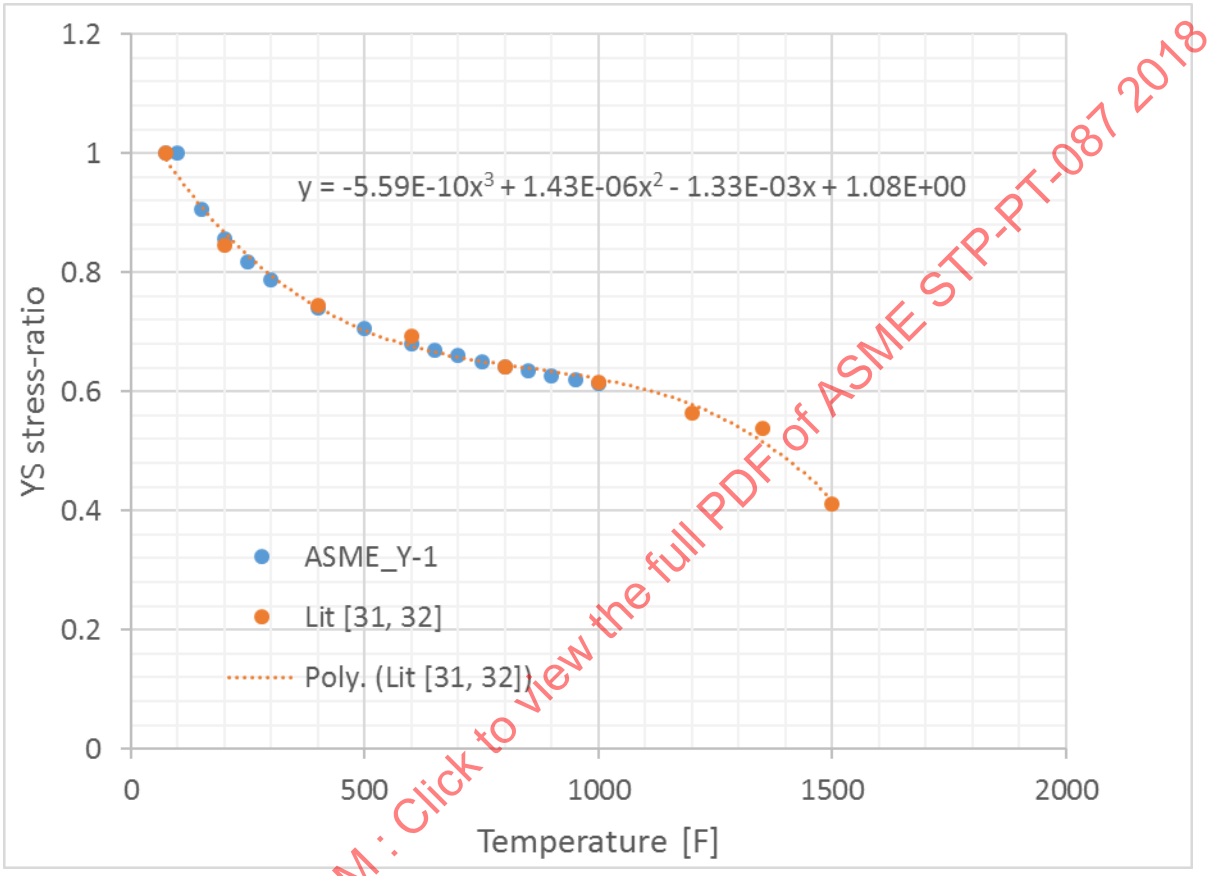
The joint polynomial would need minor changes in current Y-1 Tables.

A list of materials and maximum temperatures is presented in Figure 1-1. A list of the literature used throughout can be found in Appendix A.

2 STEELS

2.1 S20910 / XM-19/ 22Cr-13Ni-5Mn up to 1200°F

Figure 2-1: YS stress ratios from current ASME (2015) Y-1 Tables compared with literature data (Material: S20910 / XM-19/ 22Cr-13Ni-5Mn)



There is good agreement between literature data and the current Y-1 Tables

Figure 2-1). Therefore, the polynomial shown in

Figure 2-1 was used for calculation of the yield stress reduction factors for temperatures exceeding 1000°F.

Figure 2-5 and Figure 2-6 show graphical representations of the Y-1 data. The tabulated values are shown in Figure 2-4 below.

Figure 2-2: Graphical representations of the customary Y-1 data S20910 / XM-19/ 22Cr-13Ni-5Mn

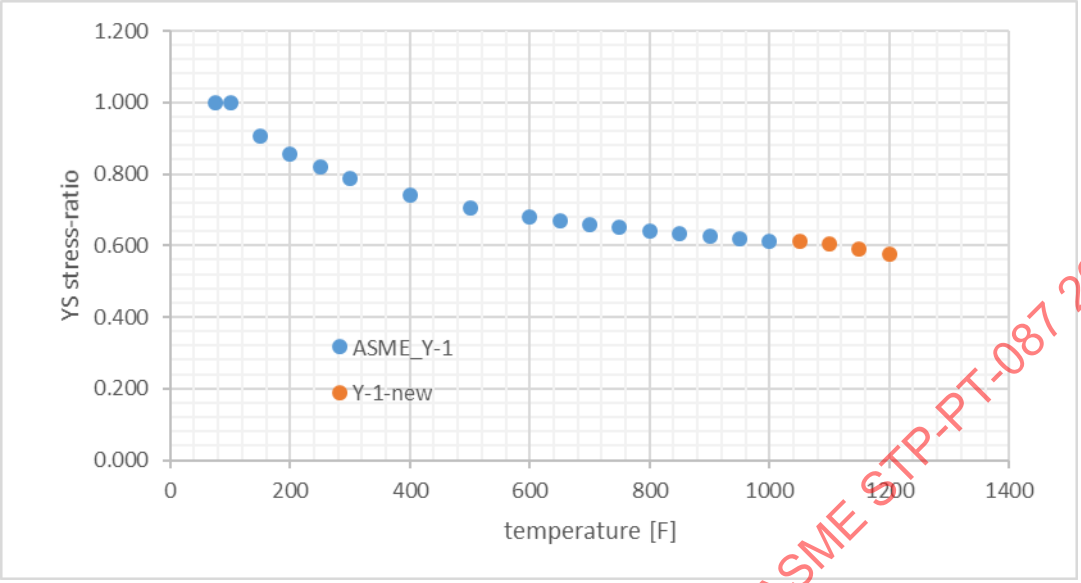


Figure 2-3: Graphical representations of the metric Y-1 data S20910 / XM-19/ 22Cr-13Ni-5Mn

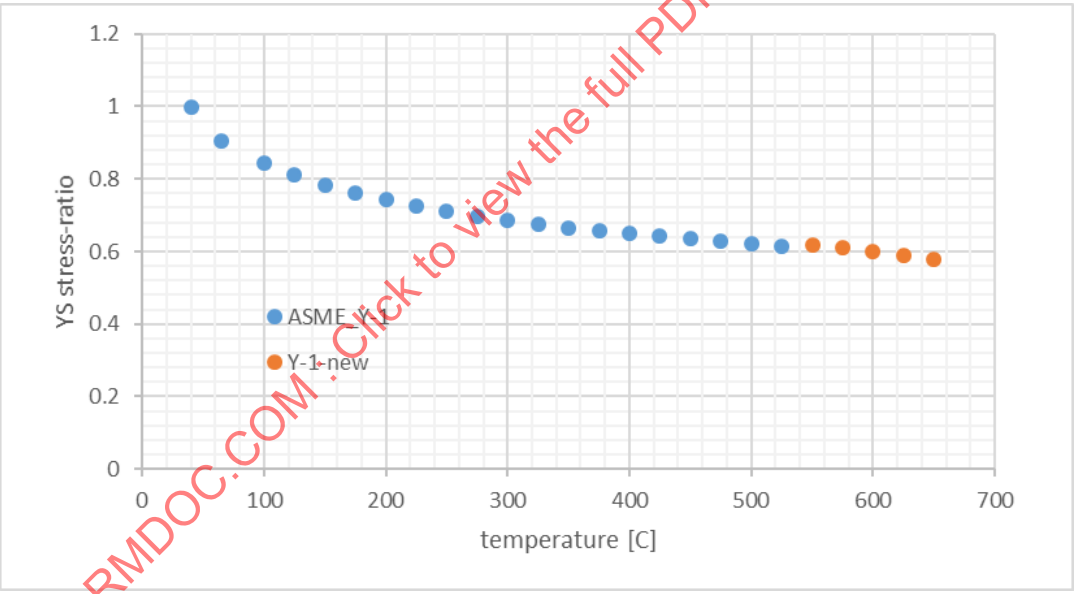


Figure 2-4: YS stress ratios (customary and metric) for XM-19 up to 1200 F

Temperature [F]	ASME_Y-1	Y-1-new		Temperature[C]	ASME_Y-1	Y-1-new
75	1.000			40	0.99736842	
100	1.000			65	0.90526316	
150	0.905			100	0.84473684	
200	0.856			125	0.81052632	
250	0.818			150	0.78421053	
300	0.787			175	0.76052632	
350				200	0.74210526	
400	0.740			225	0.72368421	
450				250	0.71052632	
500	0.705			275	0.69736842	
550				300	0.68421053	
600	0.680			325	0.67368421	
650	0.669			350	0.66578947	
700	0.660			375	0.65789474	
750	0.651			400	0.65	
800	0.642			425	0.64210526	
850	0.635			450	0.63421053	
900	0.627			475	0.62894737	
950	0.620			500	0.62105263	
1000	0.613			525	0.61578947	
1050		0.613		550		0.6176405
1100		0.603		575		0.60987409
1150		0.592		600		0.60065228
1200		0.577		625		0.58966943
				650		0.57661991

2.2 S30400/ 304/ 18Cr-8Ni up to 1500°F

Figure 2-5: YS stress ratios from current ASME (2015) Y-1 Tables compared with literature data (Material: S30400/ 304/ 18Cr-8Ni)

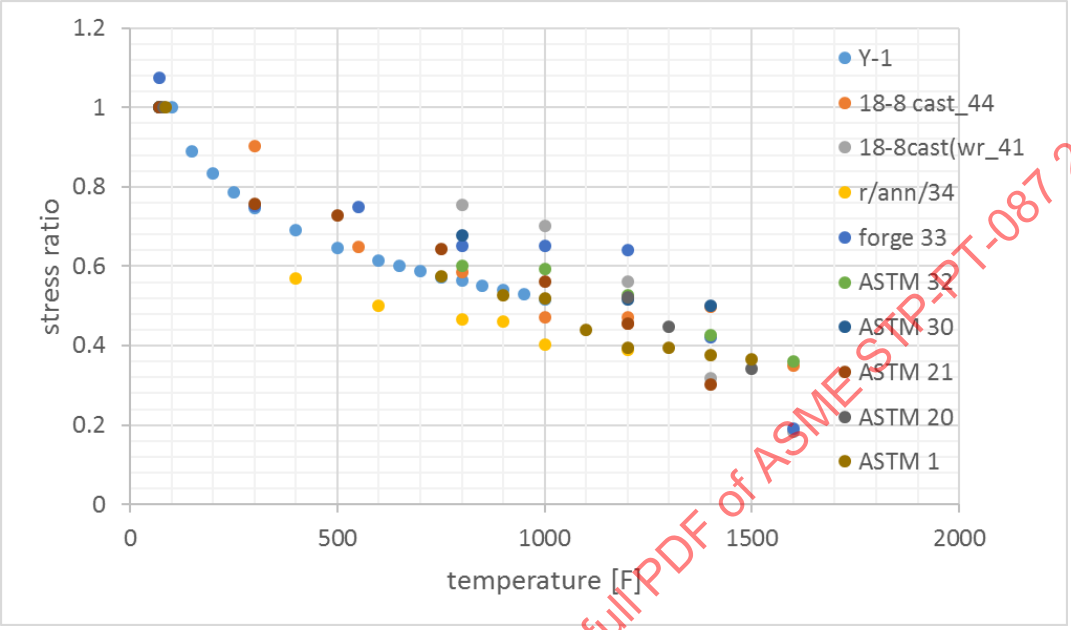
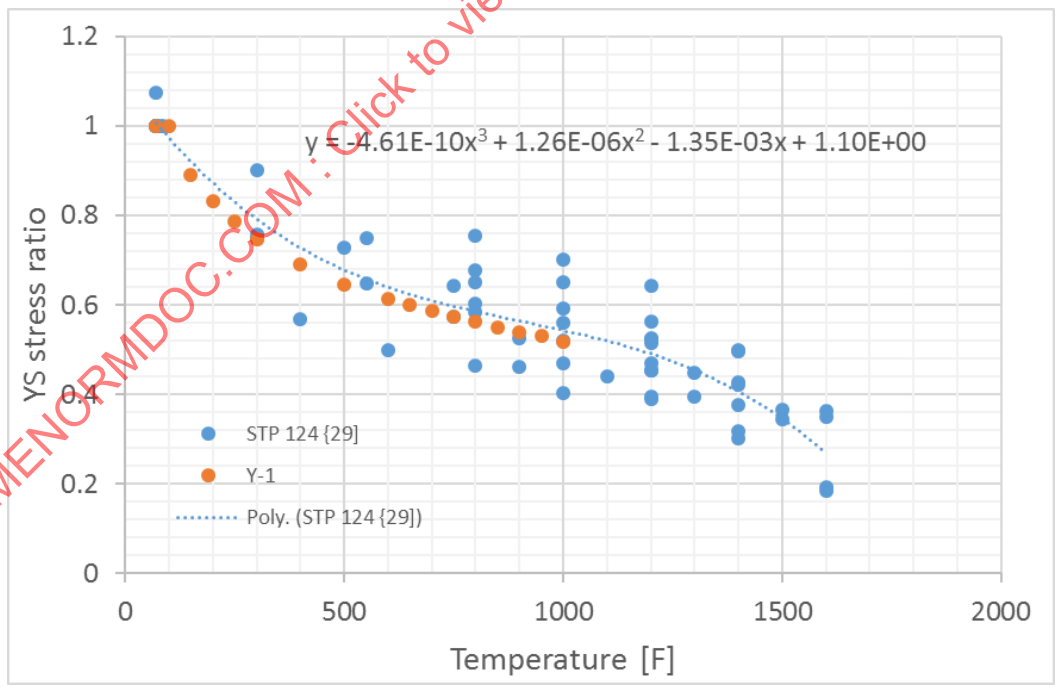


Figure 2-6: YS stress ratios from current ASME (2015) Y-1 Tables compared with polynomial fit through literature data



Old data for 304 could be found in ASME-ASTM datasheets given in the literature [29] as 18Cr-8Ni. The polynomial fit through the data differs only slightly from the current Table Y-1 values.

Figure 2-7: Plot of proposed customary YS stress reduction factors for S30400. Y-1-new obtained using 1.07 instead of 1.1 in the polynomial

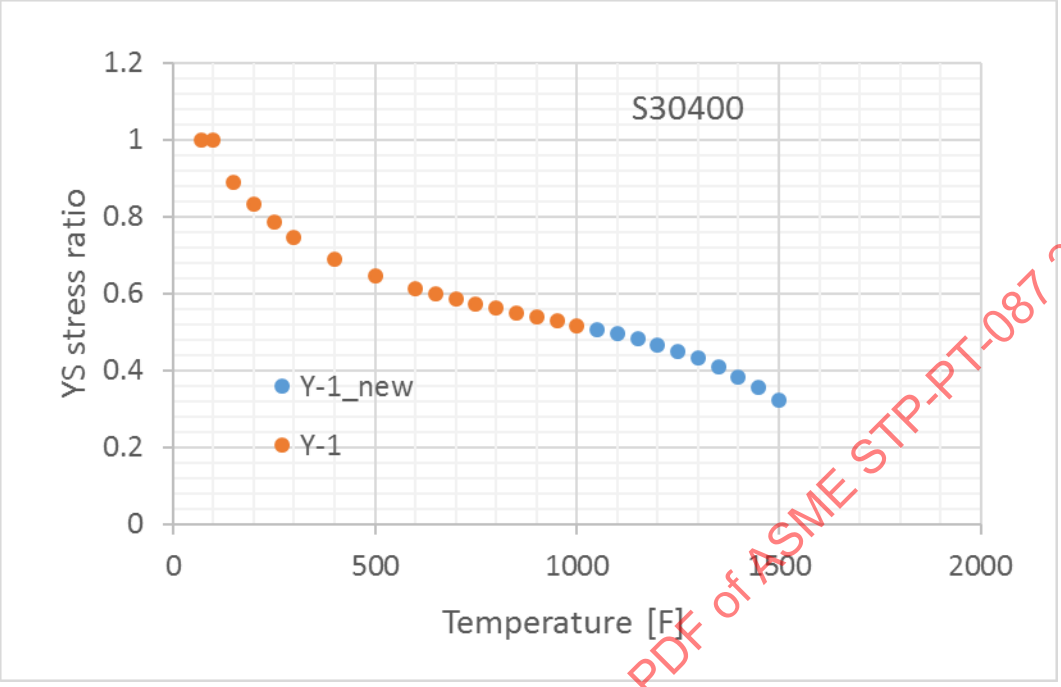


Figure 2-8: Plot of proposed metric YS stress reduction factors for S30400. Y-1-new obtained using 1.07 instead of 1.1 in the polynomial

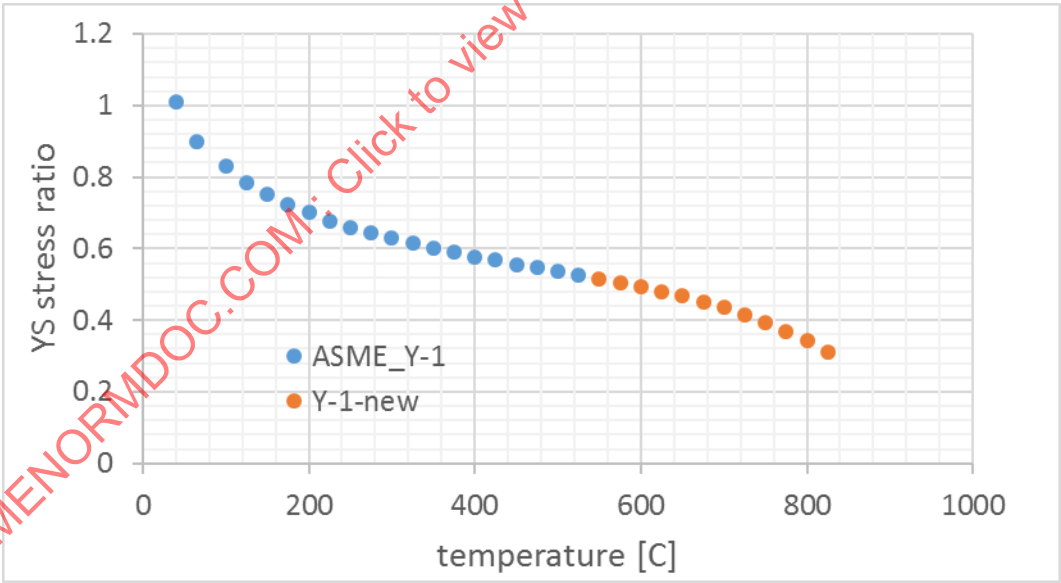


Figure 2-9: YS stress ratios (customary and metric) for SS304 up to 1500 F. Y-1-new obtained using 1.07 instead of 1.1 in the polynomial

Temperature [F]	ASME_Y-1	Y-1-new		Temperature [C]	ASME_Y-1	Y-1-new
70	1.000			40	1.0097561	
100	1.000			65	0.89756098	
150	0.890			100	0.82926829	
200	0.833			125	0.78536585	
250	0.787			150	0.75121951	
300	0.747			175	0.72195122	
350				200	0.70243902	
400	0.690			225	0.67804878	
450				250	0.65853659	
500	0.647			275	0.64390244	
550				300	0.62926829	
600	0.613			325	0.61463415	
650	0.600			350	0.6	
700	0.587			375	0.5902439	
750	0.573			400	0.57560976	
800	0.563			425	0.57073171	
850	0.550			450	0.55609756	
900	0.540			475	0.54634146	
950	0.530			500	0.53658537	
1000	0.517			525	0.52682927	
1050		0.508		550		0.51424956
1100		0.496		575		0.5040382
1150		0.483		600		0.49295342
1200		0.468		625		0.48074315
1250		0.451		650		0.46715536
1300		0.432		675		0.45193798
1350		0.410		700		0.43483897
1400		0.385		725		0.41560627
1450		0.356		750		0.39398784
1500		0.324		775		0.36973162
				800		0.34258555
				825		0.31229759

2.3 S30403/ 304L/18Cr-8Ni up to 1200°F

Figure 2-10: YS strength reduction factors from current ASME (2015)-Y-1 Tables compared with literature data (material: S30403)

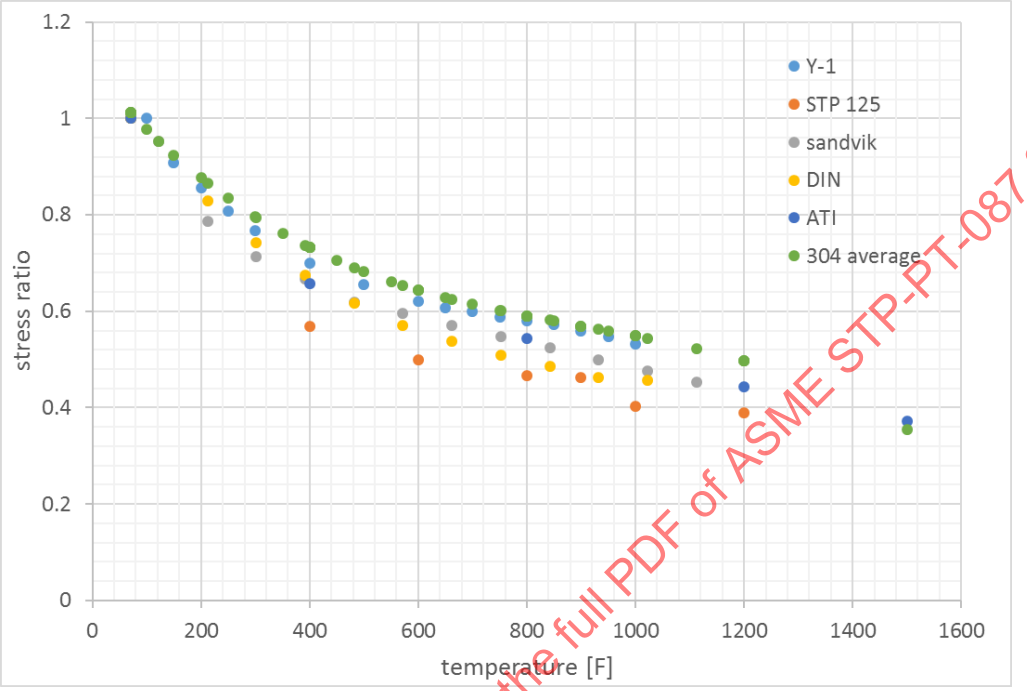


Figure 2-11: Polynomial fit through relevant data (material S30403)

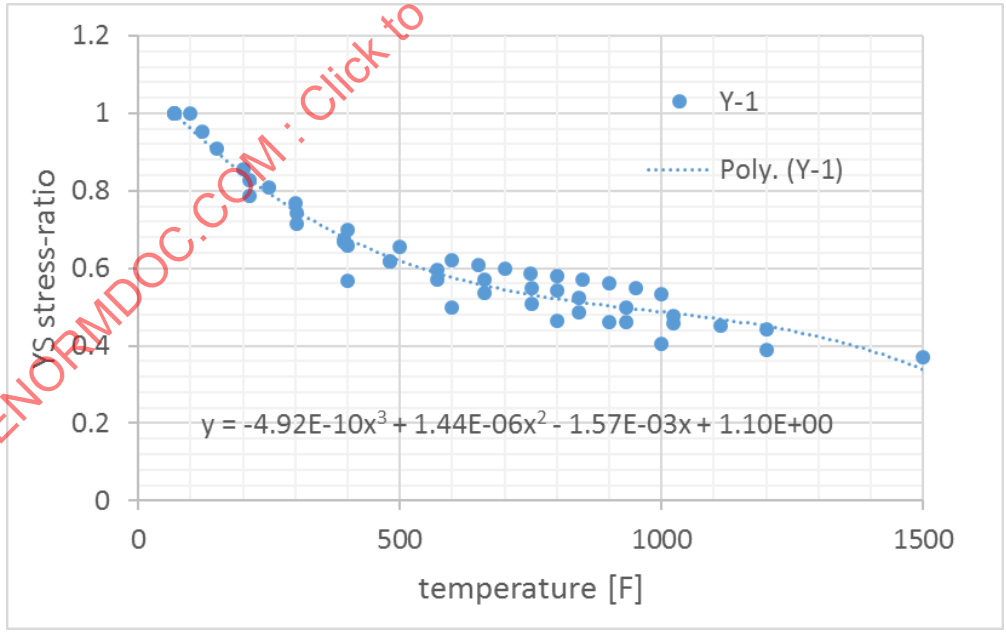


Figure 2-12: Plot of proposed customary YS stress reduction factors for S304L. Y-1-new obtained using 1.07 instead of 1.1 in the polynomial

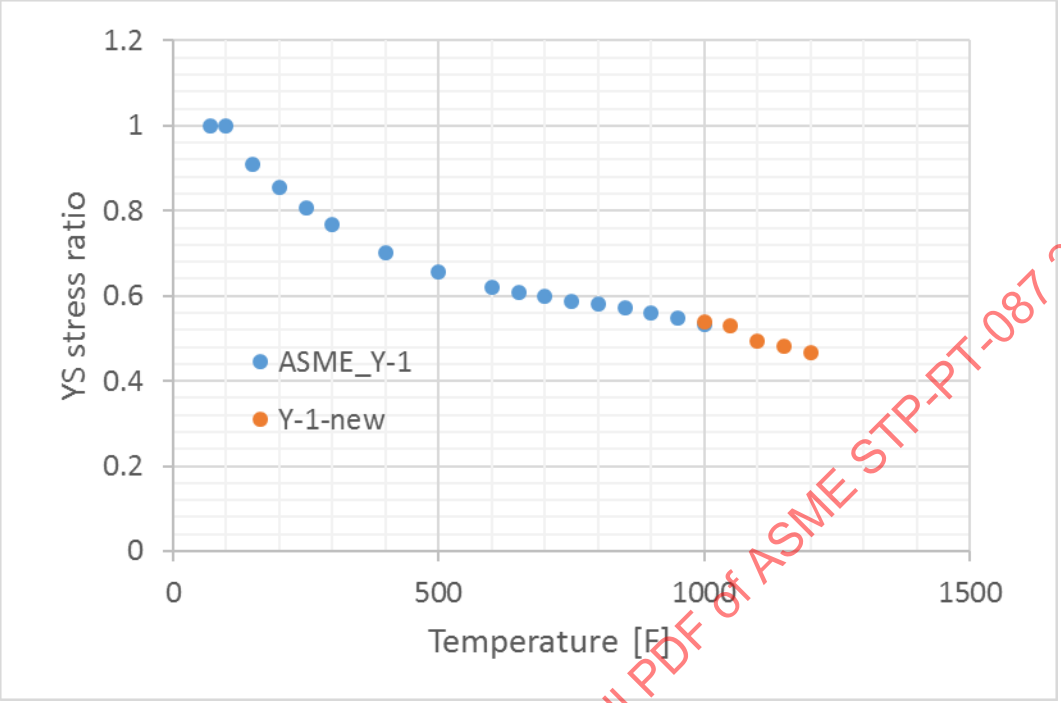


Figure 2-13: Plot of proposed metric YS stress reduction factors for S304L. Y-1-new obtained using 1.16 instead of 1.1 in the polynomial

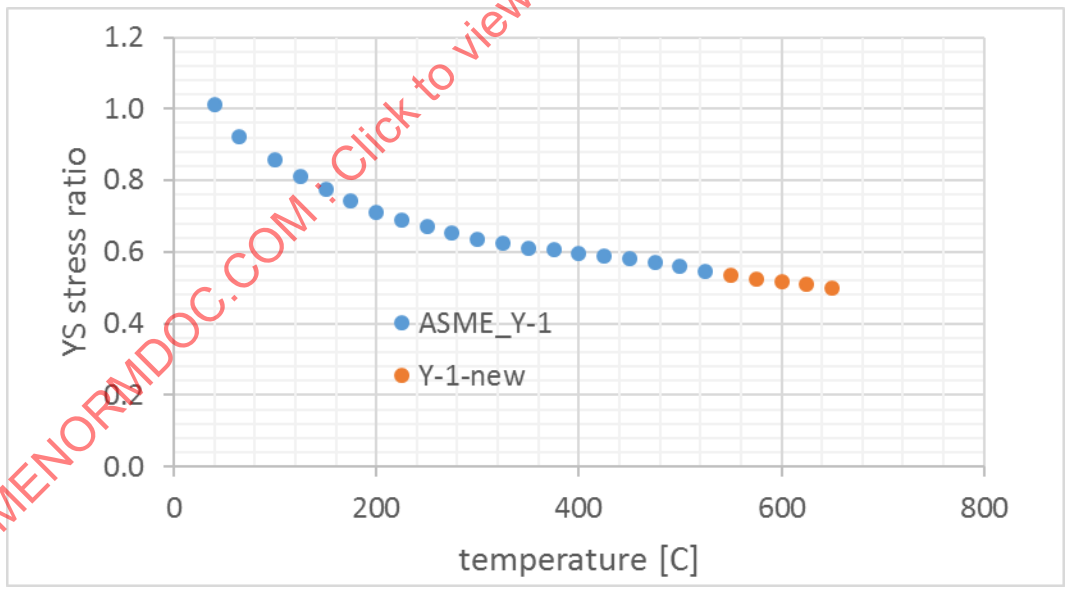


Figure 2-14: YS stress ratios (customary and metric) for S304L up to 1200°F. Y-1-new obtained using 1.16 instead of 1.1 in the polynomial

Temperature[F]	ASME_Y-1	Y-1-new		Temperature[C]	ASME_Y-1	Y-1-new
70	1.000			40	1.012	
100	1.000			65	0.924	
150	0.908			100	0.859	
200	0.856			125	0.812	
250	0.808			150	0.776	
300	0.768			175	0.741	
350				200	0.712	
400	0.700			225	0.688	
450				250	0.671	
500	0.656			275	0.653	
550				300	0.635	
600	0.620			325	0.624	
650	0.608			350	0.612	
700	0.600			375	0.606	
750	0.588			400	0.594	
800	0.580			425	0.588	
850	0.572			450	0.582	
900	0.560			475	0.571	
950	0.548			500	0.560	
1000	0.532	0.537		525	0.547	
1050		0.529		550		0.534
1100		0.494		575		0.526
1150		0.480		600		0.517
1200		0.465		625		0.508
				650		0.498

2.4 S30908/ 309 S/ 23Cr-12Ni up to 1500°F

Figure 2-15: YS strength reduction factors from current ASME (2015)-Y-1 Tables compared with literature data (material: S30908)

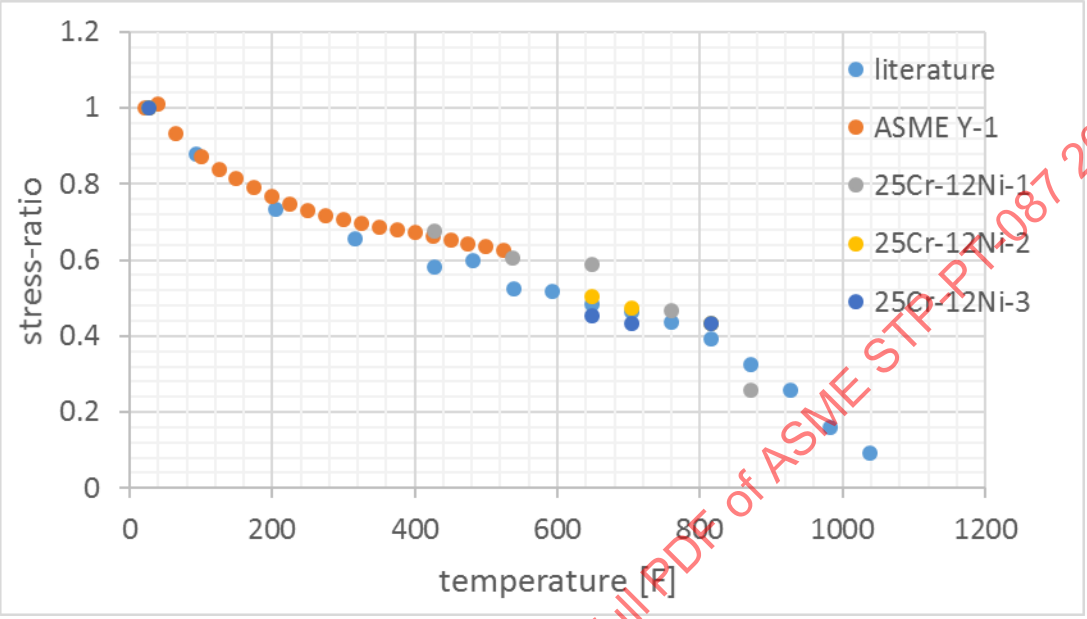


Figure 2-16: Polynomial fit through relevant data (material S30908)

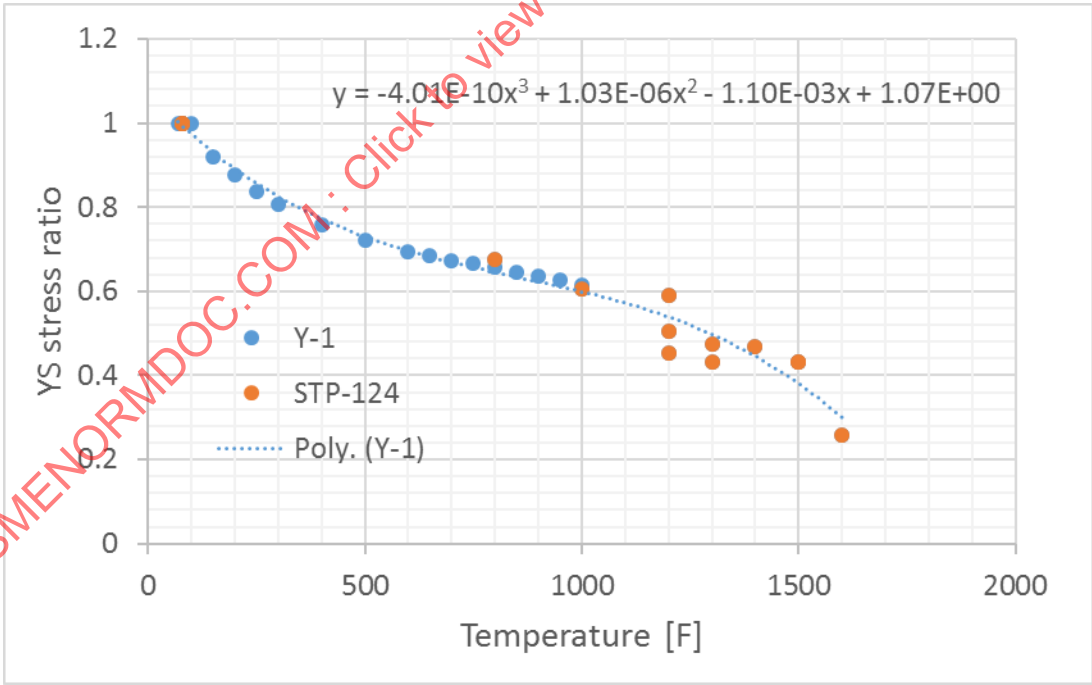


Figure 2-17: Plot of proposed customary YS stress reduction factors for S30908

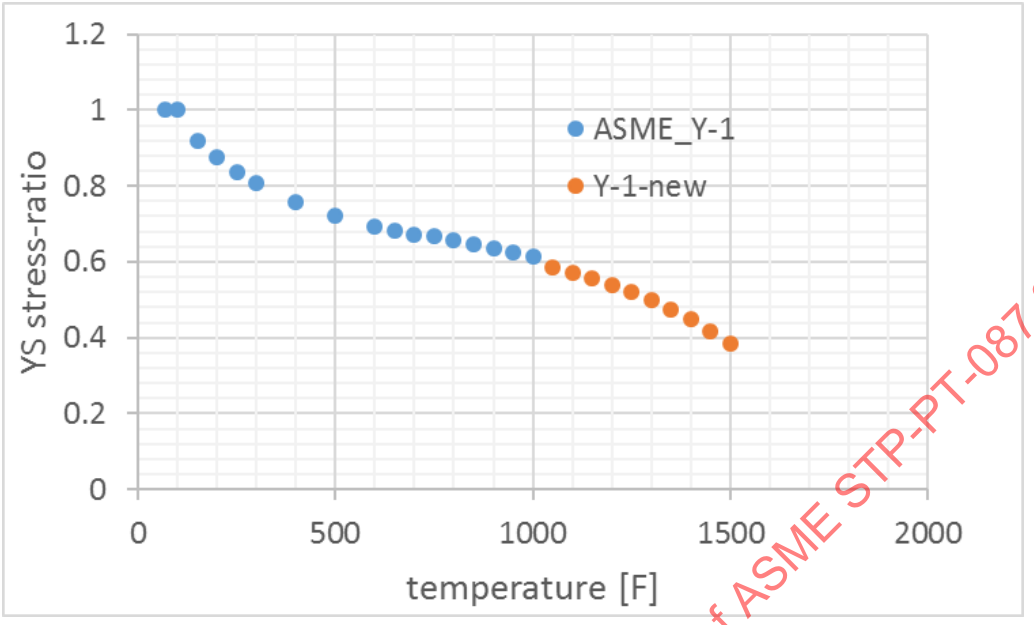


Figure 2-18: Plot of proposed metric YS stress reduction factors for S30908

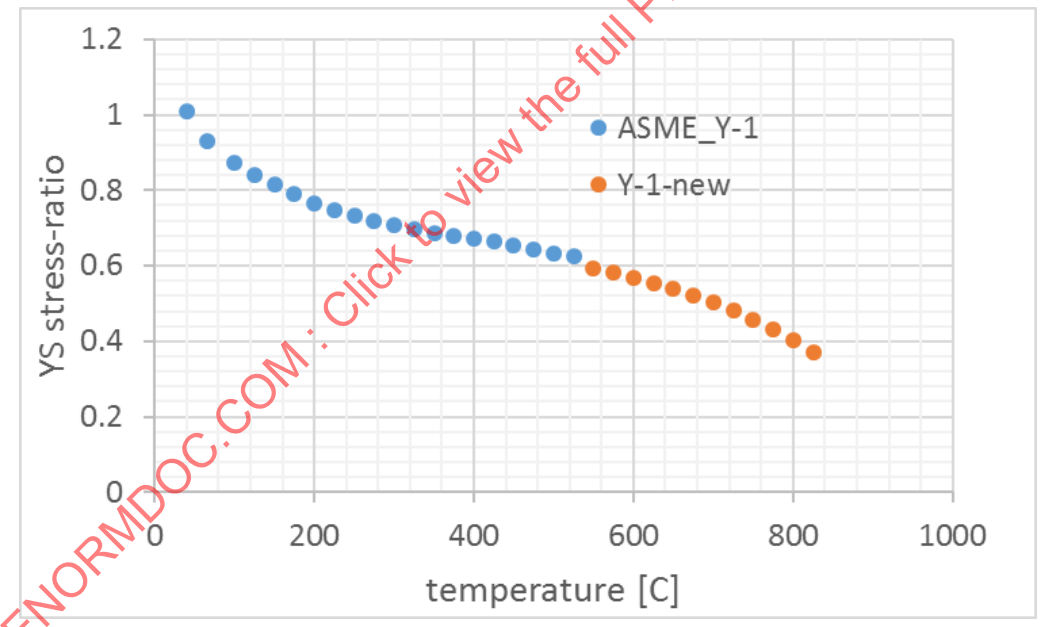


Figure 2-19: YS stress ratios (customary and metric) for S30908 up to 1500°F

Temperature [F]	ASME_Y-1	Y-1-new		Temperature [C]	ASME_Y-1	Y-1-new
70	1.000			40	1.010	
100	1.000			65	0.932	
150	0.920			100	0.873	
200	0.877			125	0.839	
250	0.837			150	0.815	
300	0.807			175	0.790	
350				200	0.766	
400	0.757			225	0.746	
450				250	0.732	
500	0.720			275	0.717	
550				300	0.707	
600	0.693			325	0.698	
650	0.683			350	0.688	
700	0.673			375	0.678	
750	0.667			400	0.673	
800	0.657			425	0.663	
850	0.647			450	0.654	
900	0.637			475	0.644	
950	0.627			500	0.634	
1000	0.613			525	0.624	
1050		0.586		550		0.594
1100		0.573		575		0.582
1150		0.557		600		0.569
1200		0.540		625		0.555
1250		0.521		650		0.540
1300		0.500		675		0.522
1350		0.476		700		0.503
1400		0.448		725		0.482
1450		0.418		750		0.459
1500		0.384		775		0.432
				800		0.404
				825		0.372

2.5 S31008/ 310 S/ 25Cr-20Ni up to 1500°F

Figure 2-20: YS strength reduction factors from current ASME (2015)-Y-1 Tables compared with literature data (material: S31008)

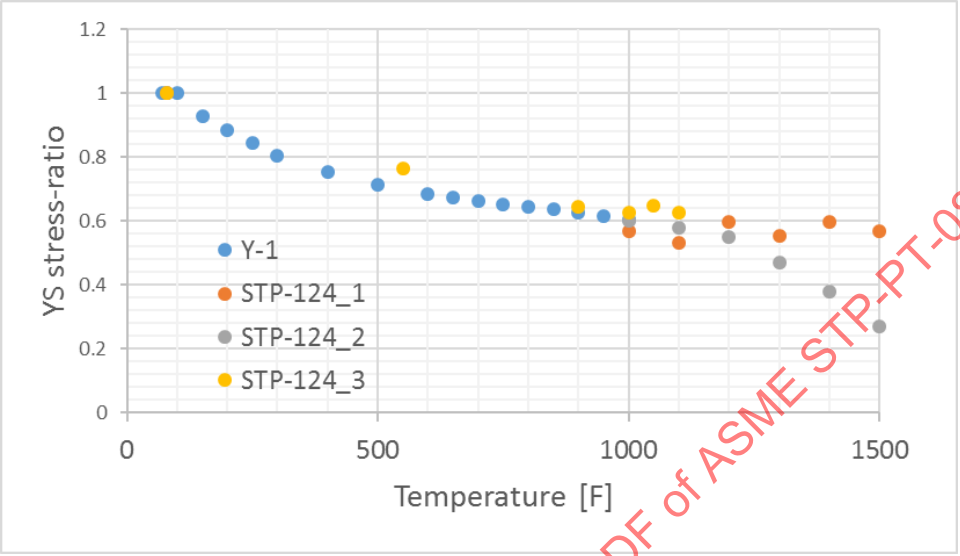


Figure 2-21: Polynomial fit through relevant data (material: S31008)

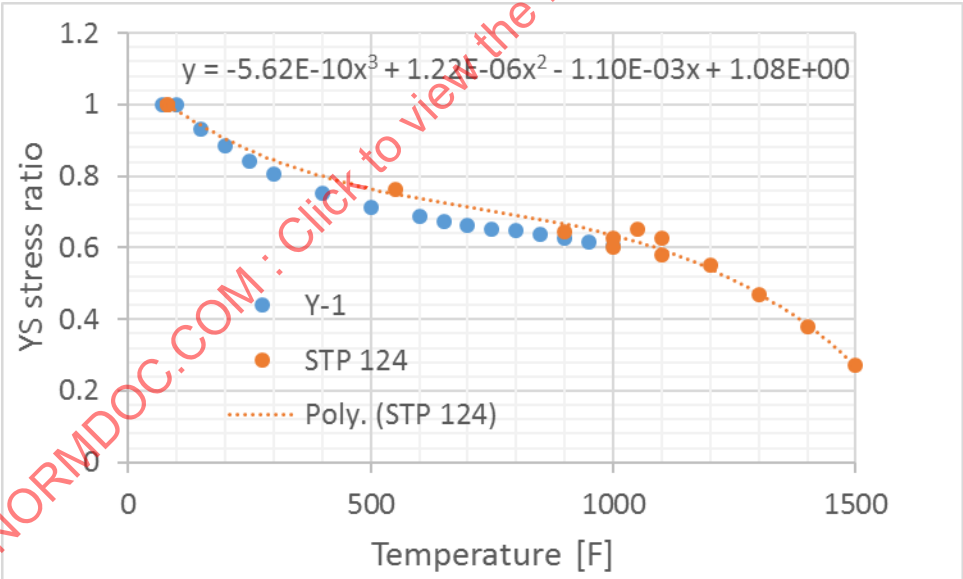


Figure 2-22: Plot of proposed customary YS stress reduction factors for S31008

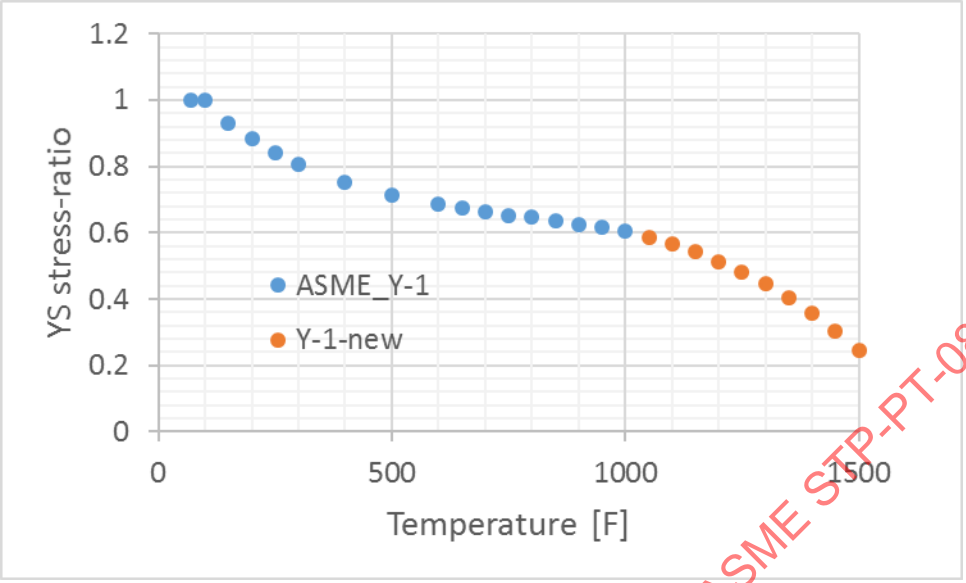


Figure 2-23: Plot of proposed metric YS stress reduction factors for S31008

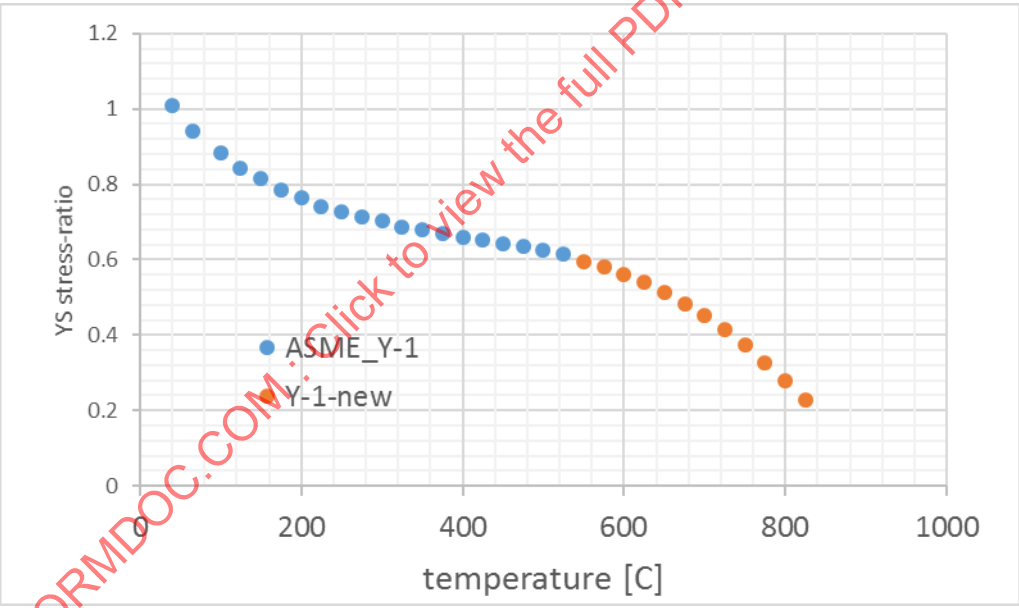


Figure 2-24: YS stress ratios (customary and metric) for S31008 up to 1500°F

Temperature [F]	ASME_Y-1	Y-1-new		Temperature [C]	ASME_Y-1	Y-1-new
70	1.000			40	1.010	
100	1.000			65	0.941	
150	0.930			100	0.883	
200	0.883			125	0.844	
250	0.843			150	0.815	
300	0.807			175	0.785	
350				200	0.766	
400	0.753			225	0.741	
450				250	0.727	
500	0.713			275	0.712	
550				300	0.702	
600	0.687			325	0.688	
650	0.673			350	0.678	
700	0.663			375	0.668	
750	0.653			400	0.659	
800	0.647			425	0.654	
850	0.637			450	0.644	
900	0.627			475	0.634	
950	0.617			500	0.624	
1000	0.607			525	0.615	
1050		0.588		550		0.594
1100		0.567		575		0.580
1150		0.542		600		0.562
1200		0.514		625		0.539
1250		0.482		650		0.514
1300		0.446		675		0.484
1350		0.404		700		0.451
1400		0.358		725		0.414
1450		0.305		750		0.373
1500		0.247		775		0.328
				800		0.280
				825		0.227

2.6 S31600/SS 316/ 16Cr-12Ni-2Mo up to 1500°F

Figure 2-25: YS strength reduction factors from current ASME (2015)-Y-1 Tables compared with literature data (material: S31600)

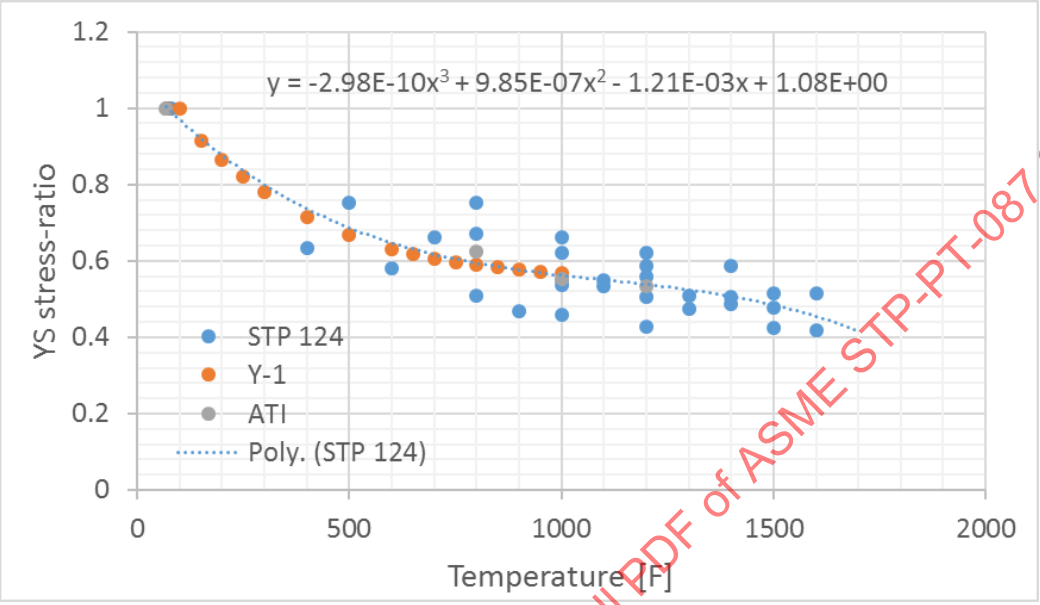


Figure 2-26: Plot of proposed customary YS stress reduction factors for S31600

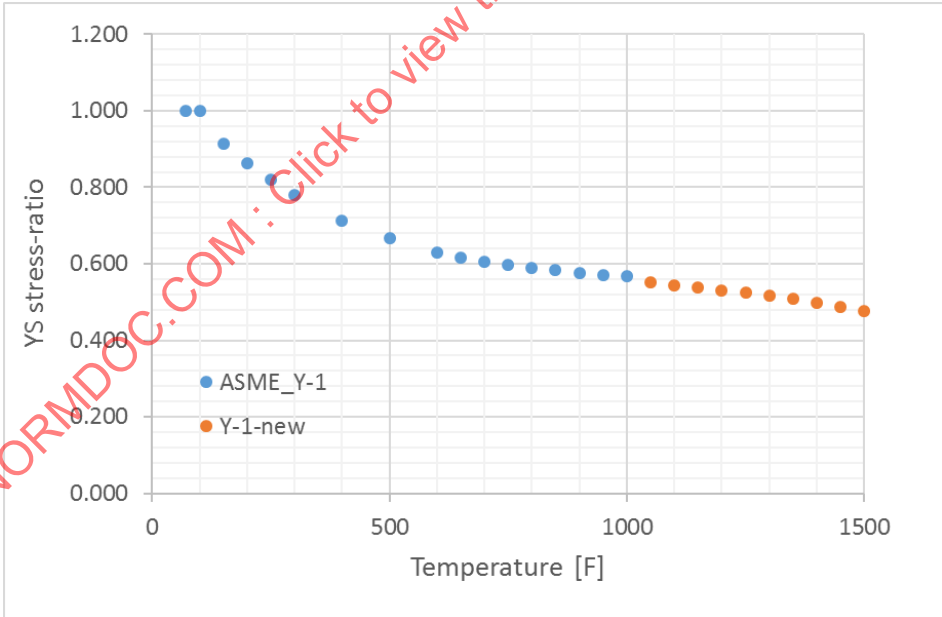


Figure 2-27: Plot of proposed metric YS stress reduction factors for S31600

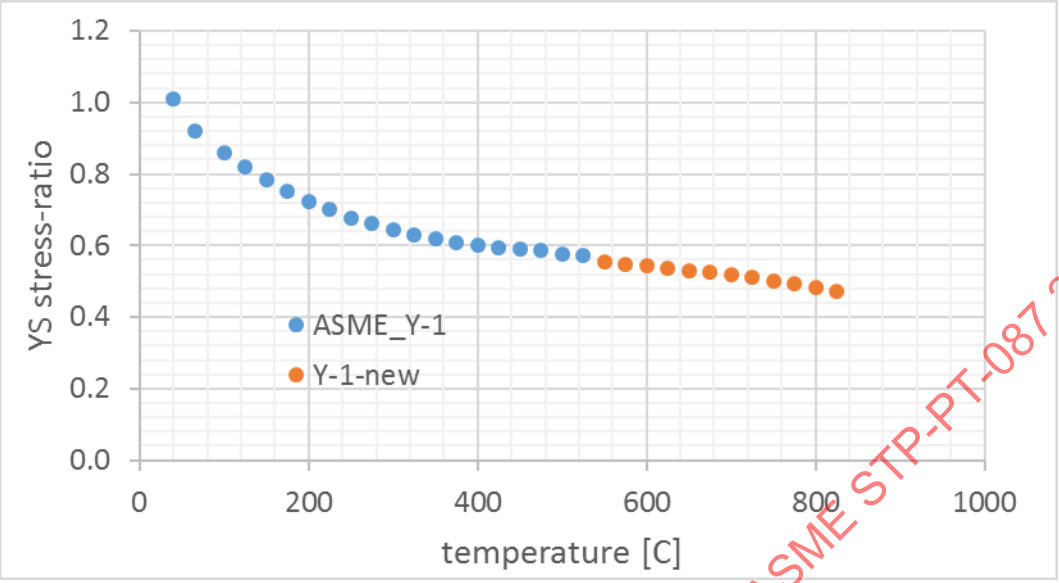
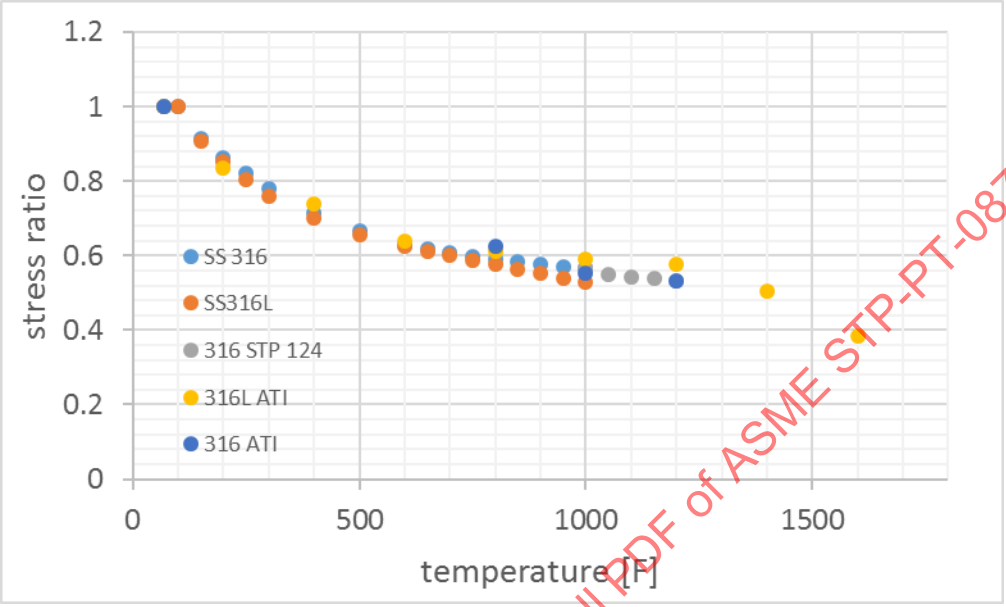


Figure 2-28: YS stress ratios (customary and metric) for S31600 up to 1500°F

Temperature [F]	ASME_Y-1	Y-1-new		Temperature [C]	ASME_Y-1	Y-1-new
70	1.000			40	1.010	
100	1.000			65	0.922	
150	0.913			100	0.859	
200	0.863			125	0.820	
250	0.820			150	0.785	
300	0.780			175	0.751	
350				200	0.722	
400	0.713			225	0.702	
450				250	0.678	
500	0.667			275	0.663	
550				300	0.644	
600	0.630			325	0.629	
650	0.617			350	0.620	
700	0.607			375	0.610	
750	0.597			400	0.600	
800	0.590			425	0.595	
850	0.583			450	0.590	
900	0.577			475	0.585	
950	0.570			500	0.576	
1000	0.567			525	0.571	
1050		0.550		550		0.554
1100		0.544		575		0.548
1150		0.538		600		0.543
1200		0.531		625		0.537
1250		0.525		650		0.531
1300		0.517		675		0.525
1350		0.508		700		0.518
1400		0.499		725		0.511
1450		0.488		750		0.502
1500		0.476		775		0.493
				800		0.483
				825		0.471

2.7 S31603/ 316L/ 16Cr-12Ni-2Mo up to 1200°F

Figure 2-29: YS strength reduction factors from current ASME (2015)-Y-1 Tables compared with literature data (material: S31603)



The Y-1 values for 316 L are only slightly different from the values of 316. The literature also considers both materials equivalent (with respect to yield strength). It is therefore proposed to use the values determined for 316 and to anchor them at 1000 F to the Y-1 values of 316L. The results are shown in Figure 2-30, Figure 2-31 and listed in Figure 2-32.

Figure 2-30: Plot of proposed customary YS stress reduction factors for S31603

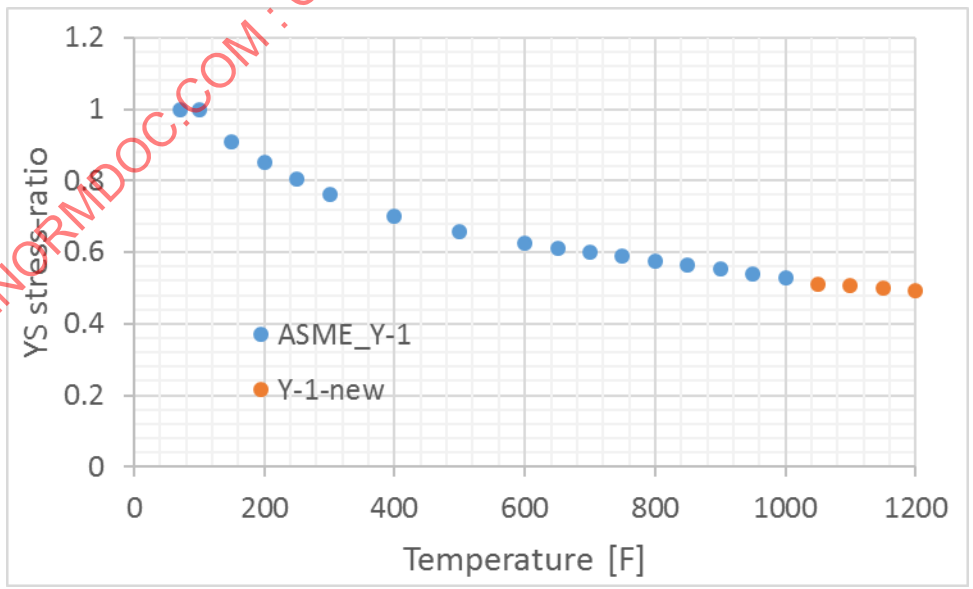


Figure 2-31: Plot of proposed metric YS stress reduction factors for S31603

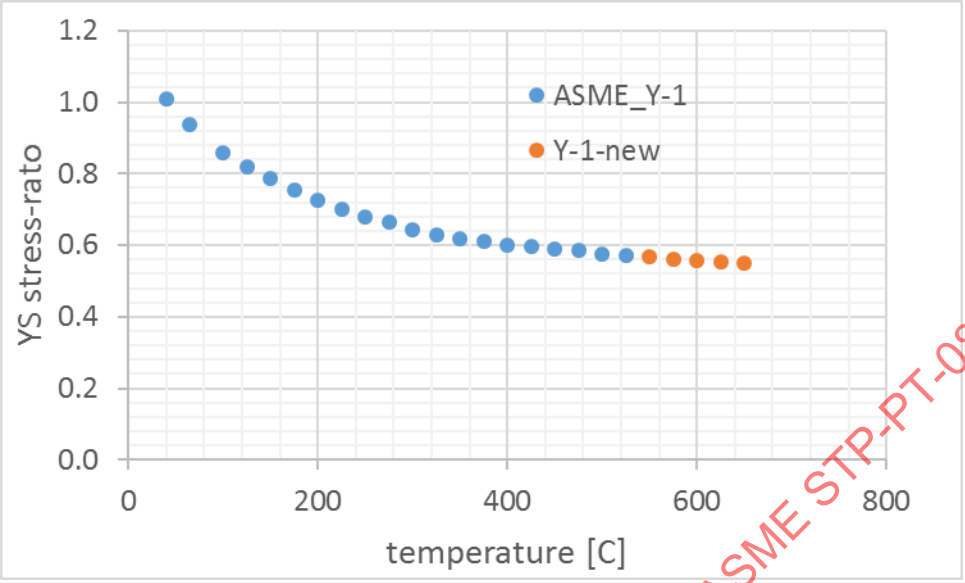
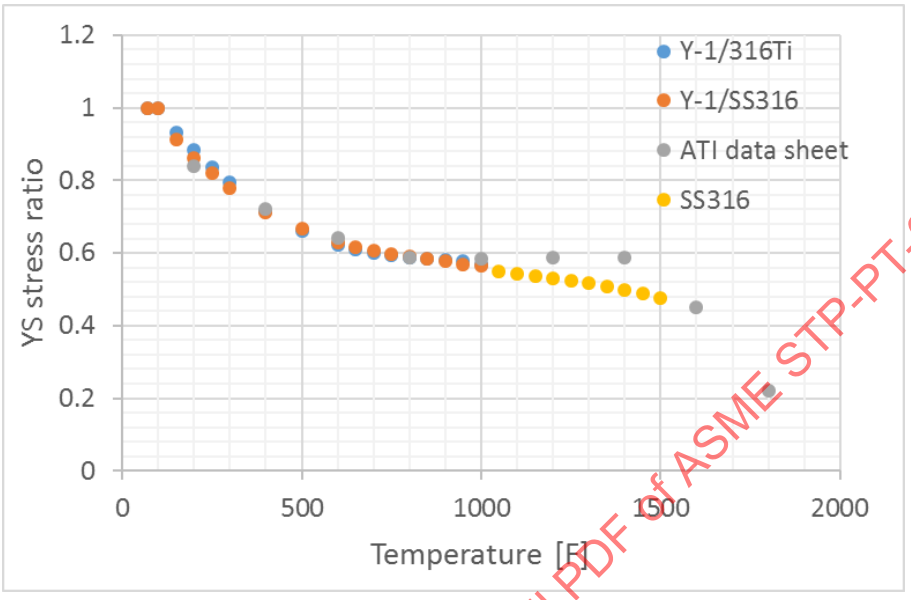


Figure 2-32: Yield strength reduction factors for S31603 up to 1200°F

Temperature [F]	ASME_Y-1	Y-1-new		Temperature [C]	ASME_Y-1	Y-1-new
70	1.000			40	1.010	
100	1.000			65	0.937	
150	0.908			100	0.859	
200	0.852			125	0.820	
250	0.804			150	0.785	
300	0.760			175	0.756	
350				200	0.727	
400	0.700			225	0.702	
450				250	0.678	
500	0.656			275	0.663	
550				300	0.644	
600	0.624			325	0.629	
650	0.612			350	0.620	
700	0.600			375	0.610	
750	0.588			400	0.600	
800	0.576			425	0.595	
850	0.564			450	0.590	
900	0.552			475	0.585	
950	0.540			500	0.576	
1000	0.528			525	0.571	
1050		0.512		550		0.567
1100		0.506		575		0.562
1150		0.499		600		0.558
1200		0.493		625		0.553
				650		0.549

2.8 S31635/ 316Ti/16Cr-12Ni-2Mo-Ti up to 1500°F

Figure 2-33: YS strength reduction factors from current ASME (2015)-Y-1 Tables compared with literature data (material: S31635)



Yield strength reduction factors for 316 and 316 Ti are considered equivalent in the current Y-1 Tables. It is therefore proposed to use the 316 data for temperatures above 1000 F. The ATI datasheet shows higher stress ratio values for this material. However, they can be considered as a member of the 316-group when compared with other ATI data (Figure 2-34). The chosen approach is certainly on the conservative side. The results are shown in Figure 2-34 and listed in Figure 2-37.

Figure 2-34: ATI data for S316, 316L, 317, 317L and 316Ti

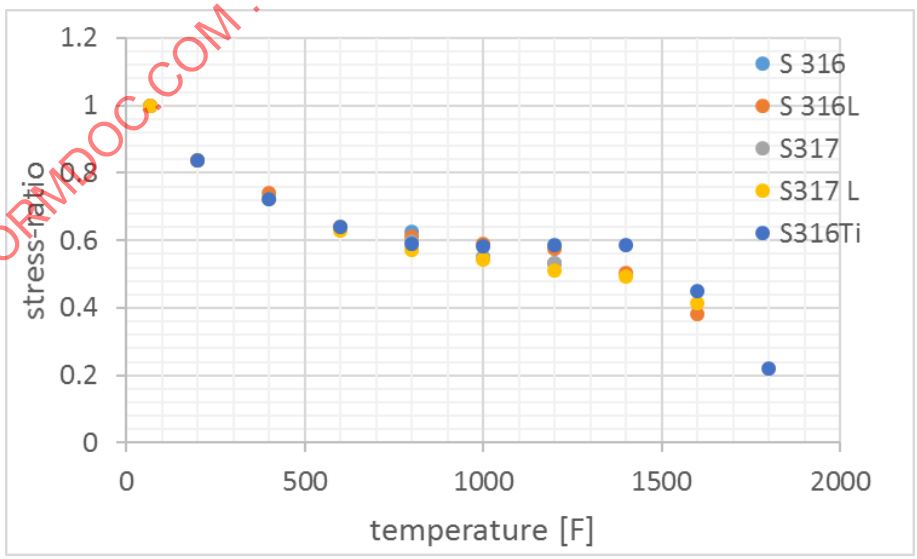


Figure 2-35: Plot of proposed customary YS stress reduction factors for S31635

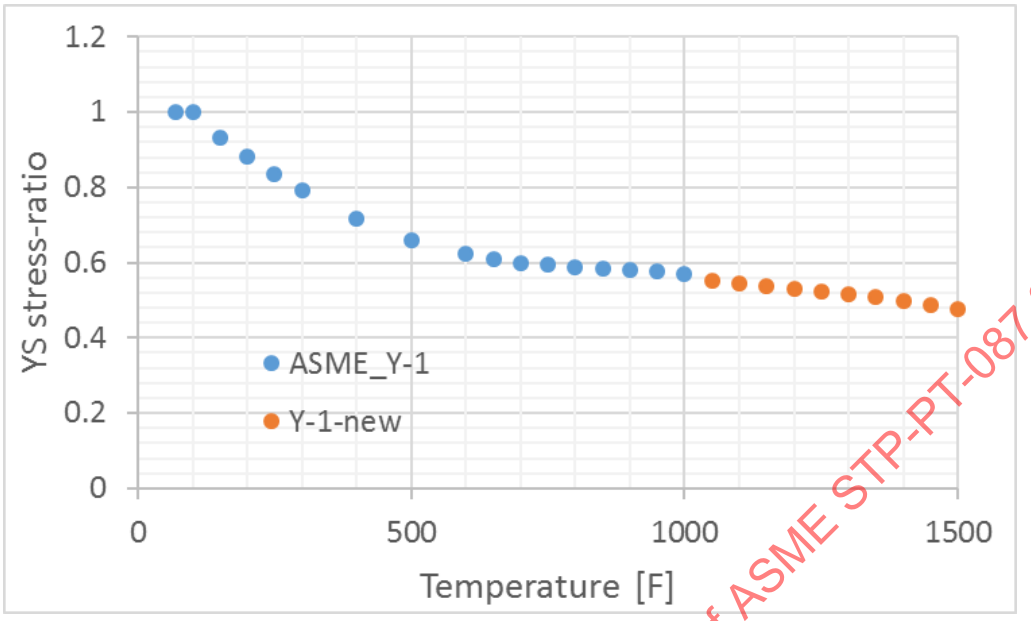


Figure 2-36: Plot of proposed metric YS stress reduction factors for S31635

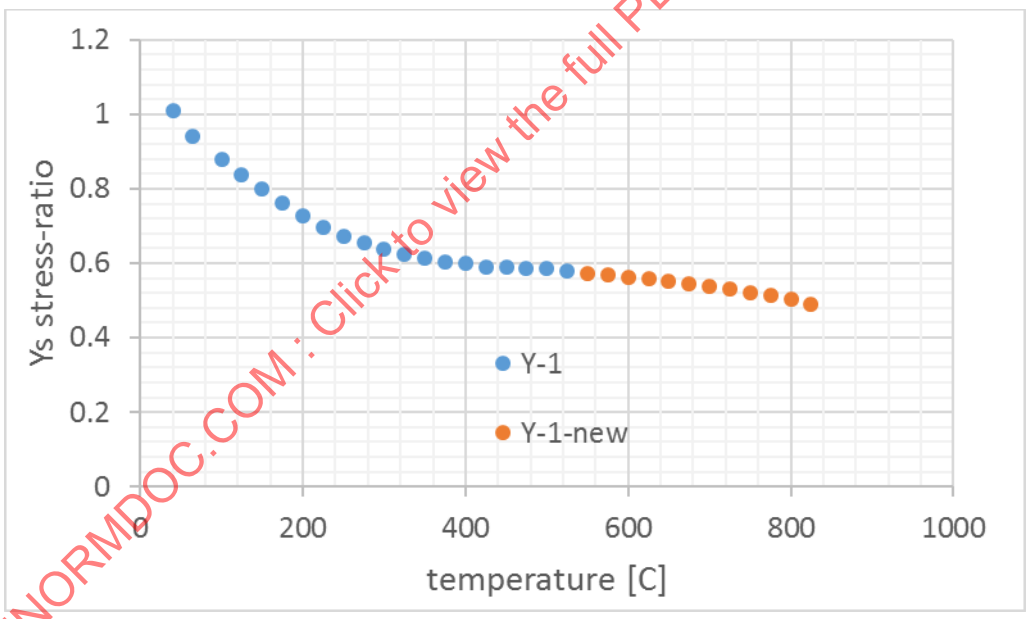
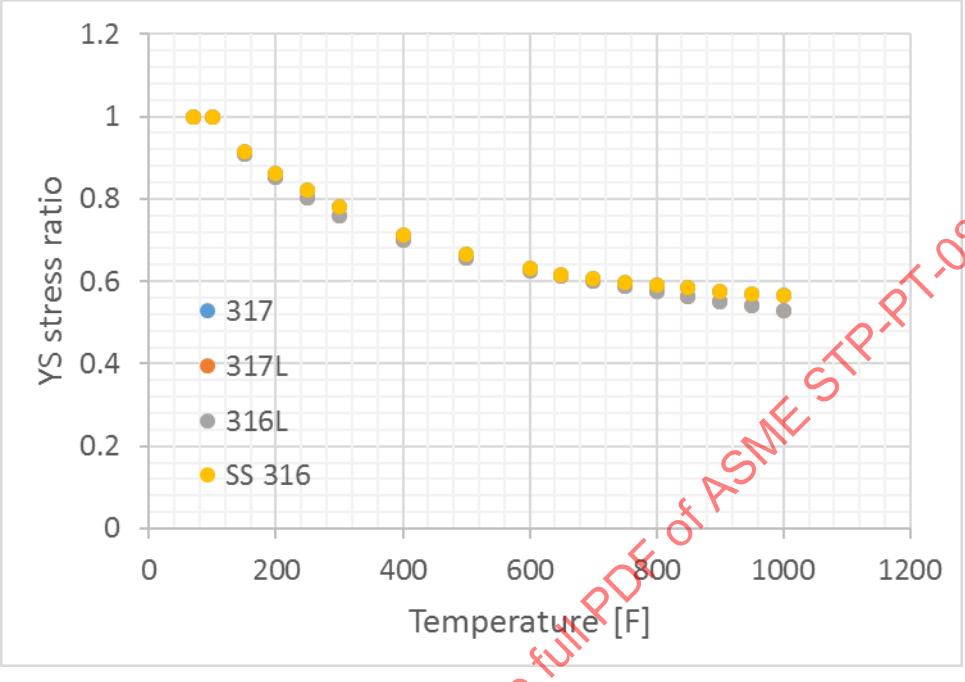


Figure 2-37: Yield strength reduction factors for S31635 up to 1500°F

Temperature [F]	ASME_Y-1	Y-1-new		Temperature [C]	Y-1	Y-1-new
70	1			40	1.010	
100	1			65	0.941	
150	0.933			100	0.878	
200	0.883			125	0.839	
250	0.837			150	0.800	
300	0.793			175	0.761	
350				200	0.727	
400	0.717			225	0.698	
450				250	0.673	
500	0.660			275	0.654	
550				300	0.639	
600	0.623			325	0.624	
650	0.610			350	0.615	
700	0.600			375	0.605	
750	0.593			400	0.600	
800	0.587			425	0.590	
850	0.583			450	0.590	
900	0.580			475	0.585	
950	0.577			500	0.585	
1000	0.570			525	0.580	
1050		0.550		550		0.574
1100		0.544		575		0.568
1150		0.538		600		0.563
1200		0.531		625		0.557
1250		0.525		650		0.551
1300		0.517		675		0.545
1350		0.508		700		0.538
1400		0.499		725		0.531
1450		0.488		750		0.522
1500		0.476		775		0.513
				800		0.503
				825		0.491

2.9 S31700/ SS317/and S31703/SS317 L/ 18Cr-13Ni-3Mo up to 1500°F (1200°F)

Figure 2-38: YS strength reduction factors for 317 and 317L from current Y-1 Tables



The two materials 317 and 317 L are considered fully equivalent to 316 and 316 L. It is therefore proposed to use this equivalency for the higher temperatures.

2.10 S32100/ SS321/ 18Cr-10Ni-Ti up to 1500°F

Figure 2-39: YS strength reduction factors from current ASME (2015)-Y-1 Tables compared with literature data (material: S32100)

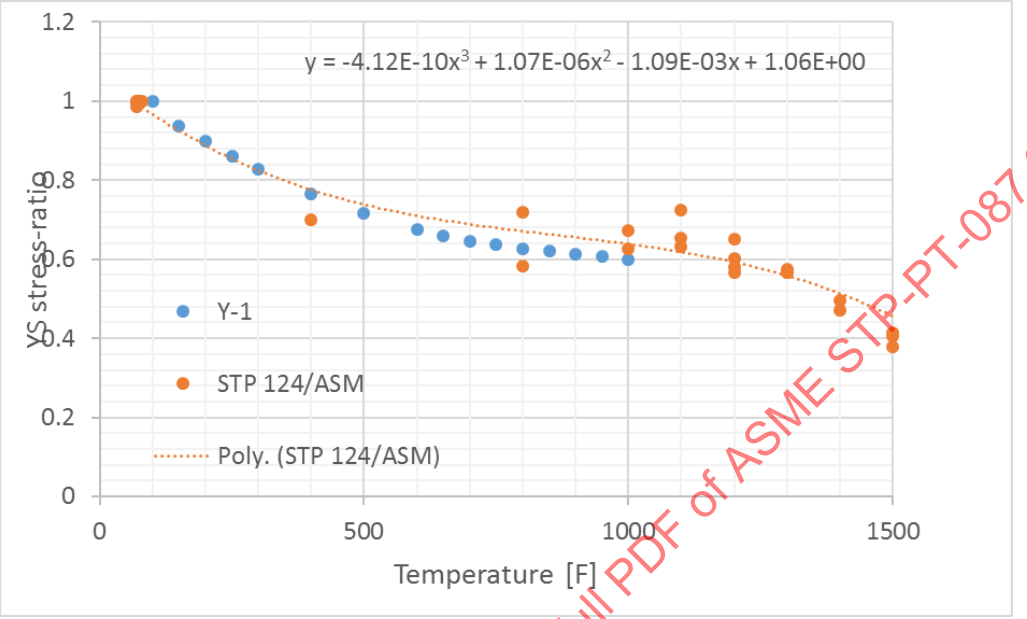


Figure 2-40: Plot of proposed customary YS stress reduction factors for S32100. Y-1-new obtained using 1.04 instead of 1.06 in the polynomial

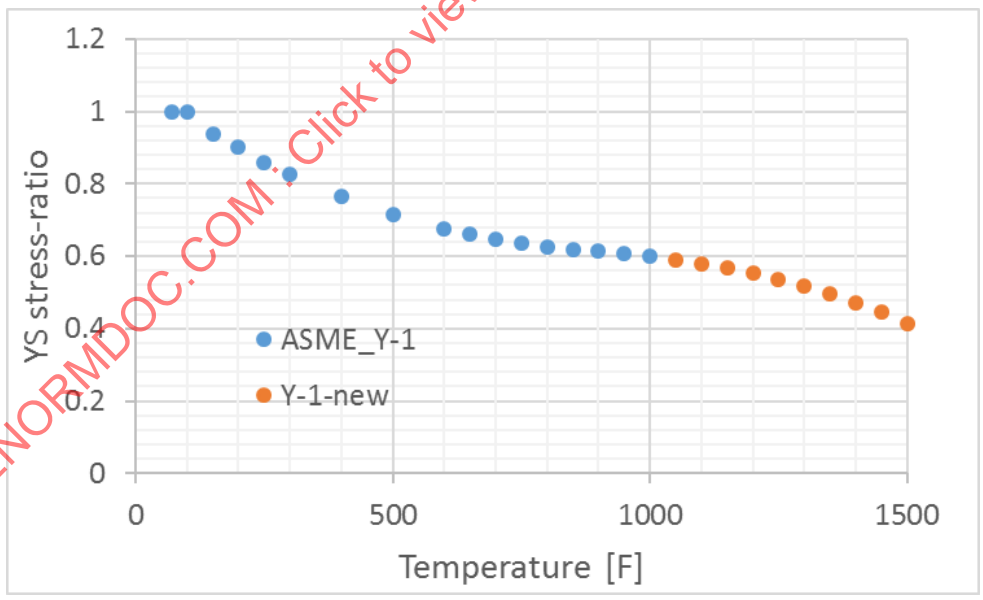


Figure 2-41: Plot of proposed metric YS stress reduction factors for S32100. Y-1-new obtained using 1.04 instead of 1.06 in the polynomial

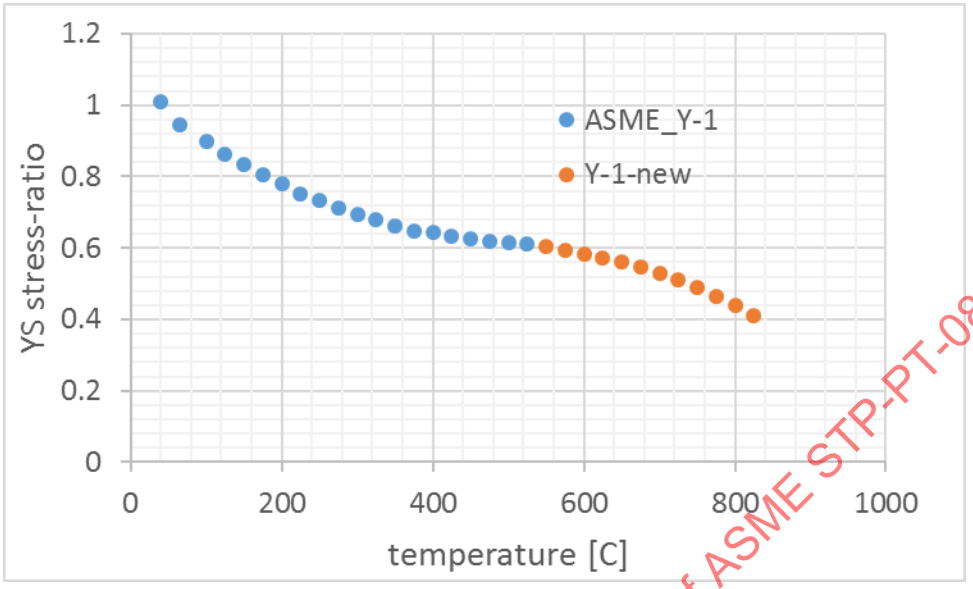


Figure 2-42: YS stress ratios (customary and metric) for S32100 up to 1500°F. Y-1-new obtained using 1.04 instead of 1.06 in the polynomial

Temperature [F]	ASME_Y-1	Y-1-new		Temperature [C]	ASME_Y-1	Y-1-new
70	1.000			40	1.010	
100	1.000			65	0.946	
150	0.937			100	0.898	
200	0.900			125	0.863	
250	0.860			150	0.834	
300	0.827			175	0.805	
350				200	0.780	
400	0.767			225	0.751	
450				250	0.732	
500	0.717			275	0.712	
550				300	0.693	
600	0.677			325	0.678	
650	0.660			350	0.663	
700	0.647			375	0.649	
750	0.637			400	0.644	
800	0.627			425	0.634	
850	0.620			450	0.624	
900	0.613			475	0.620	
950	0.607			500	0.615	
1000	0.600			525	0.610	
1050		0.598		550		0.604
1100		0.587		575		0.595
1150		0.575		600		0.585
1200		0.561		625		0.573
1250		0.545		650		0.560
1300		0.526		675		0.546
1350		0.505		700		0.529
1400		0.481		725		0.511
1450		0.453		750		0.490
1500		0.422		775		0.466
				800		0.440
				825		0.411

2.11 S34700/ SS347 and S34800/ SS348/ 18Cr-10Ni-Cb up to 1500°F

Figure 2-43: YS strength reduction factors from current ASME (2015)-Y-1 Tables compared with literature data (material: S34700)

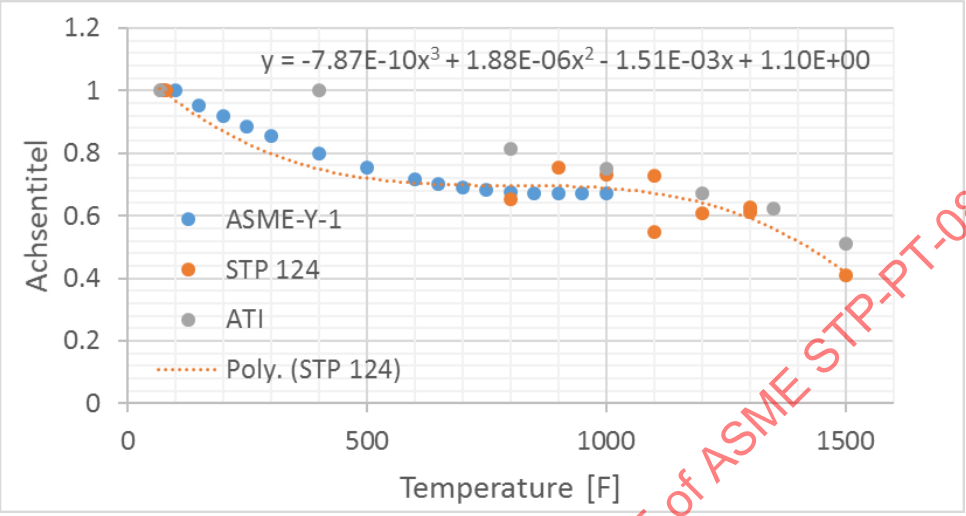


Figure 2-44: Plot of proposed customary YS stress reduction factors for S34700. Y-1-new obtained using 1.08 instead of 1.1 in the polynomial

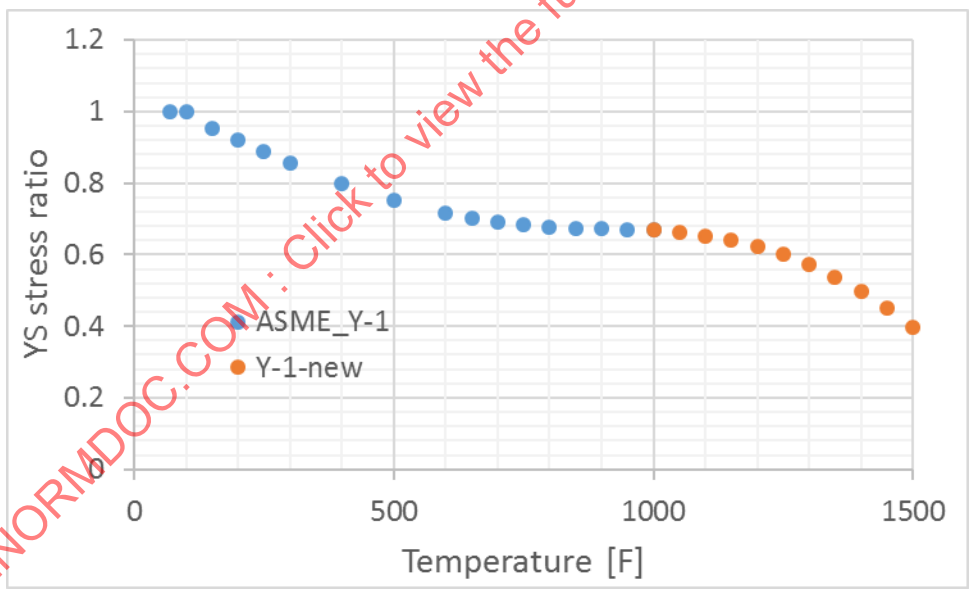


Figure 2-45: Plot of proposed metric YS stress reduction factors for S34700. Y-1-new obtained using 1.08 instead of 1.1 in the polynomial

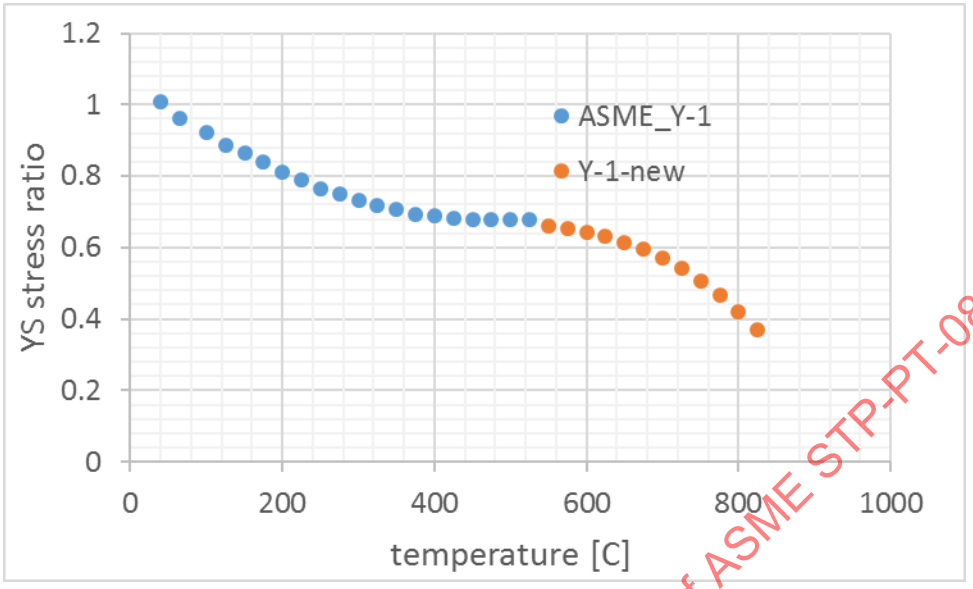


Figure 2-46: Yield strength reduction factors for SS347 and SS348 up to 1500°F

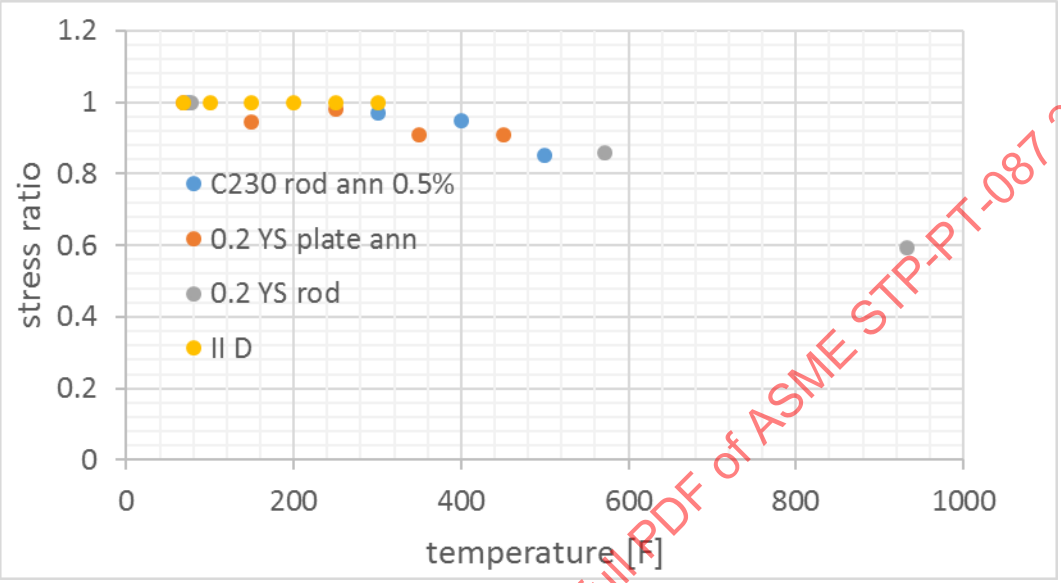
Temperature [F]	ASME_Y-1	Y-1-new		Temperature [C]	ASME_Y-1	Y-1-new
70	1			40	1.010	
100	1			65	0.961	
150	0.953			100	0.922	
200	0.920			125	0.888	
250	0.887			150	0.863	
300	0.857			175	0.839	
350				200	0.810	
400	0.800			225	0.790	
450				250	0.766	
500	0.753			275	0.751	
550				300	0.732	
600	0.717			325	0.717	
650	0.703			350	0.707	
700	0.690			375	0.693	
750	0.683			400	0.688	
800	0.677			425	0.683	
850	0.673			450	0.678	
900	0.673			475	0.678	
950	0.670			500	0.678	
1000	0.670	0.663		525	0.678	
1050		0.656		550		0.660
1100		0.646		575		0.653
1150		0.633		600		0.643
1200		0.615		625		0.631
1250		0.593		650		0.614
1300		0.565		675		0.594
1350		0.531		700		0.570
1400		0.491		725		0.541
1450		0.444		750		0.507
1500		0.389		775		0.467
				800		0.421
				825		0.368

The Y-1 new values were obtained with 1.08 instead of 1.1 for the polynomial shown in Figure 2-43.

3 COPPER

3.1 C23000 / Cu 230 / 85 Cu-15 Zn up to 500°F

Figure 3-1: Comparison of available data for C23000



IID data were derived from IID/B1 (Table 1B allowable stress*3/2 YS at RT).

Figure 3-2: Proposed YS stress ratios for C23000 up to 600°F. Current B1 Table values remain the same

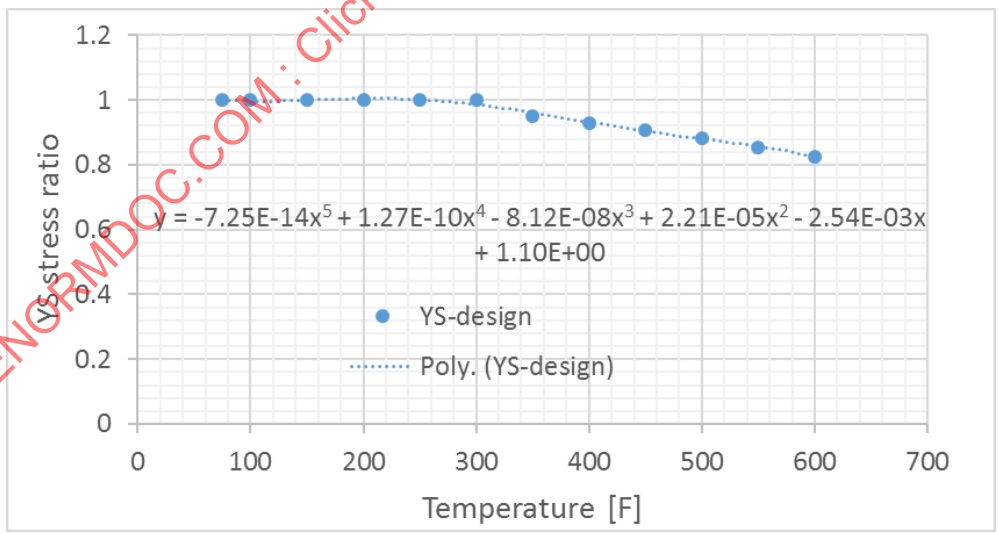


Figure 3-3: Yield strength reduction factors for C23000

Temperature [F]	Y-1	Temperature [C]	Y-1
75	1.000	40	1.000
100	1.000	65	1.000
150	1.000	100	1.000
200	1.000	125	1.000
250	1.000	150	1.000
300	1.000	175	0.951
350	0.950	200	0.934
400	0.930	225	0.914
450	0.908	250	0.892

3.2 C28000 / Cu 280 / 59 Cu-40Zn-0.07Fe-0.3Pb up to 500°F

Figure 3-4: Comparison of available data; 1_B: (Table 1B allowable stress*3)/(2 YS at RT) (material C28000)

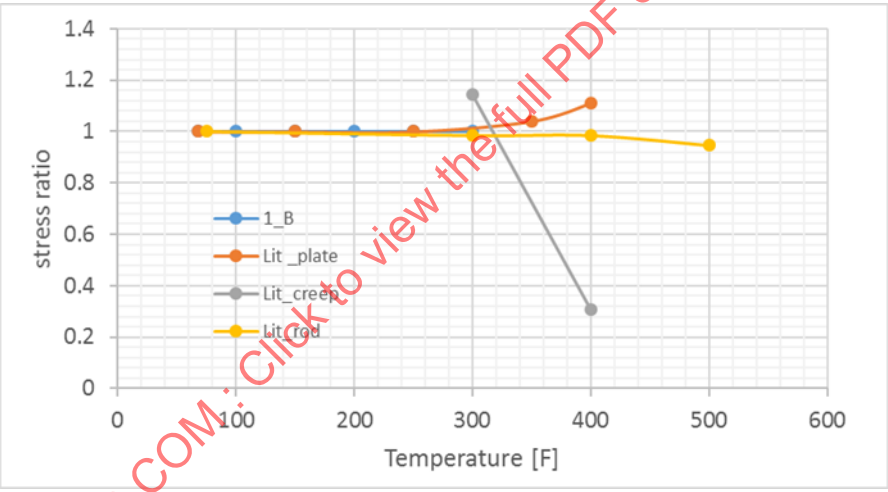


Figure 3-5: Proposed YS stress ratios for C28000 up to 500°F. Current B-1 Table values remain the same

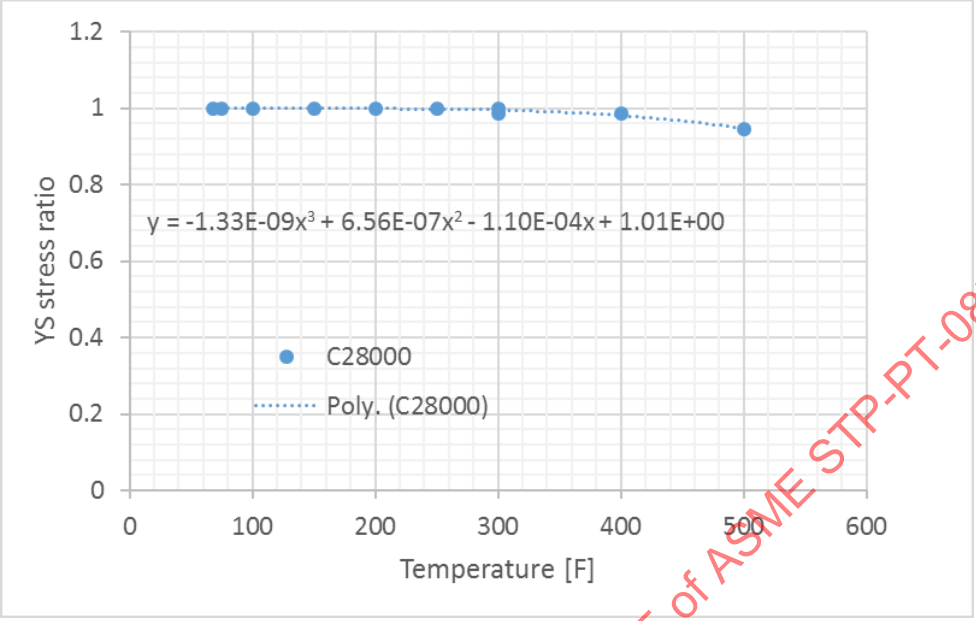
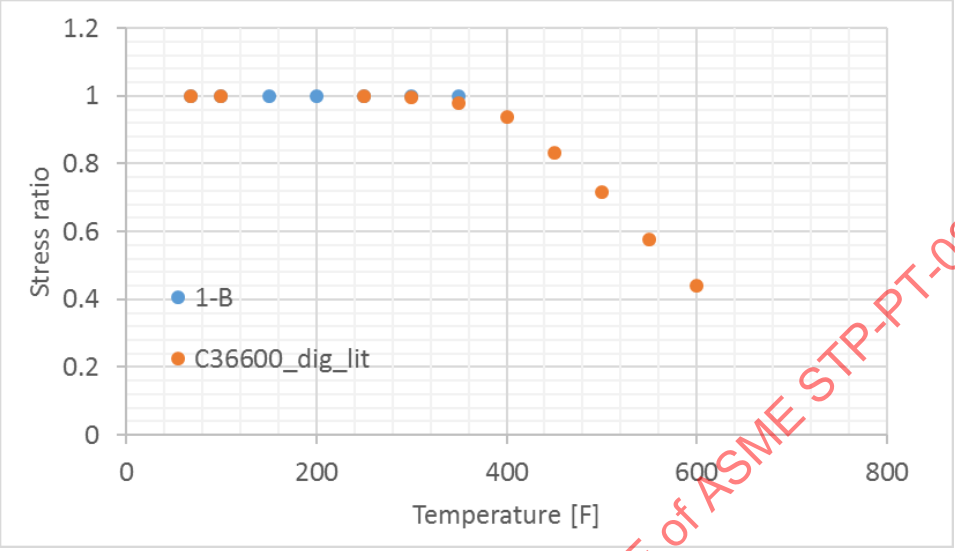


Figure 3-6: Yield strength reduction factors for C28000

Temp [F]	Y-1	Temp [C]	Y-1
68	1.01E+00	21	1.01E+00
100	1.00E+00	40	1.00E+00
150	1.00E+00	65	1.00E+00
200	1.00E+00	100	1.00E+00
250	1.00E+00	125	1.00E+00
300	1.00E+00	150	1.00E+00
350	9.95E-01	175	9.95E-01
400	9.86E-01	200	9.88E-01
		225	9.76E-01

3.3 C36500 / Cu 365 / 60Cu-39.4 Zn-0.6 Pb

Figure 3-7: Comparison of available data



1-B: (Table 1B allowable stress*3)/(2 YS at RT); dig_lit: Digitized Literature data for yield stress normalized with RT values. C36600 and C36500 are expected to show the same tensile data.

Figure 3-8: Proposed YS stress ratios for C36500 up to 500°F

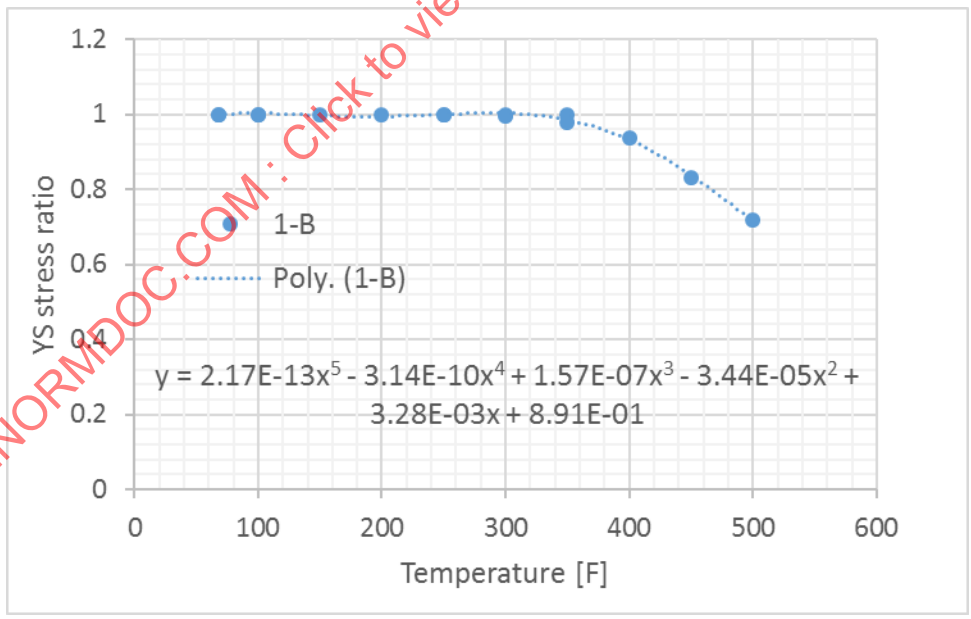


Figure 3-9: Yield strength reduction factors for C36500

Temp [F]	Y-1	Temp [C]	Y-1
68	1.000	21	1.000
100	1.000	40	1.000
150	1.000	65	1.000
200	1.000	100	1.000
250	1.000	125	1.000
300	1.000	150	1.000
350	0.984	175	0.995
400	0.931	200	0.988
		225	0.976

3.4 C44300 / Cu 443 C44400 / Cu 444 C44500 / Cu 445 up to 500°F

Figure 3-10: Comparison of available data; C44300, C44400 and C44500 are expected to show the same tensile data. B-1: (Table 1B allowable stress*3)/(2 YS at RT)

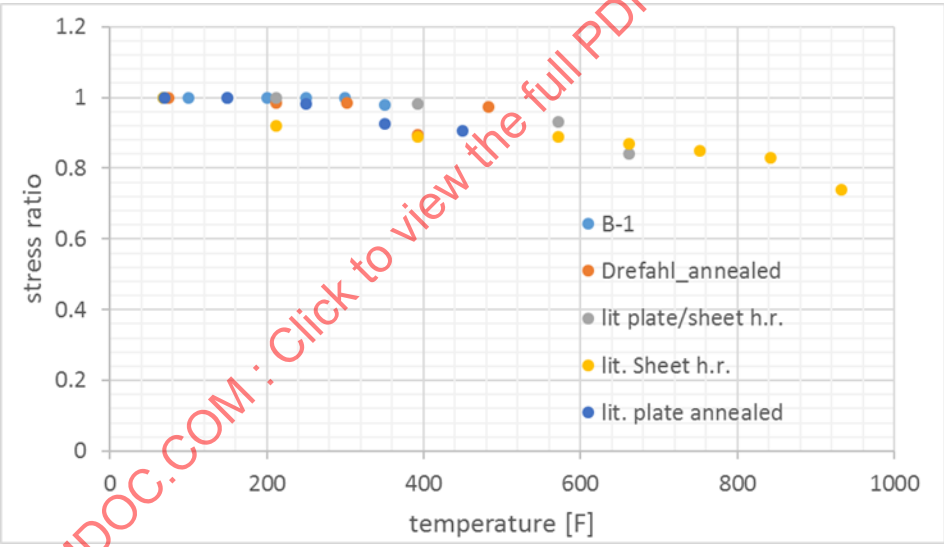


Figure 3-11: Proposed YS stress ratios for C44300, C44400 and C44500

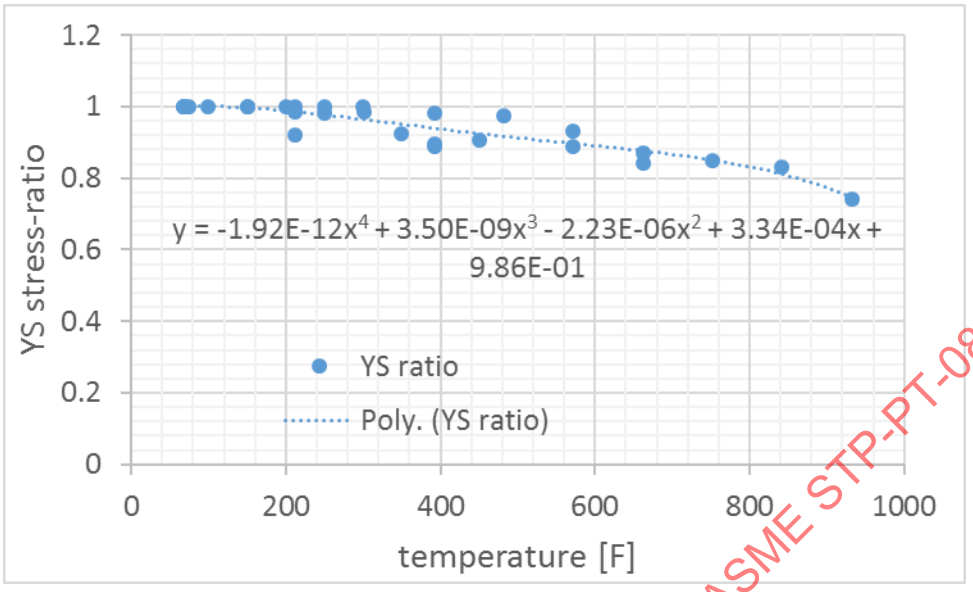


Figure 3-12: Proposed YS stress ratios for annealed C44300, C44400 and C44500

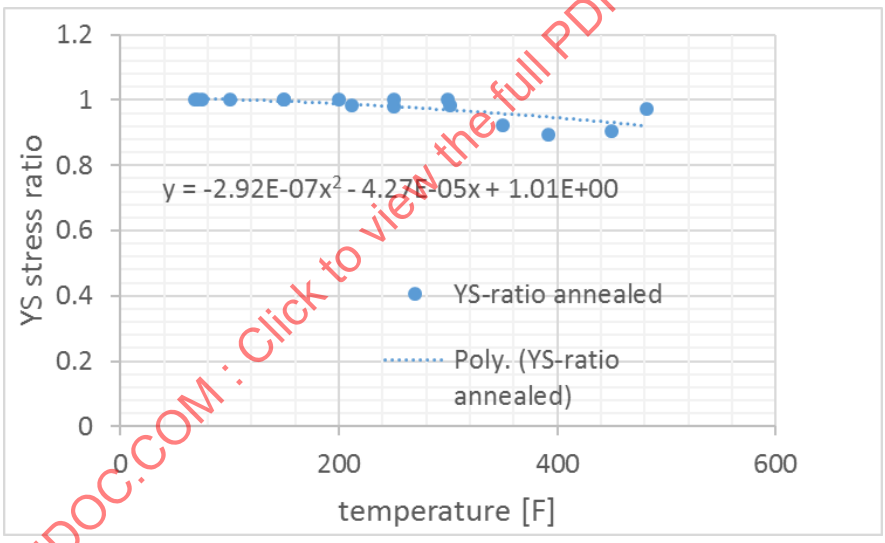


Figure 3-13: Comparison of data from Record 15-539 with data shown in Figure 3-10. It is proposed to use the 15-539 data

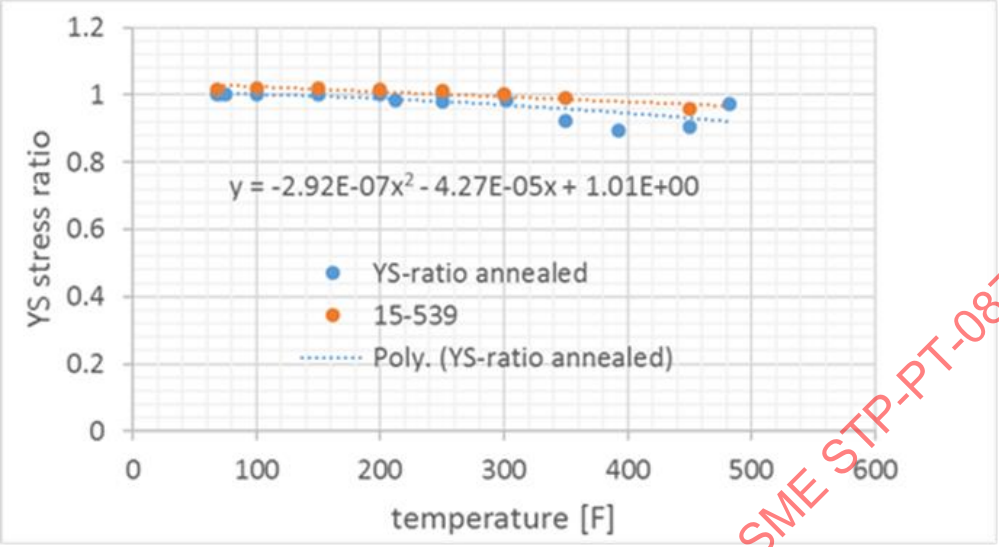


Figure 3-14: Yield strength reduction factors for C44300, C44400 and C44500 based on 15-539 data

Temp [F]	Y-1	Temp [C]	Y-1
75	1	21	1
100	1	40	1
150	1	65	1
200	1	100	1
250	1	125	1
300	1	150	1
350	1	175	1
400	0.99439835	200	0.99628765
450	0.98130427	225	0.98492692
		250	0.9716826

3.5 C46400 / Cu 464 C46500 / Cu-465 up to 500°F

Figure 3-15: Comparison of available data; C46400 and C46500 are expected to show the same tensile data. B-1: (Table 1B allowable stress*3)/(2 YS at RT)

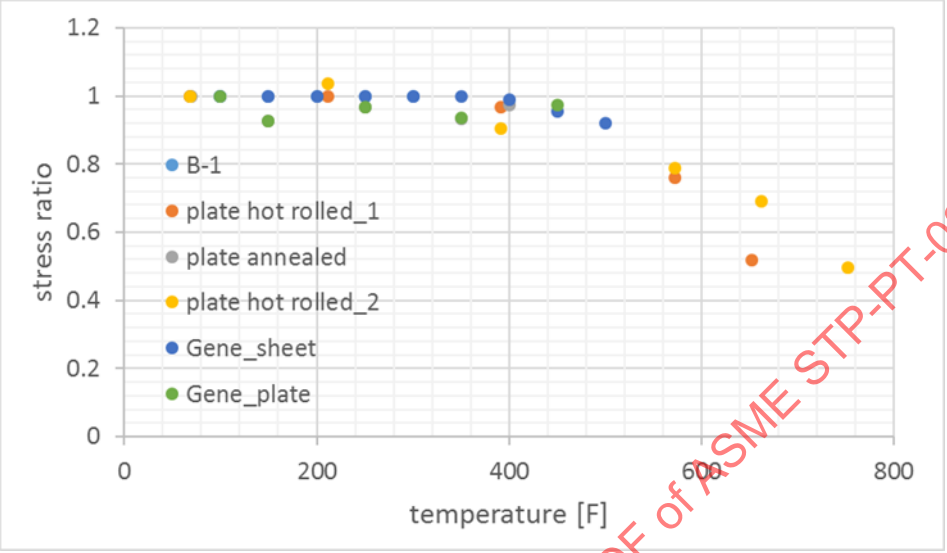


Figure 3-16: Proposed YS stress ratios for C46400 and C46500

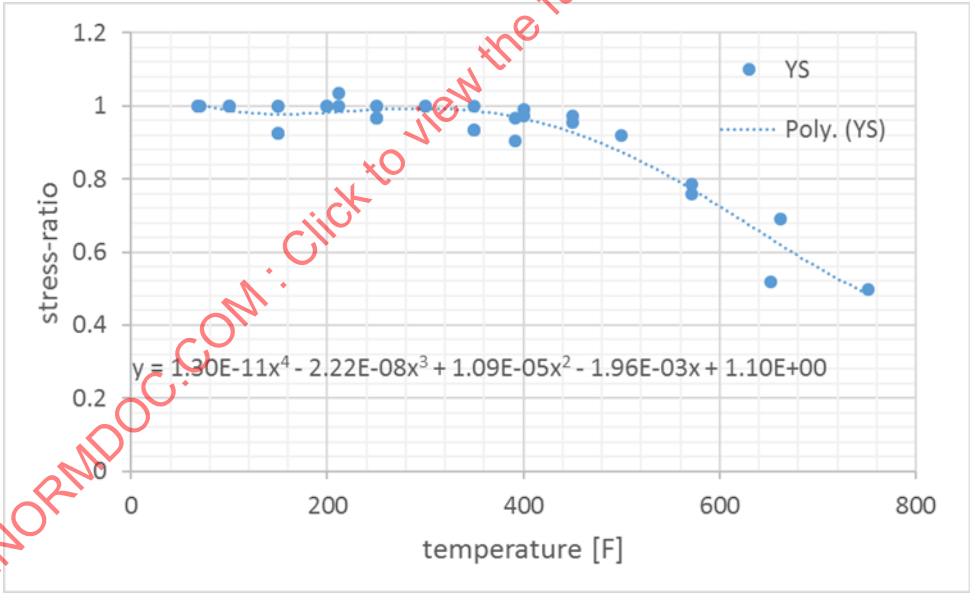


Figure 3-17: Yield strength reduction factors for C46400 and C46500

Temp [F]	Y-1	Temp [C]	Y-1
75	1	21	1.01E+00
100	1	40	1.00E+00
150	1	65	1.00E+00
200	1	100	1.00E+00
250	1	125	1.00E+00
300	1	150	1.00E+00
350	1	175	1.00E+00
400	9.72E-01	200	9.76E-01
450	9.35E-01	225	9.46E-01
		250	9.03E-01

3.6 C64200 / Cu 642 / 91.2 Cu, 7.0 Al, 1.8 Si up to 500°F

Figure 3-18: Comparison of available data; C64200. 1-B: (Table 1B allowable stress*3)/(2 YS at RT)

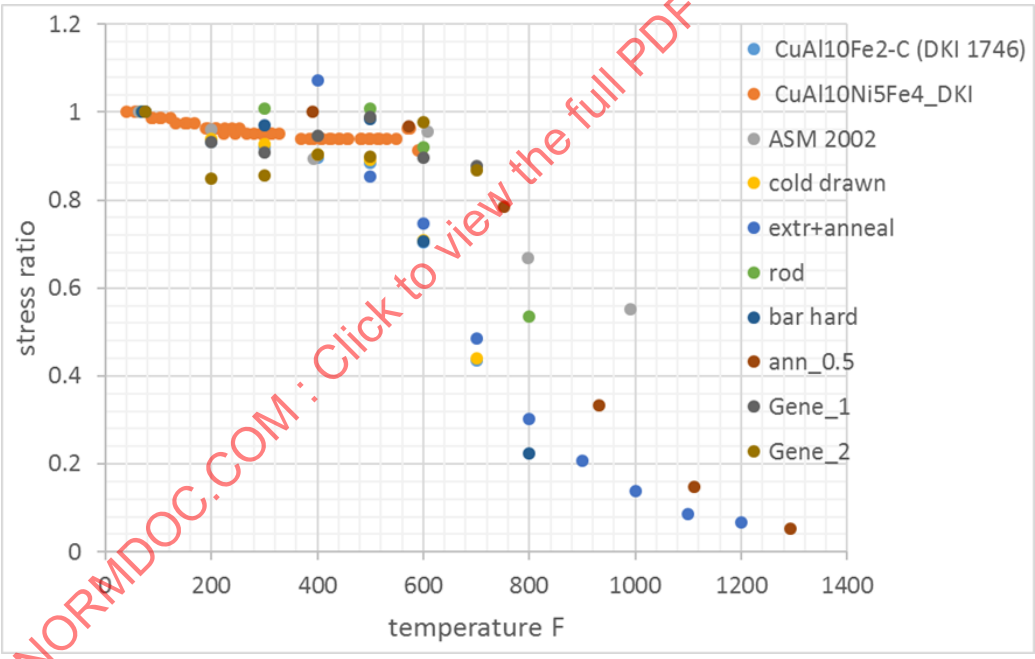


Figure 3-19: Proposed YS stress ratios for C64200

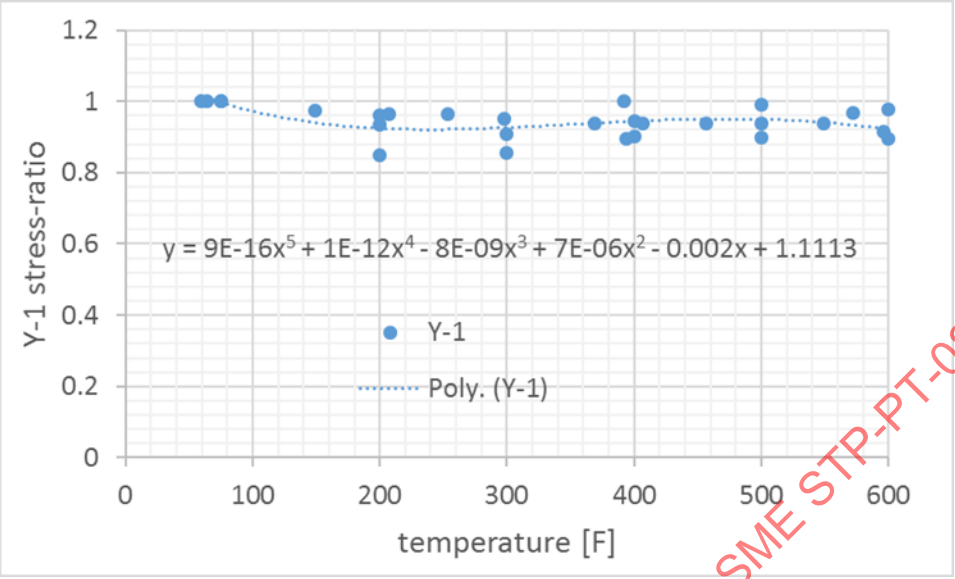


Figure 3-20: Yield strength reduction factors for C64200

	Temp [F]	Y-1	Temp [C]	Y-1
69.8	68	1.004	21	1.002
104	100	0.972	40	0.968
149	150	0.939	65	0.939
212	200	0.924	100	0.922
257	250	0.921	125	0.921
302	300	0.921	150	0.921
347	350	0.921	175	0.921
392	400	0.921	200	0.921
437	450	0.921	225	0.921
482	500	0.921	250	0.921

3.7 C68700 / Cu 687 / 77.5 Cu, 20.5 Zn, 2.0 Al, 0.1 As up to 500°F

Figure 3-21: Comparison of available data for C68700. Y-1: (Table 1B allowable stress*3)/(2 YS at RT)

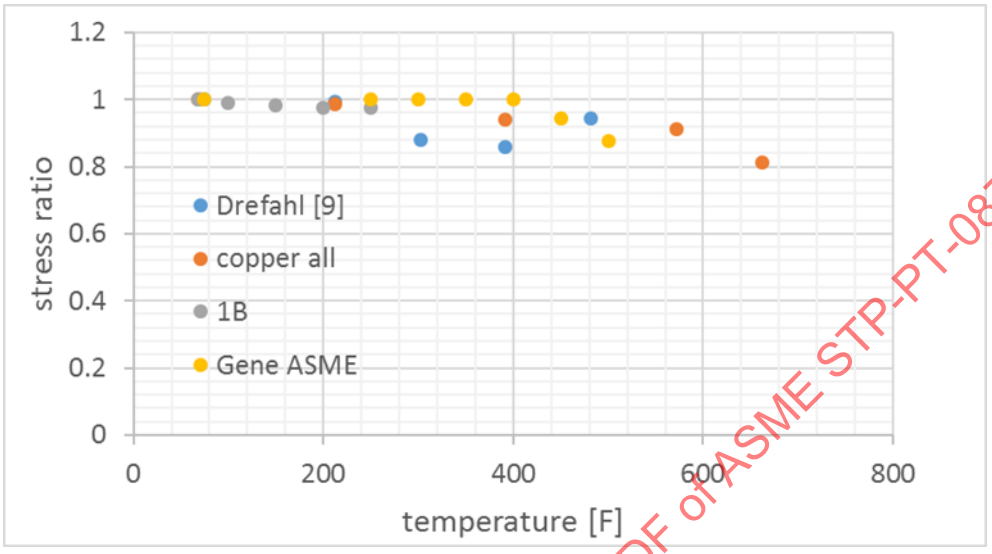


Figure 3-22: Proposed YS stress ratios for C68700

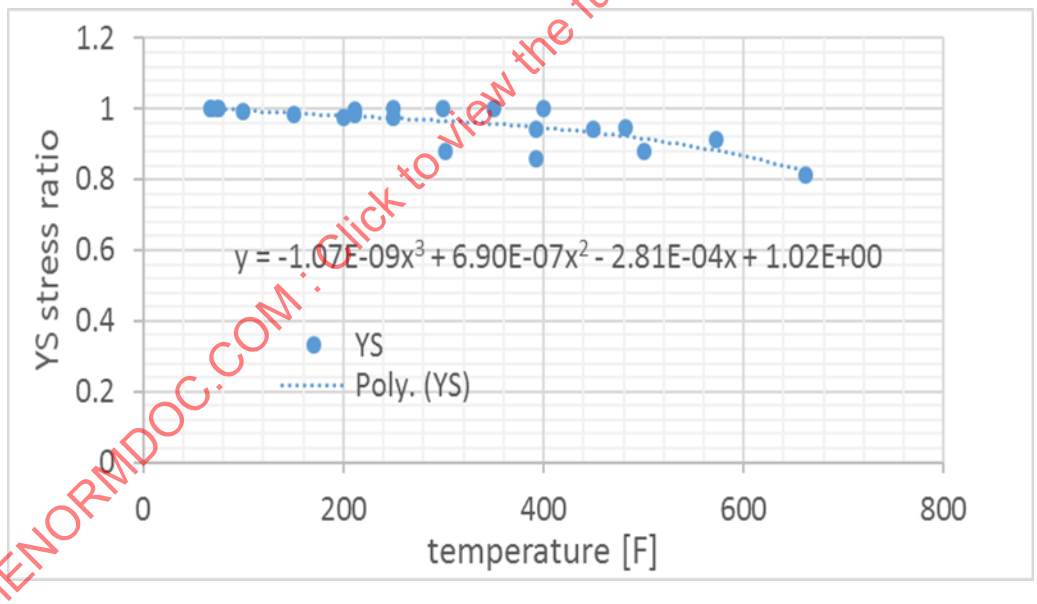


Figure 3-23: Comparison of data for C68700 from Gene Shapiro with the current evaluation. Up to 700°F no differences were found

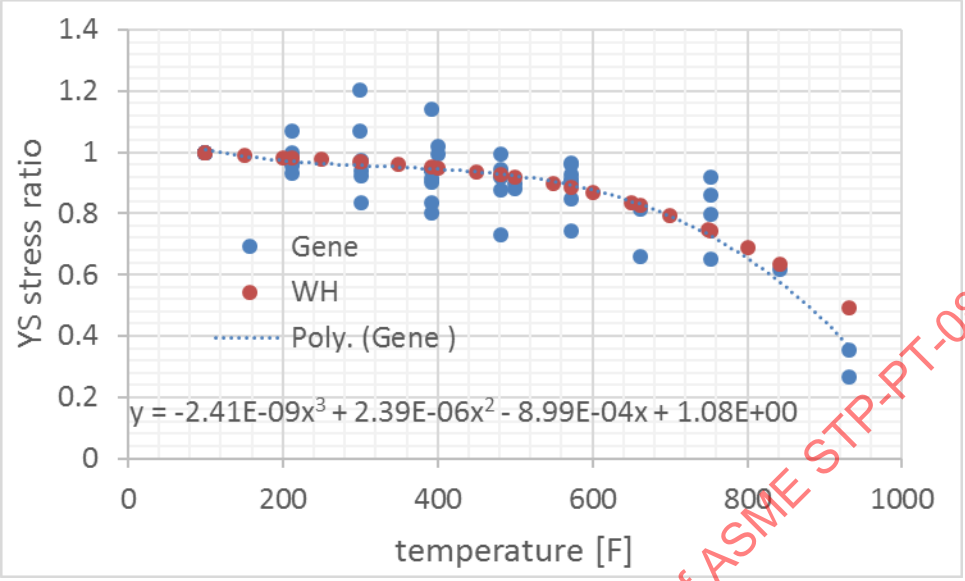


Figure 3-24: Yield strength reduction factors for C68700

Temp [F]	Y-1	Temp [C]	Y-1
68	1.00374612	21	1.00338403
100	0.99773	40	0.99703544
150	0.98976375	65	0.98991018
200	0.98284	100	0.98124426
250	0.97615625	125	0.975194
300	0.96891	150	0.9685971
350	0.96029875	175	0.96086855
400	0.94952	200	0.95142333
450	0.93577125	225	0.93967642
500	0.91825	250	0.92504278
		300	0.88477526

3.8 C70400 / Cu 704 / 92.4 Cu, 5.5 Ni, 1.5 Fe, 0.6 Mn up to 500°F

Figure 3-25: Comparison of available data for C70400

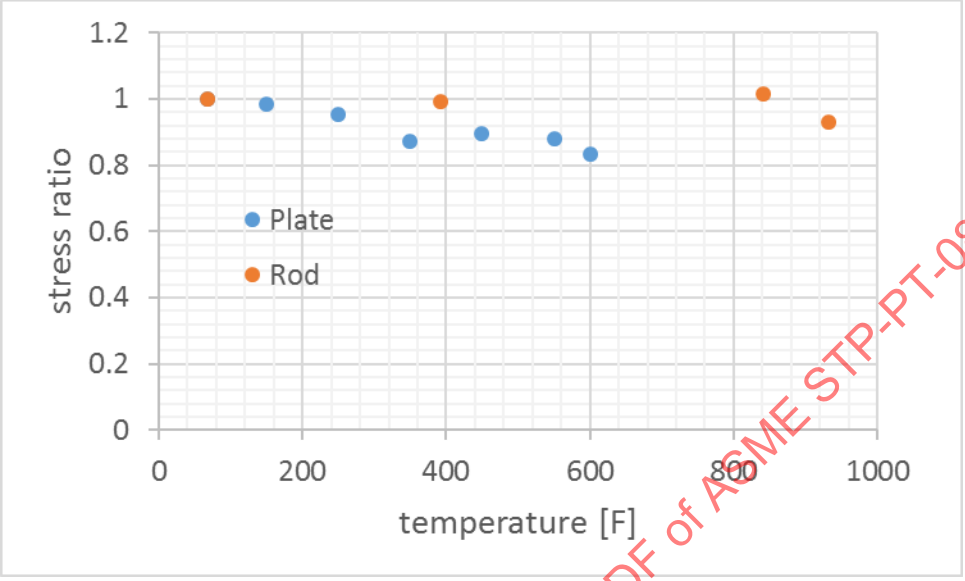


Figure 3-26: Proposed YS stress ratios for C70400

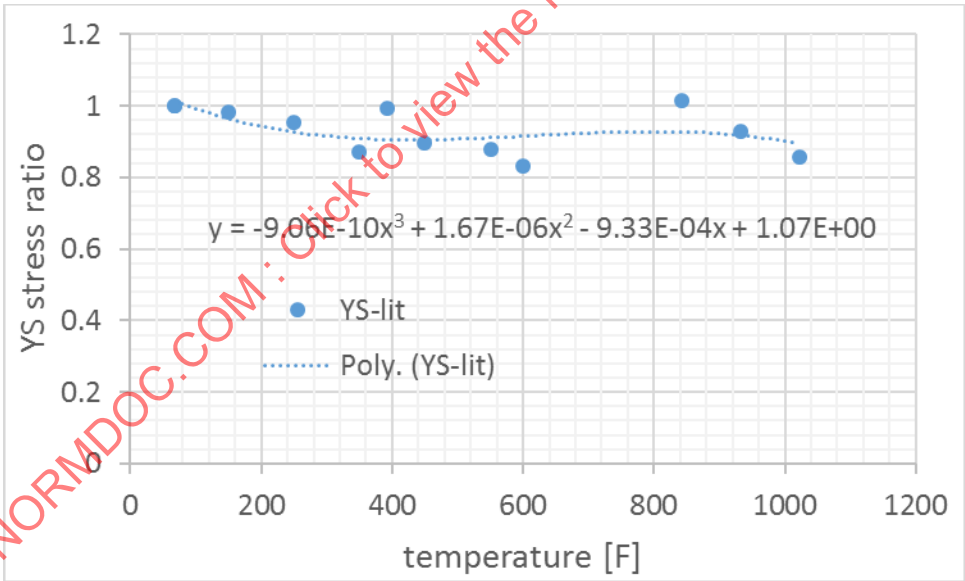


Figure 3-27: Yield strength reduction factors for C70400

Temp [F]	Y-1	Temp [C]	Y-1
68	1.01E+00	21	1.01E+00
100	9.92E-01	40	9.90E-01
150	9.65E-01	65	9.65E-01
200	9.43E-01	100	9.39E-01
250	9.27E-01	125	9.25E-01
300	9.16E-01	150	9.16E-01
350	9.09E-01	175	9.09E-01
400	9.06E-01	200	9.06E-01
450	9.06E-01	225	9.06E-01
500	9.06E-01	250	9.06E-01
		300	9.06E-01

3.9 C71000 / Cu 710 / 79 Cu, 21 Ni up to 700°F

Figure 3-28: Comparison of available data for C71000. 1-B: (Table 1B allowable stress*3)/(2 YS at RT)

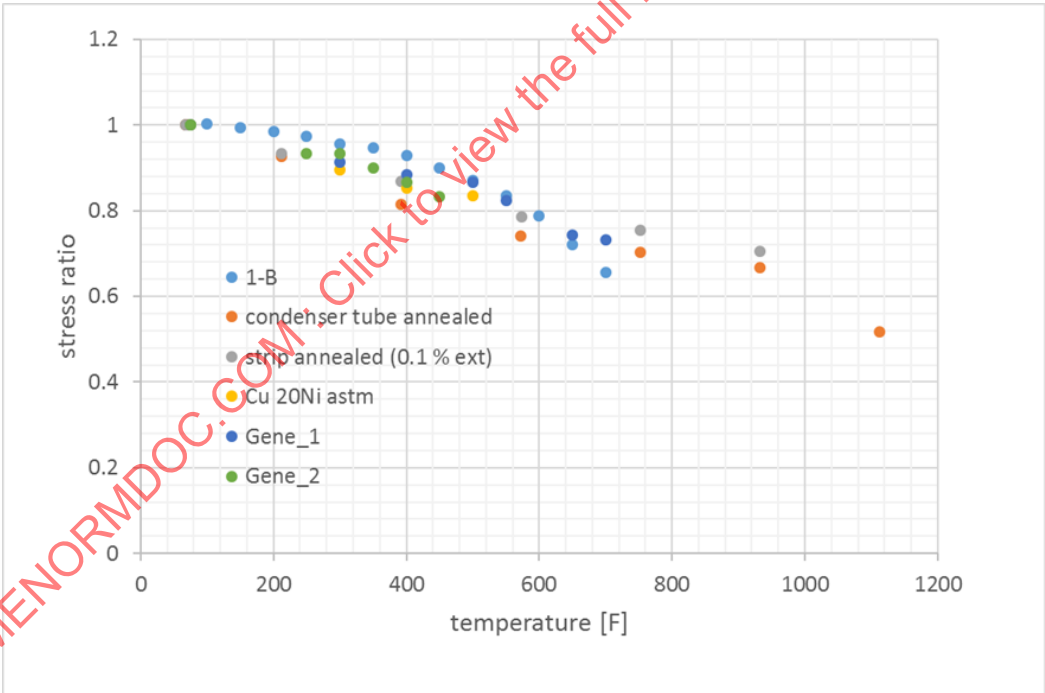


Figure 3-29: Proposed YS stress ratios for C71000

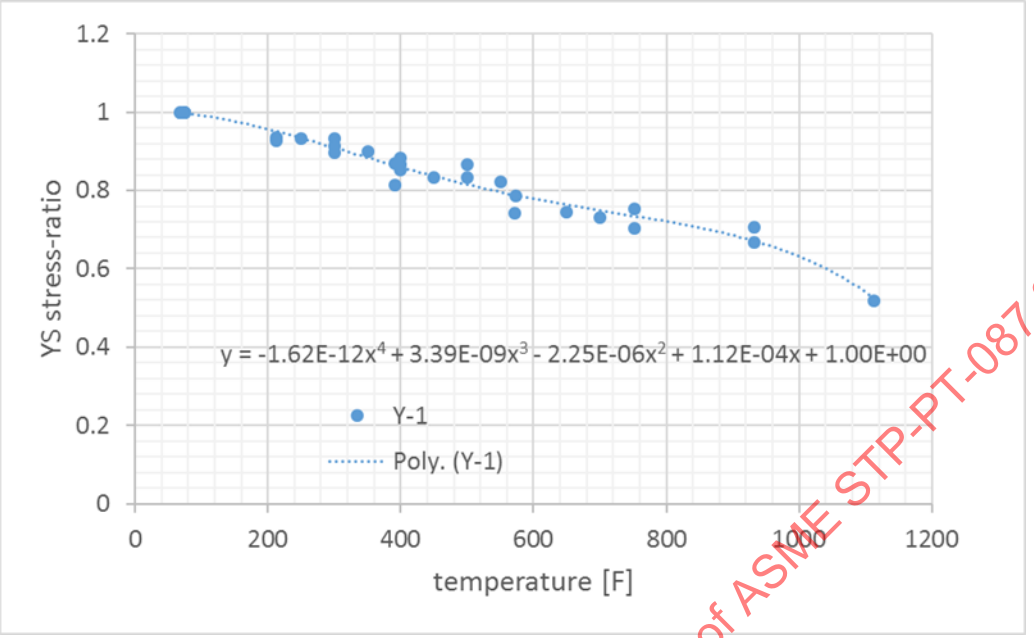


Figure 3-30: Yield strength reduction factors for C71000

Temp [F]	Y-1	Temp [C]	Y-1
68	9.98E-01	21	9.98E-01
100	9.92E-01	40	9.91E-01
150	9.77E-01	65	9.77E-01
200	9.57E-01	100	9.52E-01
250	9.34E-01	125	9.31E-01
300	9.10E-01	150	9.09E-01
350	8.85E-01	175	8.86E-01
400	8.60E-01	200	8.64E-01
450	8.37E-01	225	8.43E-01
500	8.16E-01	250	8.23E-01
550	7.97E-01	300	7.89E-01
600	7.79E-01	350	7.60E-01
650	7.64E-01	400	7.35E-01
700	7.50E-01	450	7.09E-01

4 NICKEL

4.1 N02201 / Ni 201 up to 1200°F

Figure 4-1: Comparison of available data for N02201. Y-1: Taken from Table IID Y-1

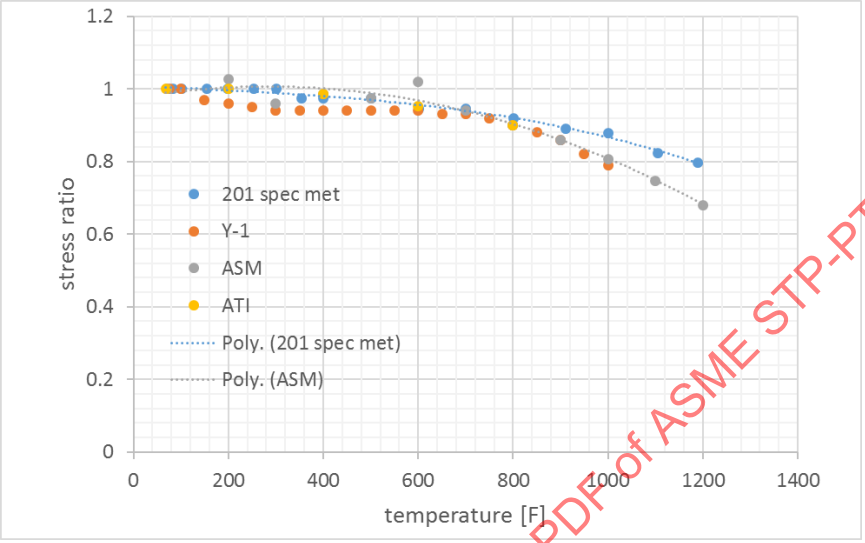


Figure 4-2: Proposed YS stress ratios for N02201

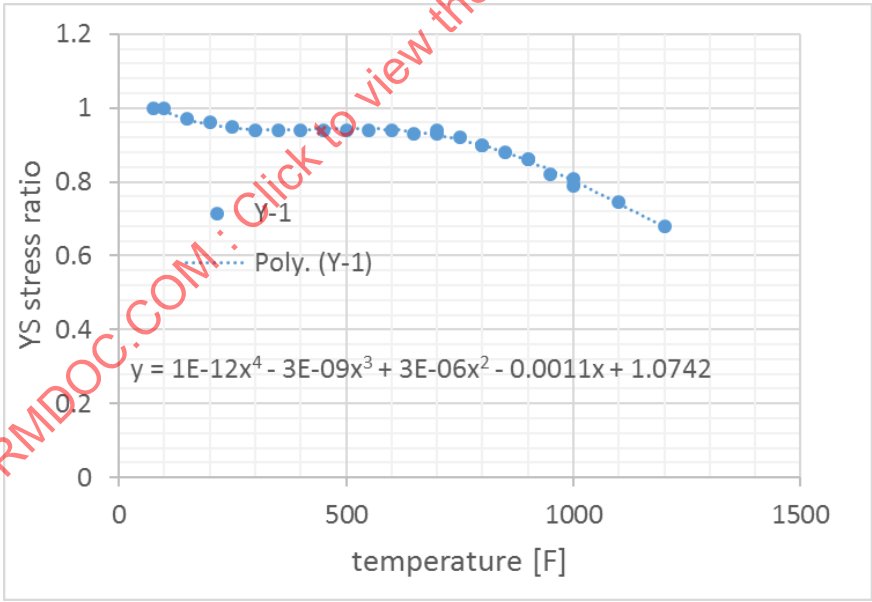
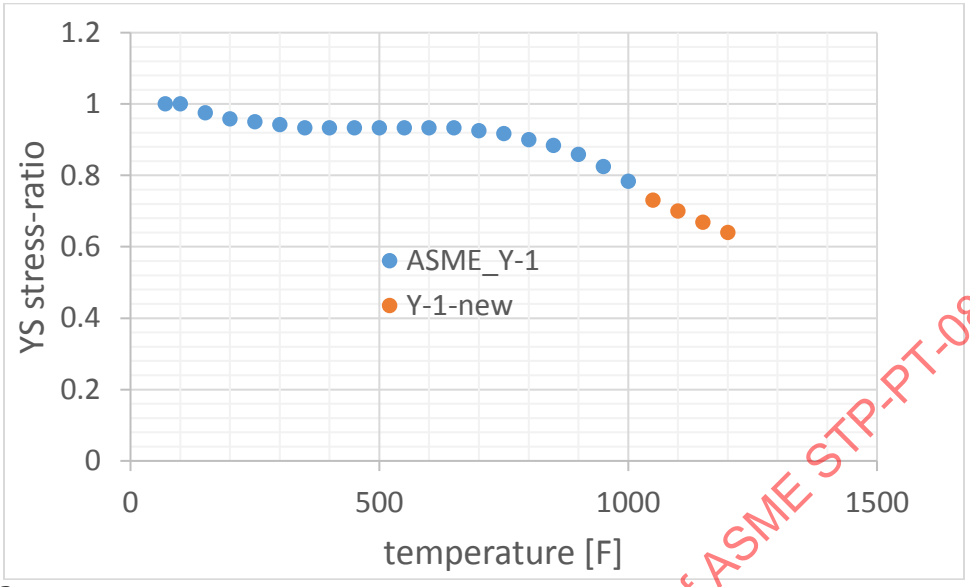


Figure 4-3: Plot of proposed customary YS stress reduction factors for N02201 using 1.03 instead of 1.07 in the polynomial



Fixed at 1.03.

Figure 4-4: Plot of proposed metric YS stress reduction factors for N02201 using 1.03 instead of 1.07 in the polynomial

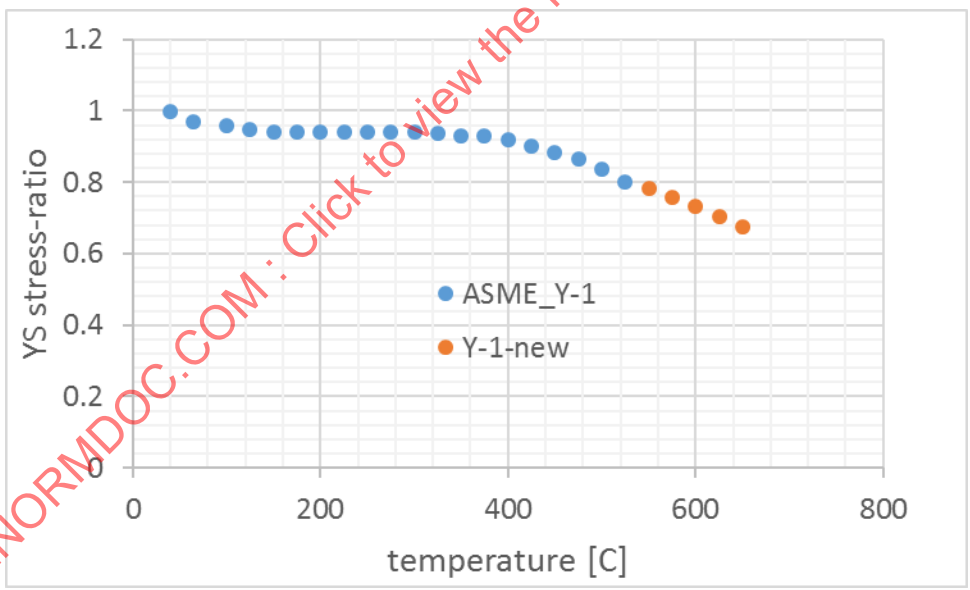


Figure 4-5: Yield strength reduction factors for N02201 using 1.03 instead of 1.07 in the polynomial

Temperature[F]	ASME_Y-1	Y-1-new		Temperature[C]	ASME_Y-1	Y-1-new
70	1.000			40	0.999	
100	1.000			65	0.970	
150	0.975			100	0.958	
200	0.958			125	0.948	
250	0.950			150	0.939	
300	0.942			175	0.939	
350	0.933			200	0.939	
400	0.933			225	0.939	
450	0.933			250	0.939	
500	0.933			275	0.939	
550	0.933			300	0.939	
600	0.933			325	0.936	
650	0.933			350	0.929	
700	0.925			375	0.929	
750	0.917			400	0.919	
800	0.900			425	0.900	
850	0.883			450	0.883	
900	0.858			475	0.867	
950	0.825			500	0.835	
1000	0.783			525	0.801	
1050		0.730		550		0.784
1100		0.700		575		0.758
1150		0.669		600		0.731
1200		0.639		625		0.704
				650		0.676

4.2 N06002 / Ni X up to 1650°F

Figure 4-6: Comparison of available data for N06002. Y-1 Hast X: Table IID Y-1 values

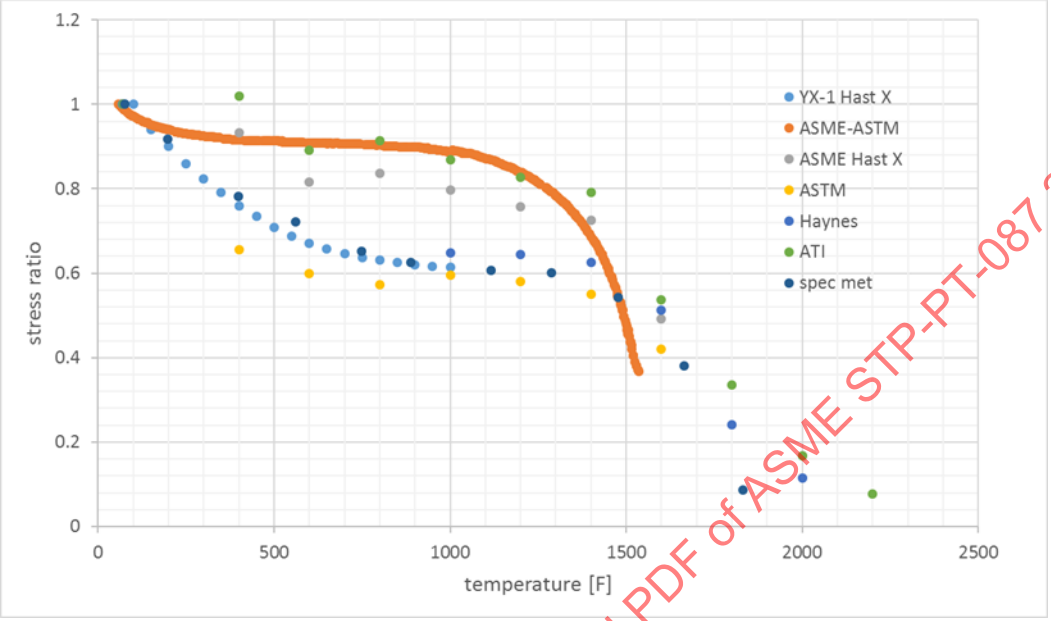


Figure 4-7: Proposed YS stress ratios for N06002

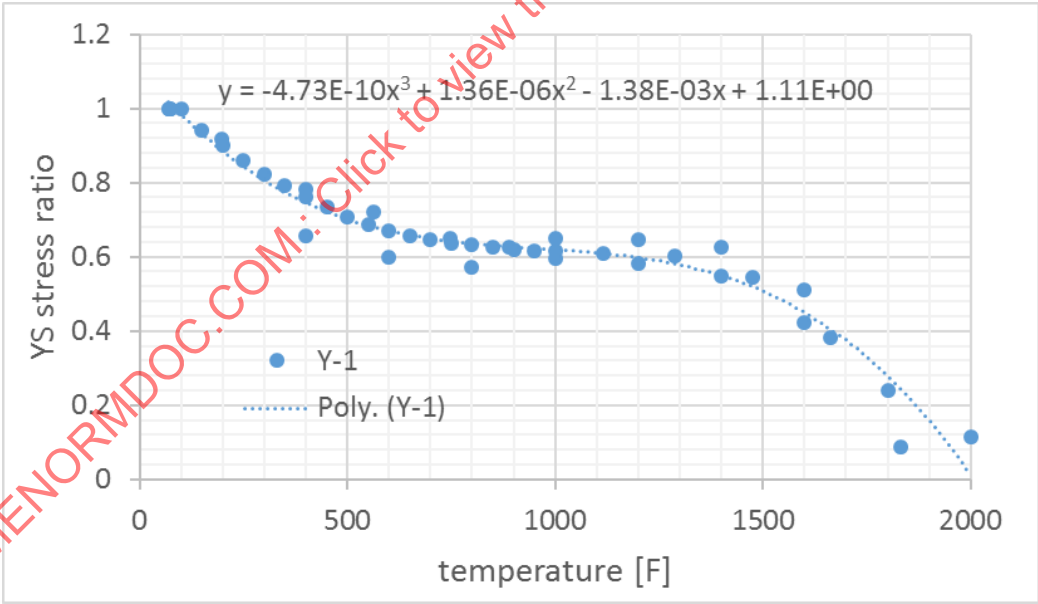


Figure 4-8: Plot of proposed customary YS stress reduction factors for N06002

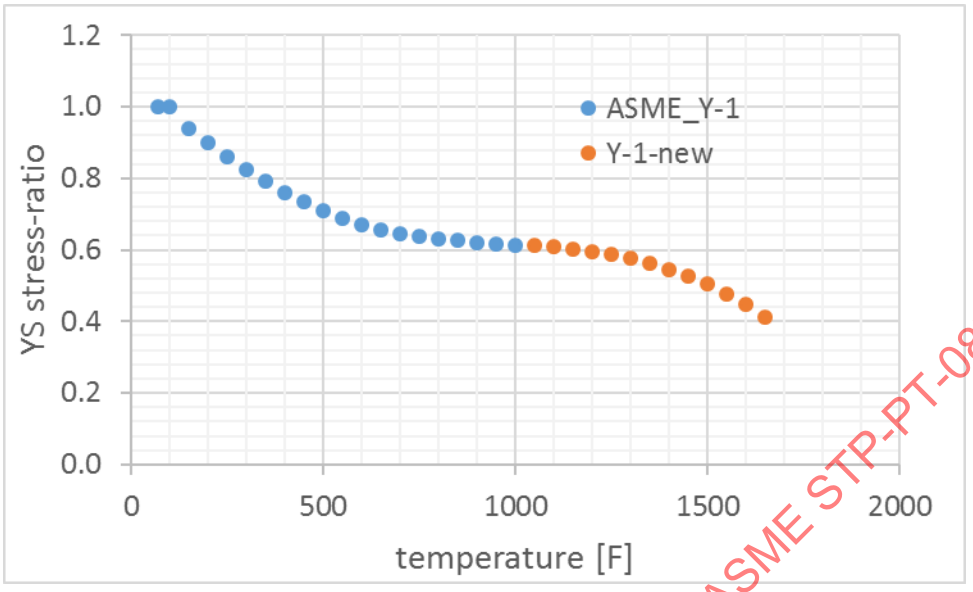


Figure 4-9: Plot of proposed metric YS stress reduction factors for N06002

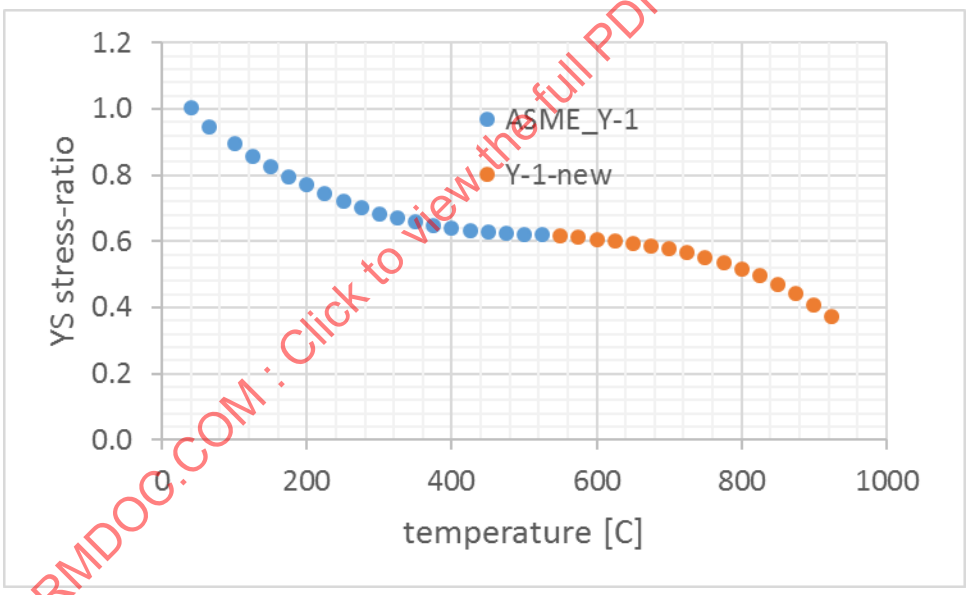


Figure 4-10: Yield strength reduction factors for N06002

Temperature [F]	ASME_Y-1	Y-1-new		Temperature [C]	ASME_Y-1	Y-1-new
70	1.000			40	1.004	
100	1.000			65	0.946	
150	0.940			100	0.896	
200	0.900			125	0.858	
250	0.860			150	0.825	
300	0.823			175	0.796	
350	0.791			200	0.771	
400	0.760			225	0.746	
450	0.734			250	0.721	
500	0.709			275	0.700	
550	0.689			300	0.683	
600	0.671			325	0.671	
650	0.657			350	0.658	
700	0.646			375	0.646	
750	0.637			400	0.642	
800	0.631			425	0.633	
850	0.626			450	0.629	
900	0.620			475	0.625	
950	0.617			500	0.621	
1000	0.614			525	0.621	
1050		0.613		550		0.615
1100		0.608		575		0.611
1150		0.602		600		0.607
1200		0.595		625		0.601
1250		0.586		650		0.595
1300		0.575		675		0.587
1350		0.562		700		0.577
1400		0.546		725		0.566
1450		0.526		750		0.552
1500		0.504		775		0.536
1550		0.477		800		0.517
1600		0.446		825		0.495
1650		0.411		850		0.470
				875		0.442
				900		0.409
				925		0.373

4.3 N06022 up to 1250°F

Figure 4-11: Comparison of available data for N06022. Y-1: Taken from Table IID Y-1

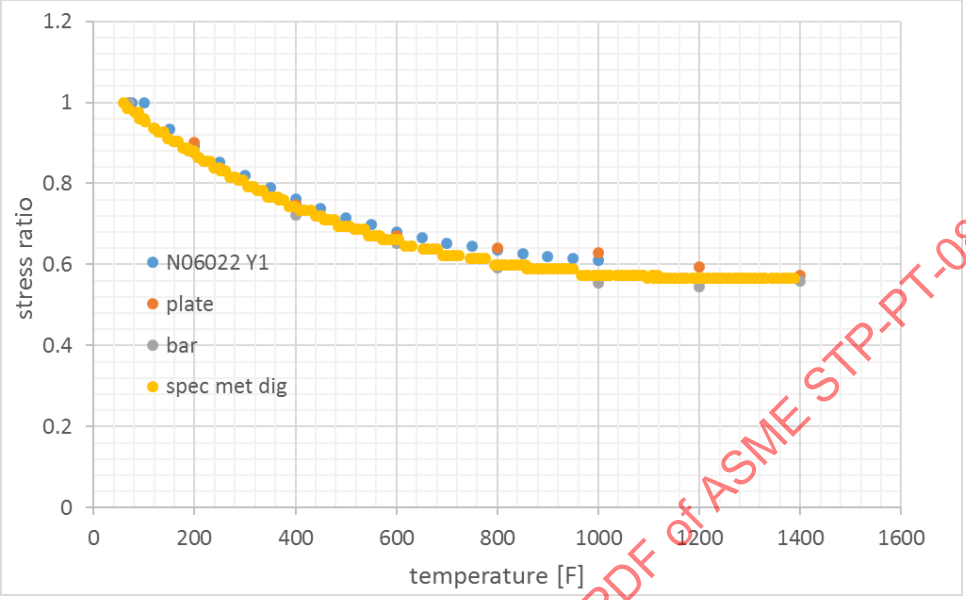


Figure 4-12: Proposed YS stress ratios for N06022

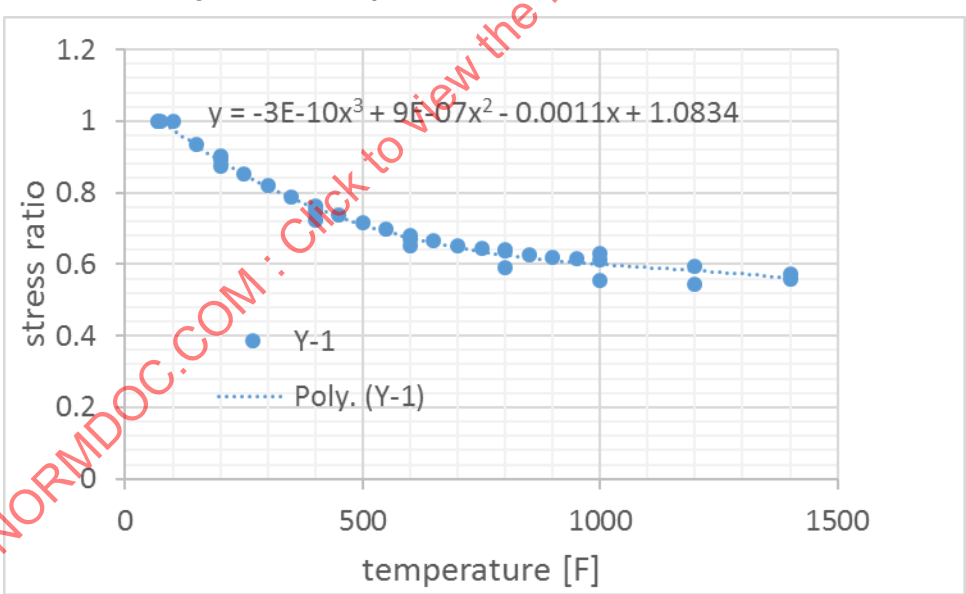


Figure 4-13: Plot of proposed customary YS stress reduction factors for N06022 using 1.09 instead of 1.0834 in the polynomial

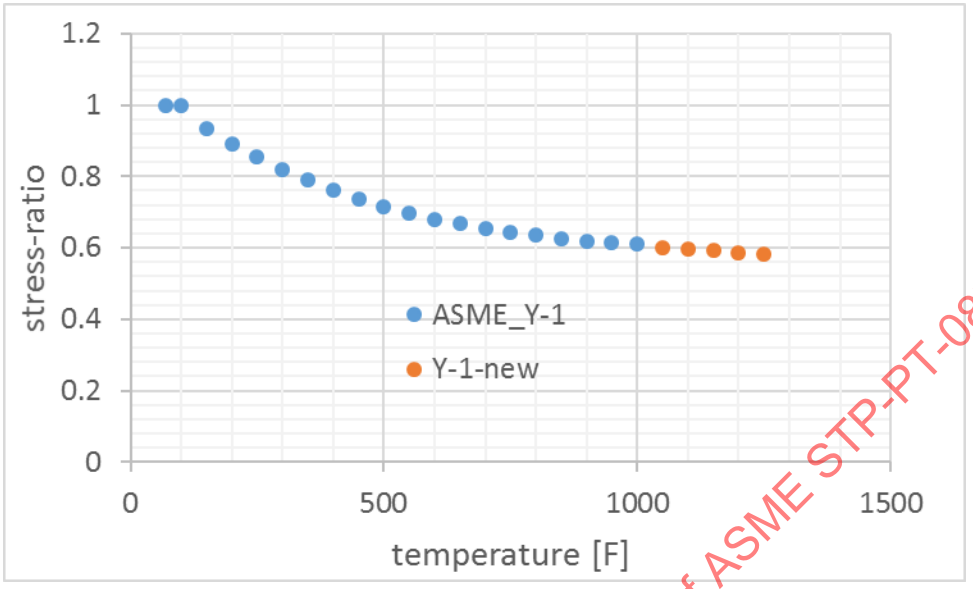


Figure 4-14: Plot of proposed metric YS stress reduction factors for N06022 using 1.09 instead of 1.0834 in the polynomial

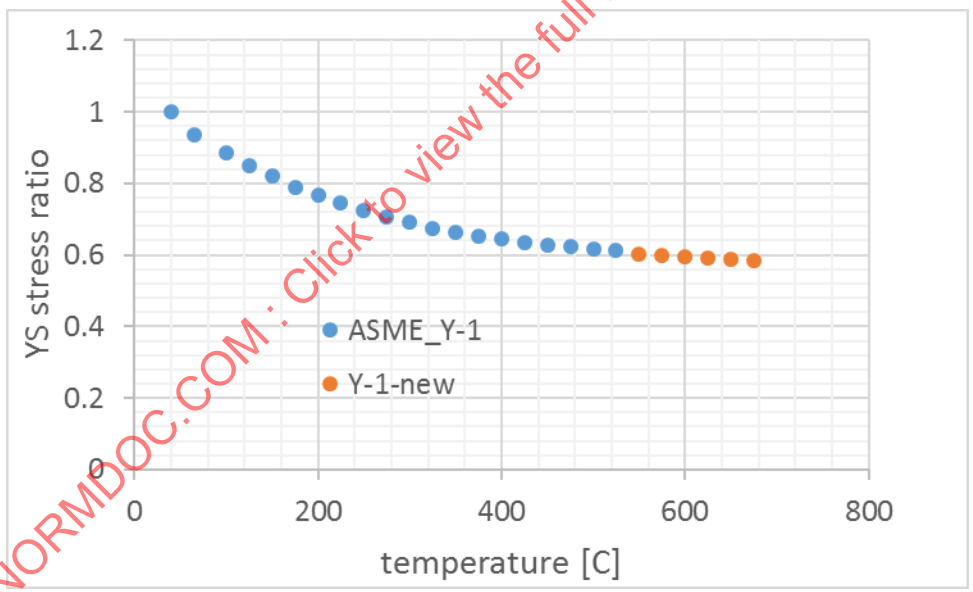
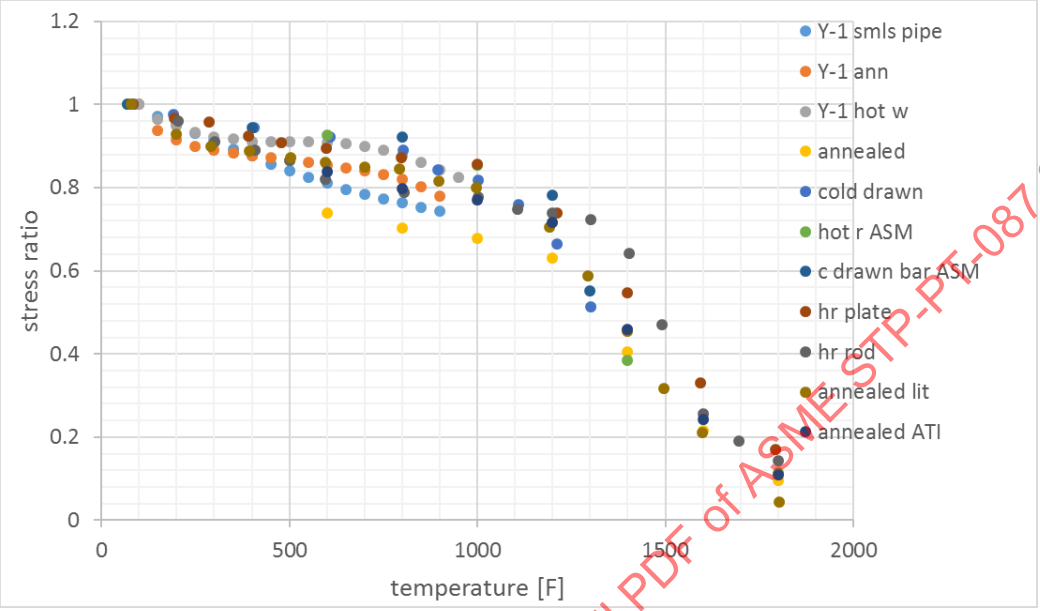


Figure 4-15: Yield strength reduction factors for N06022 using 1.09 instead of 1.0834 in the polynomial

Temperature[F]	ASME_Y-1	Y-1-new		Temperature[C]	ASME_Y-1	Y-1-new
70	1.000			40	1.000	
100	1.000			65	0.935	
150	0.933			100	0.884	
200	0.891			125	0.848	
250	0.853			150	0.819	
300	0.820			175	0.790	
350	0.789			200	0.768	
400	0.762			225	0.745	
450	0.738			250	0.723	
500	0.716			275	0.706	
550	0.698			300	0.690	
600	0.680			325	0.674	
650	0.667			350	0.665	
700	0.653			375	0.652	
750	0.644			400	0.645	
800	0.636			425	0.635	
850	0.627			450	0.629	
900	0.620			475	0.623	
950	0.616			500	0.616	
1000	0.611			525	0.613	
1050		0.600		550		0.603
1100		0.596		575		0.599
1150		0.592		600		0.595
1200		0.588		625		0.591
1250		0.583		650		0.587
				675		0.583

4.4 N06600 / Ni 600 up to 1200°F

Figure 4-16: Comparison of available data for N06600. Several Y-1 values were taken from Table IID Y-1



4.5 Annealed

Figure 4-17: Proposed YS stress ratios for N06600 annealed

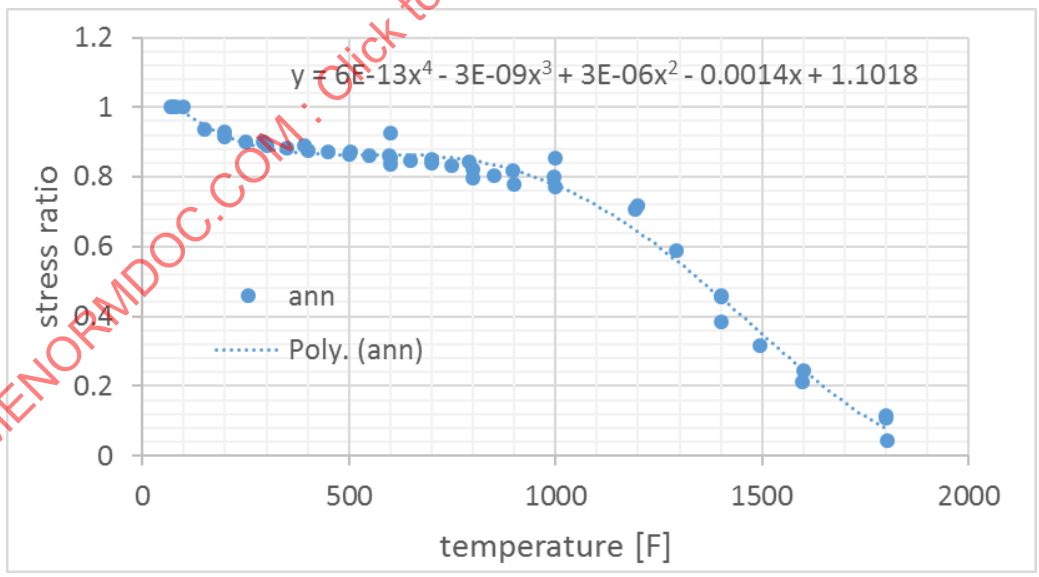


Figure 4-18: Plot of proposed customary YS stress reduction factors for N06600 annealed using 1.05 instead of 1.10 in the polynomial

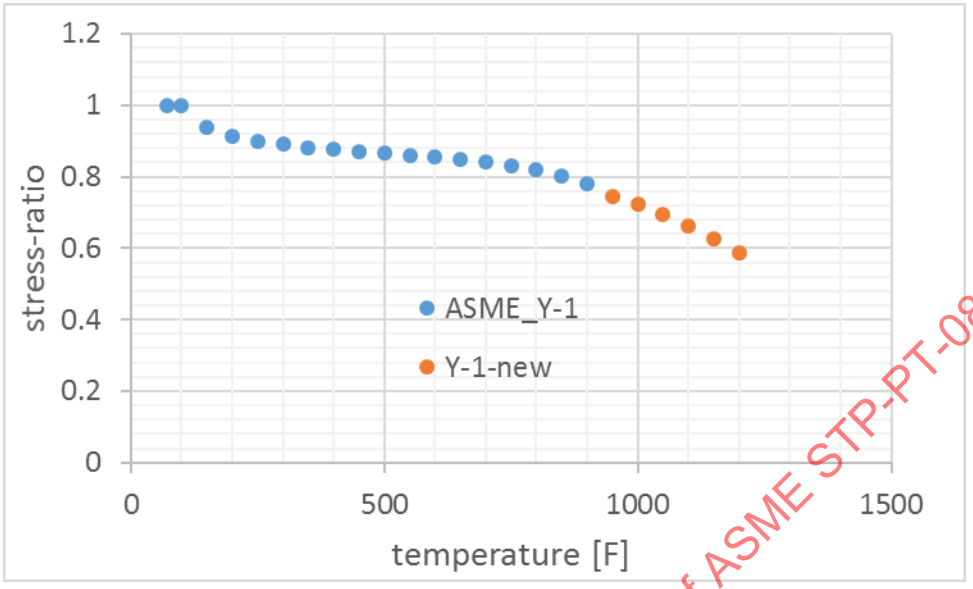


Figure 4-19: Plot of proposed metric YS stress reduction factors for N06600 annealed using 1.05 instead of 1.10 in the polynomial

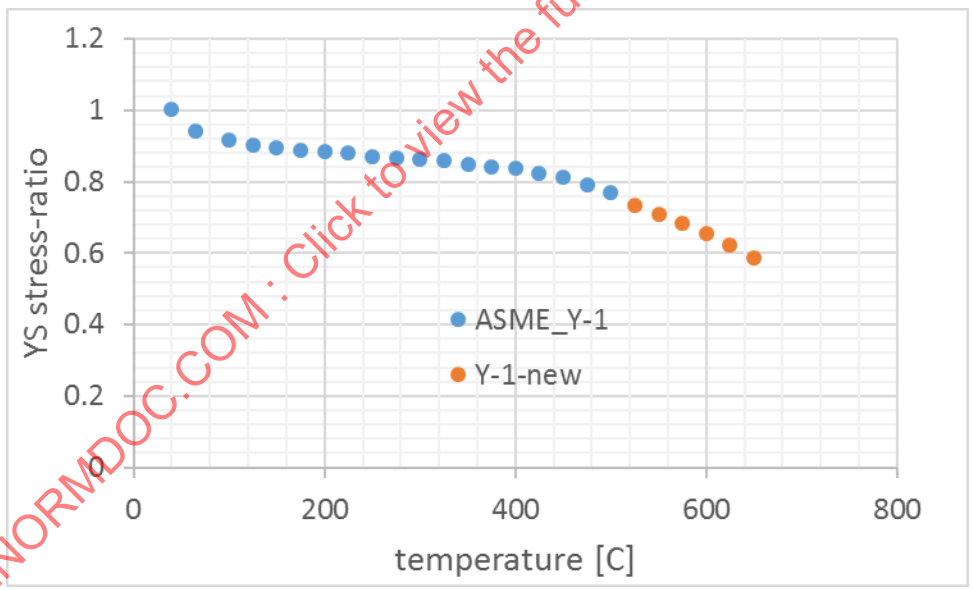


Figure 4-20: Yield strength reduction factors for N06600 annealed using 1.05 instead of 1.1 in the polynomial

Temperature [F]	ASME_Y-1	Y-1-new		Temperature [C]	ASME_Y-1	Y-1-new
70	1.000			40	1.004	
100	1.000			65	0.942	
150	0.937			100	0.917	
200	0.914			125	0.904	
250	0.900			150	0.896	
300	0.891			175	0.888	
350	0.883			200	0.883	
400	0.877			225	0.879	
450	0.871			250	0.871	
500	0.866			275	0.867	
550	0.860			300	0.863	
600	0.854			325	0.858	
650	0.849			350	0.850	
700	0.840			375	0.842	
750	0.831			400	0.838	
800	0.820			425	0.825	
850	0.803			450	0.813	
900	0.780			475	0.792	
950		0.746		500	0.771	
1000		0.722		525		0.733
1050		0.694		550		0.710
1100		0.662		575		0.684
1150		0.627		600		0.654
1200		0.587		625		0.621
				650		0.585

4.6 Hot Worked

Figure 4-21: Proposed YS stress ratios for N06600 hot worked

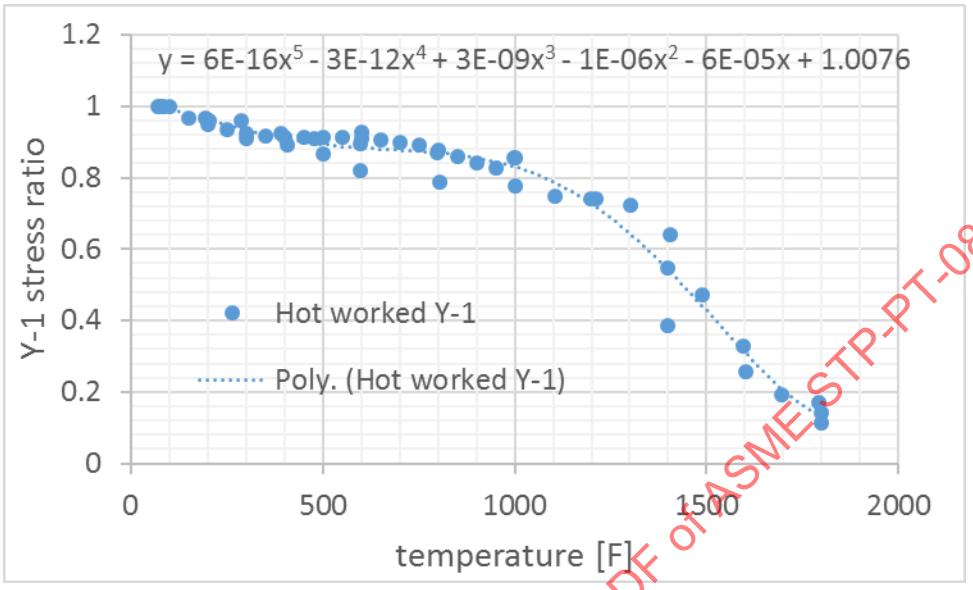


Figure 4-22: Plot of proposed customary YS stress reduction factors for N06600 hot worked using 0.98 instead of 1.0078 in the polynomial

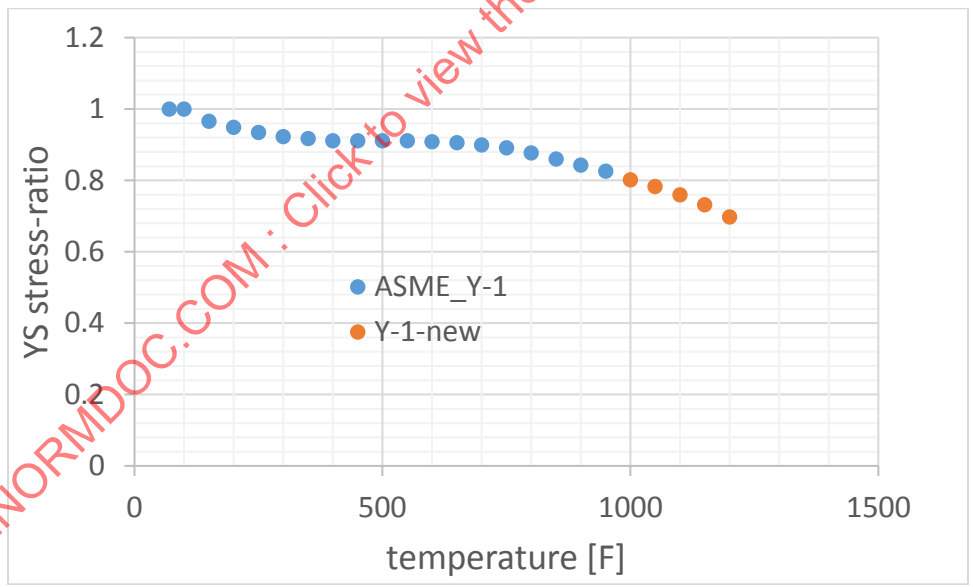


Figure 4-23: Plot of proposed metric YS stress reduction factors for N06600 hot worked using 0.98 instead of 1.0078 in the polynomial

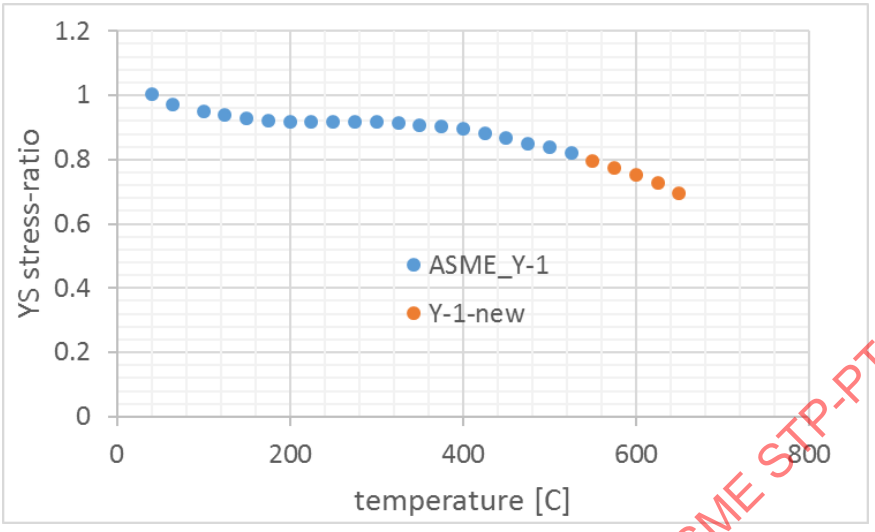


Figure 4-24: Yield strength reduction factors for N06600 hot worked using 0.98 instead of 1.0078 in the polynomial

Temperature [F]	ASME_Y-1	Y-1-new		Temperature [C]	ASME_Y-1	Y-1-new
70	1.000			40	1.004	
100	1.000			65	0.971	
150	0.966			100	0.950	
200	0.949			125	0.938	
250	0.934			150	0.929	
300	0.923			175	0.921	
350	0.917			200	0.917	
400	0.911			225	0.917	
450	0.911			250	0.917	
500	0.911			275	0.917	
550	0.911			300	0.917	
600	0.909			325	0.913	
650	0.906			350	0.908	
700	0.900			375	0.904	
750	0.891			400	0.896	
800	0.877			425	0.883	
850	0.860			450	0.867	
900	0.843			475	0.850	
950	0.826			500	0.838	
1000		0.802		525	0.821	
1050		0.783		550		0.794
1100		0.760		575		0.776
1150		0.732		600		0.754
1200		0.698		625		0.727
				650		0.697

4.7 Seamless Pipe

Figure 4-25: Proposed YS stress ratios for N06600 seamless pipe

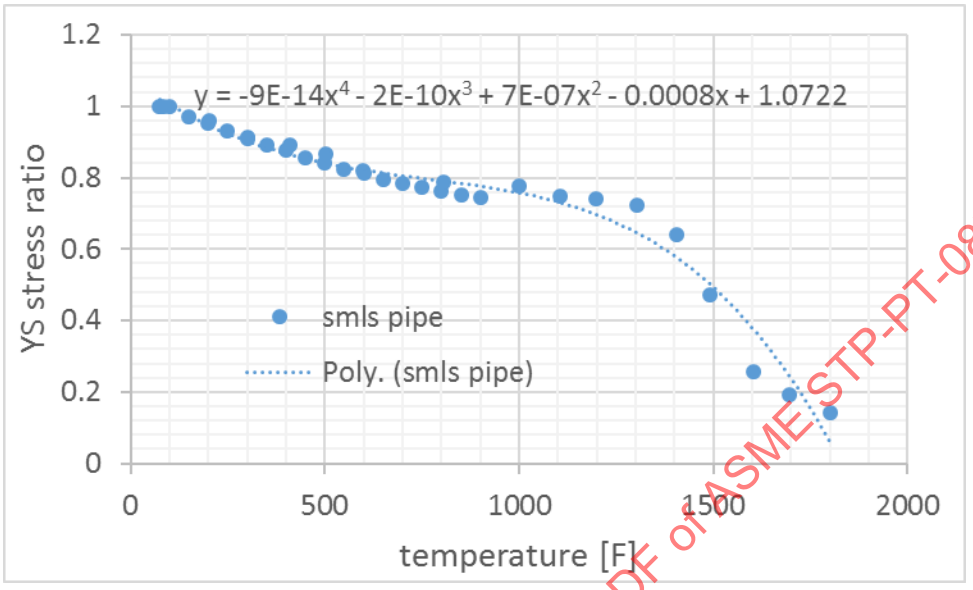


Figure 4-26: Plot of proposed customary YS stress reduction factors for N06600 seamless pipe using 1.045 instead of 1.07 in the polynomial

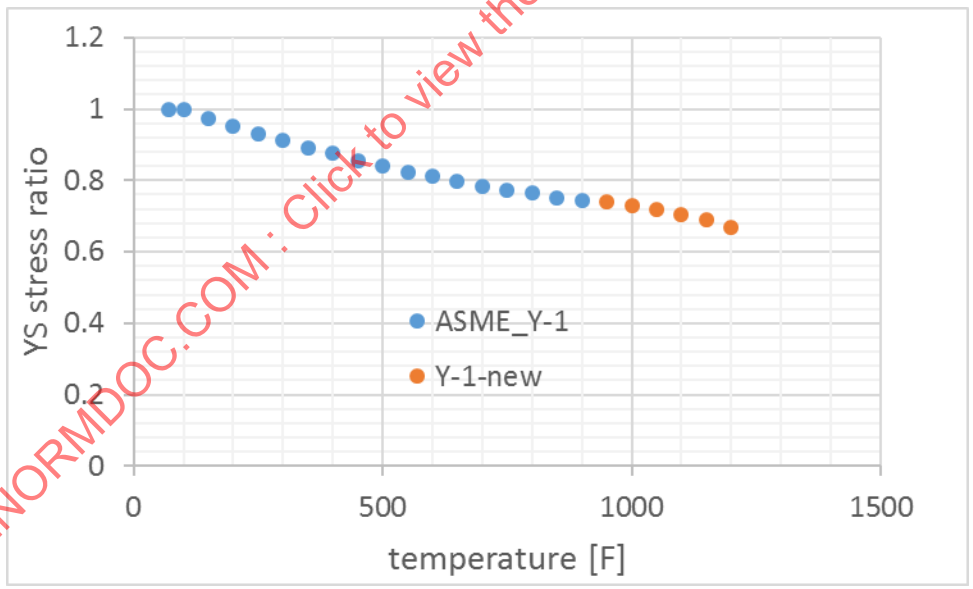


Figure 4-27: Plot of proposed metric YS stress reduction factors for N06600 seamless pipe using 1.045 instead of 1.07 in the polynomial

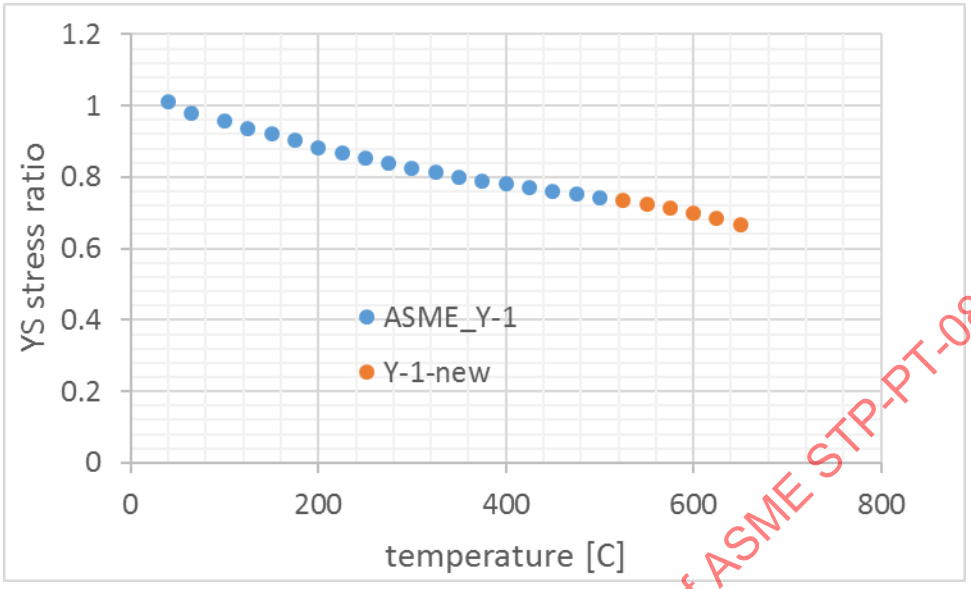


Figure 4-28: Yield strength reduction factors for N06600 seamless pipe using 1.045 instead of 1.07 in the polynomial

Temperature[F]	ASME_Y-1	Y-1-new		Temperature[C]	ASME_Y-1	Y-1-new
70	1			40	1.0097561	
100	1			65	0.9804878	
150	0.972			100	0.95609756	
200	0.952			125	0.93658537	
250	0.932			150	0.92195122	
300	0.912			175	0.90243902	
350	0.892			200	0.88292683	
400	0.876			225	0.86829268	
450	0.856			250	0.85365854	
500	0.84			275	0.83902439	
550	0.824			300	0.82439024	
600	0.812			325	0.81463415	
650	0.796			350	0.8	
700	0.784			375	0.7902439	
750	0.772			400	0.7804878	
800	0.764			425	0.77073171	
850	0.752			450	0.76097561	
900	0.744			475	0.75121951	
950		7.40E-01		500	0.74146341	
1000		7.30E-01		525		7.35E-01
1050		7.18E-01		550		7.25E-01
1100		7.05E-01		575		7.14E-01
1150		6.88E-01		600		7.01E-01
1200		6.69E-01		625		6.86E-01
				650		6.68E-01

4.8 N06625 / Ni 625 SA up to 1600°F

Figure 4-29: Comparison of available data for N06625 (sol annealed). Y-1 sol ann values were taken from Table IID Y-1

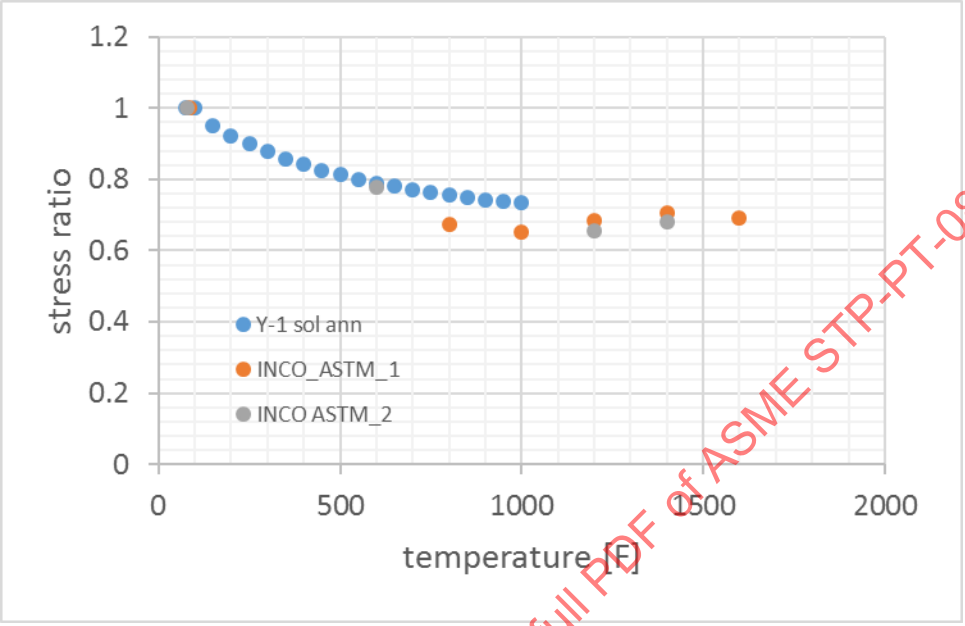


Figure 4-30: Proposed YS stress ratios for N06625 solution annealed

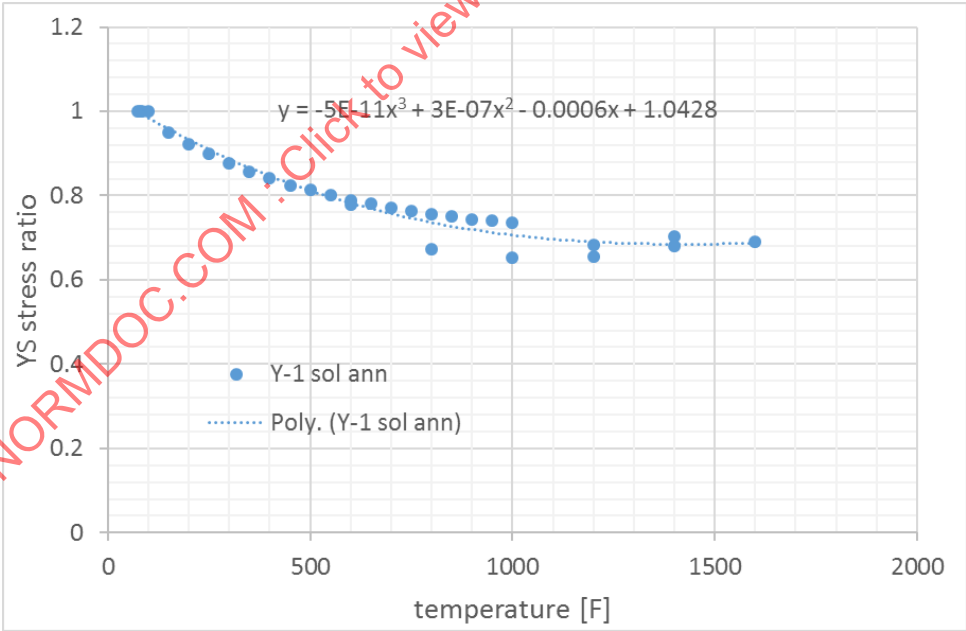


Figure 4-31: Plot of proposed customary YS stress reduction factors for N06625 solution annealed using 1.07 instead of 1.04 in the polynomial

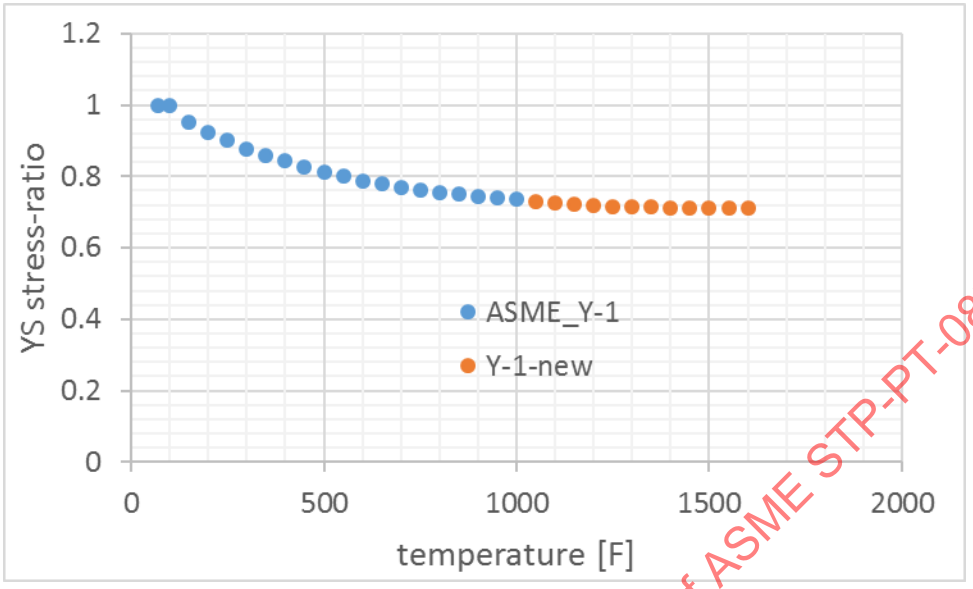


Figure 4-32: Plot of proposed metric YS stress reduction factors for N06625 solution annealed using 1.07 instead of 1.04 in the polynomial

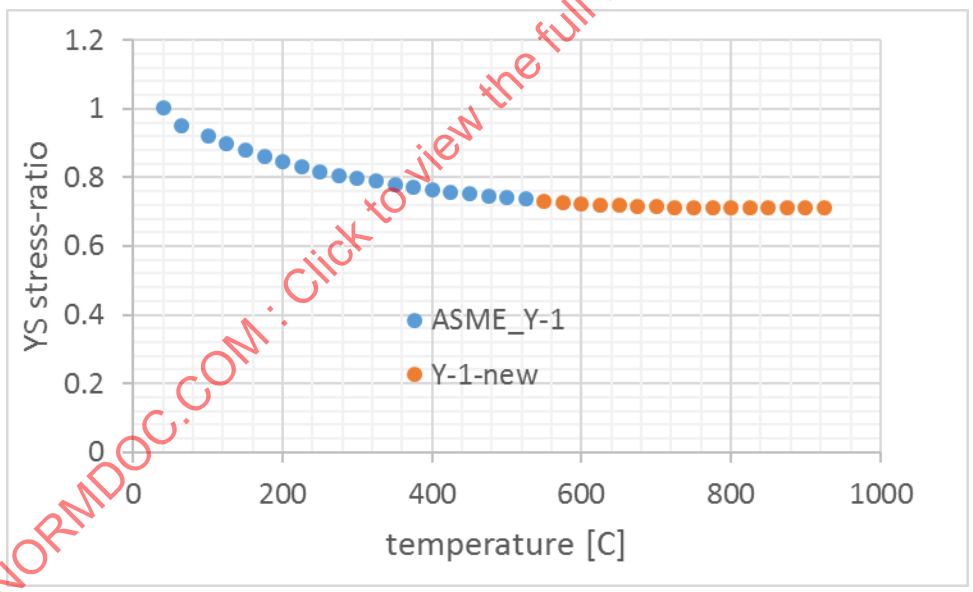


Figure 4-33: Yield strength reduction factors for N06625 solution annealed using 1.07 instead of 1.04 in the polynomial

Temperature [F]	ASME_Y-1	Y-1-new		Temperature[C]	ASME_Y-1	Y-1-new
70	1			40	1.00363636	
100	1			65	0.95272727	
150	0.95			100	0.92	
200	0.9225			125	0.89818182	
250	0.9			150	0.88	
300	0.8775			175	0.86181818	
350	0.8575			200	0.84727273	
400	0.8425			225	0.83272727	
450	0.825			250	0.81818182	
500	0.8125			275	0.80727273	
550	0.8			300	0.79636364	
600	0.7875			325	0.78909091	
650	0.78			350	0.77818182	
700	0.77			375	0.77090909	
750	0.7625			400	0.76363636	
800	0.755			425	0.75636364	
850	0.75			450	0.75272727	
900	0.7425			475	0.74545455	
950	0.74			500	0.74181818	
1000	0.735			525	0.73818182	
1050		7.29E-01		550		7.32E-01
1100		7.25E-01		575		7.28E-01
1150		7.21E-01		600		7.24E-01
1200		7.18E-01		625		7.21E-01
1250		7.16E-01		650		7.18E-01
1300		7.14E-01		675		7.16E-01
1350		7.13E-01		700		7.15E-01
1400		7.13E-01		725		7.14E-01
1450		7.13E-01		750		7.13E-01
1500		7.13E-01		775		7.13E-01
1550		7.13E-01		800		7.13E-01
1600		7.13E-01		825		7.13E-01
				850		7.13E-01
				875		7.13E-01
				900		7.13E-01
				925		7.13E-01

4.9 N06625 / Ni 625 Ann up to 1200°F

Figure 4-34: Comparison of available data for N06625 (annealed). Y-1 ann values were taken from Table IID Y-1

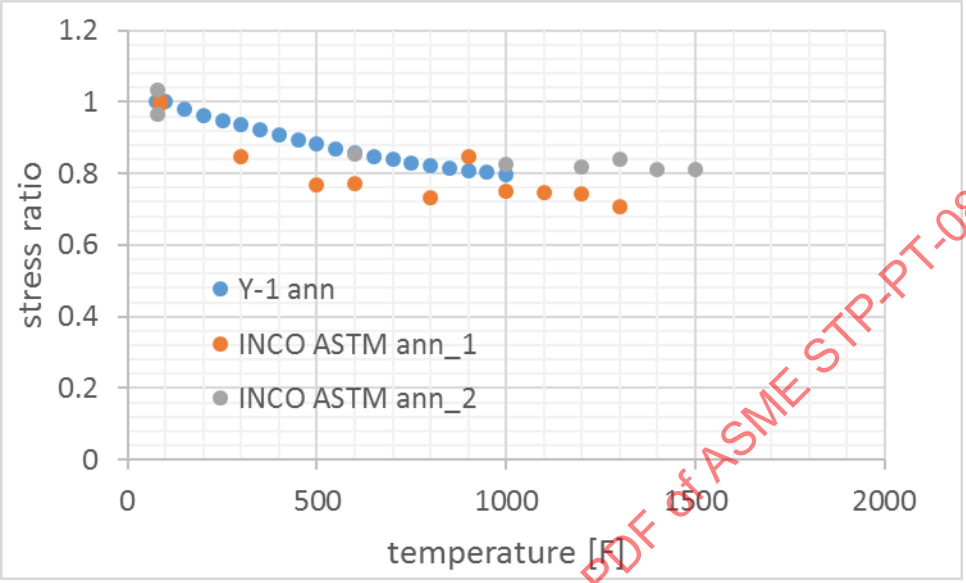


Figure 4-35: Proposed YS stress ratios for N06625 annealed

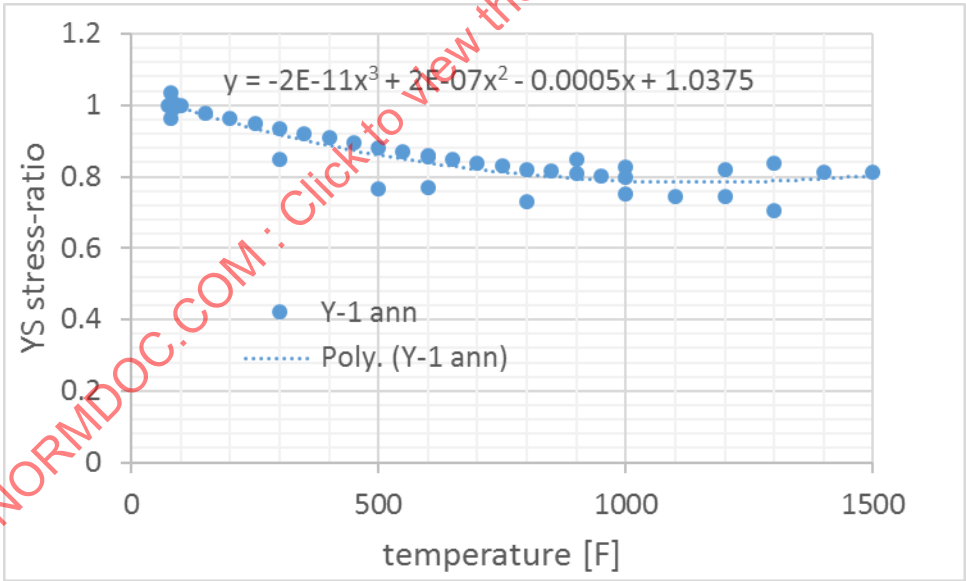


Figure 4-36: Plot of proposed customary YS stress reduction factors for N06625 annealed

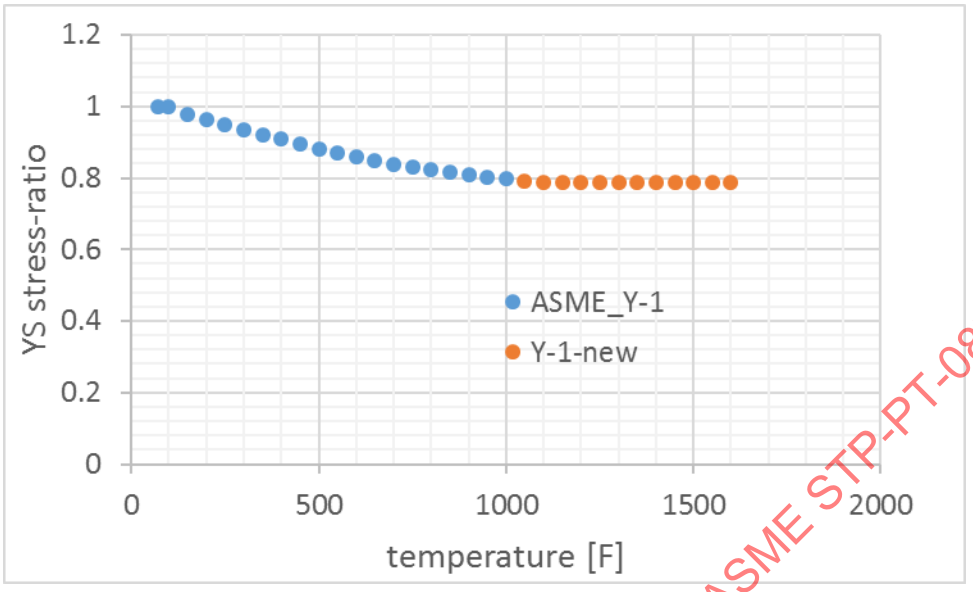


Figure 4-37: Plot of proposed metric YS stress reduction factors for N06625 annealed

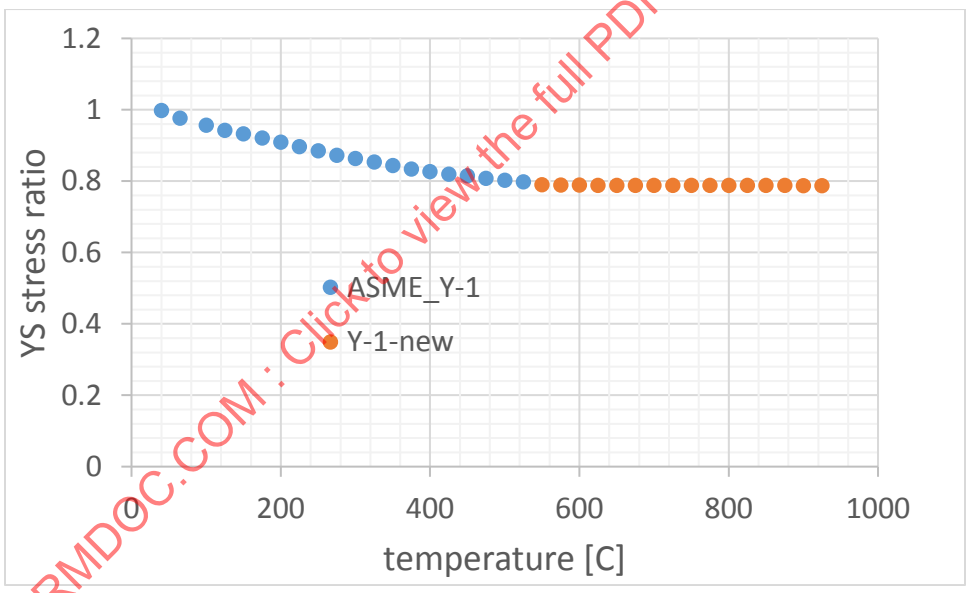


Figure 4-38: Yield strength reduction factors for N06625 annealed

Temperature [F]	ASME_Y-1	Y-1-new		Temperature[C]	ASME_Y-1	Y-1-new
70	1			40	0.99759036	
100	1			65	0.97590361	
150	0.97833333			100	0.95662651	
200	0.96333333			125	0.94216867	
250	0.94833333			150	0.93253012	
300	0.935			175	0.92048193	
350	0.92166667			200	0.90843373	
400	0.90833333			225	0.89638554	
450	0.895			250	0.88433735	
500	0.88166667			275	0.87228916	
550	0.87			300	0.8626506	
600	0.85833333			325	0.85301205	
650	0.84833333			350	0.84337349	
700	0.83833333			375	0.83373494	
750	0.83			400	0.82650602	
800	0.82166667			425	0.81927711	
850	0.815			450	0.81445783	
900	0.80833333			475	0.80722892	
950	0.80333333			500	0.80240964	
1000	0.79833333			525	0.79759036	
1050		7.90E-01		550		0.78949995
1100		7.88E-01		575		0.78882572
1150		7.88E-01		600		0.78832497
1200		7.88E-01		625		0.78797359
1250		7.88E-01		650		0.78774748
1300		7.88E-01		675		0.78762251
1350		7.88E-01		700		0.78757459
1400		7.88E-01		725		0.78757959
1450		7.88E-01		750		0.78761341
1500		7.88E-01		775		0.78765193
1550		7.88E-01		800		0.78767104
1600		7.88E-01		825		0.78764663
				850		0.78755459
				875		0.78737081
				900		0.78707118
				925		0.78663157