ALLOY 718

Alloy 718 (UNS N07718/W.Nr. 2.4668) is a high-strength, corrosion-resistant nickel chromium material used at -423° to 1300°F. Typical composition limits are shown in Table 1. The age-hardenable alloy can be readily fabricated, even into complex parts. Its welding characteristics, especially its resistance to postweld cracking, are outstanding.
The ease and economy with which Alloy 718 can be fabricated, combined with good tensile, fatigue, creep, and rupture strength, have resulted in its use in a wide range of applications. Examples of these are components for liquid fueled rockets, rings, casings and various formed sheet metal parts for aircraft and land-based gas turbine engines, and cryogenic tankage. It is also used for fasteners and instrumentation parts.

Physical Constants and Thermal Properties
Some physical constants of Alloy 718 are shown in Table 2. Modulus data appear in Tables 3 and 4, and thermal properties in Table 5. The values in these tables will vary slightly, depending on the composition and condition of the specimen tested. They are typical but are not suitable for specification purposes.

Heat Treating and Mechanical Properties
For most applications, Alloy 718 is specified as: solution annealed and precipitation hardened (precipitation hardening, age hardening, and precipitation heat treatment are synonymous terms). Alloy 718 is hardened by the precipitation of secondary phases (e.g. gamma prime and gamma double-prime) into the metal matrix. The precipitation of these nickel (aluminium, titanium, niobium) phases is induced by heat treating in the temperature range of 1100 to 1500°F. For this metallurgical reaction to properly take place, the aging constituents (aluminium, titanium, niobium) must be in solution (dissolved in the matrix); if they are precipitated as some other phase or are combined in some other form, they will not precipitate correctly and the full strength of the alloy with not be realized. To perform this function, the material must first be solution heat treated (solution annealed is a synonymous term).
Two heat treatments are generally utilized for Alloy 718:
•Solution anneal at 1700-1850°F followed by rapid cooling, usually in water, plus precipitation hardening at 1325°F for 8 hours, furnace cool to 1150°F, hold at 1150°F for a total aging time of 18 hours, followed by air cooling.
•Solution anneal at 1900-1950°F followed by rapid cooling, usually in water, plus precipitation hardening at 1400°F for 10 hours, furnace cool to 1200°F, hold at 1200°F for a total aging time of 20 hours, followed by air cooling.

If the material is to be machined, formed, or welded, it typically is purchased in the mill annealed or stress relieved condition. The material is then fabricated in its most malleable condition. After fabrication, it can be heat treated as required per the applicable specification.

1700°-1850°F Anneal and Age
The 1700°-1850°F anneal with its corresponding aging treatment as shown earlier is the optimum heat treatment for Alloy 718 where a combination of rupture life, notch rupture life and rupture ductility is of greatest concern. The highest room-temperature tensile and yield strengths are also associated with this treatment. In addition, because of the fine grain developed, it produces the highest fatigue strength.

Material in this condition will meet the following minimum requirements:

AMS 5596
Sheet, Strip, & Plate

Property	Room Temperature	1200°F
Tensile Strength, ksi	180	140[a]
		145[b]
Yield Strength (0.2% Offset), ksi	150	115[a]
		120[b]
Elongation in 2 In.,%	12	5
Hardness	Rc 36 or equivalent	-
Stress Rupture		
Stress, ksi	-	95[a]
	-	100[b]
Life, hr	-	23
Elongation, %	-	4

AMS 5589
Seamless Tubing[g]

Property	Room Temperature	1300°F
Tensile Strength, ksi	185	-
Yield Strength (0.2% Offset), ksi	150	-
Elongation in 2 In.,%	12	-
Hardness	Rc 36 or equivalent	-
Stress Rupture		
Stress, ksi	-	72.5
Life, hr	-	23
Elongation, %	-	5

AMS 5662 and 5663
Bars, Forgings, & Rings

Property	Room Temperature	1200°F
Tensile Strength, ksi	185[c]	145[c]
	180[d]	140[d]
	180[e]	140[e]
Yield Strength (0.2% Offset), ksi	150	125
Elongation in 2 In.,%	12[c]	12[c]
	10[d]	10[d]
	6[e]	6[e]
Reduction of Area, %	15[c]	15[c]
	12[d]	12[d]
	8[e]	8[e]
Hardness	331 BHN or equivalent	-
Stress Rupture		
Stress, ksi	-	100
Life, hr	-	23
Elongation, %	-	4[f]

[a]Up to 0.025-in. thickness, inclusive.
[b]Over 0.025-in. thickness.
[c]Longitudinal.
[d]Long transverse for forgings.
[e]Transverse for bars.
[f]Applies up to 5-in.-diam. or thickness, inclusive.
[g]Properties apply only to O.D. of 0.125-in. and over with wall thickness of 0.015-in. and over.

1900°-1950° Anneal and Age

The 1900°-1950° anneal with its corresponding aging treatment as shown above is the treatment preferred in tensile-limited applications because it produces the best transverse ductility in heavy sections, impact strength, and low-temperature notch tensile strength. However, this treatment has a tendency to produce notch brittleness in stress rupture. After precipitation hardening as shown, material will meet the following requirements:

Property[a]	AMS 5664 Bars, Forgings, & Rings	AMS 5597 Sheet, Strip, & Plate	AMS 5590 Seamless Tubing[d]
Tensile Strength, ksi	180	180	170
Yield Strength (0.2% Offset), ksi	150	150	145
Elongation, %	10[b]	15	15
	12[c]		
Reduction of Area, %	12[b]	-	-
	15[c]		
Hardness	341 BHN or equivalent	Rc 38 or equivalent	

[a]Transverse direction.
[b]Bars.
[c]Forgings and flash-welded rings.
[d]Properties apply only to O.D. of 0.125-in. and over with wall thickness of 0.015-in. and over.

Other Heat Treatments

alloy 718 is also being used in oil field applications. This material is produced under the NACE specification MR0175 which requires the solution annealed and aged material to meet a maximum hardness value of 40 Rockwell "C". Such material is typically solution heat treated at 1850-1900 °F and aged at 1450°F for six to eight hours and air cooled. Table 6 shows the mechanical properties this material will meet. Numerous proprietary heat treatments are used for Alloy 718 depending on the properties required. Such heat treatment sequences are usually developed by companies or agencies independent of the material supplier; consequently, discussion of procedures, tolerances, and resulting properties should be with that company or agency.

All the data shown in the following sections are typical but not to be used for specification purposes.

Room Temperature Tensile Properties

The following data are representative of the effects of the above annealing and aging treatments on room-temperature properties of a variety of products. More properties are shown under the section, High- and Low-Temperature Tensile Properties, Fatigue Strength, and Weld Properties.

Hot-Finished Products

Table 7 shows properties of hot-rolled round annealed at 1750° or 1950°F. The effects of annealing at 1750° or 1950°F and the associated aging treatments on bar of a range of diameters are given in Table 8. Properties produced by the two different annealing and aging schedules in hot-rolled round are compared in Table 9.

The effect of direct aging (1325°F/time at temperature, 8 hours, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours) on various sizes of samples is given in Table 10.

Properties of a pancake forging with samples taken from various locations, annealed at 1700°F and aged, are shown in Table 11. Properties of forged products given the 1950°F anneal and aged are shown in Tables 12 and 13. The effects of the two annealing and aging treatments on a forged pancake are compared in Table 14.

Cold-Finished Products

Properties of cold-rolled sheet aged at 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours are shown in Table 15. Table 16 gives the effect of the heat treatment specified by AMS 5597 on material of various thickness. Some properties of tubing are given in Table 17.

High- and Low-Temperature Properties

Hot Finished Products

Properties of hot-rolled bar annealed at 1800°F and aged are shown in Figure 1. Table 18 shows room-temperature properties of hot-rolled plate annealed and aged per AMS 5596H. Properties of hot-rolled round annealed at 1950°F and aged are in Table 19. Data on hot-rolled round (annealed at 1800°F and aged) for the range of -320°F to 1300°F are given in Table 20.

Table 21 compares low-temperature properties (short transverse tests) of specimens machined from a forging and given the 1800°F anneal and age with those given the 1950°F anneal and age.

Table 22 shows room and 1200°F and 1300°F properties of a variety of hot-finished products annealed at 1800°F and aged.

Cold-Finished Products
High-temperature tensile properties of cold-rolled sheet annealed in accordance with AMS 5596 are shown in Table 23. More data on 5596-processed material appear in Table 24.
Table 25 shows room-temperature tensile properties of sheet annealed and aged per AMS 5596. Low-temperature properties of sheet processed in accordance with AMS 5596 are shown in Table 26. These data indicate the effects of sheet thickness as well as annealing and aging treatment. Large increases in strength are achieved by cold working and aging.
Additional data on notch tensile strength are shown in Figure 2.
Table 27 compares data on annealed and aged sheet with direct-aged sheet over a temperature range from -110° to 1000°F.
More data on sheets of various thicknesses are shown in Table 28.

Impact Strength
Room-temperature impact strength of some hot-finished products are shown in comparison with their tensile properties in Table 29. The data also point out the effect of annealing at 1750°F and aging at 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours versus annealing at 1950°F and aging at 1400°F/10 hr, F.C. to 1200°F for total aging time of 20 hours. Some impact properties of a pancake forging are shown in Table 11.
Low-temperature impact strength of plate is shown in Table 30.

Fatigue Strength
Room-temperature fatigue properties of annealed and annealed and aged (1750°F, plus 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours) forging specimens are shown in Table 31. Table 32 presents fatigue strength of hot-rolled plate annealed and aged in accordance with AMS 5596.
Fatigue strength of cold-rolled sheet is shown in Figure 3.
If fatigue strength is of prime importance, Alloy 718 forgings can be used in the annealed rather than the annealed and aged condition; aging raises fatigue strength only slightly (less than 4 ksi in Table 31).
Grain size is a major factor in achievement of high fatigue strength. Its effect can be seen in Figure 4. The low temperature heat-treatment schedule (such as that in AMS 5596) will promote the requisite fine grain. See also Tables 31 and 32. High-temperature fatigue strength of annealed and aged bar is shown in Table 33.
Low-cycle fatigue life of Alloy 718 is the same whether tested in fully reversed bending or in zero-to maximum bending. Test results are shown in Figure 5.

Rupture and Creep Properties
For creep-limited and rupture-limited applications Alloy 718 is annealed at 1700°F-1850°F and aged at 1325°F/8 hr, F.C. to 1150°F, hold for total aging time of 18 hours (or an equivalent treatment such as in AMS 5596). Rupture and creep properties shown in this bulletin are typical of material receiving this low-temperature treatment.
Figure 6, a plot of high-temperature rupture life, also shows the excellent properties at 1200° and 1300°F of notch specimens of small-diameter bar.
Figure 7 shows creep strength of annealed and aged hot-rolled bar. These rupture and creep data have been used for construction of Larson-Miller and Manson-Haferd parameter plots (Figures 8 and 9). For convenience in design, the typical properties are also shown on the basis of 100, 1000, and 10,000 hours (Figures 10, 11 and 12). Rupture properties of annealed and aged cold-rolled sheet are shown in the form of a Larson-Miller parameter plot (Figure 13). As indicated by the specifications, thickness will influence rupture life.
Rupture life of round and sheet in comparison with tensile properties is shown in Tables 9 and 24.

Weld Properties
Alloy 718 is readily welded by the gas tungstenarc (TIG) process. Mechanical properties of its all-weld metal specimens are shown in Table 35. These test data show the effect of post welding treatment on tensile properties. Highest room temperature ductility is obtained by annealing at 1950°F prior to aging.
Slow response of Alloy 718 to age hardening enables parts to be welded and directly age-hardened without an intermediate stress relief. Joint efficiencies very close to 100% were realized in the tests shown in Table 38; these specimens were from plate that had been annealed, then welded and aged. Better properties, however, are obtained by re-annealing after welding prior to aging.
Silver brazing compounds are known to cause stress cracking in nickel-based alloys. If Alloy 718 is cold-worked and/or precipitation-hardened, silver brazing compounds should not be used. Also, brazing alloys containing cadmium are best avoided; while cadmium has not been shown to cause cracking by itself, it can aggravate cracking from other sources.

Weld Tensile Properties
Room-temperature properties of welds receiving the low-temperature anneal and/or age can be compared with results of the high-temperature anneal and/or age in Tables 38 and 39. Additional properties of welds annealed at 1950°F/15 min. and aged at 1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for a total aging time of 20 hours are shown in Table 40. Welding was by the manual gas tungsten-arc process. These welds were found satisfactory in bend tests and radiographic examination. Slightly better results were obtained when helium was used as the torch gas. Notch strength of butt-welded sheet in both the heat-affected zone and weld is shown in Table 41. These welds were heattreated by the low-temperature schedule.
Another laboratory using the high-temperature heat treatment has found that notch toughness of the parent metal and that of the weld metal are quite consistent and exceed a notch-to-smooth bar tensile ratio of 1.30 throughout the testtemperature range of -423°F to 1200°F. Test data are shown in Table 42. The weld joint efficiency is approximately 93% at -423°F and 95% at room temperature and 1200°F.

Weld Fatigue Properties
Weldments were found to have a room-temperature fatigue strength (108 cycles) of approximately 62.5 ksi (tested in R.R. Moore rotating-beam apparatus). They were made from hot-rolled , annealed (per AMS 5596) 0.500-in. plate, joined with 0.125-in.-diameter INCONEL Filler Metal 718 by the gas tungsten-arc process. Samples were aged 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours and tested as polished speci-mens. In comparable tests, Alloy 718 bar had a fatigue strength (10* cycles) of 89.0 ksi.

Weld Rupture Properties
Rupture strength at 1200° and 1300°F of heat-treated weldments in sheet is compared with parent metal in Table 44. In other tests, welds whose process steps were age, weld, and age had lives of 0.3 hr (1200°F, 100.0 ksi) and 4.9 hr (1300°F, 72.5 ksi) ; fractures were in the heat-affected zone. Notch-bar life at 1300°F and 75.0 ksi is shown in Table 45.

Spring Properties
The excellent relaxation resistance of Alloy 718 is a factor in its successful use for springs at temperatures up to 1100°F. Some relaxation data are shown in Figure 14.

Bolting
Alloy 718 combines excellent mechanical properties over a wide temperature range with superior oxidation and corrosion resistance. Because of these properties it is specified for many fastener applications where superior performance is required under varying environmental conditions.
Alloy 718 can be strengthened in two ways: (1) by solution treating and age hardening or (2) by cold working and age hardening only. See Table 46.
The use of Alloy 718 for bolting applications is addressed under Section I and Section VIII, Division I of the ASME Code by Code Case 1993.

Metallography
Alloy 718 is an age-hardenable austenitic material. Strength is largely dependent on the precipitation of a gamma prime phase during heat treatment.
A major part of the development effort with this alloy was concerned with establishment of the proper heat treatments for producing optimum properties. These heat treatments and the applications for which they are intended are described in the section, Mechanical Properties.
The microstructure of Alloy 718, especially with regard to the effects of heat treatment, has been extensively studied and reported. The literature should be consulted for detailed discussions on the various phases developed by various heat treatments and other metallurgical investigations.

Corrosion Resistance
Alloy 718 has excellent corrosion resistance to many media. This resistance, which is similar to that of other nickel-chromium alloys, is a function of its composition. Nickel contributes to corrosion resistance in many inorganic and organic, other than strongly oxidizing, compounds throughout wide ranges of acidity and alkalinity. It also is useful in combating chloride-ion stress-corrosion cracking. Chromium imparts an ability to withstand attack by oxidizing media and sulfur compounds. Molybdenum is known to contribute to resistance to pitting in many media.

Working Instructions
Heating and Pickling
When Alloy 718 is heated, care must be taken to maintain both the furnace and the material being heated at correct temperatures.
Fuels used for heating must be extremely low in sulfur. The alloy must be absolutely clean and free from all oil, paint, grease, and shop soil when charged into the furnace.
The furnace atmosphere for forging or open annealing should be slightly reducing, containing at least 2% carbon monoxide. A slight positive pressure should be maintained in the furnace to prevent air infiltration.
When Alloy 718 is heated in a reducing atmosphere, a thin, adherent green-black film of oxide will be left on the surface of the material. In oxidizing atmospheres, a heavy black scale is produced that is very difficult to remove. Every precaution should be taken in heating so that only the green-black film is formed.

Hot Forming
Because of its strength, Alloy 718 is more resistant than most materials to deformation during hot forming. Its relative resistance is shown by pressures developed in the roll gap at 20% reduction (Table 47). It is readily hot-worked if sufficiently powerful equipment is used.
Hot forming is performed in the 1650°-2050°F temperature range. In the last operation, the metal should be worked uniformly with a gradually decreasing temperature, finishing with some light reduction in the 1650°-1750°F range. This procedure is necessary to ensure notch ductility in stress-rupture applications when material has been annealed and aged. (See below). In heating for hot working, the material should be brought up to temperature, allowed to soak a short time to ensure uniformity, and withdrawn.

To avoid duplex grain structure Alloy 718 should be given uniform reductions. Final reductions of 20% minimum should be used for open-die work and 10% minimum for closed-die work. Parts should generally be aircooled from the hot-working temperature rather than waterquenched.
Care should be taken to avoid overheating the metal by heat build-up due to working. Also, the piece should be reheated when any portion has cooled below 1650°F. Preheating tools and dies to 500°F is recommended. Any ruptures appearing on the surface of the workpiece must be removed at once.
Data shown in Table 48 show the importance of a 1650°F-1750°F finish-forging temperature for achievement of notch ductility in large forgings in stress-rupture applications. In these tests, 0.75-in. square forged bar was cut into 12-in. lengths, heated to the rolling temperatures shown in Table 48, and given 25% reduction in one pass. Following annealing and aging, specimens were rupture tested at 1200°F and 100 ksi. Success in achieving notch-rupture ductility with forgings of alloy 718 through this type of procedure has also been reported by others.

Cold Forming
Alloy 718 can be cold-formed by standard procedures used for steel and stainless steel. Figure 16 shows its rate of work hardening in comparison with other materials.
The effect of cold reduction on the tensile properties of sheet in the cold-rolled and cold-rolled and aged conditions is shown in Table 49.

Machining
Alloy 718 can be readily machined, but its high strength and work-hardening characteristics must be considered in the selection and use of proper tool materials and design, operating speeds, and coolants.
When machined in the age-hardened condition the alloy will have a slightly better finish; chip action on chip breaker tools will be better. The use of annealed material, however, provides easier machining and longer tool life.

Bending
A guide to the minimum bend diameters of hot-rolled and annealed plate and annealed sheet and strip is given in Table 50. In the determination of those diameters a sample is judged to have passed the 180°-bend test if its surface shows no ductile fracturing. Because of the effect of various surface conditions and heat treatments on bendability, the bends cannot be guaranteed. Many of the materials can nevertheless be bent in stages to tighter bends than those that are suggested in Table 50, provided that the initial bend is not severe.

Annealing and Age Hardening
For most applications, Alloy 718 receives one of the following treatments:
-Anneal at 1700°-1850°F, A.C. and age at 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr, or
-Anneal at 1900°-1950°F, A.C. and age at 1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for total aging time of 20 hr.
Rate of furnace cooling during aging is not critical, but a rate of 100°F/hr is sometimes specified. Recommended total times should be observed. Properties of material receiving these heat treatments are shown in the section, Mechanical Properties.
The effect of annealing for 30 minutes at various temperatures on the grain size of sheet is shown in Figure 17.
Aging response of niobium-aluminium-titanium hardened Alloy 718 is rather slow in comparison with that of aluminium-titanium-hardened alloys. Thus, in most sizes, the alloy can be heated and cooled through the aging temperature range at normal speeds yet retain softness and ductility.

Figure 18 shows the effect of aging time and temperature on the hardness of annealed sheet. Virtually no hardening occurs during the first 2-3 minutes of exposure. This is ample time to permit air cooling after welding or annealing. An aluminium-titanium-hardened alloy having sufficient hardener content to approach the strength level of Alloy 718 would develop almost full hardness in the same period of time.

Table 1 - Limiting Chemical Composition[a], %

Nickel (plus Cobalt)	50.00-55.00
Chromium	17.00-21.00
Iron	Balance*
Niobium (plus Tantalum)	4.75-5.50
Molybdenum	2.80-3.30
Titanium	0.65-1.15
Aluminum	0.20-0.80
Cobalt	1.00 max.
Carbon	0.08 max.
Manganese	0.35 max.
Silicon	0.35 max.
Phosphorus	0.015 max.
Sulfur	0.015 max.
Boron	0.006 max.
Copper	0.30 max.

[a]Conforms to AMS specifications

*Reference to the 'balance' of a composition does not guarantee this is exclusively of the element mentioned but that it predominates and others are present only in minimal quantities.

Table 2 - Physical Constants

Density, lb/in^3	
Annealed	0.296
Annealed and Aged	0.297
Melting Range, °F	2300-2437
°C	1260-1336
Specific Heat at 70°F, Btu/lb °F (at 21°C, J/kg °C)	0.104 (435)
Curie Temperature, °F (°C)	
Annealed Material	<-320 (<-196)
Annealed and Aged Material	-170 (-112)
Permeability at 200 oersted and 70°F	
Annealed Material	1.0013
Annealed and Aged Material	1.0011

Table 3 - Modulus of Elasticity at Low Temperatures[a]

Temperature, °F	Modulus of Elasticity, ksi x 10^3		Poisson's Ratio
	Young's Modulus	Torsional Modulus	
-308	31.3	12.5	0.25
-86	30.6	11.8	0.30
70	29.0	11.6	0.29
100	29.8	11.5	0.30
200	29.4	11.3	0.31
300	28.8	11.1	0.30
400	28.5	10.9	0.31
500	28.0	10.6	0.32

[a]Cold-rolled sheet heat-treated in accordance with AMS 5596B.

Table 4 - Modulus of Elasticity[a]

Temperature, °F	Modulus of Elasticity, ksi x 10^3 Young's Modulus	Torsional Modulus	Poisson's Ratio[b]
70	29.0	11.2	0.294
100	28.8	11.2	0.291
200	28.4	11.0	0.288
300	28.0	10.9	0.280
400	27.6	10.8	0.280
500	27.1	10.6	0.275
600	26.7	10.5	0.272
700	26.2	10.3	0.273
800	25.8	10.1	0.271
900	25.3	9.9	0.272
1000	24.8	9.7	0.271
1100	24.2	9.5	0.276
1200	23.7	9.2	0.283
1300	23.0	8.9	0.292
1400	22.3	8.5	0.306
1500	21.3	8.1	0.321
1600	20.2	7.6	0.331
1700	18.8	7.1	0.334
1800	17.4	6.5	0.341
1900	15.9	5.8	0.366
2000	14.3	5.1	0.402

[a]Hot-rolled flat heat-treated 1800°F/1 hr, A.C. + 1325°F/8 hr, F.C. 20°F/hr to 1150°F, held for total aging time of 18 hr. Dynamic testing involved frequencies of from 813 to 571 cps in bending and from 3110 to 2097 cps in torsion.

[b]Computed from (E-2G)/2G, where E is Young's Modulus and G is torsional modulus.

Table 5 - Thermal Properties

Temperature, °F	Thermal Conductivity,[a] BTU•in/ft²•h•°F		Electrical Resistivity,[a] ohm circ mil/ft		Mean Linear Expansion[b,c], in/in/°F x 10^{-6}
	Ann. 1800°F/1 hr	Ann. + Aged	Ann. 1800°F/1 hr	Ann + Aged	
-320	-	-	-	-	5.9[d]
70	77	79	753	725	-
200	86	87	762	733	7.31
400	98	100	772	755	7.53
600	111	112	775	768	7.74
800	123	124	784	775	7.97
1000	135	136	798	788	8.09
1200	147	148	805	794	8.39
1400	160	161	802	797	8.91
1600	173	173	799	796	-
1800	185	186	801	800	-
2000	196	199	811	796	-

[a]Annealing was 1800°F/1 hr; aging was 1325°F/8 hr, F.C. 20°/hr to 1150°F, held at 1150°F for total aging time of 18 hr. Conductivity calculated from resistivity values.
[b]From 70°F to temperature shown.
[c]Annealed 1750°F/1 hr and aged 1325°F/8 hr, F.C. to 1150°F/8 hr, A.C.
[d]Samples tested were in both the annealed (1750°F/1 hr, A.C.) and annealed and aged (1750°F/1 hr + 1325°F/8 hr, F.C. to 1150°F, held at 1150°F for 10 hr, A.C.) conditions.

Table 6 - Mechanical Properties Aged Material for Oil Tool Applications
Room Temperature Tensile and Hardness, and Room Temperature and -75°F Impact

Condition	Diameter, in.(mm)	Tensile Strength, ksi (Kg/cm²) min.	Yield Strength (0.2% Offset), ksi (Kg/cm²)		Elongation in 2 in. (50.8 mm) or 4D% minimum	Reduction of Area, % minimum	Impact Strength, ft•lb (Kg•m) min. aver.	Hardness, Rockwell C	
			minimum	maximum				minimum	maximum
Cold worked, solution annealed & aged	0.5 (12.7) to 3 (76.2), inclusive	150 (10,545)	120 (8436)	140 (9842)	20	25	40 (5.55)	30	40
Hot worked, solution annealed & aged	0.5 (12.7) to 8 (203.2), inclusive	150 (10,545)	120 (8436)	140 (9842)	20	25	40 (5.55)	30	40
Hot worked, solution annealed & aged	8 (203.2) to 10 (254), inclusive	150 (10,545)	120 (8436)	140 (9842)	20	25	40 (5.55)	30	40

Table 7 - Room-Temperature Tensile Properties of Annealed Hot-Rolled Round

Diameter[a], in.	Annealing Temperature[b], °F	Test Orientation[c]	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %	Hardness
2.5	1750	L	135.5	77.5	45	49	-
		T	129.5	73.5	32	29	-
	1950	L	114.0	50.4	62	65	-
		T	112.0	49.8	53	49	-
4	1750	L	117.5	55.0	53	52	90 Rb
		T	119.0	56.5	50	46	88 Rb
	1950	L	112.5	48.0	60	63	87 Rb
		T	114.0	50.0	61	55	84 Rb
4	1750	L	125.5	71.5	45	49	97 Rb
		T	123.5	67.0	46	43	93 Rb
	1950	L	115.0	47.0	59	65	85 Rb
		T	99.5	47.5	32	31	84 Rb
4	1750	L	126.0	71.5	45	47	96 Rb
		T	114.0	60.0	26	25	90 Rb
	1950	L	114.5	53.0	58	61	87 Rb
		T	105.0	47.0	34	29	83 Rb
4	1750	L	122.0	63.0	51	51	92 Rb
		T	109.0	56.5	32	31	89 Rb
	1950	L	112.5	50.0	62	62	86 Rb
		T	106.5	49.5	38	33	84 Rb
4	1750	L	119.0	56.5	51	54	91 Rb
		T	114.5	54.0	45	38	85 Rb
	1950	L	110.5	47.0	60	62	86 Rb
		T	108.5	45.5	58	53	83 Rb
4	1750	T	111.0	54.5	41	35	-
	1950	T	99.0	46.0	36	36	-

[a]Eight separate heats represented.
[b]Annealing for 1 hr, A.C.
[c]L is longitudinal test orientation; T, transverse.

Table 8 - Room-Temperature Tensile Properties of Hot-Rolled Bar

Diameter[a], in.	Heat Treatment[b]	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %	Hardness
0.625	As-Rolled	140.0	85.7	46	58	23 Rc
	1750°F/1 hr	140.0	83.0	45	49	99 Rb
	1950°F/1 hr	117.5	48.5	58	64	85 Rb
	1750°F/1 hr, Age	208.0	180.0	21	39	46 Rc
	1950°F/1 hr, Age	194.0	157.0	23	34	45 Rc
0.625	As-Rolled	139.0	78.5	46	62	98 Rb
	1750°F/1 hr	138.0	75.5	54	49	97 Rb
	1950°F/1 hr	115.5	48.0	64	67	85 Rb
	1750°F/1 hr, Age	208.5	179.5	20	39	45 Rc
	1950°F/1 hr, Age	194.5	158.0	20	26	44 Rc
1.0	As-Rolled	130.0	65.0	54	67	95 Rb
	1750°F/1 hr	129.0	64.5	55	61	94 Rb
	1950°F/1 hr	112.5	52.0	64	68	87 Rb
	1750°F/1 hr, Age	201.5	175.0	20	36	46 Rc
	1950°F/1 hr, Age	188.0	152.0	21	34	45 Rc
1.5	As-Rolled	147.0	105.5	40	52	32 Rc
	1750°F/1 hr	141.5	72.5	46	45	97 Rb
	1950°F/1 hr	120.0	55.0	58	60	89 Rb
	1750°F/1 hr, Age	205.0	167.5	20	28	46 Rc
	1950°F/1 hr, Age	191.0	153.0	24	36	43 Rc
4.0	1750°F/1 hr	117.5	55.0	53	52	90 Rb
	1950°F/1 hr	112.5	48.0	60	63	87 Rb
	1750°F/1 hr, Age	192.0	165.0	17	24	46 Rc
	1950°F/1 hr, Age	195.5	165.0	21	34	43 Rc

[a]Five separate heats represented. All tests are longitudinal.
[b]When annealing is at 1750°F, aging is 1325°F/8 hr, F.C. to 1150°F for total aging time of 18 hr. When annealing is at 1950°F, aging is 1400°F/10 hr, F.C. to 1200°F for total aging time of 20 hr.

Table 9 - Tensile Properties of Hot-Rolled Round (4-in. Diameter)

Test Temperature, °F	Test Orientation	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %	Hardness, Rc
Heat Treatment: 1750°F/1 hr, A.C. + 1325°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Aging Time of 18 hr[a]						
Room	Longitudinal	199.5	178.0	15.0	24.0	44
Room	Transverse	198.5	173.5	12.0	16.0	40
1200	Longitudinal	167.0	152.5	13.0	24.0	-
Heat Treatment: 1950°F/1 hr, A.C. + 1400°F/10 hr, F.C. to 1200°F, Hold at 1200°F for Total Aging Time of 20 hr						
Room	Longitudinal	197.0	164.0	17.0	23.0	44
Room	Transverse	192.0	165.0	19.0	24.0	44

[a]In stress-rupture tests under conditions of 1300°F and 75 ksi, results were: 68.2 hr life, 10.0% elongation and 13.0% reduction of area.

Table 10 - Room-Temperature Tensile Properties of Material Hot-Rolled and Aged (1325°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Aging Time of 18 hr)

Sample	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %	Hardness, Rc
0.65625-in. Diam.	206.5	189.5	19.0	34.5	42
0.625-in.-Diam.	206.5	179.5	22.0	45.5	41
0.625-in.-Diam.	210.0	184.0	22.0	44.5	42
13/16-in.-Diam.	209.0	181.0	22.0	43.0	43
1.25- x 1.25-in. Flat	227.5	210.0	17.0	40.8	44
1.5- x 175-in. Flat	215.0	172.0	19.0	35.0	42
0.625- x 1-in. Flat	215.5	184.0	24.0	45.5	44

Table 11 - Room-Temperature Tensile Properties of Pancake Forging (1700°F/1 hr plus 1325°F/8 hr, F.C. to 1150°F, Hold at 1150° for Total Aging Time of 18 hr)[a]

Sample	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation in 2 Inches, %	Reduction of Area, %	Charpy Keyhole Impact Strength, ft•lb
Radial center, top edge	182.0	159.0	10.0	10.5	-
Radial center, center	196.0	160.0	24.0	33.0	-
Radial center, bottom edge	186.5	159.5	16.0	19.0	-
Tangential, top edge	209.0	181.0	19.0	27.5	17-21
Tangential, bottom edge	210.0	179.0	18.0	29.5	21

[a]Piece 6.75-in. long by 4.5-in. octagon, heated at 2050°F, upset to 4.5-in. thick; heated at 1800°F, upset to 2.25-in. thick by 8-in. diameter pancake.

Table 12 - Room-Temperature Tensile Properties of Forged Flats (1 x 2-in. Thick, Annealed 1950°F/1 hr, A.C. and Aged)[a]

Sample	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %	Hardness, Rc
Longitudinal	191.5	159.0	20	32	40
Transverse	187.0	153.0	13	16	40
Longitudinal	191.1	160.0	19	29	42
Transverse	185.5	152.0	14	14	42
Longitudinal	194.0	162.0	17	26	43
Transverse	192.5	160.0	17	25	43
Longitudinal	195.0	165.0	18	23	43
Transverse	195.0	163.0	16	18	43
Longitudinal	193.0	164.0	17	22	42
Transverse	191.5	159.0	16	23	42
Longitudinal	193.5	166.0	15	21	42
Transverse	190.0	158.5	14	22	42
Longitudinal	199.5	171.0	17	26	44
Transverse	200.0	167.5	19	28	44
Longitudinal	195.0	165.0	18	26	42
Transverse	195.0	160.0	20	28	42
Longitudinal	198.0	170.0	20	33	43
Transverse	192.5	163.0	15	29	43
Longitudinal	198.0	174.0	21	34	43
Transverse	196.5	170.0	18	25	43
Longitudinal	200.0	170.0	17	24	43
Transverse	193.0	158.0	17	30	43
Longitudinal	189.0	157.5	21	35	42
Transverse	189.0	157.0	18	27	42

[a]1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for total aging time of 20 hours.

Table 13 - Room-Temperature Tensile Properties of 1-in. Thick Pancake[a]

Sample	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %	Hardness, Rc
Radial	186.0	153.0	20	31	43
Tangential	186.5	154.0	18	29	43
Radial	195.0	151.0	20	33	43
Tangential	184.5	152.5	20	29	43
Radial	189.0	155.0	15	24	44
Tangential	185.0	154.0	19	23	44
Radial	188.0	153.0	20	31	43
Tangential	185.0	152.5	18	28	43

[a]Upset-forged 3 to 1 reduction from a 4.0-in. diameter round. Forging temperature, 2000°F. Heat treatment: 1950°F/1-2 hr, plus 1400°F/10 hr, F.C. to 1200°F. Hold at 1200°F for a total aging time of 20 hr. Samples are from 4 separate heats.

Table 14 - Tensile Properties of Pancake Forging[a]

Heat Treatment	Test Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %	Hardness, Rc
1800°F/1 hr, W.Q. + 1325°F/8 hr, F.C. to 1150°F, hold at 1150 °F for total aging time of 18 hr	Room	204.5	176.0	16.0	23.0	38
	Room	201.0	168.0	21.0	28.3	41
	1200	163.0	145.5	26.0	47.4	-
1950°F/1 hr, W.Q. + 1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for total aging time of 20 hr	Room	190.0	152.0	18.0	24.3	35

[a]Pieces 4-in. diameter by 2-in. length heated at 1900°F and upset-forged to 5.5-in.-diameter by 1-in.-thickness pancake. Tests are transverse center-to-midsection.

Table 15 - Room-Temperature Tensile Properties of Cold-Rolled Sheet

Thickness, in.	Cold Reduction, %	Condition[a]	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation in 2 In., %
0.025	27	As Cold-Rolled	155.0	130.0	14
		Cold-Rolled, Aged	209.0	190.0	10
		As Cold-Rolled	154.0	128.0	15
		Cold-Rolled, Aged	223.5	209.5	10
		As Cold-Rolled	154.0	132.0	14
		Cold-Rolled, Aged	211.5	194.0	8
		As Cold-Rolled	156.0	132.0	14
		Cold-Rolled, Aged	216.0	195.0	13
0.050	21	As Cold-Rolled	138.0	112.0	22
		Cold-Rolled, Aged	208.0	189.0	9
		As Cold Rolled	143.5	117.5	19
		Cold-Rolled, Aged	212.5	196.0	10
0.093	18	As Cold-Rolled	140.5	115.0	26
		Cold-Rolled, Aged	210.0	188.5	16
0.125	26	As Cold-Rolled	158.5	137.0	11
		Cold-Rolled, Aged	219.0	206.5	8
0.125	23	As Cold-Rolled	140.5	120.0	21
		Cold-Rolled, Aged	204.0	186.5	12
0.074	18.5	As Cold-Rolled	145.0	116.5	25
0.062	28	As Cold-Rolled	159.5	134.0	11

[a]Aging--1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours.

Table 16 - Room-Temperature tensile properties of Sheet Annealed and Aged in Accordance with AMS 5597

Thickness, in	Tensile Strength, ksi	Yield Strength, ksi	Elongation, %
0.010	192.5	172.5	17
0.012	204.0	169.5	19
0.015	198.0	162.0	19
0.016	196.0	163.5	19
0.018	196.5	155.5	21
0.021	202.5	169.0	20
0.025	199.0	162.5	20
0.031	197.0	160.0	21
0.040	208.0	172.0	16
0.047	199.0	166.5	20
0.050	211.0	177.0	16
0.062	203.5	171.0	18
0.078	192.0	158.5	17
0.080	200.0	163.5	20
0.093	199.0	167.0	19
0.100	208.0	176.0	18
0.109	204.0	171.0	19
0.125	203.5	172.0	16
0.156	196.5	161.0	21
0.187	207.5	182.0	18
0.210	194.5	160.0	22
0.250	205.0	170.5	19

Table 17 - Effect of Aging on Room-Temperature Properties of Tube Reduced 70% to 0.133-in. Wall, 1.513-in. O.D.

Condition	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Hardness, Rc
As-Tube Reduced	247.0	211.0	6.0	42.0
Aged 1325°F/8 hr, F.C. 100°F/hr to 1150°F/ 8 hr, A.C.	266.0	261.0	4.0	51.5

Table 18 - Room-Temperature Tensile Properties of Hot-Rolled Plate Annealed and Aged in Accordance with AMS 5596H

Thickness, In.[a]	Tensile Strength, ksi	Yield Strength, ksi	Elongation, %	Hardness, Rc
0.5	206	177	18	43
0.75	204	170	19	42
1	204	173	17	42

[a]Values for each thickness are average of six samples, different heats.

Table 19 - High-Temperature Tensile Properties of Hot-Rolled Round, Annealed and Aged (1950°F/1 hr, plus 1400°F/10 hr, F.C. 100°F/hr to 1200°F, hold at 1200°F for 8 hr)[a]

Test Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %
Room	198.0	163.0	21	30
600	183.5	156.0	16	34
1000	173.0	148.0	16	30
1200	160.0	140.0	15	25
1300	146.0	135.0	8	10
1400	123.5	116.0	5	10
1500	105.0	100.0	15	20

[a]Round, 4-in.diameter, from single heat.

Table 20 - Effect of Temperature on Tensile Properties of Hot-Rolled Round (5/8-in. Diameter, Annealed 1800°F/1 hr and Aged)[a]

Temperature, °F	Tensile Strength, ksi	Yield Strength, ksi	Elongation, %	Reduction of Area, %
-320	237.0	173.5	26.0	27.0
-60	201.5	158.0	23.0	33.5
80	190.5	153.5	22.0	32.5
1200	164.5	145.0	28.0	59.2
1300	145.5	133.0	22.0	34.0

[a]1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.

Table 21 - Low-Temperature Properties of Forging (Short Transverse Tests)[a]

Test Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2%Offset), ksi	Elongation in 4D, %	Reduction of Area, %	Notch Strength, Tensile Strength Ratio[b]
1800°F/45 min, A.C. plus 1325°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Aging Time of 18 hr					
Room	187.0	165.9	17.0	23.0	1.45
-110	198.9	174.4	17.2	20.0	1.37
-320	229.0	186.8	14.0	14.0	1.30
-423	237.2	194.9	13.5	11.5	1.30
1950°F/45 min, A.C. plus 1400°F/10 hr, F.C. to 1200°F, Hold at 1200°F for Total Aging Time of 20 hr					
Room	181.5	147.7	19.0	24.5	1.37
-110	195.9	158.1	15.0	18.5	1.41
-320	228.7	176.7	17.5	19.5	1.28
-423	244.2	186.8	16.5	18.0	1.19

[a]Specimens machined from forging with dimensions 4 by 9 by 15-in.
[b]Notch concentration factor K_t, 6.3.

Table 22 - High-Temperature Tensile Properties of Annealed and Aged Hot-Finished Material (1800°F/1 hr, plus 1325°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Aging Time of 18 hours)

Form	Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %	Hardness, Rc
Forged Pancake[a]						
Radial Center	Room	196.0	160.0	24	33	-
Tang. Mid.Rad.	1200	162.0	138.5	23	38	-
	1300	146.0	135.0	30	62	-
Hot Rolled, 0.625-in.-Diam.	Room	201.0	171.0	26	50	41
	1200	164.5	145.0	28	59	-
	1300	145.5	133.0	22	34	-
Forged Rod, 6-in.-Diam.	Room	184.5	152.0	28	42	-
	1300	129.0	113.0	14	16	-
Hot-Rolled, 0.5-in.-Diam.	Room	211.0	174.0	23	40	-
	1200	168.0	148.8	22	32	-
	1300	145.0	136.5	20	27	-
Hot-Rolled, 0.5-in.-Diam.	Room	207.5	172.0	25	44	40
	1200	163.5	145.0	26	49	-
	1300	137.0	126.0	25	25	-
Forged Square, 1- x 1-in.	Room	180.0	152.0	23	40	-
	1200	159.0	138.0	20	28	-
	1300	140.0	129.0	26	44	-
Forged Flat, 1- x 2-in.	Room	184.5	154.0	24	42	44
	1200	150.0	132.5	21	38	-
	1300	140.0	125.5	17	22	-
Hot-Rolled, 2-in.-Diam.	Room	190.0	152.0	22	37	42
	1200	153.0	130.0	30	46	-
	1300	131.5	117.0	23	34	-
Forged Round, 6-in.-Diam.	Room	187.0	155.0	20	37	42
	1200	156.0	134.0	18	24	-
	1300	136.5	123.0	12	13	-
Forged Flat, 0.625- x 0.75-in.	Room	204.0	162.5	18	33	44
	1200	165.5	147.0	26	61	-
	1300	138.0	126.0	32	68	-

[a]6.75-in. long by 4.5-in octagonal heated at 2050°F, upset-forged to 4.5-in. thick; reheated at 1800°F, upset-forged to 2.25-in. thick pancake.

Table 23 - High-Temperature Tensile Properties of Cold-Rolled 0.054-in. Sheet Annealed in Accordance with AMS 5596

Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %
Room	135.0	76.0	44.5
1000	119.5	55.5	43.0
1200	120.0	72.0	32.0
1400	103.0	64.5	7.0
1600	74.5	52.5	39.0

Table 24 - Tensile Properties of 0.065-in. Cold-Rolled Sheet

Condition[a]	Grain Size, ASTM No.	Test Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Hardness
Annealed	7	Room	141.0	73.0	38.0	99 Rb
Annealed and Aged[b]	-	Room	214.0	188.5	15.0	46 Rc
Annealed and Aged	-	1200	166.0	149.5	13.5	-

[a]In accordance with AMS 5596.
[b]Stress-rupture properties at 1300°F and 72.5 ksi: 35.3 hr life, 22.0% elongation.

Table 25 - Room-Temperature Tensile Properties of Cold-Rolled Sheet, Annealed and Aged in Accordance with AMS 5596[a]

Thickness, in.	Tensile Strength, ksi	Yield Strength, ksi	Elongation, %	Hardness, Rc
0.187	205	177	20	44
0.156	207	180	20	44
0.125	206	178	19	44
0.100	209	183	19	44
0.063	205	179	19	44
0.035	208	184	18	44
0.025	203	177	19	44

[a]Each size average of four samples, four heats.

Table 26 - Tensile Properties of Cold-Rolled Sheet (Annealed and Aged in Accordance with AMS 5596; Transverse Tests)

Thickness, in.	Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Hardness, Rc	Notch Tensile Strength, ksi (K_t=6.3)	Notch/Unnotch Tensile Strength Ratio
0.025	Room	204.5	177.0	14.0	48	-	-
	-320	253.5	203.0	12.5	48	215.5	0.85
0.062	Room	205.75	174.5	19.0	45	204.0	0.99
(30% Reduction)[a]	-320	254.25	200.0	20.0	45	219.5	0.86
0.075	Room	201.0	170.25	18.0	44	213.25	1.06
(10% Reduction)[a]	-320	249.25	194.25	18.0	44	233.25	0.94
0.93	Room	202.0	170.5	16.0	41	-	-
	-320	251.0	189.5	22.5	45	244.0	0.97
0.125	Room	205.5	181.0	13.5	47	-	-
	-320	262.5	208.5	18.0	46	255.0	0.97

[a]Values for these specimens are averages of 2 tests.

Table 27 - Tensile Properties of 0.027-in. Sheet Reduced 20% (Transverse Tests)

Sample	Test Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Notch Tensile Strength, ksi (K_t=6.3)	Tensile Strength/ 0.297 lb/cu. in.[a]	Ratio of Notch Tensile Strength to	
							Tensile Strength	Yield Strength
Cold-Rolled, Annealed and Aged in Accordance with AMS 5596	-110	212.0	168.5	25.0	195.0	714,000	0.92	1.16
	85	196.0	163.0	21.0	183.0	660,000	0.93	1.12
	85[b]	197.0	162.5	21.0	178.0	-	0.91	1.10
	350	191.0	153.0	20.0	-	-	-	-
	650	171.5	141.5	20.0	158.0	578,000	0.92	1.11
	650[b]	172.0	137.5	23.0	163.0	-	0.95	1.19
	800	188.0	141.0	23.0	156.0	-	0.83	1.11
	1000	169.0	135.0	24.0	143.0	570,000	0.85	1.06
Cold-Rolled and Aged in Accordance with AMS 5596	-320	260.5	229.0	13.0	236.5	877,000	0.91	1.03
	-110	232.0	206.5	17.0	209.0	781,000	0.88	1.01
	85	221.0	198.5	12.0	196.5	745,000	0.89	0.99
	85[b]	212.0	195.5	13.0	199.0	-	0.94	1.02
	350	205.0	188.5	12.0	179.0	-	0.88	0.96
	650	193.5	179.0	12.0	173.5	652,000	0.90	0.97
	650[b]	198.5	182.0	13.0	172.0	-	0.87	0.95
	800	-	-	-	169.0	-	-	-
	1000	180.5	165.3	10.0	166.5	608,000	0.92	1.01

[a]Room-temperature density.
[b]Stressed at 40 ksi for 1000 hr at 650°F prior to testing.

Table 28 - Low-Temperature Tensile Properties of Sheet (Heat-Treated in Accordance with 5596)

Test Temperature, °F	Test Orientation[a]	Tensile Strength, ksi	Yield Strength, ksi	Elongation, %	Notch Tensile Strength[b], psi	Notch/Unnotch Tensile Strength Ratio
		0.010-in. Material - Annealed (Heat 1)				
75	L	114.0	47.3	43	89.2	0.78
	T	116.0	47.0	49	88.8	0.77
-320	L	152.0	70.7	50	121.0	0.80
	T	157.0	75.8	43	118.0	0.75
-423	L	187.0	97.3	49	146.0	0.78
	T	176.0	91.8	40	142.0	0.81
		0.010-in. Material - Annealed and Aged (Heat 1)				
75	L	192.0	155.0	21	198.0	1.03
	T	189.0	154.0	20	196.0	1.04
-320	L	243.0	186.0	26	234.0	0.96
	T	239.0	181.0	22	229.0	0.96
-423	L	267.0	200.0	21	254.0	0.95
	T	262.0	195.0	21	259.0	0.99
		0.031-in. Material - Annealed and Aged (Heat 2)				
75	L	195.0	157.0	20	207.0	1.06
	T	194.0	157.0	20	206.0	1.06
-100	L	214.0	171.0	23	221.0	1.03
	T	213.0	170.0	23	223.0	1.04
-320	L	232.0	185.0	33	214.0	0.92
	T	247.0	192.0	26	229.0	0.93
-423	L	278.0	205.0	28	276.0	0.99
	T	276.0	204.0	27	269.0	0.97
		0.031-in. Material - 20% Cold-Rolled and Aged (Heat 2)				
75	L	214.0	197.0	15	238.0	1.11
	T	204.0	183.0	13	226.0	1.11
-320	L	268.0	227.0	25	272.0	1.01
	T	254.0	214.0	21	262.0	1.03
-423	L	286.0	239.0	28	293.0	1.02
	T	281.0	228.0	22	286.0	1.02
		0.018-0.025-in. Material - 30% Cold-Rolled and Aged (Heat 3)				
75	L	230.0	218.0	7	248.0	1.08
	T	223.0	206.0	7	248.0	1.11
-100	L	249.0	230.0	11	267.0	1.07
	T	242.0	218.0	8	262.0	1.08
-320	L	292.0	259.0	16	292.0	1.00
	T	273.0	238.0	13	285.0	1.04
-423	L	309.0	269.0	15	309.0	1.00
	T	295.0	251.0	16	301.0	1.02
		0.018-0.025-in. Material - 50% Cold-Rolled and Aged (Heat 3)				
75	L	240.0	231.0	6	261.0	1.09
-320	L	297.0	274.0	9	304.0	1.02
-423	L	337.0	287.0	12	320.0	0.95

[a]L, longitudinal; T, transverse.
[b]Notch concentration, K_t, 6.3

Table 29 - Room-Temperature Impact Strength of Hot-Finished Products

Diameter[a], in.	Tensile Properties (Longitudinal Orientation)				Charpy V-Notch Impact Strength, ft•lb
	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %	
Heat Treatment: 1750°F/1 hr, A.C. + Aged 1325°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Aging Time of 18 hours					
0.625	208.0	180.0	21.0	39.0	18.5
1	209.0	174.0	20.0	24.8	10.0
1.5	204.0	165.5	19.0	24.5	11.0
8	209.0	183.5	17.0	32.0	13.0[b]
12	196.0	165.0	25.0	39.1	24.0[b]
Heat Treatment: 1950°F/1 hr, A.C. + Aged 1400°F/10 hr, F.C. to 1200°F, Hold at 1200°F for Total Aging Time of 20 hours					
0.625	194.0	157.0	23.0	34.0	26.0
1	188.0	152.0	21.0	34.0	33.0
1.5	191.0	153.0	24.0	36.0	28.5
8	194.5	160.0	22.0	34.3	35.0[b]
12	192.5	162.0	27.0	42.0	39.0[b]

[a]Diameters of 8- and 12-in. were forged; others are hot-rolled.
[b]Average of 2 tests.

Table 30 - Impact Strength of 1-in. Plate (Annealed and Aged in Accordance with AMS 5596)

Temperature, °F	Impact Strength, ft•lb	
	Charpy Keyhole	Charpy V-Notch
Room	15.5, 16.0, 17.0	19.5, 20.5, 22.5
-320	13.5, 13.5, 15.0	18.5, 19.0, 19.5

Table 31 - Room-Temperature Fatigue Strength of 6- by 9-in. Forging[a]

Condition[b]	Tensile Properties				Grain Size, in.	Fatigue Strength, ksi		
	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %		10^6 Cycles	10^7 Cycles	10^8 Cycles
Annealed	143.0[c]	99.5[c]	32[c]	32[c]	0.0023[c]	74.0	67.5	66.5
Annealed and Aged	191.25	169.5	10.5	20	0.0021	77.5	71.0	69.5

[a]Rotating-beam fatigue tests. Values are average of 2 samples (polished specimens)--center short transverse and mid short transverse.
[b]Annealing at 1750°F/1 hr Aging at 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.
[c]Values for center short transverse only.

Table 32 - Room-Temperature Fatigue Strength of 1.125-in. Hot-Rolled Plate[a]

Heat Treatment[b]	Test Orientation	Tensile Properties				Grain Size, in.	Fatigue Strength, ksi		
		Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %		10^6 Cycles	10^7 Cycles	10^8 Cycles
Annealed	Longitudinal	132.5	58.0	46	46.6	0.0008	73.0	70.0	70.0
Annealed and Aged	Longitudinal	201.5	159.5	26	46.0	0.0005	96.0	81.0	78.0
	Transverse	199.0	158.0	24	38.0	0.0007			
Annealed and Aged	Longitudinal	202.0	160.5	26	44.5	0.0015	96.0	88.0	85
	Transverse	197.5	159.0	24	41.0	0.0005			
Annealed and Aged	Longitudinal	196.5	158.0	27	48.5	0.0009	91.0	82.0	77.0
	Transverse	196.5	158.0	27	43.0	0.0008			
Annealed and Aged	Longitudinal	191.0	153.5	28	41.5	0.0014	90.0	81.0	74.0
	Transverse	188.5	151.5	28	41.5	0.0013			
Aged	Longitudinal	215.0	193.5	20	39.1	0.0008	95.0	84.0	80.0
	Transverse	210.0	187.0	17	37.5	0.0012			

[a]Fatigue tests run on R.R. Moore rotating-beam fatigue machines at 10,000. Specimens were 0.300-in. diameter polished longitudinally.
[b]In accordance with AMS 5596.

Table 33 - High-Temperature Fatigue Strength of Hot-Rolled Bar (Annealed 1750°F/1 hr, A.C. and Aged)[a]

Test Temperature, °F	Fatigue Strength, ksi			
	10^5 Cycles	10^6 Cycles	10^7 Cycles	10^8 Cycles
Room	132.0	101.0	92.0	90.0
600	115.0	110.0	110.0	110.0
1000	111.0	102.0	95.0	90.0
1200	100.0	94.0	88.0	72.0

[a]Rotating-beam tests. Average grain size, 0.0008-in. Aging--1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.

Table 35 - Effect of Postwelding Heat Treatment on Tensile Properties
(Manual Gas Tungsten-Arc Process between 0.5-in. Plates) (Average of 2 Tests)

Filler Metal Diameter, in.[a]	Heat Treatment[b]	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %
0.045	As-Welded[c]	125.50	84.30	28.0	30.0
	1750°F, Age	180.25	148.50	7.8	12.3
	1950°F, Age	197.25	162.75	18.8	26.5
	1325°F, Age	186.00	153.50	11.0	13.5
0.045	As-Welded	120.75	82.30	28.0	30.5
	1750°F, Age	169.50	144.00	7.8	12.0
	1950°F, Age	193.50	164.85	13.3	17.0
	1325°F, Age	180.50	147.75	7.8	10.3
0.09375	As-Welded	123.75	84.00	28.0	31.3
	1750°F, Age	174.50	145.25	7.7	12.5
	1950°F, Age[c]	197.00	168.50	10.0	18.0
	1325°F, Age[c]	166.50	150.50	4.0	4.0
0.062	As-Welded[c]	125.20	83.50	28.0	37.5
	1750°F, Age	174.50	152.00	4.9	7.0
	1950°F, Age	198.00	179.25	13.8	21.5
	1325°F, Age[c]	175.50	151.00	4.0	7.5
0.062	As-Welded	123.25	75.05	34.3	35.3
	1750°F, Age	180.00	144.00	12.6	18.0
	1950°F, Age[c]	196.50	161.00	16.0	31.0
	1325°F, Age	176.75	140.00	15.5	22.5

[a]Each separate size shown represents test run on separate heat.
[b]Heat treatments: 1750°F, Age is 1750°F anneal plus age at 1325°F/8 hr , F.C. 100°F/hr to 1150°F, hold at 1150°F for a total of 18 hours. 1950°F, Age is 1950°F anneal plus age at 1400°F/10 hr, F.C. 100°F/hr to 1200°F, hold at 1200°F for a total aging time of 20 hours. 1325°F, Age is at 1325°F/8 hr, F.C. 100°F/hr to 1150°, hold at 1150°F for total aging time of 18 hr.
[c]One test only.

Table 36 - Weld-Patch Testing of Cold-Rolled, Annealed Sheet[a]
(Procedure: Anneal plus Weld plus Age plus Repair-Weld plus Re-Age)

Sheet Thickness, in.	Heat Treatment	Patch Test Assembly[b]	Condition After	
			Welding and Aging	Repair Welding and Re-Aging
0.028	AMS 5596	1	Crack-Free	Crack-Free
0.030		1	Crack-Free	Crack-Free
0.030		1	Crack-Free	Crack-Free
0.035		1	Crack-Free	Crack-Free
0.035		2	Crack-Free	Cracked
0.062		2	Crack-Free	Crack-Free
0.062	AMS 5597	2	Crack-Free	Cracked
0.062		1	Crack-Free	Crack-Free
0.062		1	Crack-Free	Crack-Free
0.062		2	Crack-Free	Crack-Free
0.078		1	Crack-Free	Cracked
0.093		2	Crack-Free	Cracked
0.109		2	Crack-Free	Crack-Free

[a]Seven different heats represented in these tests.
[b]See Figure 15.

Table 37 - Room-Temperature Tensile Properties[a]
(Transverse Tests) of Welds in 0.5-in. Plate
(Gas Tungsten-Arc Process)

Postweld Heat Treatment[b]	Tensile Strength, ksi	Yield Strength (0.2 % Offset), ksi	Elongation in 1 In., %	Reduction of Area, %
Direct Age	185.0	158.0	6.5	15.8
Annealed and Aged	190.0	163.3	7.5	13.9
Annealed and Aged	191.5	164.5	9.5	16.3

[a]Average of 2 tests.
[b]According to AMS 5596.

Table 38 - Room Temperature Tensile Properties of Welds (Aged 1325°F/8 hr, F.C. to 1150°F, Held at 1150°F for Total Aging Time of 18 Hours)[a]

Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation in 1 In., %	Reduction of Area, %
	Transverse Tests Across Joints		
183.0	159.5	8.0	19.0
183.5	158.5	7.0	16.0
186.5	162.0	6.0	12.8
185.5	163.0	6.0	21.0
184.0	163.0	6.0	16.5
192.5	166.0	9.0	17.5
191.5	164.0	6.0	12.5
182.0	156.5	4.0	6.8
188.5	168.0	4.0	11.5
188.0	170.0	5.0	10.0
Average 186.5	163.0	6.0	14.4
	All-Weld Metal Tests		
180.5	157.5	10.0	16.0
182.5	162.0	8.0	14.0
178.0	154.0	11.0	12.5
177.5	150.0	14.0	18.5
180.0	153.5	10.0	22.0
180.0	158.5	7.0	11.5
183.5	160.5	6.0	8.5
Average 180.0	156.5	9.0	15.0

[a]0.252-in.-diameter specimens prepared from TIG-welded 0.500-in. plate. Plate annealed in accordance with AMS 5596 prior to welding. All tests broke in weld.

Table 41 - Notch-Strength of Butt-Welded, 0.051-in. Cold-Rolled, Annealed Sheet

Treatment of Weld[a]	Notch Strength[b], ksi	
	Heat-Affected Zone	Weld
Aged	154.0	129.0
	183.8	133.5
Annealed	175.0	132.3
1800°F/1 hr and Aged	163.3	136.0

[a]Aging--1325°F/8 hr, F.C. to 1150°F, hold for total aging time of 18 hr, A.C. All welds milled flush to parent metal. Welds made by automatic gas tungsten-arc
[b]Average of 2 values. Notches were milled in the center of the weld and in the parent metal about 0.025-in. from the fusion zone K_t, approximately 24.

Table 39 - Room-Temperature Tensile Properties[a] of Welds in 0.5-in. Plate (Gas Tungsten-Arc Process)

Sample	Postweld Heat Treatment[b]	Tensile Strength, ksi	Yield Strength (0.2 % Offset), ksi	Elongation in 0.5 In., %	Reduction of Area, %
All-Weld Metal	Direct Age	174.50	139.25	18.3	21.5
	1950°F/1 hr, Age	185.75	155.50	22.0[c]	31.8
Transverse[d]	Direct Age	183.50	149.50	12.0	24.8
	1950°F/1 hr, Age	192.25	160.75	17.3	23.5

[a]Average of 2 tests.
[b]Age--1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for total aging time of 20 hours.
[c]One test.
[d]All fractures were in weld.

Table 40 - Room-Temperature Tensile Properties of Annealed and Aged Welds in 0.063-in. Sheet[a]

Weld	Tensile Strength, ksi	Elongation in 1 in., %
	Argon Torch Gas; Helium Root Gas	
1	188.00	11.7
2	184.20	10.0
3	184.50	10.0
4	190.20	14.3
5	192.70	17.3
	Average 187.92	12.7
	Helium Torch Gas; Argon Root Gas	
6	189.20	11.7
7	191.00	15.3
8	187.80	12.7
9	191.70	18.3
10	194.00	18.7
	Average 190.74	15.3

[a]Welded manually with INCONEL Filler Metal 718. One bead. Average of 3 tests. All sheet from same heat. Heat treatment after welding: 1950°F/15 min., plus 1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for total aging time of 20 hr.

Table 42 - Tensile Properties of Ring-Forging Specimens Gas-Tungsten-Arc Welded
(Weldments Annealed 1950°F/1 hr and Aged 1400°/10 hr, F.C. to 1200°F, Hold at 1200°F for Total Aging Time of 20 hours)[a]

Specimen	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %	Notch Tensile Strength[b], ksi	Notch/Unnotch Tensile Strength Ratio
Room Temp.						
Parent Metal	197.5	163.8	25.5	38.5	272.8	1.38
Weld	189.7	165.6	19.3	38.1	263.1	1.39
-423°F						
Parent Metal	245.9	203.6	22.5	33.1	323.8	1.32
Weld	237.9	201.0	19.7	30.7	308.7	1.30
1200°F						
Parent Metal	143.8	125.7	21.1	40.7	207.4	1.44
Weld	147.3	127.3	11.9	30.2	204.2	1.39

[a]Data are averages of 2-5 tests.
[b]Notch concentration factor, K_t, 6.3

Table 44 - Rupture Strength of Butt Joints in Annealed Sheet[a]

Treatment of Weld	Test Temperature, °F	Stress, ksi	Life, hr	Elongation, %	Location of Fracture
Parent Metal Annealed and Aged	1200	100.0	47.3	85.0	-
	1300	72.5	26.1	11.0	-
Annealed and Aged	1200	100.0	10.8	1.0	Weld
	1300	72.5	9.4	1.0	Weld
Aged	1200	100.0	16.4	1.0	Weld
	1300	72.5	15.8	2.0	Weld

[a]0.060-in. sheet. Parent metal and weld heat-treated in accordance with AMS 5596. Welds ground flush.

Table 45 - Rupture Strength of Welds[a] (Test Conditions: 1300°F and 75.0 ksi)

Specimen	Heat Treatment[b]	Life, hr	Elongation, %	Reduction of Area, %	Notch Bar Life, hr
All-Weld Metal	Aged	11.7	4.0		6.0 14.1
	Annealed and Aged	12.2	5.0		7.5 45.5
Transverse Joint[c]	Aged	25.5	4.0 (in 0.5 in)	5.0	30.1
	Annealed and Aged	15.3	3.0 (in. 0.5 in.)	8.5	25.1

[a]Weld deposit by gas tungsten-arc process between 0.5-in.
[b]In accordance with AMS 5596.
[c]All fractures in weld.

Table 46 - Cold Working and Age Hardening[a]

Diameter, in	Yield Strength (0.2% Offset), ksi	Tensile Strength, ksi	Elongation, %	Hardness, Rc
		As Cold Drawn		
0.51	-	-	-	-
0.76	161	178	16	41
1.01	150	176	15	38
1.51	-	-	-	-
Cold Drawn and Aged (1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr)				
0.51	227	243	11	48
0.76	223	234	11	47
1.01	222	237	11	47
1.51	229	244	11	46
Cold Drawn, Solution Annealed and Aged (1750°F/1 hr, A.C. then 1325°F/8 hr F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.)				
0.51	168	211	20	42
0.76	165	208	21	42
1.01	165	212	20	42
1.51	-	-	-	-

[a]Average of minumum five samples from five different heats.

Table 47 - Pressure, ksi, Developed in Roll Gap at 20% Reduction

Material	Pressure, ksi			
	Hot-Forming Temperature, °F			
	1800	1900	2000	2100
Mild Steel (1020)	22.4	18.3	14.3	10.3
Type 302 Stainless Steel	27.8	24.3	21.4	18.0
alloy 600	40.8	34.6	28.3	22.3
alloy X-750	48.6	43.3	38.4	33.3
alloy 718	63.3	55.8	48.3	41.0

Table 50 - Minimum Bend Diameters for Annealed Sheet and Strip and Hot-Rolled and Annealed Plate in 180° Bend

Alloy	Thickness (T)		Minimum Diameter[a]
	in.	mm	
alloy 718[b]	Sheet and Strip	Sheet and Strip	
	0.012-0.049	0.30-1.24	1T
	0.050-0.250	1.27-6.35	2T

[a]Bend tests were performed according to ASTM Standard Method E 290-77 with a guided-bed jig as described in ASTM Standard Method E 190-64 (Reapproved 1976).
[b]Sheared edges of samples of alloy 718 were ground or machined.

Table 48 - Effect of Hot-Forming Temperature on Rupture Properties[a] (1200°F, 100 ksi)

Hot-Forming Temperature, °F	Heat Treatment[b]	ASTM Grain Size	Smooth Bar				Notch Bar Life[c], hr
			Life, hr	Elongation, %	Reduction of Area, %	Hardness, Rc	
2050	A	20% 0.5, 30% 4.5, 40% 6.5, 10% 9	193.5	3	6.5	45	16.2
	B	100% 1.5	209.5	4	8.5	46	16.5
1950	A	70% 8, 30% 3	274.5	7	9.0	45	55.1
	B	60% 3, 30% 8, 10% 7	291.4	8	10.0	45	56.7
1850	A	95% 4.5, 5% 9	193.3	11	16.0	46	123.9
	B	35% 4.5, 60% 9, 5% 7	231.6	10	13.0	46	99.2
1750	A	20% 6, 20% 7, 60% 10	121.3	13	22.0	46	131.4
	B	40% 7, 55% 9, 5% 5	248.3	14	16.0	46	179.6
1650	A	100% 9.5	48.0	33	53.5	46	426.2[d]
	B	100% 9.5	124.3	28	43.5	46	426.1[d]

[a]Hot-finished, 25% reduction, one pass.
[b]A--1750°F/1 hr, A.C., + 1325°F/8 hr, F.C. 100°F/hr to 1150°F, hold at 1150°F/8 hr, A.C.
B--1800°F/1 hr, A.C., + 1325°F/8 hr, F.C. 100°F/hr to 1150°F, hold at 1150°F/8 hr, A.C.
[c]K_t, 3.5 to 4.0; root diameter, 0.252-in.
[d]Test discontinued.

Table 49 - Effect of Cold Reduction on Properties of Sheet

Cold Reduction, %	Tests at Room Temperature				Tests at -320°F		
	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Hardness, Rc	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %
0	117.0	44.0	60.0	87 Rb	-	-	-
5.9	115.0	68.2	45.0	19	161.0	103.0	38.0
18.5	145.0	116.5	25.0	33	189.0	153.0	24.0
27.9	159.5	134.0	10.5	36	204.0	169.0	15.0
48.3	191.0	165.0	7.0	40	231.0	204.0	15.0
Aged 1325°F/8 hr, F.C. 100°F/1 hr to 1150°F (Held for Total Aging Time of 18 hr, A.C.) after Cold Rolling							
0	187.0	172.5	19.5	44	248.0	188.5	26.0
5.9	203.0	175.5	22.0	45	255.0	211.0	13.0
18.5	217.0	201.0	16.0	47	270.0	235.0	12.5
48.3	244.0	232.5	4.0	49	289.0	269.0	2.5

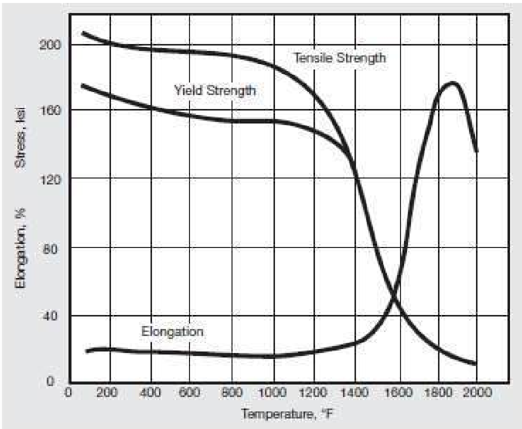

Figure 1. High-temperature properties of ½-in. diameter hot-rolled, annealed (1800°F/1 hr) and aged (1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours) bar.

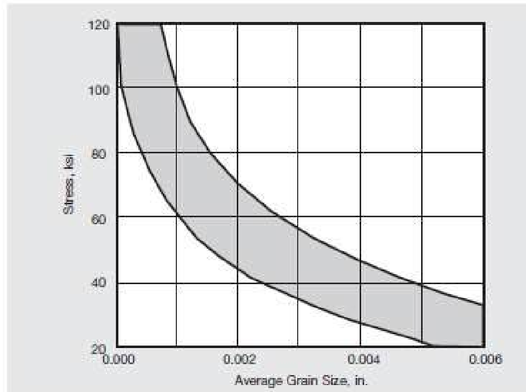

Figure 4. Effect of grain size on endurance limit (10^8 cycles) of plate annealed and aged in accordance with AMS 5596.

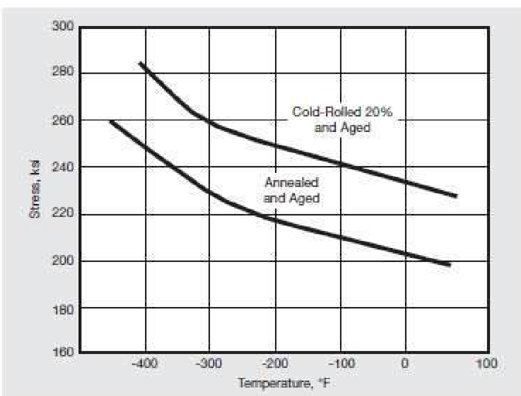

Figure 2. Notch tensile strength of 0.031-in. sheet, heat-treated in accordance with AMS 5596 (K_t=7.2; transverse tests).

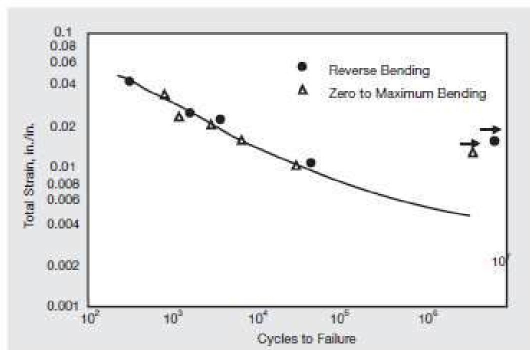

Figure 5. Low-cycle life of plate annealed and aged in accordance with AMS 5596. (Test orientation parallel to rolling direction). Grain size, 0.0021-in. Modified Krouse plate fatigue machine.

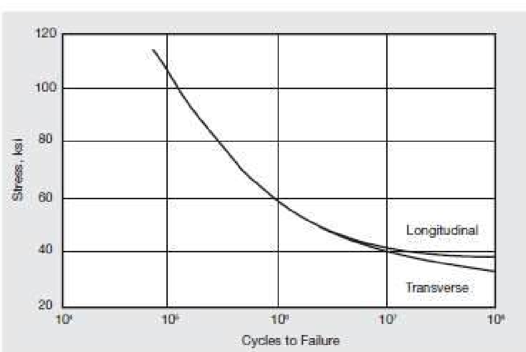

Figure 3. Room-temperature fatigue strength of 0.068-in. cold-rolled sheet annealed and aged in accordance with AMS 5596 (Krouse tests). Average grain size, 0.002 in.

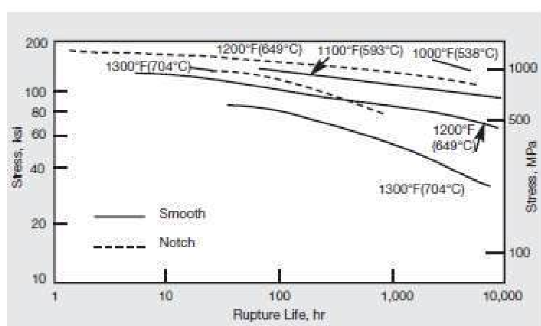

Figure 6. Smooth and notch rupture life of hot-rolled bar, 0.625-in.(15.9 mm) diameter (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr), K_t=4.

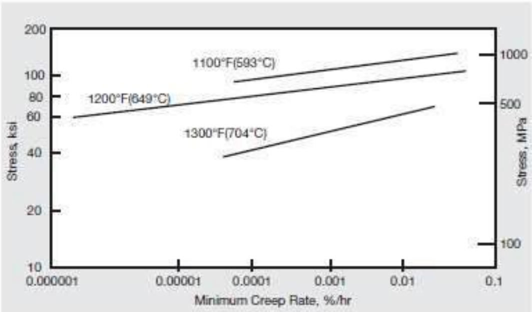

Figure 7. Creep strength of hot-rolled bar 0.625-in.(15.9 mm) diameter (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr).

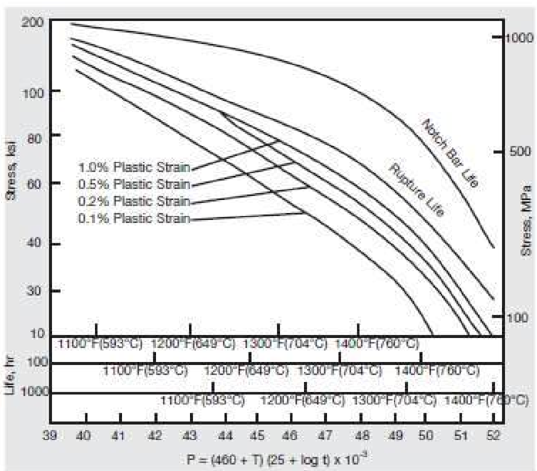

Figure 8. Larson-Miller parameter plot of rupture life of hot-rolled, 0.625-in.(15.9 mm) diameter bar (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hours). In the Larson Miller parameter, P, T is temperature, °F, and t is time, hr.

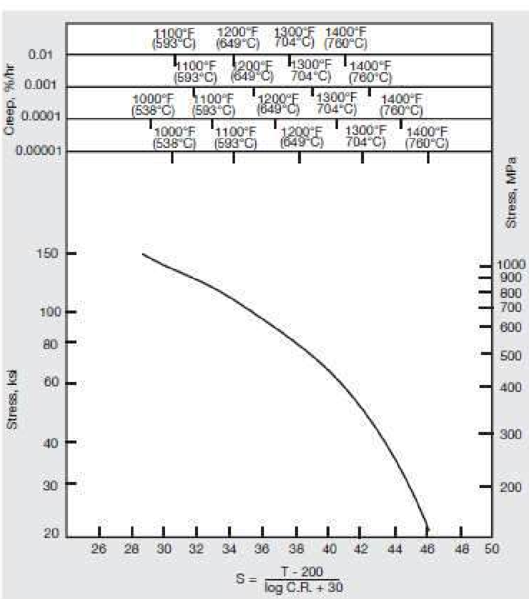

Figure 9. Manson-Haferd parameter plot of minimum creep rate of hot-rolled bar, 0.625-in. (15.9 mm) diameter (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr). In the Manson-Haferd parameter, S, T is temperature, °F, and C.R. is creep rate.

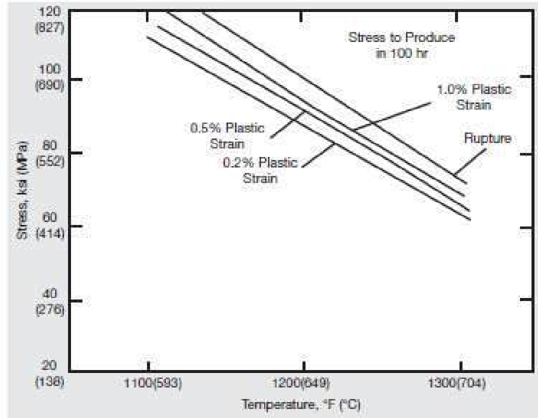

Figure 10. Creep-rupture properties (100 hr) of hot-rolled, 0.625-in. (15.9 mm) diameter bar (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr).

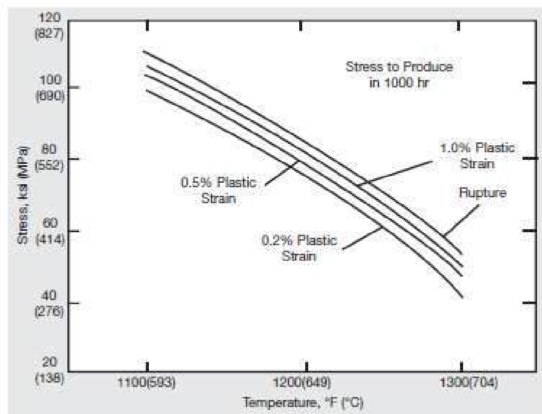

Figure 11. Creep-rupture properties (1000 hr) of hot-rolled, 0.625-in. (15.9 mm) diameter bar (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr).

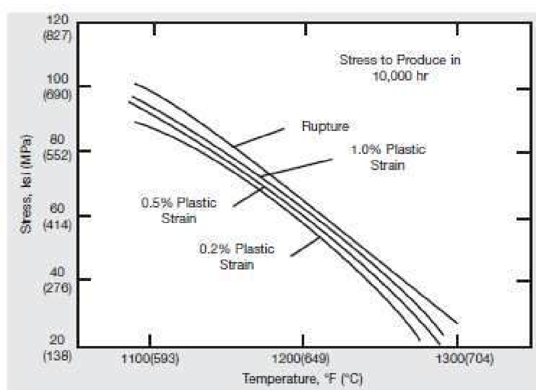

Figure 12. Creep-rupture properties (10,000 hr) of hot-rolled, 0.625-in. (15.9 mm) diameter bar (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr).

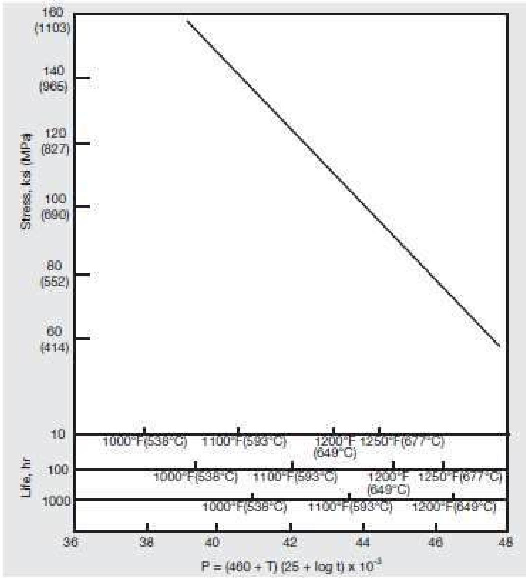

Figure 13. Larson-Miller parameter plot of rupture life of cold-rolled sheet, 0.025-0.250 in. (0.64-6.35 mm) (Annealed and aged in accordance with AMS 5596). In the Larson-Miller parameter, P, T is temperature, °F, and t is time, hr.

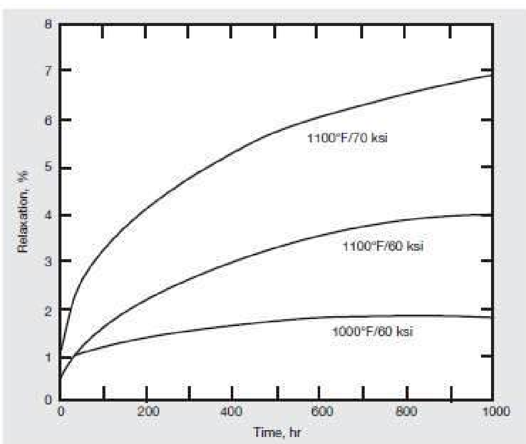

Figure 14. Relaxation of helical coil springs made from 0.148-in.-diameter cold-drawn No. 1 Temper wire. (Springs annealed 1800°F/1 hr and aged 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.

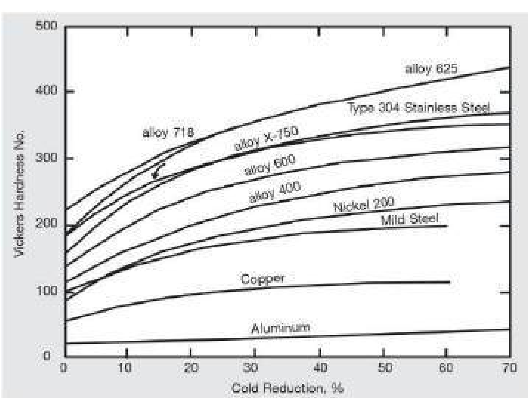

Figure 16. Effect of cold work on hardness.

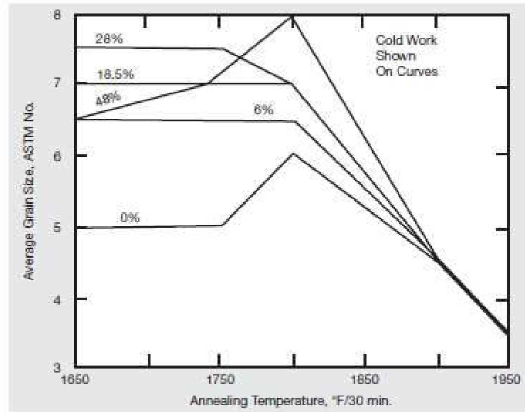

Figure 17. Effect of annealing temperature on grain size of sheet.

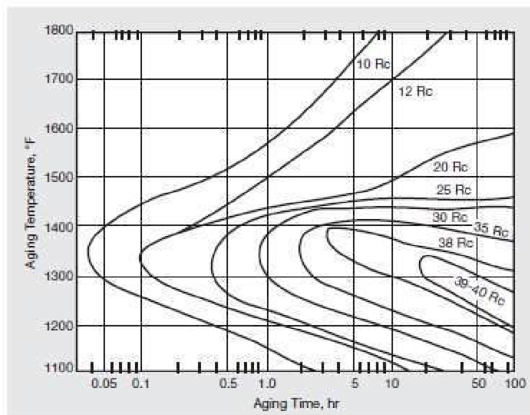

Figure 18. Effect of aging conditions on hardness of annealed sheet. (Initial hardness, as-annealed condition, Rc 4.