ALLOY 601

Nickel-chromium-iron ALLOY 601 (UNS N06601/W.Nr. 2.4851) is a general-purpose engineering material for applications that require resistance to heat and corrosion. An outstanding characteristic of ALLOY 601 is its resistance to high temperature oxidation. The alloy also has good resistance to aqueous corrosion, has high mechanical strength, and is readily formed, machined and welded. The limiting chemical composition of ALLOY 601 is listed in Table 1. The composition is a facecentered-cubic solid solution with a high degree of metallurgical stability. The alloy's nickel base, in conjunction with substantial chromium content, provides resistance to many corrosive media and high temperature environments. Oxidation resistance is further enhanced by the aluminum content.
The properties of ALLOY 601 make it a material of broad utility in such fields as thermal processing, chemical processing, pollution control, aerospace, and power generation. Alloy 601 is a standard material of construction for various types of thermal-processing equipment. Industrial-heating applications include baskets, trays, and fixtures for annealing, carburizing, carbonitriding, nitriding and other heat-treating operations. In industrial furnaces, the alloy is used for radiant tubes, muffles, retorts, flame shields, strand-annealing tubes, woven-wire conveyor belts, chain curtains, burner nozzles, and electrical resistance heating elements. Other thermal-processing applications are thermocouple protection tubes, furnace-atmosphere generators, and infrared radiant screens.
Chemical-processing applications for ALLOY 601 include process heaters, condenser tubes in sour-water strippers, and insulating cans in ammonia reformers. The alloy is also used for combustor components and catalyst grid supports in equipment for nitric acid production.
In petrochemical processing, the alloy is used for catalyst regenerators and air preheaters in the manufacture of high-density polyethylene.
In pollution-control applications, ALLOY 601 is used for thermal reactors in exhaust systems of gasoline engines and for combustion chambers in solid waste cinerators.
In the power-generation field, alloy 601 is used for super heater tube supports, grid barriers, and ash handling systems.
The alloy is also used for jet-engine igniters and for combustion-can liners, diffuser assembles, and containment rings in gas turbines for aircraft, industrial, and vehicular applications.

Physical Constants and Thermal Properties
Some physical constants for ALLOY 601 are listed in Table 2. Thermal and electrical properties at room and elevated temperatures are given in Table 3. Values shown for thermal conductivity were calculated from measurements of electrical resistivity. Specific-heat values were calculated from chemical composition.
Thermal-expansion coefficients were determined on a Leitz dilatometer; values were corrected for expansion of the quartz specimen holder. Each coefficient listed is the average coefficient over the indicated temperature range. The effect of temperature on the modulus of elasticity of ALLOY 601 is shown in Table 4.
The data were obtained by the dynamic method. The values listed for Poisson's ratio were calculated from moduli of elasticity.
All data reported for physical constants and thermal properties were determined for annealed material.

Mechanical Properties
ALLOY 601 has good mechanical strength. Nominal mechanical-property ranges for various products are shown in Table 5. As indicated by those values, the strength level exhibited by the alloy varies with the form and condition of the material.
The optimum condition for ALLOY 601 depends on the type of application and the service temperature involved. In general, the solution-treated condition is used for rupture-limited applications (temperatures of about 1000°F (540°C) and higher). The annealed condition is normally used for tensile-limited applications (temperatures below about 1000°F (540°C)).

Tensile Properties
ALLOY 601 has high tensile properties at room temperature and retains much of its strength at elevated temperatures. Typical room-temperature tensile properties of annealed material are listed in Table 6. Values are shown for both hot-finished and cold-rolled material annealed at different temperatures.
Room-temperature tensile properties of rod and bar in the hot-finished condition are given in Table 7. The tests were performed on longitudinal specimens from midway between the center and surface of the piece. Table 8 gives room-temperature properties of various product forms in the solution-treated condition.
Tensile properties of hot-finished rod annealed at 2000°F (1090°C) are given for temperatures to 1000°F (540°C) in Table 9. The test specimens were from 0.625in. (16-mm) rod having a room-temperature hardness of 80 Rb.
High-temperature properties of solution-treated (2100°F) (1150°C) material are shown in Figure 1. The tests were performed on specimens from 0.625-in. (16mm) diameter rod. Room-temperature hardness of the material was 81 Rb.

Impact Strength
ALLOY 601 is not embrittled by extended exposure to high temperatures. Table 10 shows the impact strength of the alloy after long-time exposure to temperatures from 1000 to 1600°F (540 to 870°C). The specimens retained relatively high impact strengths even after 1000 hr of exposure. The material tested was solution-treated 0.625-in. (16-mm) diameter hotfinished rod.
The results of Charpy V-notch impact tests on hot-finished rod in the annealed and solution-treated conditions are given in Table 11. Tensile properties of the material tested are also shown.

Fatigue Strength
The rotating-beam fatigue strength of ALLOY 601 in two conditions is shown in Figure 2. As indicated by the curves, annealed material has higher fatigue strength than solution-treated material.
The data for annealed material in Figure 2 were determined on 0.500-in. (13-mm) diameter hot-finished rod given an annealing treatment of 1800°F (980°C)/1 hr, A.C.

The material had a hardness of 89 Rb, a grain size of ASTM 8, and the following tensile properties:

Tensile Strength	113.8 ksi (785 MPa)
Yield Strength (0.2% Offset)	60.1 ksi (414 MPa)
Elongation	41%

The solution-treated material used to establish Figure 2 was 0.500-in. (13-mm) hot-finished rod heat-treated at 2200°F (1200°C)/1 hr, A.C. The material had a hardness of 64 Rb, a grain size of ASTM 2, and tensile properties of:

Tensile Strength	90.1 ksi (621 MPa)
Yield Strength (0.2% Offset)	29.9 ksi (206 MPa)
Elongation	61%

The results of cantilever-beam fatigue tests on annealed (1900°F) (1040°C) cold-rolled sheet are given in Figure 3. Transverse specimens having a hardness of 86 Rb and a grain size of ASTM 8 were used for the tests. Tensile properties were:

Tensile Strength	111 ksi (765 MPa)
Yield Strength (0.2% Offset)	59.5 ksi (410 MPa)
Elongation	36%

Low-cycle fatigue properties of ALLOY 601 at room temperature and 1400°F (760°C) are shown in Figure 4. The material tested was 0.125 in. x 2.0 in. (3.2 mm x 51 mm) hot-finished flat. The curves represent both annealed and solution-treated material.

Creep and Rupture Properties

ALLOY 601 has good creep-rupture strength, and the alloy is widely used for equipment that must withstand extended exposure to high temperatures. The alloy's usefulness for such applications is increased by its resistance to oxidation and other forms of high-temperature corrosion.

The rupture strength of solution-treated ALLOY 601 at various temperatures is illustrated by the Larson-Miller parameter presentation in Figure 5. Creep properties of the alloy at temperatures to 2000°F (1090°C) are shown in Figure 6. Rupture life of solution-treated material at various stresses and temperatures is shown in Figure 7. All creep and rupture properties were determined for material given a heat treatment of 2100°F (1150°C)/1 hr, A.C.

Microstructure

ALLOY 601 is a face-centered-cubic, solid-solution alloy with a high degree of metallurgical stability. Phases normally present in the alloy's microstructure include chromium carbides and titanium nitrides. Figure 8 shows the microstructure of solution-treated hot-finished rod. The large block-like structure visible in the photomicrograph is a particle of titanium nitride. The scattered small particles are chromium carbides.

ALLOY 601 has shown complete absence of embrittling intermetallic phases such as sigma.

Corrosion Resistance

The substantial nickel and chromium contents of ALLOY 601 in conjunction with its content of aluminium give the alloy superior resistance to high temperature corrosion mechanisms. Of particular significance is its resistance to oxidation at temperatures up to 2200°F (1200°C). By virtue of its contents of chromium and aluminium, ALLOY 601 offers unique resistance to oxide spalling under cyclic thermal conditions.

Oxidation
ALLOY 601 has exceptional resistance to oxidation at high temperatures. The alloy forms a protective oxide coating that resists scaling even under the severe conditions of cyclic exposure to temperature.
Figure 9 compares the performance of ALLOY 601 with the behavior of other oxidation-resistant materials in a cyclic oxidation test at 2000°F (1095°C). The specimens were subjected to cycles of exposure to 2000°F(1095°C) for 15 min and rapid cooling in air for 5 min. Weight change was determined periodically throughout the test.
The resistance of ALLOY 601 to oxidation at temperatures of 2100°F (1150°C) and 2200°F (1200°C) is illustrated in Figures 10 and 11. The data were derived from tests in which the specimens were exposed to temperature for ten consecutive 50-hr periods. After each exposure period, the specimens were cooled to room temperature, brushed lightly to remove loose oxide, and then weighed to determine weight change.
The superior oxidation resistance of ALLOY 601 is related to the amounts of nickel, chromium, and aluminium in the alloy. During high-temperature exposure, those elements form an extremely protective and adherent oxide film on the surface of the material. In addition, a slight amount of internal oxidation occurs and provides a higher chromium content in the surface oxide. The protective oxide layer is illustrated in Figures 12 and 13, which are unetched photomicrographs of the cross-sections of specimens exposed to high temperatures.

Carburization
ALLOY 601 has good resistance to carburization. Tables 13 and 14 give the results of gas carburization tests performed at three different temperatures. The weight-gain measurements indicate the amount of carbon adsorbed by the specimens during the exposure periods. ALLOY 601 also has good resistance to carbonitriding environments. Table 15 gives the results of tests performed in a gas mixture of 5% ammonia, 2% methane, and 93% hydrogen at 2000°F (1095°C).

Sulfidation
The resistance of ALLOY 601 to sulfidation in an atmosphere of 1.5 % hydrogen sulphide and 98.5 % hydrogen at temperatures from 1200 to 1400°F (650-760°C) is shown in figure 14. The weight-loss measurements are for completely descaled specimens after 100 hr of exposure to the environment.

Working Instructions
ALLOY 601 is readily formed, machined, and welded by standard procedures. Welding products are available which provide performance comparable to that of the base metal in all service environments.

Heating and Pickling
Like other high-nickel alloys, ALLOY 601 must be clean before it is heated. All foreign substances such as grease, oil, paint, and shop soil must be removed from the material before a heating operation is performed.
The alloy must be heated in a low-sulfur atmosphere. Fuels for open heating must be low in sulfur. To prevent excessive oxidation of the material, the furnace atmosphere should also be slightly reducing.
ALLOY 601 is not strengthened by heat treatment. Broad ranges of strength and hardness, however, can be achieved with the alloy by the combination of cold work and annealing treatments. The amount of cold work and the section size of the material must be considered in establishing an annealing procedure.

Figure 15 shows the effects of annealing temperature on the mechanical properties and grain size of a 0.750-in. (19mm) diameter hot-finished rod. The specimens were annealed at the indicated temperatures for 30 min and aircooled before being tested.
The effects of annealing temperature on the tensile properties of cold-drawn (45% reduction) wire are shown in Table 20. The finished size of the wire was 0.184-in. (4.67 mm). The material was annealed at the listed temperatures for 2 min and water-quenched.
The rate of cooling after heating has little effect on the mechanical properties of ALLOY 601. However, if the material is to be pickled or exposed to other aggressive environments, it should be cooled rapidly through the 10001400°F (540-760°C) temperature range to avoid sensitization.
Because of its aluminium and chromium contents, ALLOY 601 readily forms a refractory surface oxide during heating and cannot be bright-annealed in the usual industrial furnace. Pickling is normally required to produce bright surfaces on parts that have been heated. Specialized pickling procedures are required for ALLOY 601 because of its inherent resistance to chemical attack. The light oxide on material that has been annealed and cooled away from contact with air, as in hydrogen, can usually be removed by the nitric/hydrofluoric acid solution described in Table 21.
Heavy oxide, such as that resulting from hot-working operations, should be removed with the pickling procedure given in Table 22.

Hot and Cold Forming
The temperature range for hot-forming ALLOY 601 is 1600-2250°F (870-1230°C). Hot-working operations involving large deformations should be performed at 1900-2250°F (1040-1230°C). The alloy has low ductility at temperatures from 1200 to 1600°F (650-870°C) and should not be worked in that range.
Light working at temperatures below 1200°F (650°C) can be done to develop high tensile properties. Table 23 shows the effect of hot-working temperature on the mechanical properties of ALLOY 601. The material was hot-worked from 6-in. (152- mm) diameter rounds to 4-in. (102-mm) squares and air-cooled. Transverse specimens from the centers of the bars were used for the tests.
The rate of cooling following hot-working is not critical with respect to thermal cracking. To avoid sensitization, however, the alloy should be cooled rapidly through the 1000-1400°F (540-760°C) temperature range.
ALLOY 601 is cold-formed by conventional procedures. The alloy's work-hardening rate, shown in Figure 16, is somewhat higher than the rate for ALLOY 600 and ALLOY 800. Table 24 gives tensile properties of colddrawn wire after various amounts of cold reduction.

Machining
All standard machining operations are readily performed on ALLOY 601. For the best machinability, the alloy should be in the solution-treated condition.

Joining
ALLOY 601 exhibits good weldability and is readily joined by conventional welding products and processes. Welding can be by gas tungsten-arc, gas metal-arc, submerged-arc and shielded metal-arc processes.

Table 1 - Limiting Chemical Composition, %, of alloy 601

Nickel	58.0-63.0
Chromium	21.0-25.0
Iron	Remainder
Aluminum	1.0-1.7
Carbon	0.10 max.
Manganese	1.0 max.
Sulfur	0.015 max.
Silicon	0.50 max.
Copper	1.0 max.

Table 2 - Physical Constants

Density, lb/in.^{3}	0.293
Mg/m^3	8.11
Melting Range, °F	2480-2571
°C	1360-1411
Specific Heat, 70°F, Btu/lb-°F	0.107
21°C, J/kg-°C	448
Permeability at 200 oersted (15.9 kA/m)	
76°F (24°C)	1.003
-109°F (-78°C)	1.004
-320°F (-196°C)	1.016
Curie Temperature, °F	<-320
°C	<-196

Table 3 - Thermal Properties of alloy 601

Temperature, °F	Electrical Resistivity ohm-circ mil/ft	Thermal Conductivity[a] Btu-in./ft^2-hr-°F	Coefficient of Expansion[b] 10^{-6} in./in./°F	Specific Heat Btu/lb-°F
70	710	78	-	0.107
200	716	87	7.60	0.112
400	727	100	8.01	0.119
600	735	113	8.11	0.126
800	741	126	8.30	0.133
1000	747	139	8.50	0.140
1200	751	153	8.87	0.147
1400	751	165	9.19	0.155
1600	754	178	9.51	0.162
1800	758	190	9.82	0.169
2000	763	203	10.18	0.176
°C	μΩ-m	W/m-°C	μm/m/°C	J/kg-°C
20	1.180	11.2	-	448
100	1.192	12.7	13.75	469
200	1.207	14.3	14.36	498
300	1.220	16.0	14.58	523
400	1.229	17.7	14.83	548
500	1.239	19.5	15.19	578
600	1.247	21.0	15.62	603
700	1.249	22.8	16.11	632
800	1.249	24.4	16.67	657
900	1.259	26.1	17.24	686
1000	1.262	27.8	17.82	712

[a]Calculated from electrical resistivity.
[b]Average coefficient between 80°F (27 °C) and temperature shown.

Table 4 - Modulus of Elasticity

Temperature, °F	Modulus of Elasticity, 10^3 ksi		Poisson's Ratio[a]	Temperature, °C	Modulus of Elasticity, GPa		Poisson's Ratio[a]
	Tension	Torsion			Tension	Torsion	
70	29.95	11.77	0.272	20	206.5	81.2	0.272
200	29.42	11.49	0.280	100	202.4	79.2	0.278
400	28.50	11.10	0.284	200	196.8	76.5	0.286
600	27.59	10.67	0.293	300	191.2	73.8	0.296
800	26.57	10.21	0.301	400	184.8	71.2	0.299
1000	25.43	9.68	0.314	500	178.2	68.1	0.308
1200	24.12	9.05	0.333	600	170.8	64.3	0.327
1400	22.48	8.32	0.351	700	161.3	60.2	0.340
1600	20.54	7.52	0.366	800	150.2	55.6	0.350
1800	18.43	6.63	0.390	900	137.9	50.3	0.370
2000	16.20	5.68	0.426	1000	124.7	44.7	0.395

[a]Calculated from modulus of elasticity.

Table 5 - Nominal Room-Temperature Mechanical-Property Ranges[a]

Form and Condition	Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Hardness, Rb
	ksi	MPa	ksi	MPa		
ROD and BAR						
Hot-Finished	85-120	585-825	35-100	240-690	60-15	65-95
Annealed	80-115	550-790	30-60	205-415	70-40	60-80
PLATE						
Annealed	80-100	550-690	30-45	205-310	65-45	60-75
SHEET						
Cold-Rolled	115-190	790-1310	100-175	690-1205	20-2	-
Annealed	85-100	585-690	30-50	205-345	55-35	65-80
STRIP						
Cold-Rolled	115-190	790-1310	100-175	690-1205	20-2	-
Annealed	85-100	585-690	30-50	205-345	55-35	65-80
TUBE and PIPE						
Cold-Drawn						
Annealed	80-110	550-760	30-60	205-415	65-35	70-95
WIRE						
Cold-Drawn	120- 205	825-1415	100-195	690-1345	20-3	-
Annealed	90-115	620-790	35-70	240-480	45-35	-
ALL FORMS						
Solution-Treated	75-110	515-760	25-55	160-380	75-40	55-95

[a]Values shown are composites for various products sizes and therefore are not suitable for specifications.

Table 6 - Typical Room-Temperature Tensile Properties of Annealed Material

Form	Size		Annealing Temperature[a]		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %
	in.	mm	°F	°C	ksi	MPa	ksi	MPa	
Hot-Finished Rod	0.625 Dia.	16 Dia.	2000	1090	107.5	741	42.1	290	47
Hot-Finished Rod	0.625 Dia.	16 Dia.	1800	980	112.0	772	66.0	455	41
Hot-Finished Bar	0.5 x 1.0	13 x 25	2000	1090	102.8	709	37.6	259	46
Hot-Finished Bar	2.5 x 2.5	64 x 64	2000	1090	91.0	627	31.0	214	57
Hot-Finished Bar	0.125 x 2.0	3.2 x 51	1800	980	101.6	701	47.1	248	42
Hot-Finished Plate	0.312	7.9	2000	1090	99.7	687	40.7	281	46
Cold-Rolled Sheet	0.125	3.2	2000	1090	97.9	675	42.3	292	46
Cold-Rolled Sheet	0.062	1.57	1900	1040	115.5	796	61.0	421	36

[a]Annealing time varied with section size.

Table 7 - Typical Tensile Properties of Hot-Finished Rod and Bar

Size		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %
in.	mm	ksi	MPa	ksi	MPa	
2.5 x 2.5	64 x 64	93.0	641	60.0	414	40
2.0 x 2.0	51 x 51	97.5	672	44.0	303	49
3.0 Dia.	76 Dia.	98.0	676	50.5	348	45
4.0 Dia.	102 Dia.	94.0	648	41.5	286	-

Table 8 - Typical Tensile Properties of Solution-Treated[a] Material

Form	Size		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %
	in.	mm	ksi	MPa	ksi	MPa	
Hot-Finished Rod	1.5 Dia.	38 Dia.	87.5	603	30.0	207	59
Hot-Finished Flat	0.250 x 2.0	6.4 x 51	85.2	587	27.6	190	70
Cold-Rolled Sheet	0.062	1.57	99.5	686	43.7	301	47
Hot-Finished Plate	0.250	6.4	85.7	591	39.4	272	52
Cold-Drawn Tube	0.250[b] x 2.562[c]	6.4[b] x 65.1[c]	84.9	585	37.4	258	63

[a]2150°F (1180°C)
[b]Wall thickness.
[c]Outside diameter.

Table 9 - Tensile Properties of Annealed[a] Hot-Finished Rod

Temperature	Tensile Strength	Yield Strength (0.2% Offset)	Elongation
°F	ksi	ksi	%
70	107.5	42.1	47
200	102.0	36.5	44
400	99.5	34.1	43
600	97.5	32.0	47
800	94.3	31.7	45
1000	91.0	29.0	46
°C	MPa	MPa	%
20	741	290	47
100	701	250	44
200	687	236	43
300	674	221	46
400	654	219	45
500	640	203	45

[a]2000°F (1090°C) annealing temperature.

Table 10 - Effect of High-Temperature Exposure on Room-Temperature Impact Strength

Temperature		Time, hr	Charpy V-Notch Impact Strength	
°F	°C		ft-lb	J
80	27	-	130	176
1000	540	100	86	117
		400	89	121
		1000	89	121
1100	590	100	88	119
		300	92	125
		1000	93	126
1200	650	100	93	126
		300	90	122
		1000	94	127
1300	700	100	95	129
1400	760	146	105	142
1500	820	159	117	159
1600	870	103	117	159

Table 11 - Impact Strength of Hot-Finished Rod

Condition	Diameter		Charpy V-Notch Impact Strength		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %
	in.	mm	ft-lb	J	ksi	MPa	ksi	MPa	
Solution-Treated[a]	0.750	19	136	184	102.0	703	35.9	248	49
Solution-Treated[a]	0.625	16	130	176	102.0	703	34.6	239	50
Annealed[b]	0.750	19	99	134	115.0	793	65.5	452	41
Annealed[b]	0.625	16	103	140	112.0	772	66.0	455	41

[a]2100°F (1150°C)/1 hr, A.C.
[b]1800°F (980°C)/1 hr, A.C.

Table 13 - Gas Carburization Tests[a] at 1700°F (925°C) and 1800°F (980°C)

Alloy	Weight Gain in 100 hr, mg/cm^2	
	1700°F (925°C)	1800°F (980°C)
alloy 600	2.66	-
alloy 601	2.72	4.32
alloy 800	4.94	11.6

[a]Tests conducted in mixture of 2% methane and 98% hydrogen.

Table 14 - Gas Carburization Tests[a] at 2000°F (1095°C)

Alloy	Weight Gain in 25 hr, mg/cm^2
alloy 600	2.78
alloy 601	3.67
alloy 800	5.33

[a]Tests conducted in mixture of 2% methane and 98% hydrogen.

Table 15 - Resistance to Carbonitriding Atmosphere[a] at 2000°F (1095°C)

Alloy	Weight Gain[b] in 100 hr, mg/cm^2
alloy 600	8.65
alloy 601	16.66
alloy 800	24.94

[a]Atmosphere consisted of 5% ammonia, 2% methane, and 93% hydrogen.
[b]Average of two tests.

Table 20 - Effects of Annealing Temperature on Room-Temperature Tensile Properties of Cold-Drawn Wire[a]

Annealing Temperature[b]		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %
°F	°C	ksi	MPa	ksi	MPa	
As-Drawn		174.0	1200	166.0	1145	5
1750	950	114.0	786	56.5	390	32
1800	980	113.5	783	53.5	369	34
1850	1010	105.0	724	43.0	296	37
1900	1040	107.0	738	41.0	283	36
1950	1070	104.0	717	43.0	296	39
2000	1090	97.0	669	35.5	245	40
2050	1120	96.0	662	34.5	238	42
2100	1150	92.5	638	32.6	225	44

[a]45% cold reduction. 0.184-in. (4.67-mm) diameter finished size.
[b]Time at temperature was 2 min.

Table 23 - Effect of Hot-Working Temperature on Room-Temperature Mechanical Properties

Hot Working Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Hardness, Rb
°F	°C	ksi	MPa	ksi	MPa		
1600	870	109.1	752	86.0	593	11	97
1800	980	100.7	694	47.4	327	41	82
1920	1050	103.0	710	53.0	365	36	84
2210	1210	91.0	627	41.5	286	46	76

Table 24 - Effect of Cold Work on Tensile Properties of Wire

Cold Reduction, %	Wire Diameter		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %
	in.	mm	ksi	MPa	ksi	MPa	
45	0.184	4.67	174.0	1200	166.0	1145	5
68	0.142	3.61	192.0	1324	185.0	1276	4
77.5	0.119	3.02	197.0	1358	183.0	1262	4
83	0.103	2.62	202.0	1393	193.0	1331	3

Table 21 - Pickling Solution for Removal of Light Oxide

Water	1 gal	1000 cm^3
Nitric Acid (42°Bé)	2 1/2 pt	296 cm^3
Hydrofluoric Acid (30°Bé)	1/2 pt	50 cm^3
Solution Temperature	125°F max.	52°C max.
Pickling Time	5-60 min.	5-60 min.

Table 22 - Pickling Procedure for Removal of Heavy Oxide

Step	Procedure	Solution Temperature	Immersion Time
1	Immerse in solution of: 20-25% Nitric Acid 1½-2% Hydrofluoric Acid 2-3% Sodium Chloride Balance Water	130°F (54°C)	10-20 min
2	Water Rinse	140°F (60°C)	-
3	Immerse in solution of: 15-20% Sodium Hydroxide 3-5% Potassium Permanganate Balance Water	190-200°F (88-93°C)	1-2 hr
4	Immerse in solution of Step 1	130°F (54°C)	10-20 min
5	Water Rinse	140°F (60°C)	-
6	Immerse in solution of: 2-3% Ammonium Hydroxide Balance Water	70°F (21°C)	3-5 min
7	Water Rinse	140°F (60°C)	-

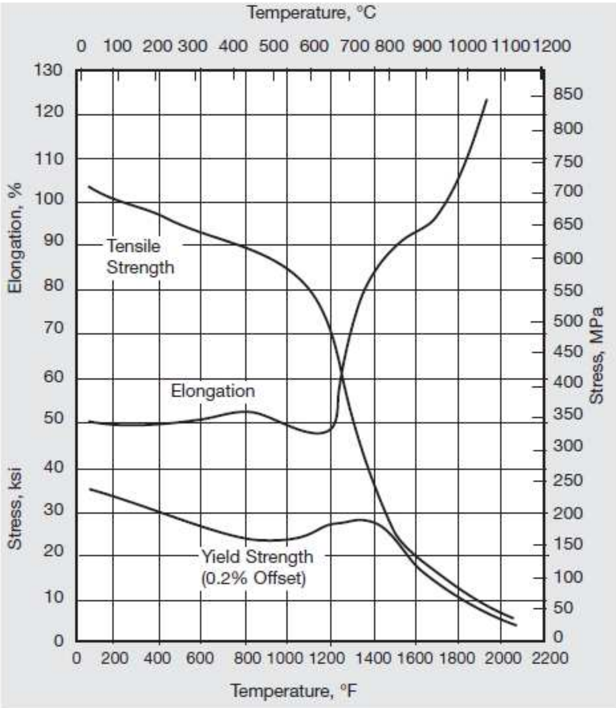

Figure 1. High-temperature tensile properties of solution-treated (2100°F) (1150°C) hot-finished rod.

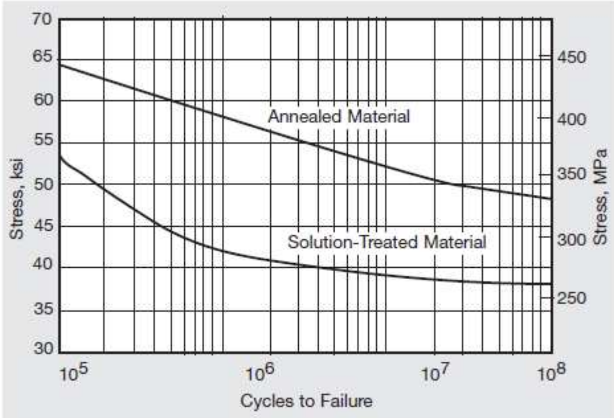

Figure 2. Rotating-beam fatigue strength at room temperature.

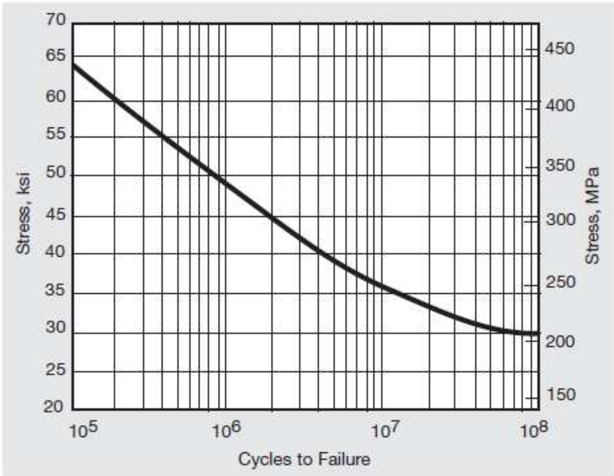

Figure 3. Room-temperature fatigue strength of annealed (1900°F) (1040°C) cold-rolled sheet.

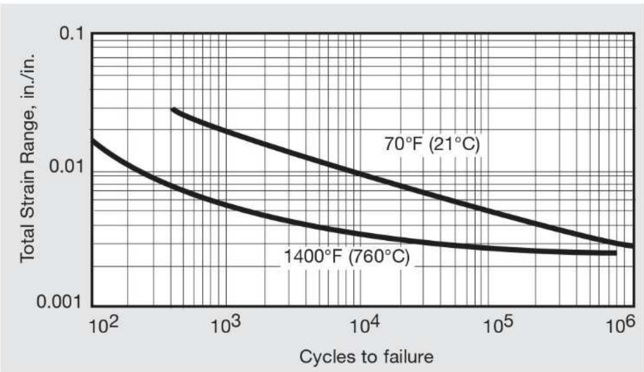

Figure 4. Low-cycle fatigue strength of alloy 601.

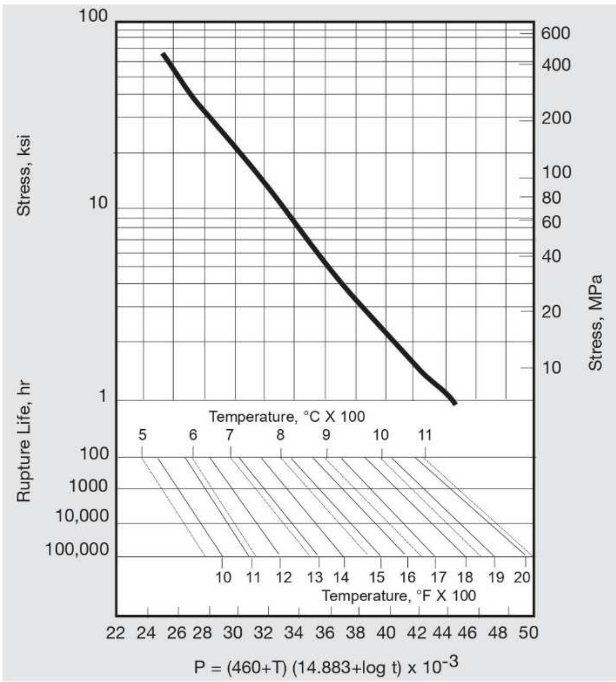

Figure 5. Larson-Miller parameter plot of rupture strength of solution-treated (2100°F) (1150°C) alloy 601. In the parameter, T is temperature in °F, and t is time in hours.

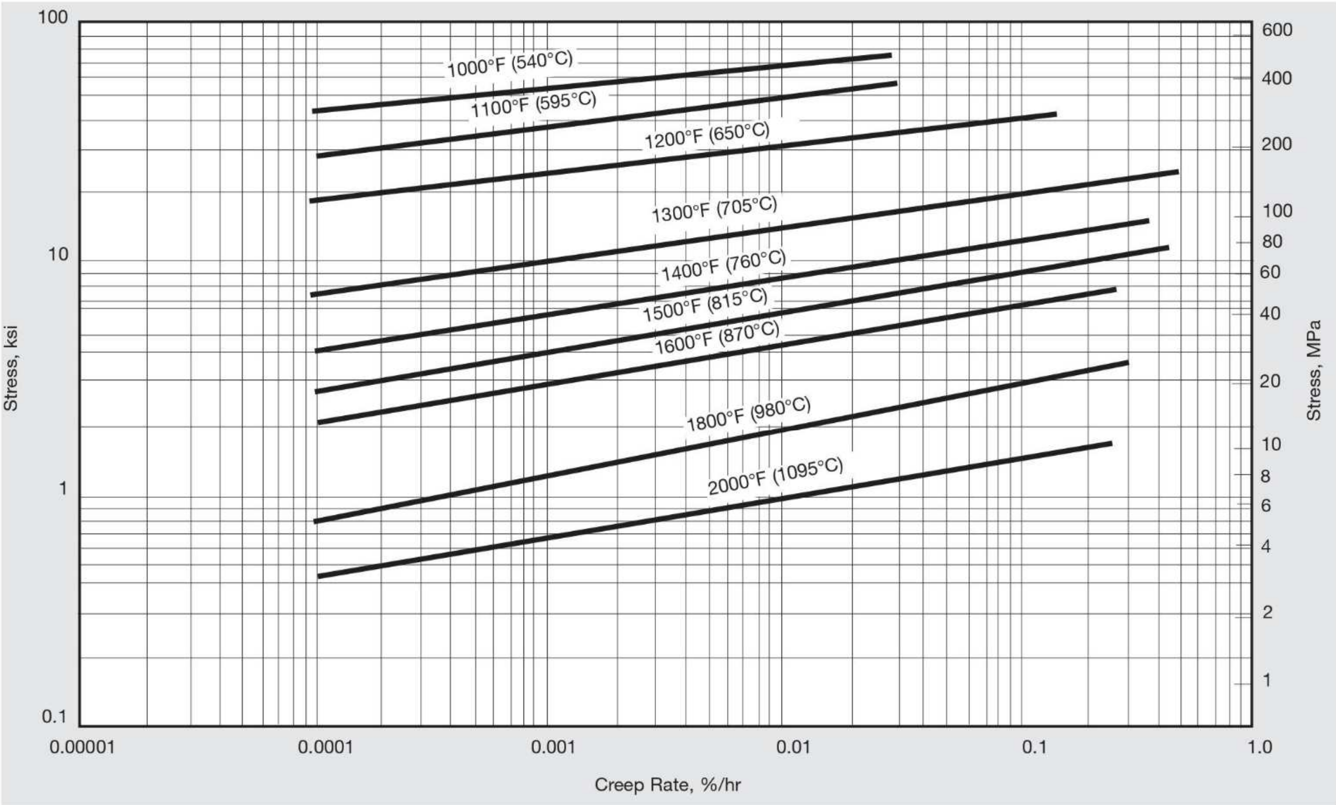

Figure 6. Typical creep strength of solution-treated (2100°F) (1150°C) alloy 601.

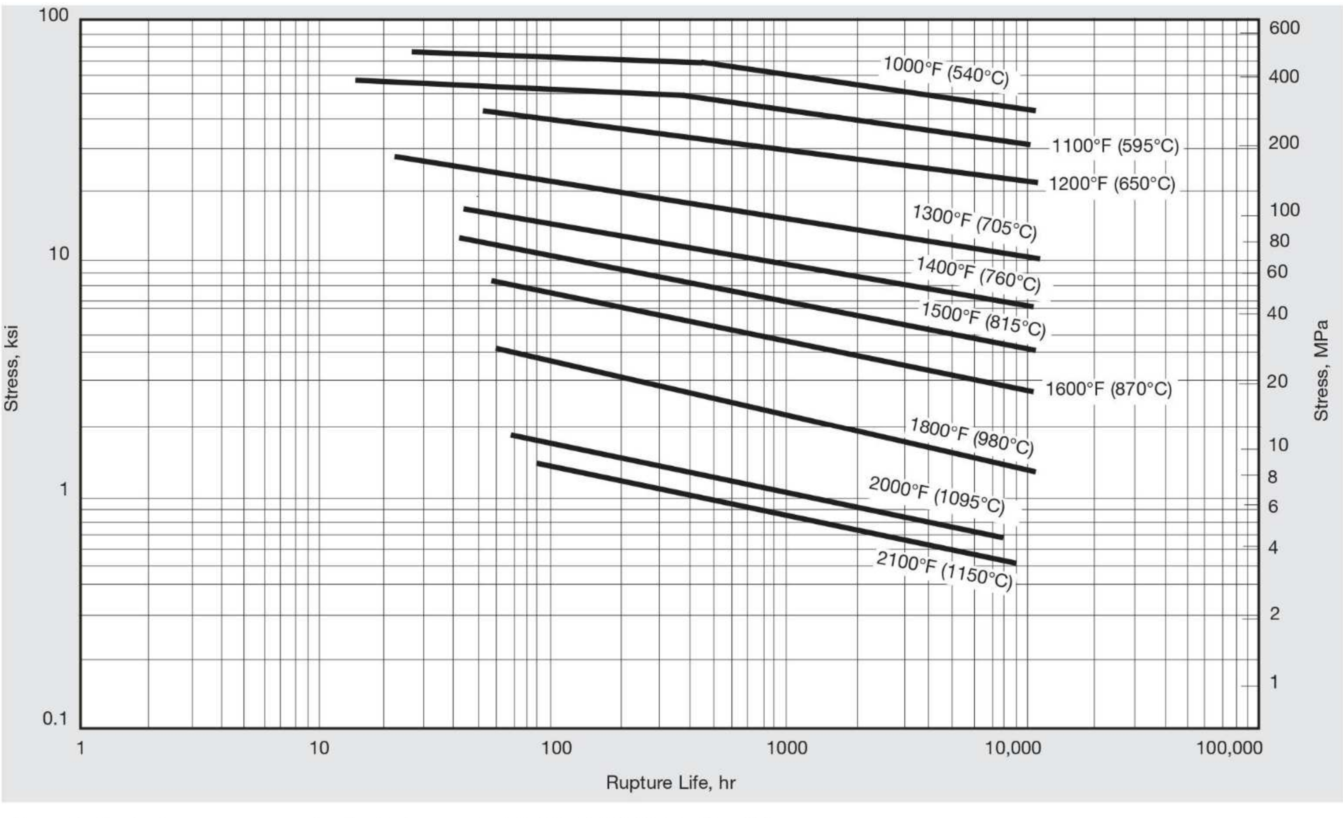

Figure 7. Typical rupture strength of solution-treated (2100°F) (1150°C) alloy 601.

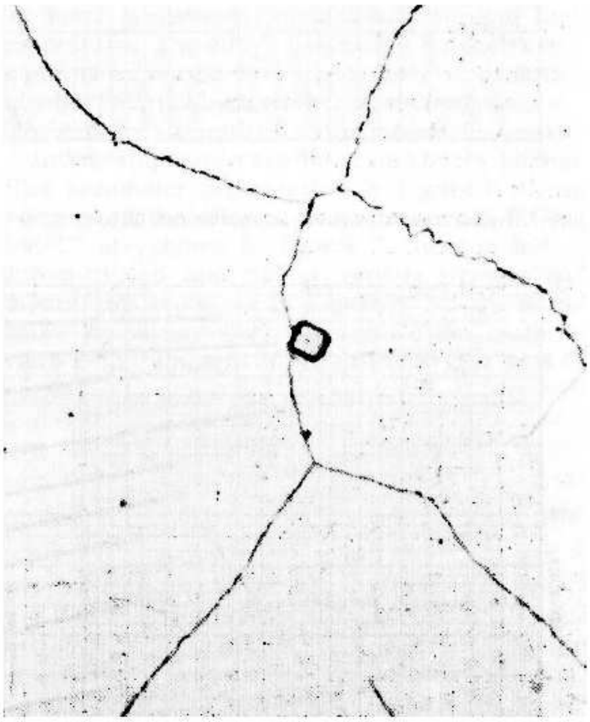

Figure 8. Typical microstructure of solution-treated hot-finished rod. 500X. Etchant: 5% Nital electrolytic.

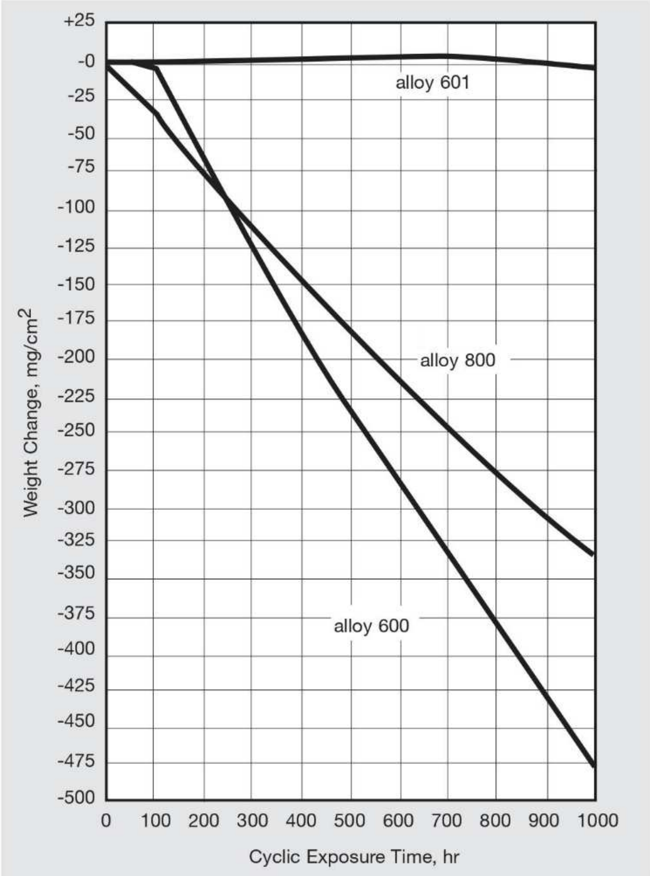

Figure 9. Results of cyclic oxidation tests at 2000°F (1095°C). Cycles consisted of 15 min heating and 5 min cooling in air.

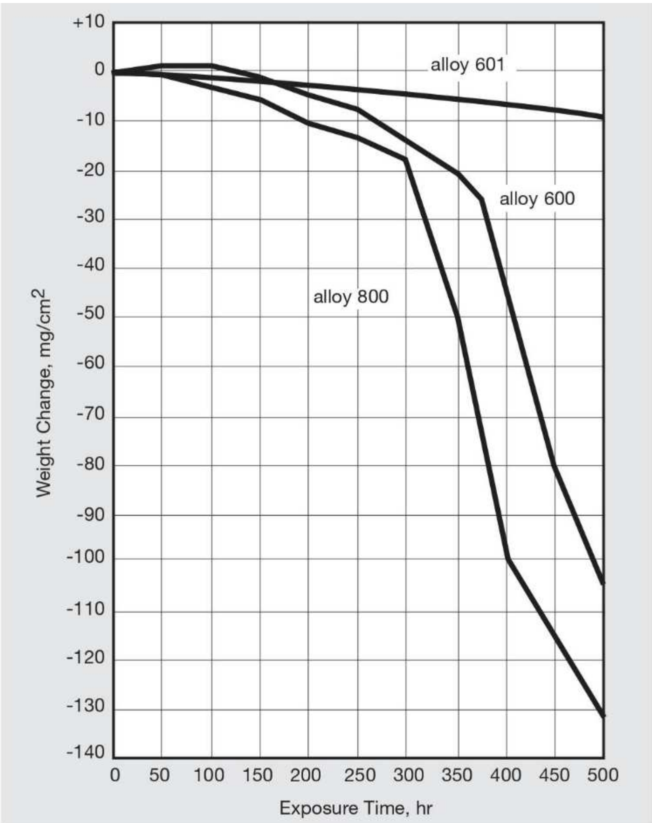

Figure 10. Results of oxidation tests at 2100°F (1150°C). Test cycles consisted of 50 hr at exposure temperature followed by air-cooling to room temperature.

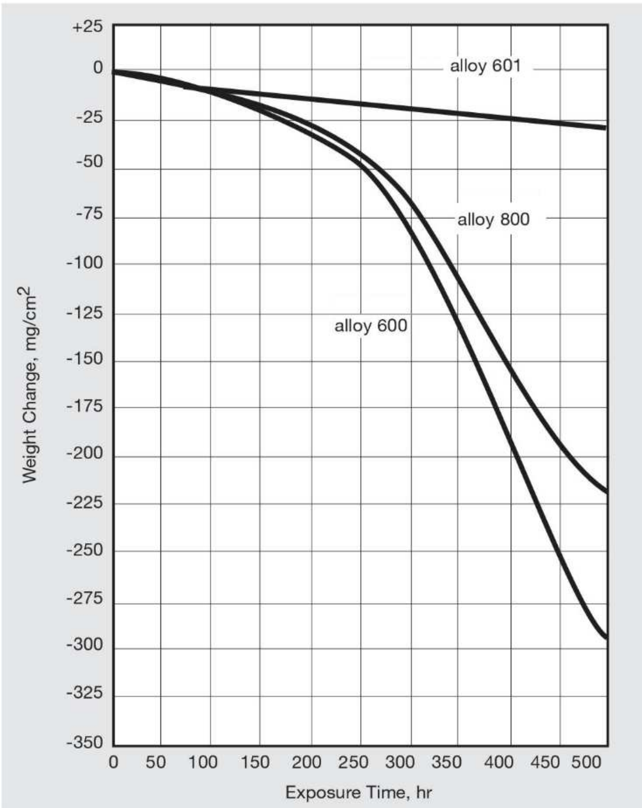

Figure 11. Results of oxidation tests at 2200°F (1205°C). Test cycles consisted of 50 hr at exposure temperature followed by air-cooling to room temperature.

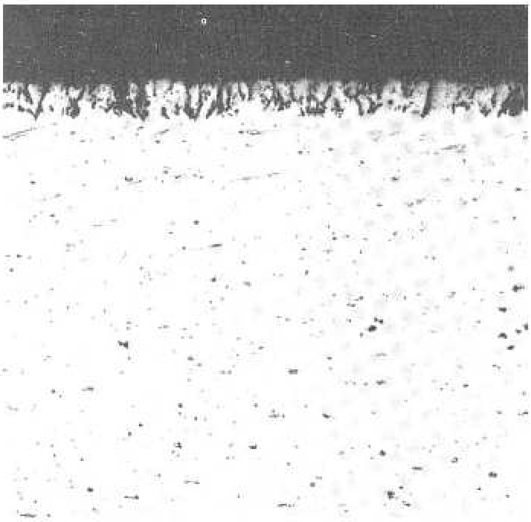

Figure 12. Oxide layer on specimen exposed to 2100°F (1150°C) for 500 hr. 75X. Unetched.

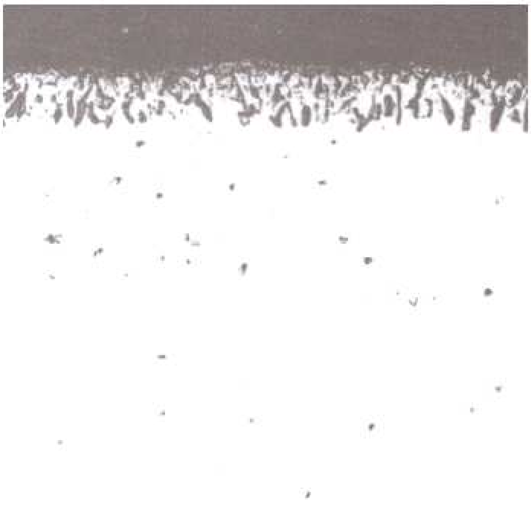

Figure 13. Oxide layer on specimen exposed to 2200°F (1205°C) for 500 hr. 75X. Unetched.

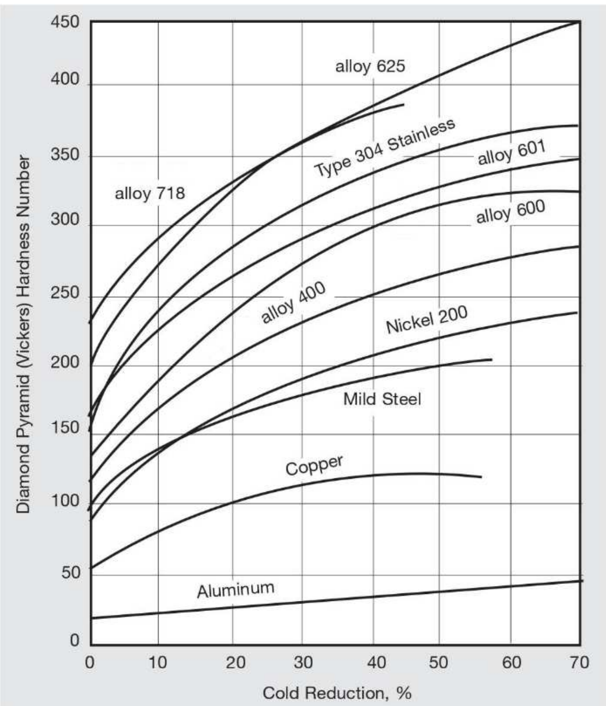

Figure 16. Work-hardening rates for alloy 601 and other materials.

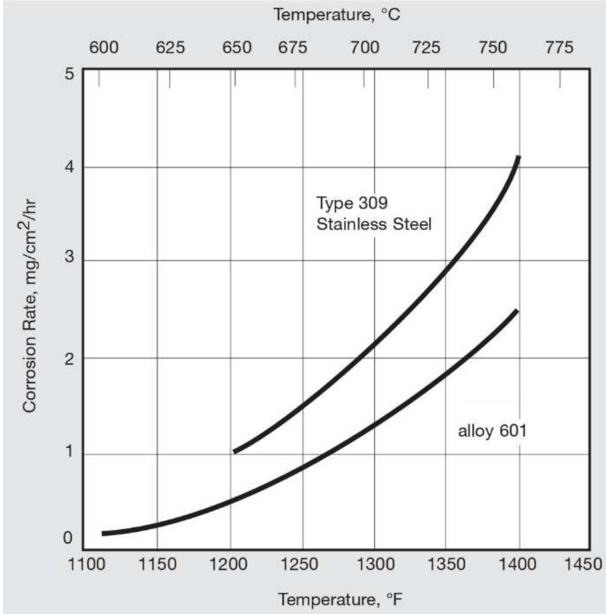

Figure 14. Results of sulfidation tests in an atmosphere of 1.5% hydrogen sulfide and 98.5% hydrogen.

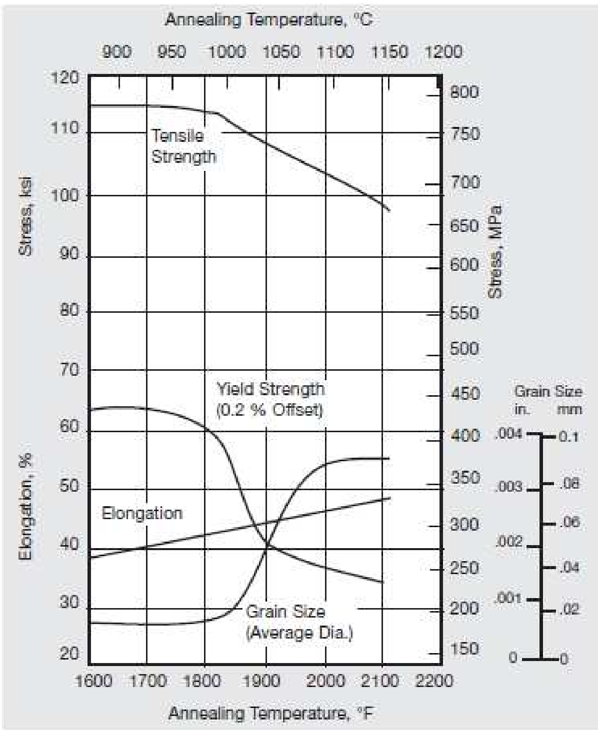

Figure 15. Effect of annealing temperature on properties of a 0.750-in. (19-mm) hot-finished rod.