Metallic Material Limits for Wellhead Equipment Used in High Temperature for API 6A and 17D Applications

API TECHNICAL REPORT 6MET
FIRST EDITION, OCTOBER 2010

AMERICAN PETROLEUM INSTITUTE

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Upstream Segment

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Introduction

This API-funded project was conducted by a Task Group charged by the Association of Well Head Equipment Manufacturers (AWHEM). The Task Group examined mechanical properties of metallic materials used for API 6A and API 17D wellhead equipment for service above 250 °F. A total of eleven different alloys meeting API 6A, PSL 3 conditions were supplied “in condition” by a variety of suppliers. Materials in this test program included alloys common to the oil and gas industry. The alloys tested included low alloy steels, martensitic, precipitation hardened and duplex stainless steels, and nickel alloys. Yield strength reduction ratios at temperatures of 300 °F, 350 °F, 400 °F, and 450 °F are reported. As a result of testing, yield strength reduction ratios at 300 °F to 450 °F ranged from 92 % to 87 % for the low alloy steels, 92% to 88% for the martensitic stainless steels 81 % to 73 % for super duplex, 99 % to 89 % for the precipitation hardened stainless steel and 94 % to 89 % for the nickel alloys. The reported results represent an average over the different heats for each type of material. These results are intended to expand the data shown in API 6A, Annex G.

Metallic Material Limits for Wellhead Equipment Used in High Temperature for API 6A and 17D Applications

1 Scope

Testing was performed in three phases, presented herein in chronological order as Phase I, II, and III. Initially, all testing was to be completed in two phases, but testing anomalies in Phase II prompted re-testing of some alloys in Phase III.

Alloy candidates were recommended by AWHEM membership for analysis and confirmed by API's approval of New Work Item No. 2003-100786 in June 2002. Several material suppliers and several AWHEM member companies donated material for testing. Metallurgists on the Task Group screened material certificates to ensure a "normal" chemistry without enhancements for the material candidates listed in Table 1, Table 2, and Table 3.

Alloy chemistries from the material certificates for each of the supplied alloy candidates are provided in Table 6 through Table 16, located at the end of this report for readability.

Table 1—List of Alloys Included in Phase I Testing

Material	Yield Strength Class	Application	Bar Size
AISI 4130	75K	Pressure Containing	5 in. ER
AISI 8630	75K	Pressure Containing	5 in. ER
2 1/4 Cr 1 Mo	75K	Pressure Containing	5 in. ER
AISI 4140	75K	Pressure Containing	5 in. ER
AISI 410 SS	75K	Pressure Containing	5 in. ER
F6NM	75K	Pressure Containing	5 in. ER

Table 2—List of Alloys Included in Phase II Testing

Material	Yield Strength Class	Application	Material Size
25 Cr Super Duplex*	110K	Pressure Containing	2.4 in. to 5.5 in. OD
ASTM A453 Gr 660	100K	Pressure Retaining	0.75 in. to 1.5 in. OD
718 (per Spec 6A718)	130K	Pressure Containing	1.25 in. to 8.5 in. OD x 5.5 in.
725/625 Plus	130K	Pressure Containing	0.63 in. to 6.5 in. OD data 9 in.OD test
925	110K	Pressure Containing	1 in. to 6.5 in. OD
* Pitting resistance equivalence number, PREN >40.			

Table 3—List of Alloys Included in Phase III Testing

Material	Yield Strength	Application	Material Size
Nickel Alloy 725/625 Plus	120K	Pressure Containing	1.25 in. to 6.0 in.OD
Nickel Alloy 925	110K	Pressure Containing	1.0 in. to 8.7 in. OD

2 Procedure

In Phase I and II testing, three material test laboratories were selected to conduct elevated temperature tests in accordance with ASTM E21 using 0.505 in. diameter test specimens. One of the three laboratories with the best performance was selected to conduct all testing in Phase III. Phase I tensile specimens were removed from the mid-radius position. In Phase II and III tensile specimens were removed from the $^{1}/_{4}$T position where possible. Mechanical tests were then performed at room temperature (RT), 300 °F, 350 °F, and 450 °F to permit bracketing of results. The Task Group analyzed the resulting yield strength (YS) data from all the labs for each heat of material. Finally each supplier's data will be reported confidentially to that supplier only in exchange for the donation of material.

The tensile properties at elevated temperature used conventional tensile testing equipment modified slightly to accommodate a radiant heating chamber. For precise control of temperature the chamber was well insulated which also minimized specimen exposure to undesirable surface contamination.

The heating chamber was monitored using two thermocouples to maintain precise temperature control. A single thermocouple was used to control chamber atmosphere temperature while the second thermocouple was attached to the test specimen. Testing was initiated once the specimen and chamber atmosphere temperatures both reached equilibrium. Predetermined strain rates were maintained through break.

Tensile strength determination was made by use of an attached Class B-2 extensometer. The extensometer was modified to accommodate an extended reach into the heating chamber to fully engage the test piece through break while shielding the instrument from extreme temperatures.

Full size round test specimens were utilized. Measurements to determine Percent Elongation and Percent Reduction of Area within the gage length were conducted on broken specimens after cooling sufficiently to facilitate handling.

All test procedures and calibrations were in full compliance of ASTM E-21 without exception. No special equipment or processes were utilized in conducting hot tensile testing and there were no deviations to standard testing practices.

3 Results

3.1 Phase I Results

Each material type was analyzed by comparing Yield Strength readings at RT, 300 °F, 350 °F, and 450 °F for each heat and laboratory individually using a pivot table. In this manner, differences due to material behavior and/or laboratory abnormalities could be easily detected. Since the data set was too small to afford any statistical analysis, the results were averaged.

Room temperature yield strength test results from three of the five heats of AISI 4130 were below 75 ksi. One heat was only 2 % below the required RT properties. However two of those three heats were 12 % and 17 % below the minimum requirement. Material certification reports were reviewed by metallurgists on the Task Group and reasons for the low properties were not obvious. Averaging data from all the heats produced higher yield derating factors than seemed appropriate [92 % at 350 °F compared with current values in API 6A, for Carbon and Low Alloy steels of 85 % (see Bibliography)]. Consequently, results from two lowest property heats were ignored in the average, resulting in a yield derating of 90 % at 350 °F. This discrepancy from reported RT yield properties was not found on any of the other five alloys tested. The conclusion from this discovery is that low hardenability alloys used for heavy section equipment must have proper design qualification. Thus averaging only three heats of 4130 produced an improved correlation to the other low alloy steel's yield reduction ratio than averaging all five heats (see Annex A).

One data point for $2^{1}/_{4}$ Cr 1 Mo at 450 °F appeared bad so it was excluded from the average. In all other cases, all data points for all five heats of the material were used. The variation of results for heats within a material showed approximately 15 % over each temperature ranges, except for 410 which ran approximately 20 %. The variation between labs was approximately 10 % for most materials with one lab measuring on the low side in a majority of cases. A sample plot of average YS reduction ratio (derating factor) for 8630 is shown in Figure 1. Thus the derating factor at 400 °F was interpolated as 88.5 %.

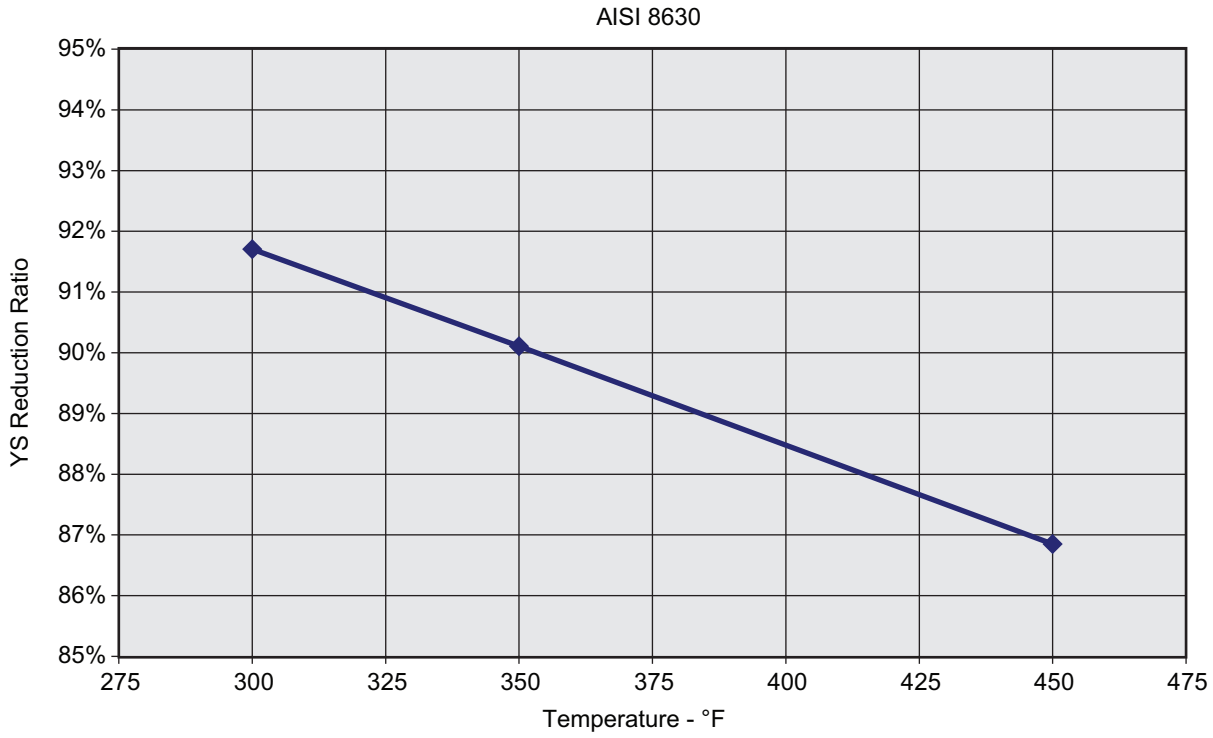


Figure 1—AISI 8630 Strength Reduction with Temperature

3.2 Phase II Results

As a result of limited material availability, material size for testing was variable and in one case the Task Group had to purchase a limited amount of one heat. One supplier furnished their own test data for several heats in two material types. Test temperatures were slightly different and results did not correlate exactly with actual test data from our material testing. The greatest data correlation problem was with 725/625 Plus. Each material type was analyzed by comparing yield strength readings at RT, 300 °F, 350 °F, and 450 °F for each heat and laboratory individually using a pivot table. In this manner, differences due to material behavior and/or laboratory abnormalities could be detected. Since the data set was too small to afford much statistical analysis, the results were averaged. In a few cases inconsistent data (11 points) were rejected to prevent distortion of results. In each of those cases, the rationale used was to drive the results in a conservative direction. Inconsistent data points were examined with the labs. At one lab some strange data points were caused by the extensometer extensions slipping or by movement of the test specimen. Examination of stress/strain curves verified the problem. These data were rejected and re-tested as Phase III.

3.3 Phase III Results

Seven heats of 725/625 Plus and eight heats of 925 were tested. To maintain consistency in the data analysis methodology of Phase I and Phase II testing, the yield strength reduction factors were averaged. A linear relationship between temperature and reduction factor was assumed, given the narrow temperature range in the study. Typically, for high strength nickel alloys the temperature range that is of interest spans a much larger range. Each material type was analyzed by comparing yield strength readings at RT, 300 °F, 350 °F, and 450 °F for each heat. Since the data set was too small to afford much statistical analysis, the results were averaged. The raw data along with the stress/strain curves were examined to cull any data that would appear unusual. No anomalies in the data were observed which allowed the use of the entire data set to define the reduction factors.

4 Conclusions

Material selection for HPHT equipment and validation for actual properties are important. For example AISI 4130 properties must be validated in the section of interest. This material lacks the hardenability of other materials tested. Bar stock appeared to produce lower properties than did forged material, but hardenability was the real issue. Three heats out of five of 4130 fell below the minimum YS even though the material certification report showed the YS above the minimum.

The eleven materials produced a fairly tight range of YS reduction ratios. Yield strength derating factors from testing the eleven alloys are as shown in Table 4.

Detailed results for each material are shown in the Appendices.

For comparison, available data from published literature compared favorably as shown in Table 5.

Table 4—Recommended Yield Strength Reduction Ratios in Percent by Temperature

All temperatures in °F.

Material	Temperature			
	300	350	400	450
AISI 4130 Low Alloy Steel	91	90	89	88
AISI 8630 Low Alloy Steel	92	90	89	87
2-1/4 Cr 1 Mo Low Alloy Steel	92	91	90	89
AISI 4140 Low Alloy Steel	92	90	89	88
AISI 410 Martensitic Stainless Steel	91	90	89	88
F6NM Martensitic Stainless Steel	92	91	89	88
25 Cr Super Duplex	81	78	76	73
ASTM A453 Gr 660 Precipitation Hardened Austenitic Stainless Steel	99	95	96	97
718 (per Spec 6A718) Nickel Alloy	94	93	92	91
725/625 Plus Nickel Alloy	93	92	90	89
925 Nickel Alloy	92	92	91	90

Table 5—Yield Strength Reduction Factors in Percent by Temperature (from Literature)

All temperatures in °F.

Material	Temperature				Reference
	300	350	400	450	
25 Cr (various UNS)	80	78	76	–	ASME *BPVC* Part D, Table Y-1
718	96	95	95	–	*MIL Handbook 5* (not 6A718?)
725/625 Plus	93	92	92	92	Special Metals Corporation
925	93	92	90	90	Special Metals Corporation
Carbon and Low Alloy Steels	–	–	85	–	API 6A, Annex G
Martensitic Stainless Steels	–	–	85	–	API 6A, Annex G
Austenitic and Duplex Stainless Steels	–	–	80	–	API 6A, Annex G
Corrosion Resistant Alloys	–	–	95	–	API 6A, Annex G

5 Recommendations

The factors presented herein should be used as the basis for estimating the nominal reduction of yield strength with temperature for the alloys presented. As a cautionary note the data presented herein does not include a statistical analysis such as a prediction interval to establish a confidence level for defining a lower bound. A full statistical analysis for a more robust prediction tool would require additional data points for one or more of the alloys tested to benchmark the total number of data points required for a valid statistical analysis.

Table 6—Alloy Composition for AISI 4130

Heat Code	Element, wt-%													Heat Treat Condition
	C	Si	Mn	P	S	Cr	Mo	Al	Cu	Sn	V	Ca	Ni	
1	0.32	0.25	0.5	0.016	0.011	0.99	0.15	0.017	0.13	0.007	0.024	0.0005	0.09	Q+T
2	0.30	0.24	0.56	0.009	0.012	1.04	0.22	0.022	0.17	NR	0.003	0.0004	0.13	Q+T
3	0.28	0.25	0.52	0.009	0.007	1.02	0.224	0.022	0.14	NR	0.028	0.0017	0.2	N+Q+T
4	0.31	0.23	0.54	0.007	0.005	1.03	0.22	0.028	0.19	0.011	0.003	NR	0.16	Q+T
5	0.315	0.25	0.57	0.009	0.02	1.05	0.24	0.028	0.19	0.011	0.003	NR	0.22	N+Q+T

Table 7—Alloy Composition for 8630M

Heat Code	Element, wt-%								Heat Treat Condition
	C	Si	Mn	P	S	Cr	Mo	Ni	
1	0.31	0.27	0.89	0.006	0.0039	0.95	0.41	0.85	N+Q+T
2	0.31	0.23	0.86	0.007	0.012	0.92	0.40	0.82	N+Q+T
3	0.33	0.28	0.81	0.007	0.009	0.93	0.37	0.76	N+Q+T
4	0.31	0.27	0.92	0.014	0.015	0.97	0.37	0.78	N+Q+T
5	0.32	0.27	0.88	0.009	0.002	0.93	0.39	0.80	N+Q+T

Table 8—Alloy Composition for $2^{1}/_{4}$Cr-1Mo (F22)

Heat Code	Element, wt-%											Heat Treat Condition
	C	Mn	P	S	Si	Cr	Mo	Ni	V	Al	Cu	
1	0.15	0.54	0.012	0.008	0.32	2.22	1.00	0.41	0.009	0.034	0.12	Q+T
2	0.01	0.49	0.019	0.005	0.27	2.15	0.94	0.12	0.007	0.048	0.27	N+Q+T
3	0.12	0.50	0.01	0.002	0.31	2.17	0.93	0.28	0.007	0.022	0.18	Q+T
4	0.13	0.40	0.01	0.020	0.23	2.14	0.94	0.19	0.008	0.023	0.15	N+Q+T
5	0.14	0.54	0.013	0.011	0.27	2.24	0.99	0.18	0.010	0.038	0.18	N+Q+T

Table 9—Alloy Composition for AISI 4140 Test Material

Heat Code	Element, wt-%											Heat Treat Condition
	C	Mn	Si	S	P	Cr	Mo	Al	V	Cu	Ni	
1	0.40	0.92	0.29	0.012	0.014	1.06	0.235	0.017	0.005	0.192	0.20	Q+T
4	0.41	0.95	0.25	0.018	0.009	1.04	0.24	0.032	0.003	0.140	0.18	Q+T
2	0.42	0.81	0.24	0.010	0.011	0.93	0.18	0.036	0.005	0.230	0.13	N+Q+T
3	0.43	0.92	0.24	0.013	0.014	1.00	0.19	0.011	0.026	0.180	0.10	N+Q+T
5	0.41	0.93	0.20	0.015	0.010	0.98	0.18	0.026	0.020	0.240	0.20	N+Q+T

Table 10—Alloy Composition for 410 Stainless Steel

Heat Code	Element, wt-%										Heat Treatment
	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	V	
1	0.125	0.34	0.45	0.023	0.010	11.58	0.37	0.40	0.05	0.020	1796 °F / 4Hr OQ, 1310 °F / 7Hr AC, 1274 °F / 5Hr AC
2	0.125	0.37	0.60	0.015	0.001	13.15	0.04	0.40	0.06	0.039	1805 °F / 5Hr OQ, 1283 °F / 8Hr AC, 1220 °F / 8Hr AC
3	0.130	0.38	0.46	0.015	0.001	13.30	0.02	0.33	0.06	0.030	1800 °F / 7.45Hr OQ, 1310 °F / 5.53Hr AC, 1256 °F / 5Hr AC
4	0.143	0.29	0.83	0.02	0.001	12.64	0.03	0.43	0.07	0.075	1800 °F / 5Hr OQ, 1300 °F / 6Hr AC, 1250 °F / 6Hr AC
5	0.136	0.29	0.83	0.018	0.001	12.77	0.02	0.42	0.07	0.082	1750 °F / 5.5Hr OQ, 1325 °F / 5.5Hr AC, 1300 °F / 5.5Hr AC

Table 11—Alloy Composition for F6NM Stainless Steel

Heat Code	Element, wt-%								Heat Treatment
	C	Si	Mn	S	P	Cr	Mo	Ni	
1	0.007	0.38	0.72	0.001	0.014	12.68	0.53	3.89	1886 °F / 2.5Hr AQ, 1256 °F / 20Hr AC, 1130 °F / 20Hr AC
2	0.013	0.48	0.63	0.001	0.010	12.65	0.56	3.86	1875 °F / 5Hr AQ, 1250 °F / 6Hr AC, 1125 °F / 6.25Hr AC
3	0.023	0.53	0.79	0.002	0.017	12.64	0.57	4.29	1900 °F / 6Hr, 1275 °F / 6Hr, 1150 °F / 6Hr
4	0.020	0.39	0.73	0.015	0.016	12.12	0.60	3.65	1875 °F / 2.75Hr AQ, 1250 °F / 12.5Hr AC, 1130 °F / 12Hr AC
5	0.005	0.39	0.67	0.001	0.017	12.80	0.60	4.00	1850 °F / 4.5Hr OQ, 1275 °F / 6Hr AC, 1175 °F / 6Hr AC

Table 12—Alloy Composition for 25Cr Super Duplex

Heat Code	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N	W	Al	Heat Treatment
1	0.017	0.28	0.84	0.017	0.0009	25.15	7.11	3.87	0.11	0.274	NR	NR	2012 °F / 0.5Hr WQ
2	0.017	0.53	0.48	0.022	0.0002	25.42	7.20	3.81	1.71	0.264	0.89	0.015	2048 °F / 2.3Hr WQ
3	0.019	0.53	0.61	0.024	0.0002	25.26	7.03	3.61	0.55	0.263	0.68	0.007	2012 °F / 3Hr WQ
4	0.016	0.52	0.48	0.023	0.0003	25.58	7.02	3.82	1.67	0.256	0.89	0.011	2048 °F / 2.5Hr WQ
5	0.016	0.23	0.47	0.022	0.0005	25.33	7.05	3.68	0.58	0.226	0.56	NR	2012 °F / 2.5Hr WQ

Table 13—Alloy Composition for ASTM A453 Gr 660 Precipitation Hardened Austenitic Stainless Steel

Heat Code	Element, wt-%														Heat Treatment
	C	P	S	Mn	Ni	Si	Cr	Mo	V	Ti	Al	B	Co	Cu	
1	0.041	0.016	0.0003	0.29	24.64	0.21	14.48	1.17	0.21	2.10	0.22	0.01	0.09	0.05	1650 °F / 2Hr WQ, 1325 °F / 16Hr AC
2	0.040	0.011	0.001	0.27	25.54	0.07	14.05	1.19	0.21	2.08	0.23	0.01	0.02	0.13	1800 °F / 2Hr WQ, 1325 °F / 16Hr AC
3	0.040	0.016	0.0005	0.17	25.51	0.17	14.66	1.23	0.27	2.21	0.17	0.01	0.05	0.07	1650 °F / 2Hr WQ, 1330 °F / 16Hr AC
4	0.040	0.015	0.005	0.25	25.40	0.19	14.50	1.22	0.30	2.23	0.15	0.01	NR	NR	1795 °F / 1Hr WQ, 1325 °F / 16Hr AC
5	0.040	0.013	0.0005	0.21	24.42	0.14	13.96	1.22	0.30	2.23	0.14	0.01	0.04	0.06	1650 °F / 2Hr WQ, 1330 °F / 16Hr AC

Table 14—Alloy Composition for Nickel Alloy 718 (per Spec 6A718)

Heat Code	Element, wt-%																		Heat Treatment
	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Al	Ti	Nb	Co	B	Se	Pb	Bi	Fe	
1	0.03	0.11	0.06	0.0050	0.0010	18.3	2.91	52.7	0.04	0.49	0.99	5.17	0.200	0.004	0.0001	0.0003	0.00003	Rem	1890 °F / 1Hr FanC, 1455 °F / 6Hr AC
2	0.03	0.11	0.05	0.0050	0.0050	18.3	2.90	52.6	0.03	0.45	0.99	5.10	0.200	0.004	0.0001	0.0003	0.00003	Rem	1890 °F / 1Hr AC, 1455 °F / 6Hr AC
3	0.03	0.13	0.08	0.0060	0.0010	18.1	3.19	52.6	0.07	0.53	0.96	4.96	0.300	0.003	0.0001	0.0001	0.00001	Rem	1877 °F / 2Hr WQ, 1472 °F / 6Hr AC
4	0.02	0.14	0.10	0.0085	0.0005	18.5	3.00	54.7	0.01	0.45	0.88	5.08	0.011	0.004	0.0001	0.0001	0.00003	Rem	1885 °F / 1.5Hr WQ, 1435 °F / 6Hr AC
5	0.02	0.16	0.10	0.0079	0.0002	18.4	2.99	54.5	0.03	0.44	0.88	5.09	0.028	0.0042	0.0001	0.0001	0.00003	Rem	1885 °F / 1.5Hr WQ, 1435-1455 °F / 6.5Hr AC

Table 15—Alloy Composition for Nickel Alloys 725 and 625 Plus

Heat Code	Element, wt-%													Heat Treatment
	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Al	Ti	Nb	Fe	
1	0.02	0.11	0.05	0.0138	0.0003	21.03	8.08	61.06	0.04	0.21	1.37	3.38	Rem	1875-1925 °F / 1Hr WQ + Dbl Aged AC
2	0.02	0.11	0.07	0.0115	0.0004	20.76	7.98	61.02	0.07	0.25	1.34	3.35	Rem	1875-1925 °F / 1Hr WQ + Dbl Aged WQ
3	0.011	0.02	0.02	0.002	0.0007	21.01	8.00	60.97	0.01	0.18	1.28	3.38	Rem	1895 °F / 2Hr + Age 1355 °F / 8Hr, 1148 °F / 8Hr AC
4	0.01	0.02	0.09	0.003	0.0002	21.05	8.03	57.91	NR	0.24	1.51	3.44	Rem	1900 °F / 45Min + Age 1350 °F / 8Hr, 1150 °F / 8Hr AC
6*	0.01	0.02	0.07	0.003	8.04	21.04	8.04	57.79	NR	0.25	1.53	3.46	Rem	1900 °F / 0.5Hr AC, Age 1350 °F / 8Hr 16 Min. 1150 °F / 6Hr 17 Min, AC
7*	0.01	0.02	0.07	0.003	8.04	21.04	8.04	57.79	NR	0.25	1.53	3.46	Rem	1900 °F / 2Hr AC, Age 1350 °F / 8Hr 21 Min., 1150 °F / 8Hr 21 Min, AC
8	0.006	0.05	0.08	0.005	0.001	20.74	8.40	57.4	NR	0.22	1.50	3.38	Rem	1900 °F / 2Hr AC + Age 1350 °F / 8Hr FC, 1150 °F / 8Hr AC

* Test material is from the same ingot, but with different reduction ratios and heat treatments.

NOTE 1 Head Code 6: 256:1 Reduction Ratio

NOTE 2 Heat Code 7: 178:1 Reduction Ratio

Table 16—Alloy Composition for Nickel Alloy 925

Heat Code	Element, wt-%													Heat Treatment
	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Al	Ti	Nb	Fe	
1	0.010	0.16	0.56	0.014	0.001	20.21	3.23	43.28	1.66	0.20	2.12	0.31	Bal	1850 °F / 2Hr AC, 1365 °F / 8.5Hr FC to 1150 °F / 6.5Hr AC
2*	0.011	0.20	0.75	0.010	0.002	20.61	2.70	42.65	1.86	0.25	2.35	0.27	Bal	1850 °F / 4.0Hr WQ: 1364 °F / 8Hr FC to 1148 °F Air Cool
3*	0.011	0.20	0.75	0.010	0.002	20.61	2.70	42.65	1.86	0.25	2.35	0.27	Bal	1850 °F / 3.1Hr WQ: 1364 °F / 8Hr FC to 1247 °F Air Cool (2)
4	0.007	0.15	0.74	0.008	0.002	20.58	2.57	42.9	1.89	0.24	2.18	0.28	Bal	1850 °F / 4Hr WQ, 1364 °F / 8Hr FC to 1148 °F AC
5	0.007	0.18	0.73	0.009	0.002	21.58	2.64	42.9	1.89	0.24	2.22	0.30	Bal	1850 °F / 4Hr WQ, 1364 °F / 8Hr FC to 1247 °F AC
6	0.009	0.16	0.77	0.011	0.002	20.69	2.59	43.29	1.93	0.21	2.20	0.31	Bal	1850 °F / 6Hr WQ, 1364 °F / 8Hr FC to 1148 °F AC
7	0.017	0.07	0.46	0.017	0.0003	20.90	2.93	44.21	1.89	0.22	2.12	0.30	Bal	Sol. Ann. (not reported), 1385 °F / 8Hr FC to 1200 °F / 8Hr AC
8	0.01	0.20	0.60	0.010	0.001	20.80	3.10	43.7	1.80	0.20	2.06	0.30	Bal	1850 °F / 1Hr WQ, 1365 °F / 8Hr FC to 1150 °F / 6Hr AC

* Test material is from the same ingot, but with different reduction ratios and heat treatments.

NOTE 1 Head Code 2: 14:1 Reduction Ratio

NOTE 2 Heat Code 3: 6:1 Reduction Ratio

Annex A
(informative)

AISI 4130 Test Results

Table A.1—AISI 4130 Test Results

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of All Heats at Temp.	YS Avg. of Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
1	A	B	A	75	83,000	101,000	74,300	78,589	72,840	**Valid Heats**		
1	B	B	B	75	83,000	103,100	74,900			78,589	75	100.00%
1	C	B	C	75	83,000	98,300	71,400			71,611	300	91.12%
2	A	F	A	75	79,600	102,800	82,100			70,566	350	89.78%
2	B	F	B	75	79,600	104,600	81,700			69,367	450	88.27%
2	C	F	C	75	79,600	100,200	78,700					
3	A	B	A	75	76,000	95,100	67,500			**All Heats**		
3	B	B	B	75	76,000	96,600	66,900	Questionable results		72,840	75	100.00%
3	C	B	C	75	76,000	92,400	64,300	based on pivot table		67,313	300	92.41%
4	A	F	A	75	80,500	101,700	81,000			67,300	350	92.39%
4	B	F	B	75	80,500	104,000	81,700			66,767	450	91.66%
4	C	F	C	75	80,500	101,900	81,500					
5	A	B	A	75	87,159	94,500	62,900					
5	B	B	B	75	87,159	96,700	63,000	Questionable results				
5	C	B	C	75	87,159	92,400	60,700	based on pivot table				
1	A	B	A	300		91,100	66,800	71,611	67,313			
1	B	B	B	300		91,000	64,000					
1	C	B	C	300		90,700	65,000					
2	A	F	A	300		94,400	74,700					
2	B	F	B	300		96,100	75,700					
2	C	F	C	300		94,500	73,300					
3	A	B	A	300		87,100	61,100					
3	B	B	B	300		87,500	65,000	Questionable results				
3	C	B	C	300		86,200	61,400	based on pivot table				
4	A	F	A	300		94,600	75,100					
4	B	F	B	300		95,600	75,900					
4	C	F	C	300		95,000	74,000					
5	A	B	A	300		86,700	58,900					
5	B	B	B	300		87,200	60,500	Questionable results				
5	C	B	C	300		87,100	58,300	based on pivot table				
1	A	B	A	350		90,600	65,000	70,566	67,300			
1	B	B	B	350		92,700	66,500					
1	C	B	C	350		91,200	65,100					
2	A	F	A	350		94,400	73,000					
2	B	F	B	350		95,100	74,300					
2	C	F	C	350		94,600	72,700					
3	A	B	A	350		85,900	62,000					
3	B	B	B	350		87,300	62,000	Questionable results				
3	C	B	C	350		85,700	63,300	based on pivot table				
4	A	F	A	350		93,500	72,200					
4	B	F	B	350		95,100	73,300					
4	C	F	C	350		95,500	72,900					

4130

Table A.1—AISI 4130 Test Results (Continued)

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of All Heats at Temp.	YS Avg. of Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
5	A	B	A	350		85,800	61,000					
5	B	B	B	350		87,300	63,900	Questionable results				
5	C	B	C	350		85,300	62,300	based on pivot table				
1	A	B	A	450		92,300	63,700	69,367	66,767			
1	B	B	B	450		91,300	64,900					
1	C	B	C	450		91,300	65,000					
2	A	F	A	450		95,700	72,000					
2	B	F	B	450		94,400	72,900					
2	C	F	C	450		94,200	72,000					
3	A	B	A	450		87,000	63,000					
3	B	B	B	450		87,100	63,100	Questionable results				
3	C	B	C	450		87,600	65,500	based on pivot table				
4	A	F	A	450		93,600	69,800					
4	B	F	B	450		94,300	72,600					
4	C	F	C	450		95,400	71,400					
5	A	B	A	450		86,900	60,800					
5	B	B	B	450		87,500	63,200	Questionable results				
5	C	B	C	450		86,800	61,600	based on pivot table				

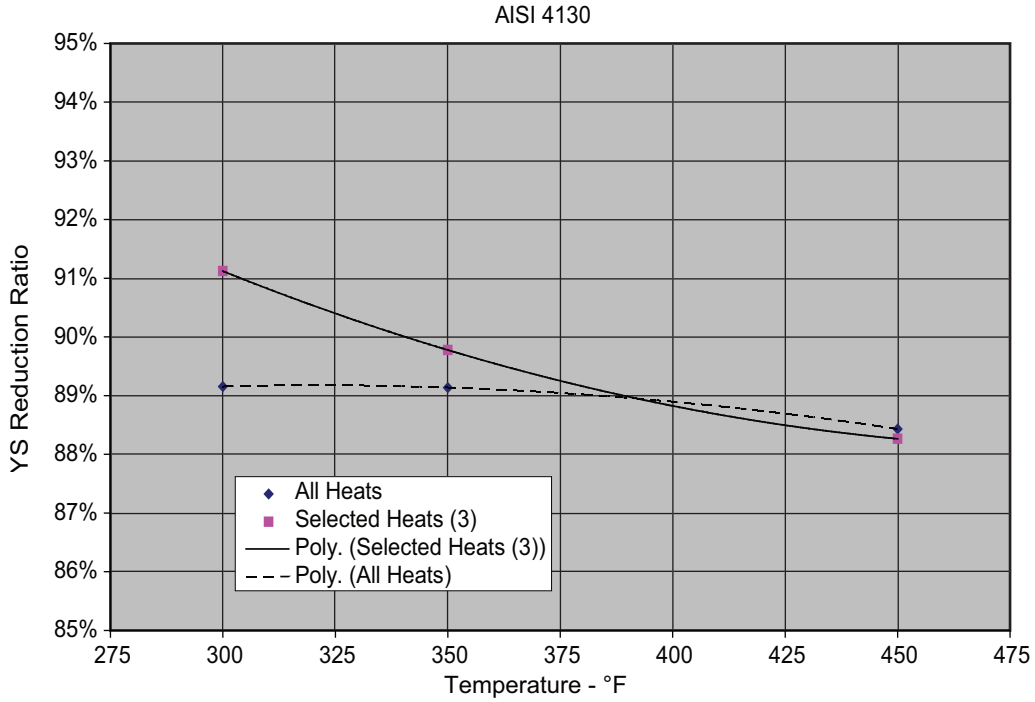


Figure A.1—Plot of 4130 Test Results

Annex B
(informative)

AISI 8630 Test Results

Table B.1—AISI 8630 Test Results

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of Valid Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
1	A	B	A	75	90,203	109,400	85,400	85,933	85,933	75	100.0%
1	B	B	B	75	90,203	110,900	89,200		78,807	300	91.7%
1	C	B	C	75	90,203	103,300	77,200		77,433	350	90.1%
2	A	F	A	75	82,600	102,100	83,900		74,633	450	86.9%
2	B	F	B	75	82,600	103,400	87,900				
2	C	F	C	75	82,600	97,300	79,700				
3	A	F	A	75	90,000	109,700	91,200				
3	B	F	B	75	90,000	108,500	86,400				
3	C	F	C	75	90,000	102,400	82,700				
4	A	B	A	75	89,300	109,900	89,100				
4	B	B	B	75	89,300	110,400	87,300				
4	C	B	C	75	89,300	105,300	84,900				
5	A	F	A	75	98,300	112,800	91,200				
5	B	F	B	75	98,300	113,700	90,900				
5	C	F	C	75	98,300	103,600	82,000				
1	A	B	A	300		100,000	73,600	78,807			
1	B	B	B	300		101,500	76,200				
1	C	B	C	300		95,700	76,400				
2	A	F	A	300		92,800	75,100				
2	B	F	B	300		94,400	79,800				
2	C	F	C	300		90,400	73,100				
3	A	F	A	300		100,600	82,500				
3	B	F	B	300		100,900	82,100				
3	C	F	C	300		96,500	78,200				
4	A	B	A	300		101,400	80,800				
4	B	B	B	300		102,900	82,200				
4	C	B	C	300		99,400	78,900				
5	A	F	A	300		105,100	84,000				
5	B	F	B	300		104,900	83,600				
5	C	F	C	300		97,700	75,600				
1	A	B	A	350		99,300	76,500	77,433			
1	B	B	B	350		100,500	78,600				
1	C	B	C	350		96,300	77,200				
2	A	F	A	350		91,900	73,200				
2	B	F	B	350		93,500	76,900				
2	C	F	C	350		89,100	70,000				
3	A	F	A	350		98,900	80,300				
3	B	F	B	350		99,800	80,700				
3	C	F	C	350		97,200	75,200				
4	A	B	A	350		99,900	78,900				
4	B	B	B	350		101,000	80,500				
4	C	B	C	350		94,800	73,300				

8630

Table B.1—AISI 8630 Test Results (Continued)

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of Valid Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
5	A	F	A	350		104,600	83,200				
5	B	F	B	350		103,000	81,500				
5	C	F	C	350		98,500	75,500				
1	A	B	A	450		99,900	75,200	74,633			
1	B	B	B	450		100,000	79,200				
1	C	B	C	450		99,000	74,200				
2	A	F	A	450		93,200	71,400				
2	B	F	B	450		92,200	72,500				
2	C	F	C	450		93,700	69,200				
3	A	F	A	450		98,200	75,400				
3	B	F	B	450		99,100	77,300				
3	C	F	C	450		97,200	71,900				
4	A	B	A	450		97,000	73,900				
4	B	B	B	450		99,500	76,700				
4	C	B	C	450		96,700	72,600				
5	A	F	A	450		105,100	80,400				
5	B	F	B	450		102,800	78,400				
5	C	F	C	450		97,500	71,200				

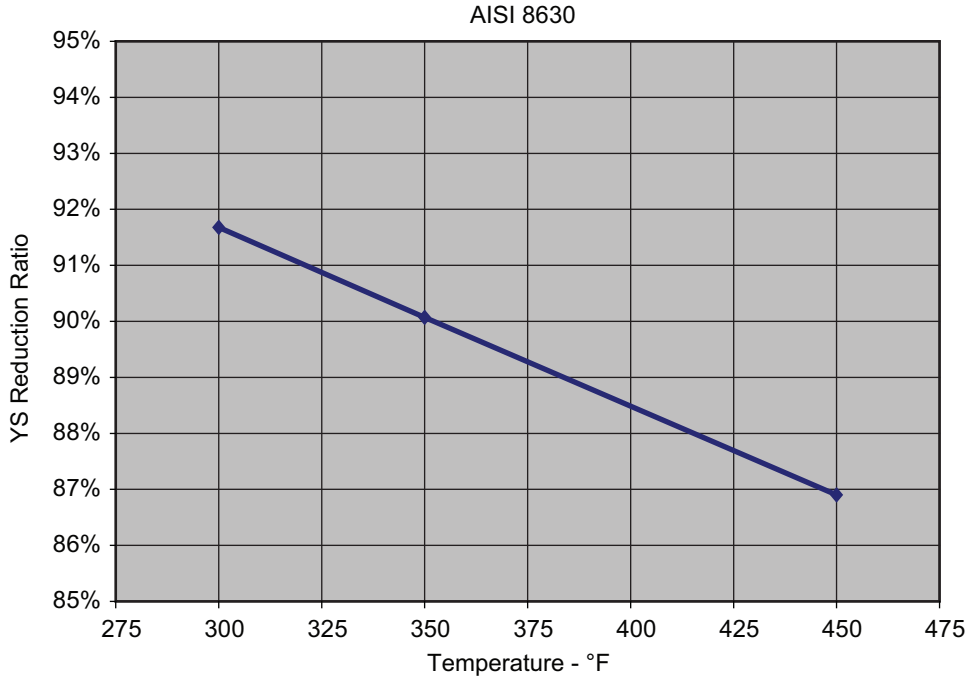


Figure B.1—Plot of 8630 Test Results

Annex C
(informative)

$2^1/_4$ Cr 1 Mo Test Results

Table C.1—$2^1/_4$ Cr 1 Mo Test Results

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of Valid Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
1	A	F	A	75	87,000	106,600	89,900	84,993	84,993	75	100.00%
1	B	F	B	75	87,000	107,000	87,700		78,607	300	92.5%
1	C	F	C	75	87,000	104,700	86,000		76,960	350	90.5%
2	A	F	A	75	85,500	101,400	88,000		75,400	450	88.7%
2	B	F	B	75	85,500	102,800	87,400				
2	C	F	C	75	85,500	101,600	80,500				
3	A	F	A	75	79,500	98,000	83,400				
3	B	F	B	75	79,500	100,100	82,900				
3	C	F	C	75	79,500	98,400	80,900				
4	A	F	A	75	82,400	96,100	79,900				
4	B	F	B	75	82,400	102,900	84,300				
4	C	F	C	75	82,400	95,000	73,400				
5	A	F	A	75	89,900	106,500	90,500				
5	B	F	B	75	89,900	108,000	90,500				
5	C	F	C	75	89,900	106,600	89,600				
1	A	F	A	300		97,200	82,500	78,607			
1	B	F	B	300		97,300	81,100				
1	C	F	C	300		95,600	80,000				
2	A	F	A	300		92,900	80,400				
2	B	F	B	300		93,800	80,000				
2	C	F	C	300		92,200	78,800				
3	A	F	A	300		88,700	75,800				
3	B	F	B	300		90,000	73,300				
3	C	F	C	300		89,500	75,000				
4	A	F	A	300		87,600	71,500				
4	B	F	B	300		94,800	79,900				
4	C	F	C	300		90,500	73,100				
5	A	F	A	300		97,700	83,200				
5	B	F	B	300		96,300	83,100				
5	C	F	C	300		95,800	81,400				
1	A	F	A	350		95,100	80,000	76,960			
1	B	F	B	350		96,900	80,900				
1	C	F	C	350		94,600	78,900				
2	A	F	A	350		97,800	79,600				
2	B	F	B	350		92,500	79,800				
2	C	F	C	350		91,200	77,400				
3	A	F	A	350		87,900	74,600				
3	B	F	B	350		90,600	76,400				
3	C	F	C	350		86,500	72,000				
4	A	F	A	350		90,000	73,600				
4	B	F	B	350		85,400	67,300				
4	C	F	C	350		88,200	69,600				

$2^1/_4$ Cr 1 Mo

Table C.1—2 1/4 Cr 1 Mo Test Results (Continued)

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of Valid Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
5	A	F	A	350		94,400	80,800				
5	B	F	B	350		97,200	82,900				
5	C	F	C	350		95,300	80,600				
1	A	F	A	450		95,100	79,000	75,400			
1	B	F	B	450		95,600	79,600				
1	C	F	C	450		93,200	76,700				
2	A	F	A	450		90,300	76,100				
2	B	F	B	450		89,800	74,800				
2	C	F	C	450		90,200	74,800				
3	A	F	A	450		86,100	71,800				
3	B	F	B	450		88,200	74,200				
3	C	F	C	450		85,500	71,000				
4	A	F	A	450		87,200	71,000				
4	B	F	B	450		88,200	69,600				
4	C	F	C	450		77,000	51,200	Bad data point?			
5	A	F	A	450		92,300	78,900				
5	B	F	B	450		94,300	79,800				
5	C	F	C	450		92,900	78,300				

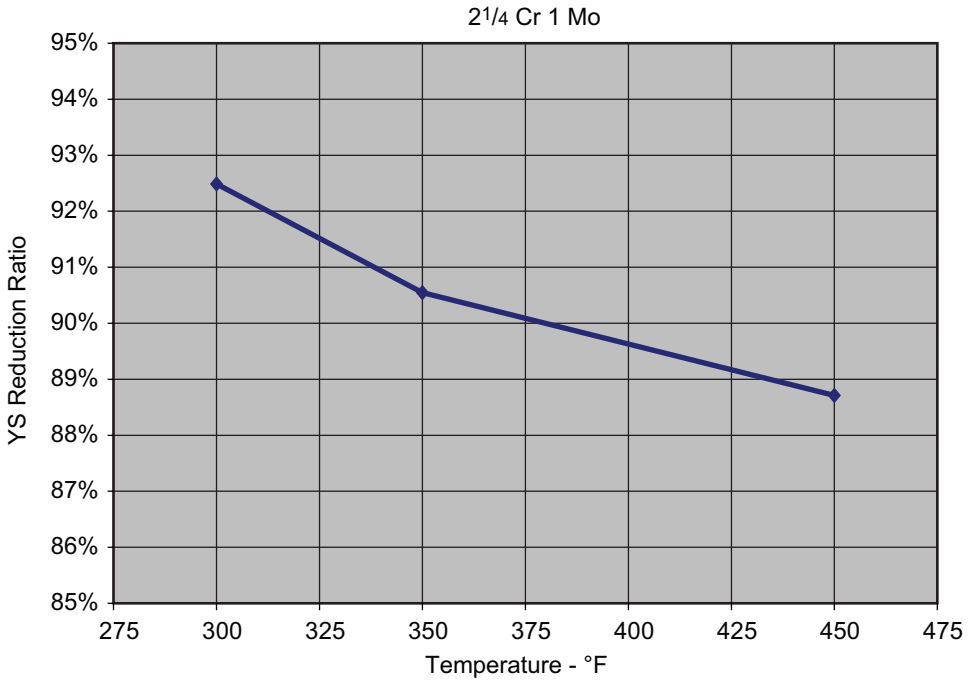


Figure C.1—Plot of 2 1/4 Cr 1 Mo Test Results

Annex D
(informative)

AISI 4140 Test Results

Table D.1—AISI 4140 Test Results

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of Valid Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
1	A	B	A	75	85,550	109,000	82,700	81,067	81,067	75	100.00%
1	B	B	B	75	85,550	110,000	83,000		74,947	300	92.5%
1	C	B	C	75	85,550	105,400	81,000		73,327	350	90.5%
2	A	F	A	75	81,700	106,600	79,100		71,127	450	87.7%
2	B	F	B	75	81,700	103,900	74,600				
2	C	F	C	75	81,700	105,900	76,700				
3	A	F	A	75	80,900	102,800	80,600				
3	B	F	B	75	80,900	103,000	78,700				
3	C	F	C	75	80,900	101,800	77,900				
4	A	F	A	75	88,820	111,500	85,400				
4	B	B	B	75	88,820	113,400	84,800				
4	C	B	C	75	88,820	105,200	78,700				
5	A	B	A	75	95,500	108,200	83,600				
5	B	F	B	75	95,500	110,000	84,700				
5	C	F	C	75	95,500	109,800	84,500				
1	A	B	A	300		98,900	75,400	74,947			
1	B	B	B	300		100,600	77,700				
1	C	B	C	300		100,200	76,800				
2	A	F	A	300		95,600	71,100				
2	B	F	B	300		96,900	70,900				
2	C	F	C	300		96,800	69,200				
3	A	F	A	300		94,800	74,200				
3	B	F	B	300		94,200	73,000				
3	C	F	C	300		92,700	71,000				
4	A	B	A	300		102,000	79,100				
4	B	B	B	300		103,300	78,900				
4	C	B	C	300		100,200	73,900				
5	A	F	A	300		100,200	79,400				
5	B	F	B	300		98,900	76,200				
5	C	F	C	300		100,600	77,400				
1	A	B	A	350		98,700	77,100	73,327			
1	B	B	B	350		99,700	75,900				
1	C	B	C	350		98,000	73,300				
2	A	F	A	350		92,700	66,900				
2	B	F	B	350		93,500	67,100				
2	C	F	C	350		93,000	65,600				
3	A	F	A	350		94,400	74,100				
3	B	F	B	350		93,300	71,600				
3	C	F	C	350		92,500	69,600				
4	A	B	A	350		101,900	77,700				
4	B	B	B	350		102,100	76,900				
4	C	B	C	350		101,200	74,700				

4140

Table D.1—AISI 4140 Test Results (Continued)

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of Valid Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
5	A	F	A	350		100,500	78,300				
5	B	F	B	350		100,200	76,500				
5	C	F	C	350		99,700	74,600				
1	A	B	A	450		99,700	71,300	71,127			
1	B	B	B	450		97,800	72,700				
1	C	B	C	450		100,700	72,200				
2	A	F	A	450		97,100	70,400				
2	B	F	B	450		92,600	64,700				
2	C	F	C	450		94,200	63,600				
3	A	F	A	450		94,700	72,800				
3	B	F	B	450		93,200	70,100				
3	C	F	C	450		93,400	69,500				
4	A	B	A	450		101,800	75,400				
4	B	B	B	450		102,400	75,300				
4	C	B	C	450		102,400	73,500				
5	A	F	A	450		96,600	71,700				
5	B	F	B	450		98,900	73,400				
5	C	F	C	450		98,600	70,300				

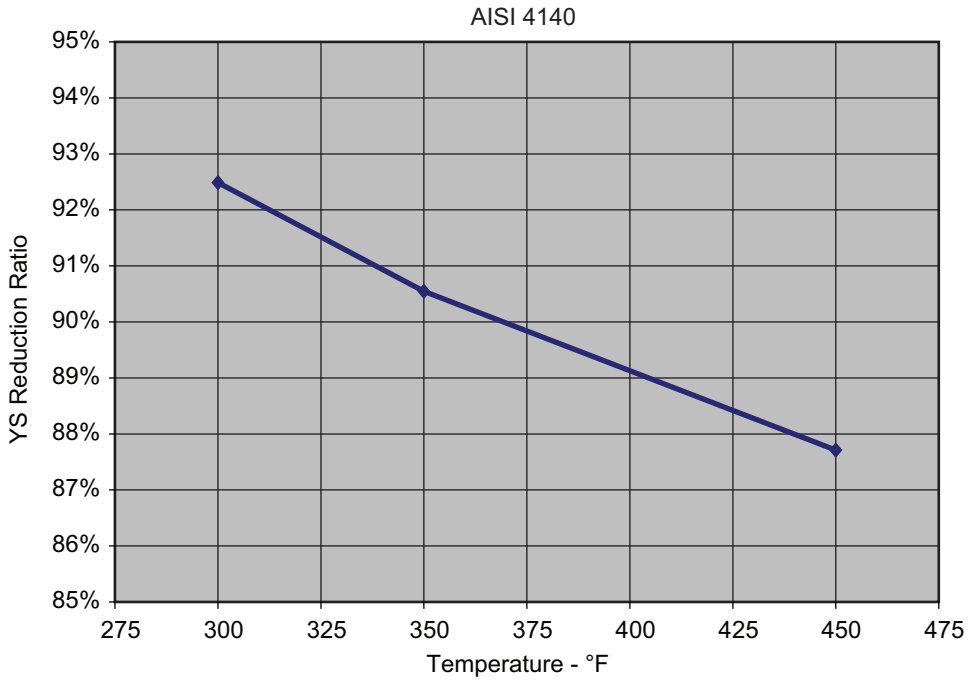


Figure D.1—Plot of AISI 4140Test Results

Annex E
(informative)

410 Stainless Steel Test Results

Table E.1—AISI 410 Test Results

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of Valid Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
1	A	B	A	75	80,400	110,700	87,400	84,727	84,727	75	100.00%
1	B	B	B	75	80,400	111,400	88,800		77,247	300	91.2%
1	C	B	C	75	80,400	107,100	85,400		76,613	350	90.4%
2	A	B	A	75	89,000	111,200	86,800		74,207	450	87.6%
2	B	B	B	75	89,000	112,400	87,600				
2	C	B	C	75	89,000	108,800	85,700				
3	A	B	A	75	93,300	114,000	91,800				
3	B	B	B	75	93,300	113,900	91,500				
3	C	B	C	75	93,300	110,800	89,000				
4	A	B	A	75	79,100	103,400	85,200				
4	B	B	B	75	79,100	104,000	72,300				
4	C	B	C	75	79,100	99,200	67,900				
5	A	F	A	75	82,000	105,700	86,000				
5	B	F	B	75	82,000	106,400	84,300				
5	C	F	C	75	82,000	102,100	81,200				
1	A	B	A	300		99,600	80,500	77,247			
1	B	B	B	300		100,900	82,400				
1	C	B	C	300		98,000	79,100				
2	A	B	A	300		99,400	79,000				
2	B	B	B	300		101,600	81,600				
2	C	B	C	300		98,200	77,300				
3	A	B	A	300		103,700	86,100				
3	B	B	B	300		104,100	85,700				
3	C	B	C	300		101,200	72,300				
4	A	B	A	300		93,200	65,700				
4	B	B	B	300		94,500	71,100				
4	C	B	C	300		95,800	68,300				
5	A	F	A	300		94,100	77,700				
5	B	F	B	300		95,600	77,800				
5	C	F	C	300		92,300	74,100				
1	A	B	A	350		97,600	79,400	76,613			
1	B	B	B	350		99,000	81,200				
1	C	B	C	350		97,000	78,100				
2	A	B	A	350		97,600	76,500				
2	B	B	B	350		99,100	80,500				
2	C	B	C	350		96,700	78,300				
3	A	B	A	350		101,200	82,400				
3	B	B	B	350		102,600	85,200				
3	C	B	C	350		99,800	81,700				
4	A	B	A	350		91,500	66,200				
4	B	B	B	350		92,900	69,300				
4	C	B	C	350		90,800	66,200				

410

Table E.1—AISI 410 Test Results (Continued)

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of Valid Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
5	A	F	A	350		92,300	74,900				
5	B	F	B	350		93,200	75,400				
5	C	F	C	350		91,900	73,900				
1	A	B	A	450		93,600	74,000	74,207			
1	B	B	B	450		96,100	76,800				
1	C	B	C	450		93,700	72,000				
2	A	B	A	450		95,100	76,100				
2	B	B	B	450		96,800	77,800				
2	C	B	C	450		92,200	74,200				
3	A	B	A	450		98,300	80,000				
3	B	B	B	450		98,800	81,100				
3	C	B	C	450		96,000	79,600				
4	A	B	A	450		89,300	67,200				
4	B	B	B	450		89,200	71,000				
4	C	B	C	450		86,300	65,700				
5	A	F	A	450		89,500	73,400				
5	B	F	B	450		90,600	74,200				
5	C	F	C	450		87,100	70,000				

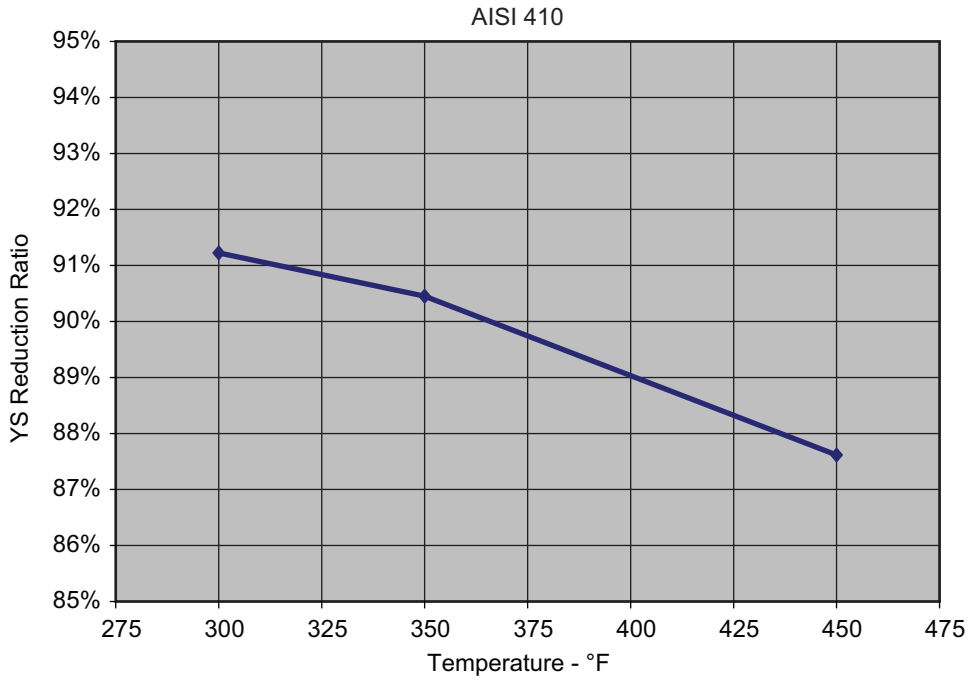


Figure E.1—Plot of AISI 410 Stainless Steel Test Results

Annex F
(informative)

F6NM Test Results

Table F.1—F6NM Test Results

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of Valid Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
1	A	B	A	75	84,000	105,800	88,500	87,900	87,900	75	100.00%
1	B	B	B	75	84,000	111,400	93,700		81,233	300	92.4%
1	C	B	C	75	84,000	104,300	87,300		80,211	350	91.3%
2	A	F	A	75	79,500	110,000	91,900		77,400	450	88.1%
2	B	F	B	75	79,500	107,100	89,800				
2	C	F	C	75	79,500	107,500	89,000				
3	A	F	A	75	87,200	111,700	88,600				
3	B	F	B	75	87,200	112,800	88,400				
3	C	F	C	75	87,200	108,500	84,500				
4	A	F	A	75	85,200	103,200	85,300				
4	B	F	B	75	85,200	103,300	84,200				
4	C	F	C	75	85,200	100,400	81,400				
5	A	F	A	75	80,300	114,700	81,400				
5	B	F	B	75	80,300	117,000	81,500				
5	C	F	C	75	80,300	113,100	79,400				
1	A	B	A	300		94,300	82,200	81,233			
1	B	B	B	300		95,300	83,300				
1	C	B	C	300		93,000	80,200				
2	A	F	A	300		97,900	85,600				
2	B	F	B	300		99,000	87,100				
2	C	F	C	300		96,500	83,900				
3	A	F	A	300		98,500	85,300				
3	B	F	B	300		99,400	84,900				
3	C	F	C	300		97,200	83,100				
4	A	F	A	300		90,700	78,500				
4	B	F	B	300		90,100	75,700				
4	C	F	C	300		89,300	74,600				
5	A	F	A	300		101,700	82,900				
5	B	F	B	300		103,700	85,800				
5	C	F	C	300		100,800	81,800				
1	A	B	A	350		92,300	86,200	80,211			
1	B	B	B	350		92,900	80,600				
1	C	B	C	350		91,400	78,700				
2	A	F	A	350		96,400	86,000				
2	B	F	B	350		96,100	85,000				
2	C	F	C	350		94,300	82,300				
3	A	F	A	350		99,900	81,500				
3	B	F	B	350		96,700	84,300				
3	C	F	C	350		94,600	81,200				
4	A	F	A	350		88,900	74,500				
4	B	F	B	350		89,500	75,600				
4	C	F	C	350		87,100	73,000				

F6NM

Table F.1—F6NM Test Results (Continued)

Heat Code	Cylinder	Barstock or Forging	Test Agency	Test temp. (°F)	VENDOR REPORTED RT YIELD	Tensile	Yield 2%	YS Avg. of Valid Heats at Temp.	YS Avg. of Valid Heats at Temp.	Test Temp. (°F)	YS Reduction Ratio
5	A	F	A	350		99,400	81,900				
5	B	F	B	350		101,000	85,400				
5	C	F	C	350		99,200	81,700				
1	A	B	A	450		89,500	77,000	77,400			
1	B	B	B	450		90,400	80,000				
1	C	B	C	450		89,200	76,500				
2	A	F	A	450		93,700	83,700				
2	B	F	B	450		94,000	83,100				
2	C	F	C	450		92,600	80,200				
3	A	F	A	450		94,400	81,500				
3	B	F	B	450		94,100	82,300				
3	C	F	C	450		92,800	79,500				
4	A	F	A	450		86,300	72,600				
4	B	F	B	450		85,300	71,900				
4	C	F	C	450		85,300	71,600				
5	A	F	A	450		96,800	81,200				
5	B	F	B	450		99,100	84,300				
5	C	F	C	450		96,200	80,900				

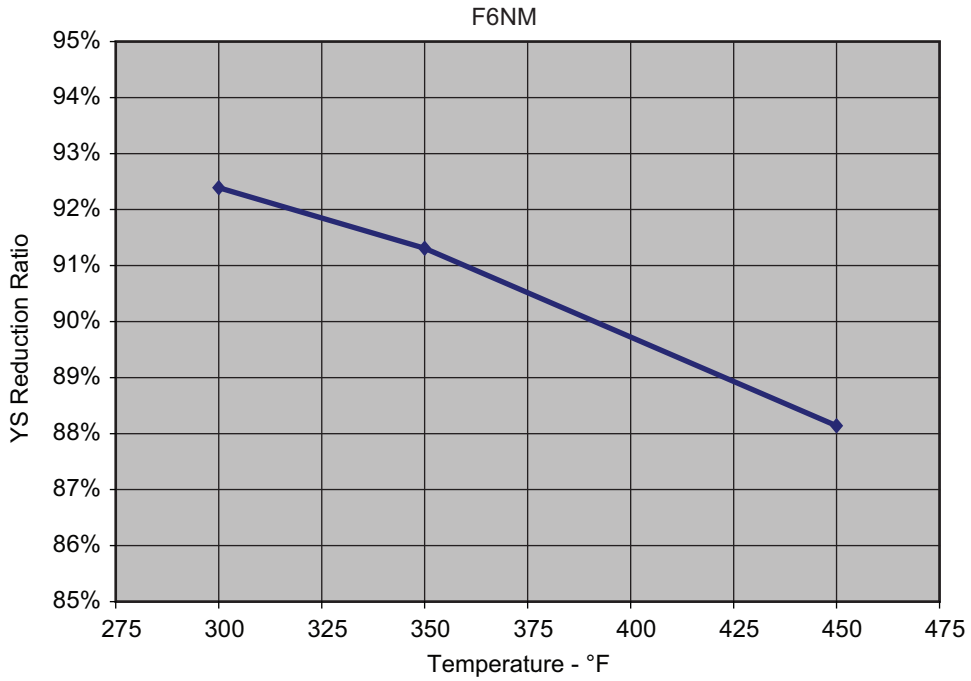


Figure F.1—Plot of F6NM Test Results

Annex G
(informative)

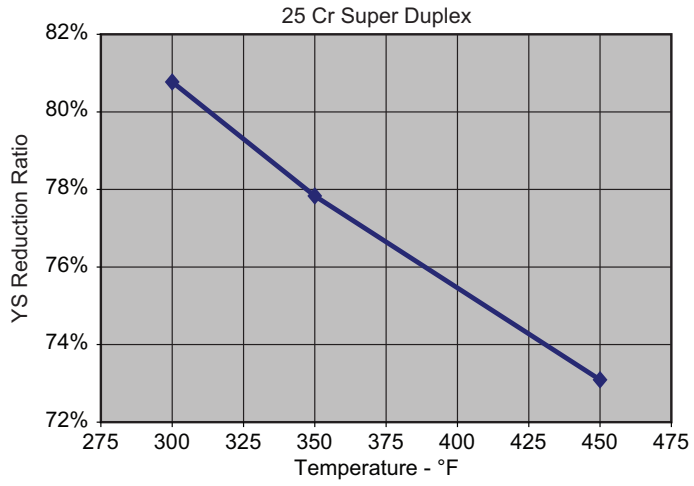
25 Chrome Super Duplex Test Results

Table G.1—25 Chrome Super Duplex Test Results

Material Code	Supplier Code	Heat Code	Test Agency	Test Temp. (F)	Vendor Reported RT Yield	Tensile	Yield 0.2%	YS Avg of All Heats at Temp	YS Reduction Ratio	Hardness 1	Hardness 2
1	A	1	A	75	95,000	121,200	94,100	89,627	100.0 %	255 HBW	285 HBW
1	A	1	B	75	95,000	115,500	83,800			229 HBW	241 HBW
1	A	1	C	75	95,000	117,800	86,100			19.7 HRC	20.0 HRC
1	B	2	A	75	91,200	120,200	88,600			269 HBW	269 HBW
1	B	2	B	75	91,200	120,200	100,300			255 HBW	255 HBW
1	B	2	C	75	91,200	121,400	87,600			22.7 HRC	23.7 HRC
1	C	3	A	75	84,000	122,400	94,400			255 HBW	255 HBW
1	C	3	B	75	84,000	113,000	88,900			241 HBW	241 HBW
1	C	3	C	75	84,000	115,100	79,000			20.7 HRC	19.7 HRC
1	D	4	A	75	91,400	122,300	92,200			255 HBW	255 HBW
1	D	4	B	75	91,400	121,600	99,900			262 HBW	262 HBW
1	D	4	C	75	91,400	120,900	87,400			23.3 HRC	22.7 HRC
1	E	5	A	75	87,800	116,400	86,800			255 HBW	241 HBW
1	E	5	B	75	87,800	114,900	88,100			255 HBW	248 HBW
1	E	5	C	75	87,800	117,300	87,200			19.7 HRC	20.0 HRC
1	A	1	A	300		105,100	71,600	72,320	80.7 %	255 HBW	241 HBW
1	A	1	B	300		100,500	69,100			229 HBW	255 HBW
1	A	1	C	300		101,400	65,800			20.0 HRC	21.7 HRC
1	B	2	A	300		103,600	74,500			269 HBW	262 HBW
1	B	2	B	300		105,600	76,600			255 HBW	262 HBW
1	B	2	C	300		105,100	65,900			22.7 HRC	25.0 HRC
1	C	3	A	300		99,300	68,100			241 HBW	241 HBW
1	C	3	B	300		100,200	77,200			248 HBW	248 HBW
1	C	3	C	300		98,900	67,200			20.7 HRC	23.0 HRC
1	D	4	A	300		108,200	78,700			262 HBW	255 HBW
1	D	4	B	300		105,700	77,100			269 HBW	269 HBW
1	D	4	C	300		104,600	71,600			23.0 HRC	22.3 HRC
1	E	5	A	300		97,900	72,000			255 HBW	241 HBW
1	E	5	B	300		101,600	81,800			248 HBW	235 HBW
1	E	5	C	300		98,900	67,600			20.0 HRC	19.7 HRC
1	A	1	A	350		98,300	60,500	69,813	77.9 %	248 HBW	241 HBW
1	A	1	B	350		100,300	69,600			229 HBW	255 HBW
1	A	1	C	350		100,500	62,400			20.3 HRC	22.0 HRC
1	B	2	A	350		101,800	67,900			262 HBW	262 HBW
1	B	2	B	350		105,400	75,200			255 HBW	269 HBW
1	B	2	C	350		101,700	66,900			23.3 HRC	24.0 HRC
1	C	3	A	350		98,900	69,300			248 HBW	241 HBW
1	C	3	B	350		99,100	75,800			248 HBW	262 HBW

Table G.1—25 Chrome Super Duplex Test Results (Continued)

Material Code	Supplier Code	Heat Code	Test Agency	Test Temp. (F)	Vendor Reported RT Yield	Tensile	Yield 0.2%	YS Avg of All Heats at Temp	YS Reduction Ratio	Hardness 1	Hardness 2
1	C	3	C	350		97,500	63,700			21.3 HRC	20.3 HRC
1	D	4	A	350		104,600	79,900			262 HBW	255 HBW
1	D	4	B	350		104,600	83,300			262 HBW	262 HBW
1	D	4	C	350		102,800	71,600			23.7 HRC	23.7 HRC
1	E	5	A	350		98,600	68,700			255 HBW	241 HBW
1	E	5	B	350		99,600	69,400			248 HBW	248 HBW
1	E	5	C	350		96,000	63,000			20.7 HRC	20.0 HRC
1	A	1	A	450		99,600	63,800	65,473	73.1 %	255 HBW	241 HBW
1	A	1	B	450		100,100	66,300			229 HBW	255 HBW
1	A	1	C	450		100,500	58,700			20.0 HRC	20.0 HRC
1	B	2	A	450		98,900	65,500			269 HBW	262 HBW
1	B	2	B	450		96,000	65,600			255 HBW	255 HBW
1	B	2	C	450		103,000	65,700			23.3 HRC	24.3 HRC
1	C	3	A	450		94,600	60,200			255 HBW	241 HBW
1	C	3	B	450		97,700	66,600			241 HBW	241 HBW
1	C	3	C	450		98,800	58,000			19.7 HRC	19.7 HRC
1	D	4	A	450		99,000	67,400			262 HBW	255 HBW
1	D	4	B	450		103,200	76,100			262 HBW	262 HBW
1	D	4	C	450		103,400	68,200			22.7 HRC	23.3 HRC
1	E	5	A	450		93,300	62,800			248 HBW	241 HBW
1	E	5	B	450		105,700	76,000			241 HBW	255 HBW
1	E	5	C	450		98,500	61,200			21.0 HRC	21.3 HRC



300	80.7 %
350	77.9 %
400	75.5 %
450	73.1 %

Interpolated

300	81 %
350	78 %
400	76 %

Rounded Results

Figure G.1—Plot of 25 Chrome Super Duplex Test Results

Annex H
(informative)

ASTM A453 Gr. 660 Test Results

Table H.1—ASTM A453 Gr. 660 Test Results

Material Code	Supplier Code	Heat Code	Test Agency	Test Temp. (°F)	Vendor Reported RT Yield	Bar Dia.- in.	Tensile	Yield 0.2%	YS Avg of All Heats at Temp	YS Reduction Ratio	Hardness 1	Hardness 2
2	A	1	A	75	116,300	0.75	167,900	122,100	111,873	100.0 %	321 HBW	321 HBW
2	A	1	B	75	116,300	0.75	164,000	120,200			321 HBW	321 HBW
2	A	1	C	75	116,300	0.75	163,600	121,600			33.7 HRC	32.7 HRC
2	B	2	A	75	108,200	1.00	162,600	96,700			293 HBW	302 HBW
2	B	2	B	75	108,200	1.00	160,000	98,800			302 HBW	293 HBW
2	B	2	C	75	108,200	1.00	162,700	100,200			30.3 HRC	30.0 HRC
2	C	3	A	75	106,000	1.25	166,600	111,200			321 HBW	321 HBW
2	C	3	B	75	106,000	1.25	167,400	112,600			321 HBW	321 HBW
2	C	3	C	75	106,000	1.25	167,100	112,300			33.0 HRC	34.3 HRC
2	D	4	A	75	106,000	1.38	157,800	104,500			302 HBW	302 HBW
2	D	4	B	75	106,000	1.38	158,000	103,900			302 HBW	302 HBW
2	D	4	C	75	106,000	1.38	158,900	108,900			30.3 HRC	31.0 HRC
2	E	5	A	75	118,000	1.50	173,000	121,200			341 HBW	321 HBW
2	E	5	B	75	118,000	1.50	166,600	122,300			321 HBW	321 HBW
2	E	5	C	75	118,000	1.50	165,500	121,600			33.0 HRC	33.7 HRC
2	A	1	A	300			156,000	118,500	110,460	98.7 %	321 HBW	321 HBW
2	A	1	B	300			156,400	120,700			321 HBW	321 HBW
2	A	1	C	300			155,500	116,500			33.3 HRC	34.7 HRC
2	B	2	A	300			150,500	120,800			302 HBW	302 HBW
2	B	2	B	300			154,400	97,800			302 HBW	302 HBW
2	B	2	C	300			152,500	97,000			29.7 HRC	30.7 HRC
2	C	3	A	300			160,500	108,800			321 HBW	321 HBW
2	C	3	B	300			158,400	110,000			321 HBW	321 HBW
2	C	3	C	300			159,500	106,800			33.0 HRC	33.7 HRC
2	D	4	A	300			144,900	90,300			302 HBW	302 HBW
2	D	4	B	300			151,000	109,800			302 HBW	321 HBW
2	D	4	C	300			150,500	101,300			30.3 HRC	32.0 HRC
2	E	5	A	300			162,700	122,200			341 HBW	321 HBW
2	E	5	B	300			157,700	122,800			321 HBW	311 HBW
2	E	5	C	300			156,900	113,600			32.7 HRC	34.7 HRC
2	A	1	A	350			134,100	98,500	106,458	95.2 %	321 HBW	321 HBW
2	A	1	B	350			154,800	118,400			321 HBW	321 HBW
2	A	1	C	350			151,600	115,000			33.0 HRC	33.7 HRC
2	B	2	A	350			143,700	86,300*			293 HBW	302 HBW
2	B	2	B	350			151,400	92,900			302 HBW	293 HBW
2	B	2	C	350			150,700	97,000			30.0 HRC	30.0 HRC
2	C	3	A	350			158,600	124,900*			321 HBW	321 HBW
2	C	3	B	350			156,000	106,200			321 HBW	321 HBW

Table H.1—ASTM A453 Gr. 660 Test Results (Continued)

Material Code	Supplier Code	Heat Code	Test Agency	Test Temp. (°F)	Vendor Reported RT Yield	Bar Dia.- in.	Tensile	Yield 0.2%	YS Avg of All Heats at Temp	YS Reduction Ratio	Hardness 1	Hardness 2
2	C	3	C	350			161,000	108,700			33.0 HRC	32.7 HRC
2	D	4	A	350			150,800	105,200			302 HBW	302 HBW
2	D	4	B	350			148,800	106,900			302 HBW	302 HBW
2	D	4	C	350			149,600	103,100			29.7 HRC	32.7 HRC
2	E	5	A	350			158,400	123,300*			341 HBW	321 HBW
2	E	5	B	350			156,800	111,100			321 HBW	321 HBW
2	E	5	C	350			155,000	114,500			32.7 HRC	34.7 HRC
2	A	1	A	450			156,000	124,300*	108,658	97.1 %	321 HBW	321 HBW
2	A	1	B	450			152,300	117,400			321 HBW	321 HBW
2	A	1	C	450			144,400	116,800			32.7 HRC	34.3 HRC
2	B	2	A	450			148,500	117,200			285 HBW	302 HBW
2	B	2	B	450			149,300	87,600*			302 HBW	302 HBW
2	B	2	C	450			147,600	93,900*			30.0 HRC	30.3 HRC
2	C	3	A	450			154,100	106,100			321 HBW	321 HBW
2	C	3	B	450			149,500	100,700			321 HBW	311 HBW
2	C	3	C	450			154,100	103,000			32.7 HRC	33.0 HRC
2	D	4	A	450			147,300	105,600			302 HBW	302 HBW
2	D	4	B	450			144,200	96,800			302 HBW	311 HBW
2	D	4	C	450			147,200	99,500			31.0 HRC	32.3 HRC
2	E	5	A	450			156,100	117,500			341 HBW	321 HBW
2	E	5	B	450			151,600	107,600			321 HBW	321 HBW
2	E	5	C	450			153,800	115,700			32.3 HRC	34.3 HRC

*Rejected

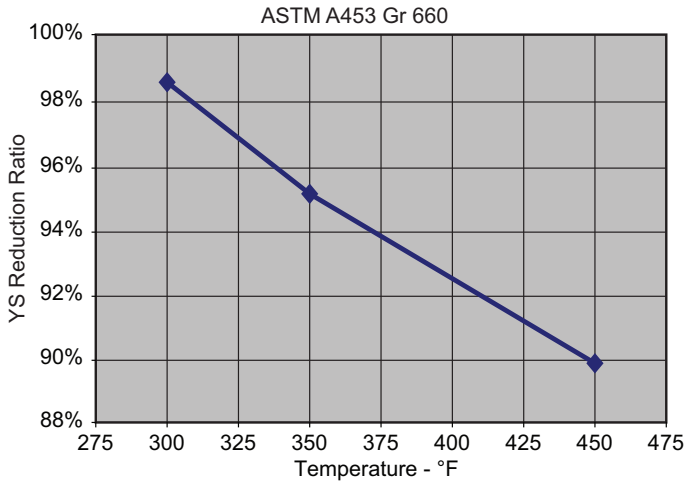


Figure H.1—Plot of ASTM A453 Gr. 660 Test Results

300	98.7 %
350	95.2 %
400	96.1 %
450	97.1 %

Interpolated

300	99 %
350	95 %
400	96 %

Rounded Results

Annex I
(informative)

718 (per Spec 6A718) Test Results

Table I.1—718 (per Spec 6A718) Test Results

Material Code	Supplier Code	Heat Code	Test Agency	Test Temp. (°F)	Vendor Reported RT Yield	Tensile	Yield 0.2%	YS Avg of All Heats at Temp	YS Reduction Ratio	Hardness 1	Hardness 2
3	A	1	A	75	130,000	183,400	134,800	134,200	100.0 %	352 HBW	331 HBW
3	A	1	B	75	130,000	181,800	135,100			341 HBW	341 HBW
3	A	1	C	75	130,000	182,400	132,300			37.3 HRC	36.3 HRC
3	B	2	A	75	135,000	183,500	133,800			331 HBW	341 HBW
3	B	2	B	75	135,000	182,400	129,900			341 HBW	352 HBW
3	B	2	C	75	135,000	178,700	130,500			36.7 HRC	35.3 HRC
3	C	3	A	75	133,400	188,100	137,900			363 HBW	341 HBW
3	C	3	B	75	133,400	175,400	119,700*			341 HBW	341 HBW
3	C	3	C	75	133,400	185,600	129,300			37.3 HRC	37.7 HRC
3	D	4	A	75	132,700	184,000	136,200			341 HBW	341 HBW
3	D	4	B	75	132,700	179,300	129,900			341 HBW	341 HBW
3	D	4	C	75	132,700	184,100	136,800			37.3 HRC	36.0 HRC
3	E	5	A	75	135,800	177,200	136,300			352 HBW	341 HBW
3	E	5	B	75	135,800	182,900	136,000			341 HBW	341 HBW
3	E	5	C	75	135,800	183,600	140,000			37.3 HRC	36.7 HRC
3	A	1	A	300		172,400	130,200	126,429	94.2 %	352 HBW	331 HBW
3	A	1	B	300		171,500	128,400			341 HBW	341 HBW
3	A	1	C	300		170,800	118,800			36.7 HRC	37.3 HRC
3	B	2	A	300		171,600	125,500			352 HBW	341 HBW
3	B	2	B	300		175,200	123,800			341 HBW	341 HBW
3	B	2	C	300		169,500	122,000			37.0 HRC	36.7 HRC
3	C	3	A	300		171,800	123,200			363 HBW	341 HBW
3	C	3	B	300		177,700	133,500			341 HBW	341 HBW
3	C	3	C	300		177,400	127,000			37.0 HRC	36.7 HRC
3	D	4	A	300		172,600	130,700			352 HBW	341 HBW
3	D	4	B	300		170,800	124,900			341 HBW	341 HBW
3	D	4	C	300		174,400	127,000			37.3 HRC	38.3 HRC
3	E	5	A	300		169,000	165,700*			352 HBW	341 HBW
3	E	5	B	300		173,600	130,500			341 HBW	352 HBW
3	E	5	C	300		170,600	124,500			37.0 HRC	35.7 HRC
3	A	1	A	350		169,200	120,200	124,508	92.8 %	341 HBW	331 HBW
3	A	1	B	350		171,000	134,600			341 HBW	341 HBW
3	A	1	C	350		170,400	122,000			37.3 HRC	37.3 HRC
3	B	2	A	350		160,500	137,600*			341 HBW	341 HBW
3	B	2	B	350		171,500	122,100			341 HBW	352 HBW
3	B	2	C	350		171,500	122,000			37.3 HRC	38.0 HRC
3	C	3	A	350		167,500	120,700			363 HBW	341 HBW
3	C	3	B	350		174,800	123,800			341 HBW	352 HBW

Table I.1—718 (per Spec 6A718) Test Results (Continued)

Material Code	Supplier Code	Heat Code	Test Agency	Test Temp. (°F)	Vendor Reported RT Yield	Tensile	Yield 0.2%	YS Avg of All Heats at Temp	YS Reduction Ratio	Hardness 1	Hardness 2
3	C	3	C	350		175,900	121,000			38.0 HRC	38.3 HRC
3	D	4	A	350		171,600	128,000			363 HBW	341 HBW
3	D	4	B	350		169,800	127,400			341 HBW	352 HBW
3	D	4	C	350		172,200	125,700			37.3 HRC	38.0 HRC
3	E	5	A	350		167,400	151,900*			352 HBW	341 HBW
3	E	5	B	350		168,100	126,300			341 HBW	352 HBW
3	E	5	C	350		171,300	124,800			36.3 HRC	35.7 HRC
3	A	1	A	450		165,300	121,400	122,095	91.0 %	341 HBW	331 HBW
3	A	1	B	450		167,900	118,130			341 HBW	341 HBW
3	A	1	C	450		167,400	116,700			37.3 HRC	36.3 HRC
3	B	2	A	450		170,700	128,100			341 HBW	341 HBW
3	B	2	B	450		169,300	129,900			341 HBW	352 HBW
3	B	2	C	450		167,000	116,700			36.7 HRC	37.0 HRC
3	C	3	A	450		164,800	114,100			352 HBW	341 HBW
3	C	3	B	450		174,800	115,200			341 HBW	352 HBW
3	C	3	C	450		168,000	112,900			37.0 HRC	35.0 HRC
3	D	4	A	450		167,700	127,500			352 HBW	341 HBW
3	D	4	B	450		166,400	123,300			341 HBW	341 HBW
3	D	4	C	450		169,700	128,300			37.3 HRC	38.0 HRC
3	E	5	A	450		162,200	126,400			363 HBW	341 HBW
3	E	5	B	450		163,000	126,800			341 HBW	352 HBW
3	E	5	C	450		170,200	126,000			37.0 HRC	38.3 HRC

*Rejected

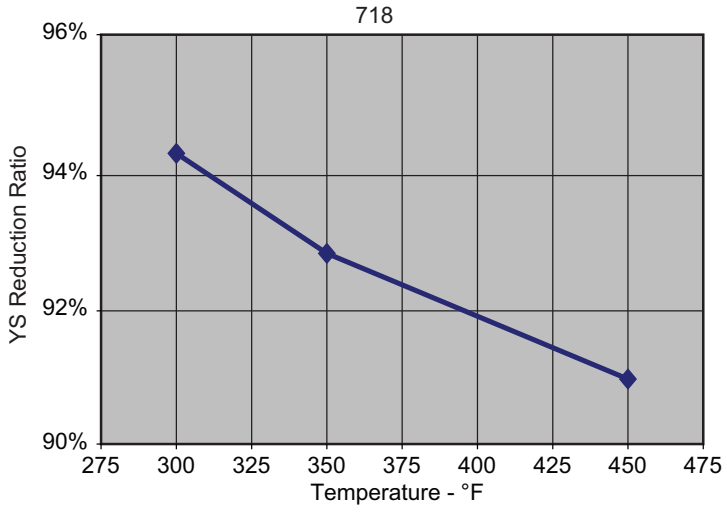


Figure I1—Plot of 718 (per Spec 6A718) Test Results

300	94.2 %
350	92.8 %
400	91.9 %
450	91.0 %

Interpolated

300	94 %
350	93 %
400	92 %

Rounded Results

Annex J
(informative)

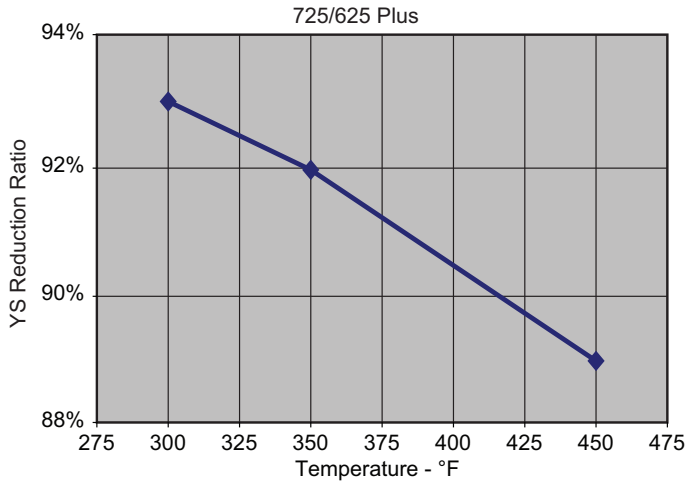
725/625 Plus Test Results

Table J.1—725/625 Plus Test Results

Supplier Code	Heat Code	Test Agency	Test Temp. (°F)	Vendor Reported RT Yield, Ksi	Tensile, Ksi	Yield 0.2, Ksi	YS Avg of All Heats at Temp, Ksi	YS Reduction Factor	Hardness 1 (HRC)	Hardness 2 (HRC)
C	1	C	75	136.1	178.7	134.9	130.3		39	37
C	2	C	75	134.1	176.9	140.8			38	28
D	3	C	75	125.3	186.0	128.9			29	30
A	4	C	75	123.9	177.8	127.8			26	27
A	5	C	75	127.0	181.0	132.4			27	26
A	6	C	75	127.1	184.3	122.2			31	31
A	7	C	75	124.9	181.7	124.9			37	36
C	1	C	300			136.2	120.8	0.93	34	36
C	2	C	300			125.8			29	32
D	3	C	300			117.2			35	28
A	4	C	300			118.5			27	35
A	5	C	300			121.8			34	37
A	6	C	300			114.7			36	38
A	7	C	300			111.4			37	36
C	1	C	350			128.3	120.2	0.92	33	37
C	2	C	350			127.2			33	35
D	3	C	350			123.4			37	25
A	4	C	350			117.8			35	32
A	5	C	350			123.4			31	37
A	6	C	350			111.1			37	36
A	7	C	350			110.2			33	37
C	1	C	450			125.4	116.4	0.89	37	37
C	2	C	450			121.1			31	37
D	3	C	450			116.8			32	35
A	4	C	450			114.7			37	35
A	5	C	450			115.7			34	36
A	6	C	450			110.5			33	35
A	7	C	450			110.4			37	36

Table J.1—725/625 Plus Test Results

Supplier Code	Heat Code	Test Agency	Test Temp. (°F)	Vendor Reported RT Yield, Ksi	Tensile, Ksi	Yield 0.2, Ksi	YS Avg of All Heats at Temp, Ksi	YS Reduction Factor	Hardness 1 (HRC)	Hardness 2 (HRC)



300	93 %	
350	92 %	
400	90 %	Interpolated
450	89 %	

300	93 %	
350	92 %	Rounded Results
400	89 %	

Figure J.1—Plot of 725/625 Plus Test Results

Annex K
(informative)

925 Test Results

Table K.1—925 Test Results

Supplier Code	Heat Code	Test Agency	Test Temp. (°F)	Vendor Reported RT Yield	Tensile	Yield 0.2%	YS Avg of All Heats at Temp	YS Reduction %	Hardness 1	Hardness 2
A	1	C	75	117.2	175.8	121.0	116.4		30	30
B	2	C	75	116.0	170.0	110.1			28	31
B	3	C	75	116.0	159.0	117.9			33	32
B	4	C	75	116.0	159.0	109.1			29	22
B	5	C	75	115.0	160.0	114.6			25	21
B	6	C	75	113.0	152.0	119.0			28	30
C	7	C	75	119.1	168.8	118.2			30	32
D	8	C	75	119.0	170.0	119.3			26	28
A	1	C	300			110.7	106.8	92	30	30
B	2	C	300			104.0			32	29
B	3	C	300			105.3			30	28
B	4	C	300			101.7			28	27
B	5	C	300			100.9			29	28
B	6	C	300			110.3			27	27
C	7	C	300			111.5			28	28
D	8	C	300			109.8			25	29
A	1	C	350			110.2	106.9	92	32	37
B	2	C	350			107.4			26	31
B	3	C	350			104.2			30	29
B	4	C	350			101.9			29	31
B	5	C	350			101.6			29	28
B	6	C	350			111.1			30	29
C	7	C	350			109.1			29	26
D	8	C	350			109.3			25	29

Table K.1—925 Test Results

Supplier Code	Heat Code	Test Agency	Test Temp. (°F)	Vendor Reported RT Yield	Tensile	Yield 0.2%	YS Avg of All Heats at Temp	YS Reduction %	Hardness 1	Hardness 2
A	1	C	450			107.8	104.8	90	32	32
B	2	C	450			103.3			33	29
B	3	C	450			105.7			31	28
B	4	C	450			99.1			24	27
B	5	C	450			100.2			27	37
B	6	C	450			107.3			26	28
C	7	C	450			105.6			32	30
D	8	C	450			109.1			29	34

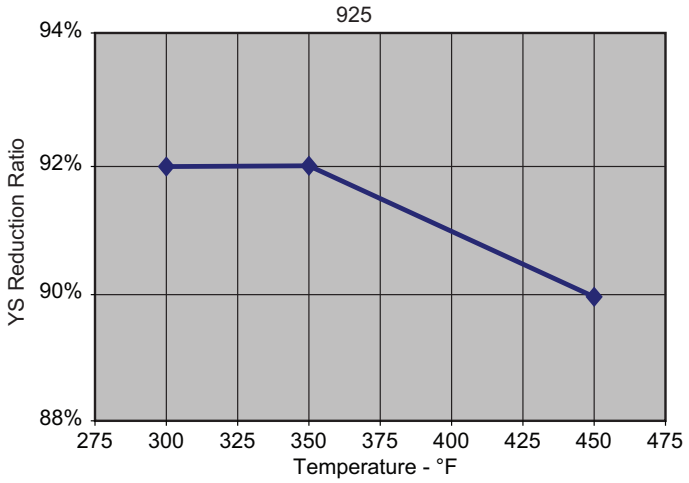


Figure K.1—Plot of 925 Test Results

300	92 %
350	92 %
400	91 %
450	90 %

Interpolated

300	92 %
350	92 %
400	90 %

Rounded Results

Bibliography

[1] API Specification 6A, *Specification on Wellhead and Christmas Tree Equipment*, 19th Edition, Annex G.

[2] ASTM E21 [1], *Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials*

[1] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

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