LION® alloy X-750 (UNS N07750/W. Nr. 2.4669) is a precipitation-hardenable nickel-chromium alloy used for its corrosion and oxidation resistance and high strength at temperatures to 1300°F. Although much of the effect of precipitation hardening is lost with increasing temperature over 1300°F, heat-treated material has useful strength up to 1800°F. Alloy X-750 also has excellent properties down to cryogenic termperatures. Composition is shown in Table 1.

The economics of LION alloy X-750 coupled with its availability in all standard mill forms has resulted in applications in a wide variety of industrial fields. In gas turbines, it is used for rotor blades and wheels, bolts, and other structural members. LION alloy X-750 is used extensively in rocket-engine thrust chambers. Airframe applications include thrust reversers and hot-air ducting systems. Large pressure vessels are formed from LION alloy X-750. Other applications are heat-treating fixtures, forming tools, extrusion dies, and test machine grips. For springs and fasteners, LION alloy X-750 is used from sub-zero to 1200°F.

Depending on the application and the properties desired, various heat treatments are employed. For service above 1100°F, particularly where loads are to be sustained for long times, optimum properties are achieved by solution treating (2100°F) plus stabilization treating (1550°F) plus precipitation treating (1300°F). For service below 1100°F, the alloy may be strengthened by precipitation treating after hot or cold working or by precipitation treating after equalizing or solution treating. A furnace-cooling treatment is also used to develop optimum properties for some applications.

The various heat treatments and the properties developed are described under the section on Mechanical Properties.

Property values in this bulletin – the results of extensive testing – are typical of the alloy but, unless shown as limiting, should not be used as specification values.

Table 1 - Limiting Chemical Composition, %

Nickel (plus Cobalt)	70.00 min.
Chromium	14.0-17.0
Iron	5.0-9.0
Titanium	2.25-2.75
Aluminum	0.40-1.00
Niobium (plus Tantalum)	0.70-1.20
Manganese	1.00 max.
Silicon	0.50 max.
Sulfur	0.01 max.
Copper	0.50 max.
Carbon	0.08 max.
Cobalt[1]	1.00 max

[1] Determination not required for routine acceptance.

Physical Constants and Thermal Properties

Some physical constants and thermal properties of LION alloy X-750 are given in Tables 2 and 3.

Values for thermal expansion, thermal conductivity, specific heat, and diffusivity are from Lucks and Deem and electrical resistivity from tests conducted at Lehigh University.

Effects of temperature on modulus of elasticity and additional data on resistivity are in Tables 4 and 5. More modulus values can be found in the section on Mechanical Properties.

Table 2 – Physical Constants

Density, lb/in^3	0.299
g/cm^3	8.28
Melting Range, °F	2540-2600
°C	1393-1427
Curie Temperature, °F	
As hot-rolled	-225
Triple-heat-treated (2100°F/2 hr, A.C.,+1500°F /24 hr, A.C., + 1300°F/20 hr, A.C.)	-193
Magnetic Permeability, 70°F, 200H	
As Hot-Rolled	1.0020
Triple-heat-treated (2100°F/2 hr, A.C.,+1500°F /24 hr, A.C., + 1300°F/20 hr, A.C.)	1.0035
Emissivity, oxidized surface	
600°F	0.895
2000°F	0.925
Linear Contraction during Precipitation Treatment (1300°F/20 hr), in/in	
Hot-Rolled	0.00044
20% Cold-Rolled	0.00052
Annealed	0.00026

Table 3 - Thermal Properties[a]

Temperature, °F	Mean Linear Expansion, in./in./°F x 10^{-6} from 70° F to Temperature Shown	Thermal Conductivity, Btu/in./hr/sq ft/°F	Specific Heat Btu/lb/°F	Diffusivity, sq ft/hr	Electrical Resistivity, ohm/circ mil/ft
-250	6.5	67	0.073	0.150	–
-200	6.6	70	0.080	0.143	–
-100	6.7	74	0.090	0.135	–
70	–	83	0.103	0.132	731
200	7.0	89	0.109	0.133	739
400	7.2	98	0.116	0.140	746
600	7.5	109	0.120	0.148	761
800	7.8	120	0.125	0.158	771
1000	8.1	131	0.130	0.169	783
1200	8.4	143	0.137	0.173	786
1400	8.8	154	0.151	0.172	775
1600	9.3	164	0.171	0.164	761
1800	9.8	–	–	–	–

[a] Material heat-treated 2100°F/3 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.

Table 4 - Effect of Heat Treatment on Room-Temperature Resistivity of Hot-Rolled Bar

Heat Treatment	Resistivity, ohm/circ mil/ft
As hot-rolled	759
2000°F/1 hr, A.C.	763
2100°F/1 hr, A.C.+1500°F/24 hr, A.C.+ 1300°F/20 hr, A.C.	724
1800°F/1 hr, A.C.+1350°F/8 hr,F.C. to 1150°F, hold at 1150°F for total time of 18 hr, A.C.	739

Table 5 - Modulus of Elasticity

Temperature, °F	Modulus of Elasticity, 10^3 ksi		
	Tension		Torsion
	Static	Dynamic	Static
80[a]	31.0	31.0	11.0
500	28.7	29.1	10.2
1000	25.0	26.7	9.0
1200	23.0	25.5	8.1
1350	21.0	24.4	–
1500	18.5	23.2	–
1600	–	22.1	–
1800	–	20.0	–

[a] Poisson's ratio = 0.29

Mechanical Properties

LION alloy X-750 may be given any one of a variety of heat treatments. Each develops special properties and puts the product form in the best condition for its intended application. In all conditions, alloy X-750 is resistant to oxidation up to 1800°F. The most often used heat treatments have been incorporated by the Society of Automotive Engineers in their AMS specifications* for various product forms. The heat treatments, specifications, and product forms are summarized in Table 6.

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*AMS specifications are subject to revision. The ones referenced in this publication were current when it was released. Publisher is the Society of Automotive Engineers, Inc.

Table 6 - Applicable Heat Treatments for LION Alloy X-750 Product Forms

Product Form	AMS Specifications	Heat Treatment	Remarks
Rods, bars and forgings	5667	1625°F/24 hr, AC, + 1300°F/20 hr, AC (Equalizing plus precipitation treatment).	High strength and notch rupture ductility up to 1100°F.
Rods, bars and forgings	5670, 5671, & 5747	1800°F anneal + 1350°F/8 hr, FC to 1150°F, Hold at 1150°F for total precipitation-treating time of 18 hr, AC (Solution treatment plus furnace-cool precipitation treatment).	Increased tensile properties and reduced heat treating time for service up to about 1100°F.
Rods, bars and forgings	-	1800°F anneal + 1400°F/1 hr, FC to 1150°F, Hold at 1150°F for total precipitation-treating time of 6 hr, AC (Solution treatment plus short furnace-cool precipitation treatment).	Short furnace-cool aging. Achieves only slightly lower properties than does AMS 5670 and AMS 5671.
Rods, bars and forgings	5668	2100°F anneal + 1550°F/24 hr, AC, + 1300°F/20 hr, AC (Triple heat treatment).	Maximum creep, relaxation and rupture strength above about 1100°F.
Sheet, strip and plate (Supplied in annealed condition)	5542	1300°F/20 hr, AC (Constant-temperature precipitation treatment).	High strength to 1300°F.
Sheet, strip and plate (Supplied in annealed condition)	5598	1350°F/8 hr, FC to 1150°F, Hold at 1150°F for total precipitation-treating time of 18 hr, AC (Furnace-cool precipitation treatment).	High strength up to 1300°F (Increased tensile properties to about 1100°F).
Sheet, strip and plate (Supplied in annealed condition)	-	1400°F/1 hr, FC to 1150°F, Hold at 1150°F for total time of 6 hr, AC (Short furnace-cool precipitation treatment).	Increased tensile properties and reduced heating time for service up to about 1100°F.
Seamless tubing	5582	1300°F/20 hr, AC (Constant-temperature precipitation treatment).	High strength up to about 1300°F.
Wire, No. 1 temper	5698	1350°F/16 hr, AC (Constant-temperature precipitation treatment).	For springs requiring optimum resistance to relaxation from about 700°F to 850°F and at low to moderate stresses to about 1000°F.
Wire, spring temper	5699	1200°F/4 hr, AC (Constant-temperature precipitation treatment).	High strength up to about 700°F.
Wire, spring temper	5699	2100°F anneal + 1550°F/24 hr, AC + 1300°F/20 hr, AC (Triple heat treatment).	For springs for service requiring maximum relaxation resistance at about 850°F to 1200°F.

Rods, Bars and Forgings

Intermediate-Temperature Service (Below 1100°F) – Equalized plus Precipitation-Treated Material

For applications requiring high strength and ductility at service temperatures up to 1100°F, LION alloy X-750 rod, bar, and forgings are given the following heat treatment:

1625°F/24 hr, A.C. – Equalizing
1300°F/20 hr, A.C. – Precipitation Heat Treatment

This heat treatment is described by AMS 5667, which requires that material so heat-treated have the following minimum room-temperature properties. Hardness will lie in the range of 302-363 BHN.

Size, in.	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elongation in 4D, %	Reduction of Area %
Under 4.0	165.0	105.0	20	25
4.0 and over	160.0	100.0	15	17

The results of two series of tests of high-temperature tensile properties are shown in Tables 7 and 8. Relaxation data are in Figure 1.

Fatigue strength of equalized plus precipitation-treated material is higher than that of triple-heat-treated material (2100° + 1550° +1300°F) up to about 1200°F (see Figure 2). More data on high-temperature fatigue are shown in Figure 3, and room-temperature notch fatigue is compared with test results on smooth specimens in Figure 4. Pull-pull fatigue strength of notched and smooth equalized and precipitation-treated rod is shown in Figure 5.

Creep properties of hot-rolled bar equalized plus precipitation-treated are given in Figure 6, and rupture lives of smooth and notched specimens in Figure 7. A Larson-Miller parameter plot of creep rupture data is shown in Figure 8.

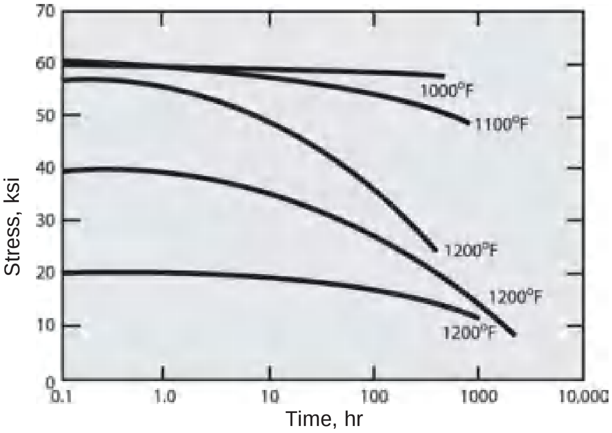

Figure 1. High-temperature relaxation of hot-rolled bar equalized and precipitation-treated (1625°F/24 hr, A.C.,+ 1300°F/20 hr, A.C.)

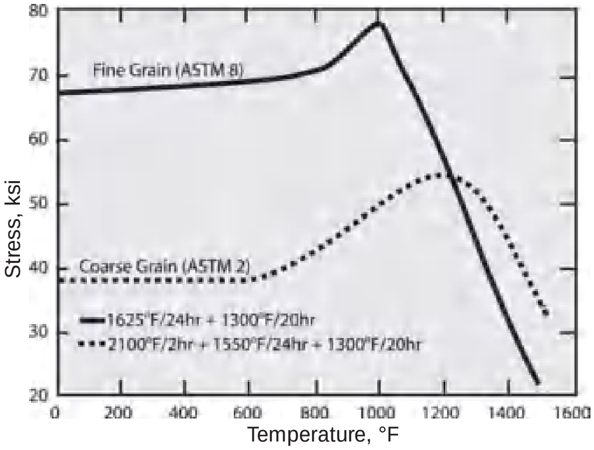

Figure 2. High-temperature fatigue strength (10^8 cycles) of bar. Rotating-beam tests (3450 rpm).

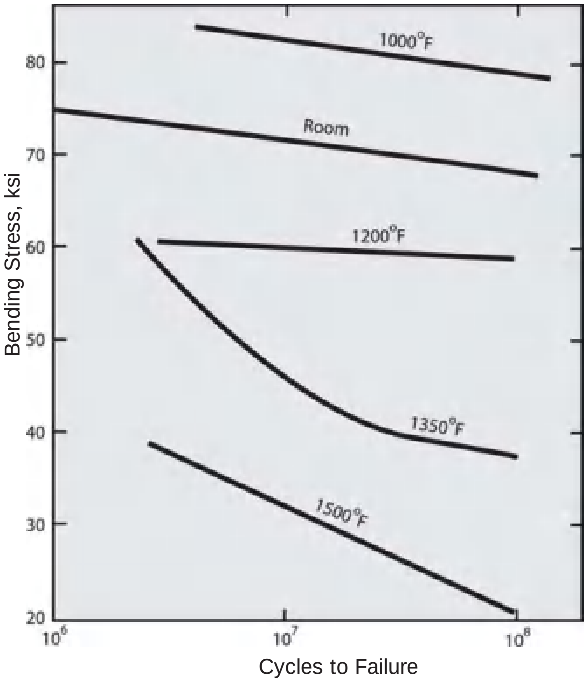

Figure 3. High-temperature fatigue strength of 5/8-in.-dia. hot-rolled material equalized and precipitation-treated (1625°F/24 hr +1300°F/20 hr).

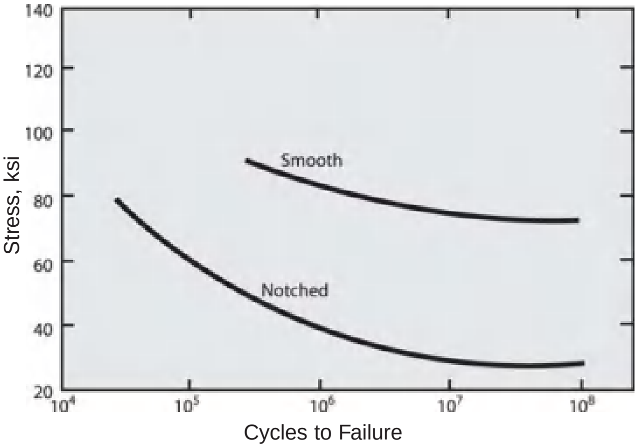

Figure 4. Fatigue strength of 3/4-in. hot-rolled bar equalized and precipitation-treated (1625°F/24 hr, A.C.,+ 1300°F/20 hr, A.C.). R.R. Moore rotating-beam tests at 10,000 rpm. K_t=3.4.

Table 7 - High-Temperature Properties of Hot-Rolled 1 $^3/_{16}$-in. Bar Equalized and Precipitation-Treated (1625°F/24 hr + 1300°F/20 hr).

Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of area, %	Modulus of of Elasticity in Tension,10^3 ksi
85[a]	174.0	118.5	26.8	45.4	30.2
300[a]	168.3	113.3	26.0	44.1	31.3
400	165.5	111.5	26.0	42.7	29.1
800	156.0	107.5	26.5	44.8	25.9
1000	152.0	105.0	25.5	40.7	23.2
1100	153.5	105.5	19.0	22.0	26.4
1200	136.5	103.0	10.0	17.7	21.7

[a] Average of 2 tests.

Table 8 - High-Temperature Tensile Properties of $^3/_4$-in. Equalized and Precipitation-Treated Hot-Rolled Round (1625°F/24 hr, AC + 1300°F/20 hr, AC).

Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of area, %
Room	184.0	126.0	25.0	41.5
600	169.0	116.5	23.0	35.0
800	166.0	114.0	24.0	39.0
1000	163.5	115.0	20.0	25.0
1100	159.0	112.0	10.0	13.0
1200	143.0	110.0	7.0	7.8
1350	107.0	98.3	6.0	10.0
1500	65.4	64.7	17.0	19.5

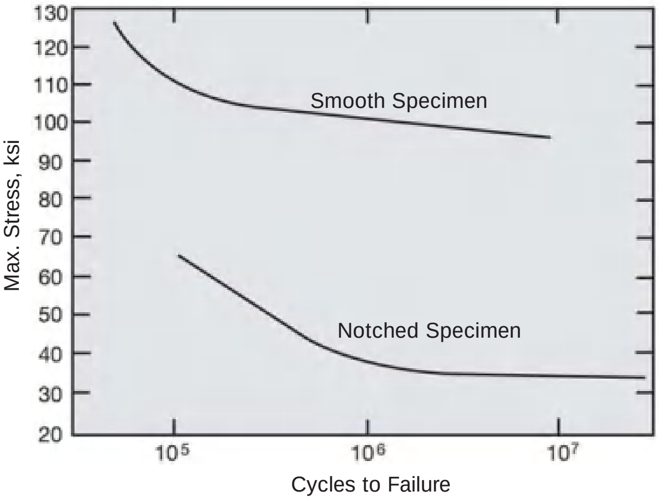

Figure 5. Pull-pull fatigue strength of 1-in. hot-rolled rod equalized and precipitation-treated (1625°F/24 hr, A.C., + 1300°F/20 hr, A.C.).

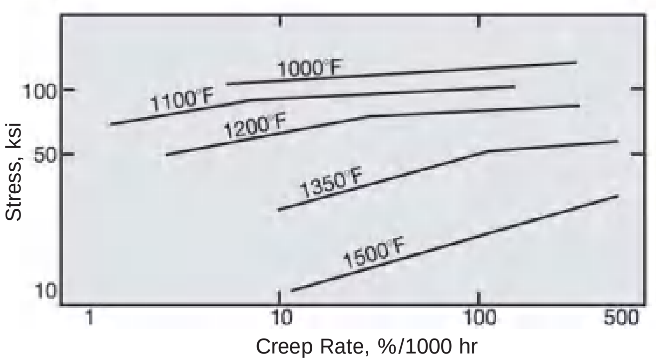

Figure 6. Creep properties of hot-rolled bar equalized and precipitation-treated (1625°F/24 hr, A.C., + 1300°F/20 hr, A.C.).

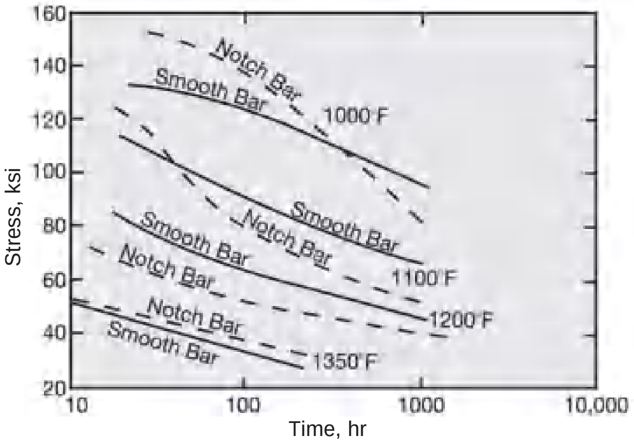

Figure 7. Rupture life of bar equalized and precipitation-treated (1625°F/24 hr, A.C., + 1300°F/20 hr, A.C.). Smooth bar, 0.3-in. dia. x 1½ in. long; notched bar, 50% 60° V-notch, 0.005-in. root radius.

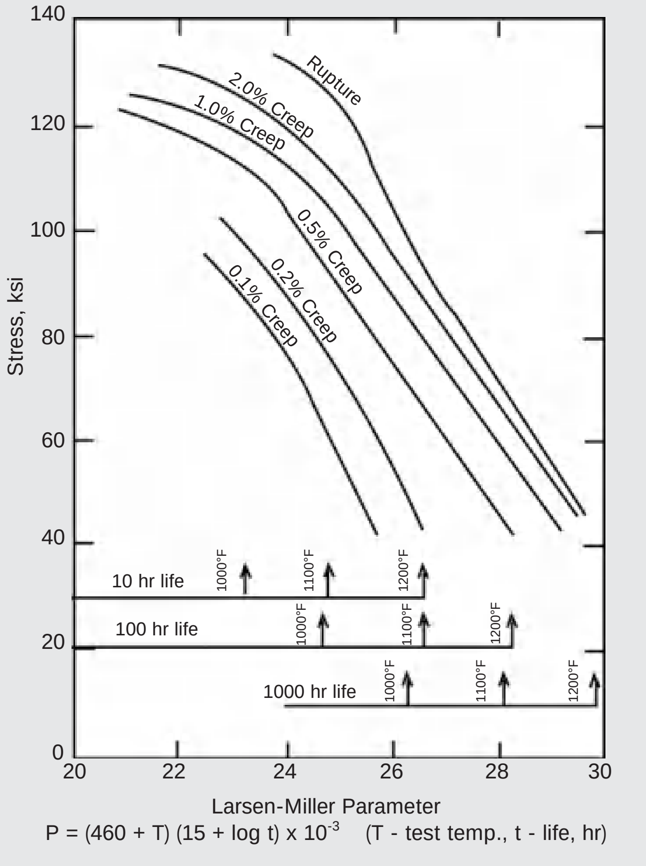

Figure 8. Creep and rupture strength of hot-rolled bar equalized and precipitation-treated (1625°F/24 hr. A.C., +1300°F/20 hr, A.C.).

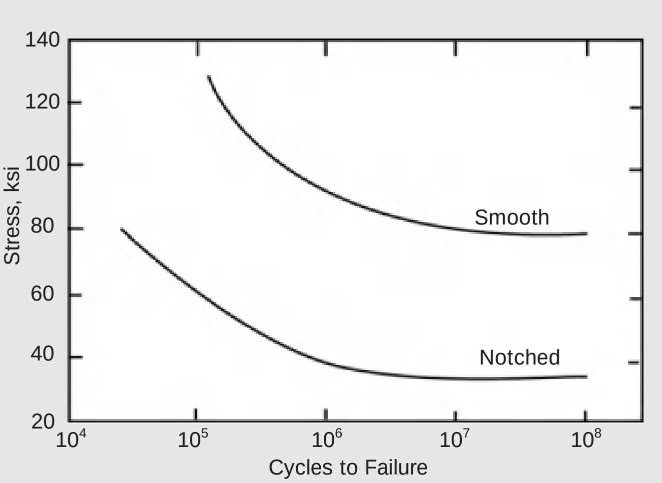

Figure 9. Fatigue life of ¾-in. hot-rolled bar solution-treated and precipitation-treated (1800°F/1 hr, A.C., +1350°F/8 hr, F.C. to 1150°F, hold at 1150°F for total precipitation-treating time of 18 hr). R.R. Moore rotating-beam tests at 10,000 rpm. K_t = 3.4.

Rods, Bars and Forgings

Intermediate-Temperature Service (Below 1100°F) –Solution-Treated plus Furnace-Cool Precipitation-Treated Material

For applications requiring optimum tensile properties at service temperatures below 1100°F, LION alloy X-750 rod, bar, and forgings are given the following heat treatment:

1800°F – Solution Heat Treatment
1350°F/8 hr, F.C. to 1150°F, hold at 1150°F for total time of 18 hr, A.C. – Furnace-Cool Precipitation Heat Treatment

This heat treatment is described by AMS Specifications 5670, 5671 and 5747, which require that heat-treated material have the following minimum room-temperature properties. Hardness must lie between 32-42 Rc.

Size, in.	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elongation in 2 in., %	Reduction of Area %
Under 2.50	170.0	115.0	18	18
2.5 to 4.00, excl.	170.0	115.0	15	15
4.0 and over	–	As agreed upon between purchaser & vendor		

Typical room-temperature properties of various sizes of bar solution-treated and furnace-cool precipitation-treated (1800°F/1 hr + 1350°F/8 hr, F.C. to 1150°F, hold at 1150°F for total precipitation-treatment time of 18 hr, A.C.) are shown in Table 9.

A shorter heat treatment may be used if slightly lower tensile properties would be satisfactory: 1800°F/1 hr + 1400°F/1 hr, F.C. to 1150°F, hold at 1150°F for total precipitation-treating time of 6 hr, A.C. Room-temperature tensile properties developed by this heat treatment in various sizes of bar are shown in Table 9.

Room- and high-temperature properties of both solution-treated and solution-treated/furnace-cool precipitation-treated material are shown in Tables 10, 11, 12 and 13. Notch strength of a specimen of ¾-in.-diameter hot-finished round heat-treated (1800°F/1 hr, A.C., + 1350°F/8 hr, F.C. to 1150°F for total precipitation-treating time of 18 hr, A.C.) was found to be 246.0 ksi. This specimen had a tensile strength of 192.5 ksi; yield strength (0.2% offset), 137.0 ksi; elongation, 25%; and reduction of area, 42%. Tensile properties of welds precipitation-treated by the short furnace-cool treatment are in Table 14.

Fatigue life of smooth and notch specimens of alloy X-750 bar annealed and furnace-cool precipitation-treated is shown in Figure 9.

Table 9 - Comparison of Room-Temperature Tensile Properties of Hot-Finished Bar Solution-Treated and Precipitation-Treated (A) 1800°F/1 hr, A.C., + 1400°F/1 hr, F.C. to 1150°F, Hold at 1150°F for Total Precipitation-Treating Time of 6 hr, and (B) 1800°F/1 hr, A.C., + 1350°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Precipitation-Treating Time of 18 hr

Heat Treat-ment	Dia., in.	Tensile Strength, ksi	Yield Strength (0.2% offset) ksi	Elonga-tion, %	Reduction of Area, %	Hard-ness, Rockwell
A	½	199.0	146.0	25.0	41.5	36.0
B		196.0	149.0	24.0	42.3	38.0
A	21/32	194.0	139.0	27.0	46.4	38.0
B		192.5	139.0	25.0	47.7	39.0
A	¾	193.5	137.5	25.0	38.5	38.0
B		191.0	140.0	22.0	38.8	39.0
A	7/8	194.5	140.0	24.0	40.2	40.0
B		197.0	146.0	21.0	42.8	40.0
A	1	187.5	130.5	25.0	41.8	33.0
B		190.0	139.0	22.0	35.4	39.4
A	1 3/16	189.5	134.5	24.0	39.5	39.0
B		192.5	137.5	23.0	41.0	40.0
A	1 3/16	195.0	132.5	25.0	43.2	35.0
B		195.5	138.5	26.0	43.5	42.0
A	1 3/8	190.5	136.0	24.0	43.0	38.0
B		190.5	136.5	23.0	43.0	37.0
A	1 ½	188.0	132.8	27.0	46.0	34.0
B		189.0	132.0	26.0	45.0	40.0
A	1 ½	198.0	141.0	24.0	42.0	41.0
B		196.5	142.0	25.0	46.3	40.0
A	1 ½	190.5	129.5	26.0	43.0	40.0
B		190.5	131.0	25.0	40.5	41.0
A	2 ¼	189.5	138.5	22.0	30.5	39.0
B		189.5	140.5	21.0	21.5	39.0
A	2 ½	184.0	135.0	23.0	38.0	38.0
B		184.5	137.5	22.0	36.0	39.0
A	2 15/16	180.5	128.5	24.0	35.0	34.0
B		184.0	137.0	23.0	38.0	38.0

Table 13 - High-Temperature Tensile Properties of ¾-in.-dia. Hot-Rolled Round Solution-Treated & Precipitation-Treated (1800°F/1 hr, A.C. + 1350°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Precipitation-Treating Time of 18 hr, A.C.) [a]

Test Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elongation, %	Reduction of Area, %
Room	195.5	140.0	24.0	40.5
600	178.0	131.5	21.0	41.0
800	173.0	131.5	21.0	38.0
1000	168.5	128.0	13.0	18.0
1100	157.5	126.5	8.0	11.0
1200	143.0	122.5	6.0	8.0
1350	114.0	107.0	5.0	8.0
1500	77.3	76.8	10.0	13.5

[a] Typical Charpy V-Notch room-temperature impact strength – 29 ft-lb.

Table 10 - Room-Temperature Hardness, R_C, of Hot-Rolled Rod

Diameter, in.	Solution-Treated (1800°F/1 hr, A.C.)	Solution-Treated & Precipitation-Treated (1800°F/1 hr, A.C., + 1400°F/1 hr, F.C. to 1150°F, A.C., Hold for Total Precipitation-Treating Time of 6 hr, A.C.)
0.875	21	36
	26	37
1.250	31	38
	27	36
1.937	25	36
	30	36

Table 11 - High-Temperature Properties of Hot-Rolled Solution-Treated (1800°F/1 hr) 1-in. Round

Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elongation in 2 in., %	Reduction of Area, %
85	174.0	115.0	27.5	41.0
400	168.0	113.2	29.0	40.0
600	160.5	107.5	30.0	37.0
800	159.0	106.5	31.0	42.0

Table 12 - High-Temperature Properties of 1-in. Hot-Rolled Bar Solution-Treated & Precipitation-Treated (1800°F, A.C., + 1400°F/1 hr, F.C. to 1150°F, Hold at 1150°F for Total Precipitation-Treating Time of 6 hr)

Tempera-ture, °F	Modulus of Elasticity, 10^3 ksi	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elongation in 2 in., %	Reduction of Area, %
85	31.8	187.5	130.5	25.0	41.0
400	28.3	185.5	134.0	22.5	35.8
600	28.3	179.0	133.5	24.5	36.5
800	26.6	175.5	132.5	24.5	37.5
1000	21.9	172.0	129.2	16.0	26.0
1200	22.9	142.5	120.0	6.0	9.5

Table 14 - High-Temperature Tensile Properties of Welds in 0.625-in. Plate (Welded with LION Filler Metal 69)

Condition	Test Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elongation, %	Reduction of Area, %
Plates were annealed & precipitation-treated (1800°F/1 hr, A.C., + 1400°F/1 hr, F.C. to 1150°F, hold at 1150°F for total precipitation-treating time of 6 hr) before welding. Tested in as-welded condition. Transverse tests.	80	124.0	87.0	21	39.2
	80	122.5	85.8	20	44.5
	800	109.0	80.5	21	35.0
	800	108.0	79.0	19	42.0
	1000	102.5	78.5	17	34.0
	1000	103.5	79.5	18	30.2
Plates were annealed (1800°F/1 hr, A.C.) before welding. Weldment was annealed & precipitation-treated (1800°F/1 hr, A.C., + 1400°F/1 hr, F.C. to 1150°F, hold at 1150°F for total precipitation-treating time of 6 hr) before testing. Transverse tests.	80	174.5	127.0	16	21.5
	80	173.0	127.5	15	30.0
	800	151.0	120.0	15	27.8
	800	151.5	121.5	15	32.4
	1000	146.0	124.0	13	27.8
	1000	145.5	116.5	10	27.0
Plates were annealed (1800°F/1 hr, A.C.) before welding. Tested in as-welded condition. All-weld-metal tests.	80	124.0	86.5	38	48.7
	800	104.0	71.7	40	43.8
	1000	98.0	69.2	33	42.3

Rods, Bars and Forgings

High-Temperature Service (Above 1100°F) – Triple-Heat-Treated Material (2100°F + 1550°F + 1300°F)

For maximum creep and rupture strength and high relaxation resistance at service temperatures above about 1100°F, LION alloy X-750 rods, bars, and forgings are given the following triple heat treatment:

2100°F/2-4 hr, A.C. – Solution Treatment
1550°F/24 hr, A.C. – Stabilization Heat Treatment
1300°F/20 hr, A.C. – Precipitation Heat Treatment

This heat treatment is described by AMS Specification 5668, which requires that heat-treated material tested at 1350°F under a stress of 45 ksi have a minimum rupture life of 100 hr.

Typical tensile properties of $^{5}/_{8}$-in. diameter hot-finished rod triple-heat-treated (2100°F/2 hr, A.C. + 1550°F/24 hr, A.C. + 1300°F/20 hr, A.C.) are shown in Figure 10.

Low-temperature tensile properties are shown in Table 15. Other high- and low-temperature properties shown are hot hardness (Figure 11), impact strength (Table 16), fatigue strength (Figure 12), and relaxation (Figure 13).

High-temperature creep rates and rupture properties are shown in Figures 14 and 15. Creep-rupture properties are in Figure 16. Figure 17 compares notch and smooth rupture lives. For convenience in design, typical creep-rupture properties of triple-heat-treated bar at temperatures of 1200°F, 1350°F and 1500°F are plotted in Figures 18, 19 and 20.

Table 15 - Low-Temperature Properties of Rod Triple-Heat-Treated (2100°F/2 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.) [a]

Specimen	Room Temperature Hardness, R_C	Temperature, °F	Tensile Strength, ksi	Yield Strength, [b] ksi	Elongation in 1 in., %	Reduction of Area, %
Smooth	33	79	173.5	101.5	25.0	28.5
	32	-104	186.0	115.0	22.5	25.7
	34	-320	208.8	118.0	19.0	19.0
	34	-423	208.15	130.0	14.5	14.5
Notched (60°V, 0.037 in. deep, 0.005 in. radius)	33	78	200.5	–	–	–
	35	-104	200.0	–	–	–
	35	-320	218.5	–	–	–
	36	-423	225.0	–	–	–

[a] Average of 2 tests. Source: “Materials for Use at Liquid Hydrogen Temperature”, ASTM Special Publication No. 287, p. 108 (1960).

[b] 0.2% offset except initial yield point at -423°F.

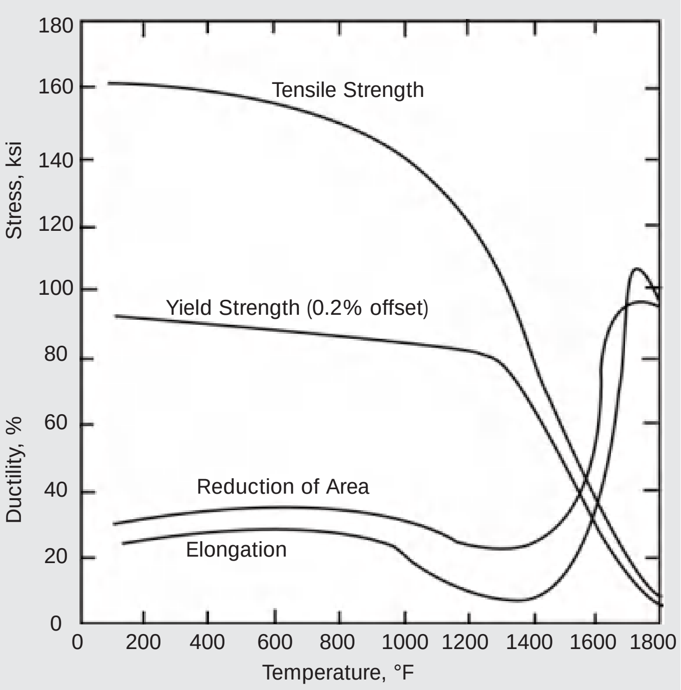

Figure 10. High-temperature tensile properties of bar triple-heat-treated (2100°F/2 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.).

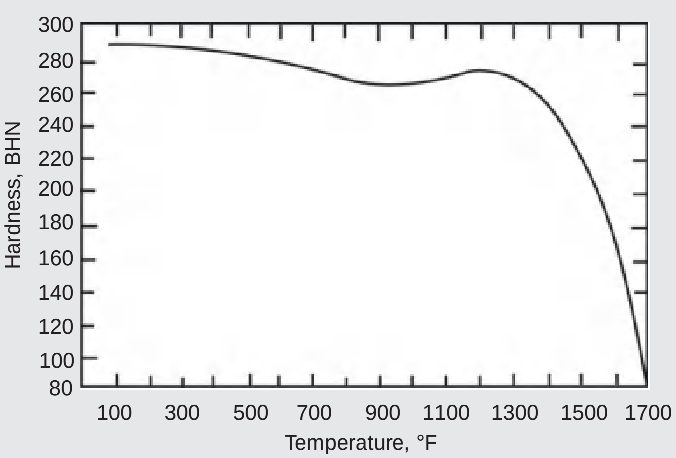

Figure 11. High-temperature hardness of hot-rolled material triple-heat-treated (2100°F/4 hr + 1550°F/24 hr + 1300°F/20 hr.).

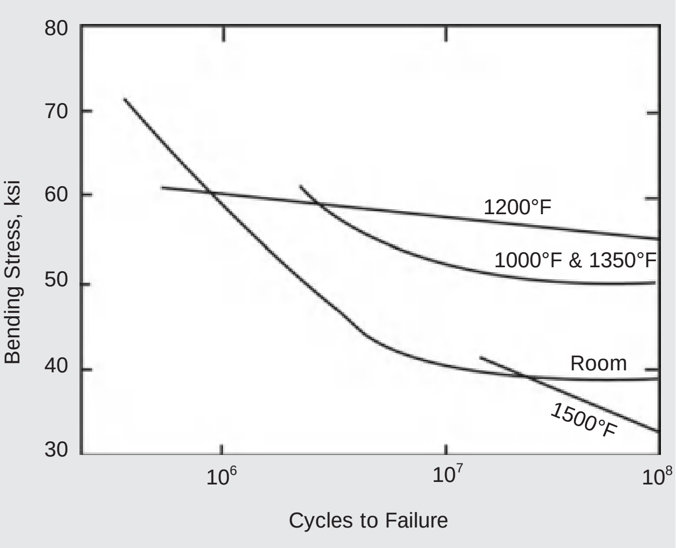

Figure 12. High-temperature fatigue strength of 5/8-in-dia. hot-rolled bar triple-heat-treated (2100°F/2 hr + 1550°F/24 hr + 1300°F/20 hr). Samples tested in completely reversed bending.

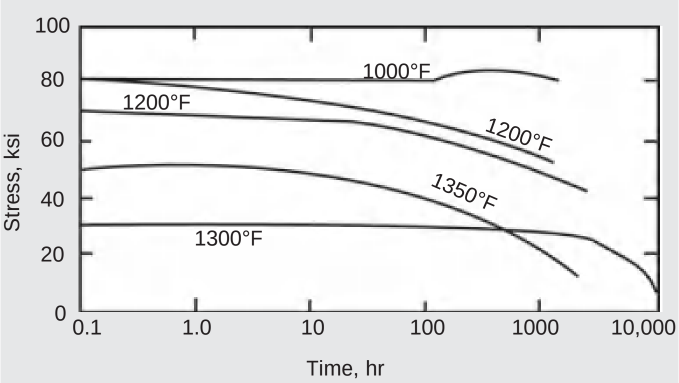

Figure 13. Relaxation of bar triple-heat-treated (2100°F/2 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.).

Table 16 - High- and Low-Temperature Impact Strength (Charpy V-Notch) of Hot-Rolled Bar Triple-Heat-Treated (2100°F/2 hr + 1550°F/24 hr + 1300°F/20 hr)

Test Temperature, °F	Impact Strength, ft-lb
-320	33
-109	36
75	37
400	42
800	50
1000	49
1200	45
1350	49
1500	67
1600	113

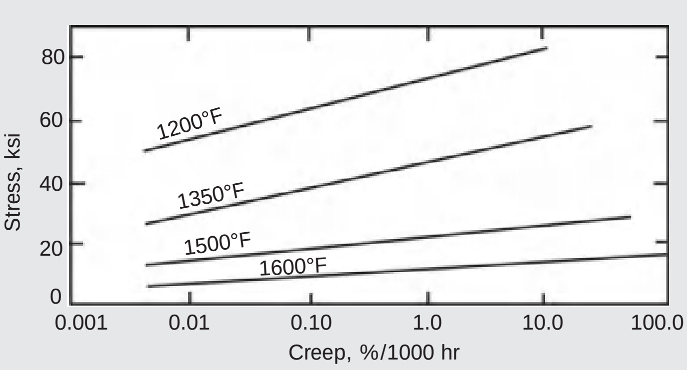

Figure 14. Creep properties of bar triple-heat-treated (2100°F/4 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr).

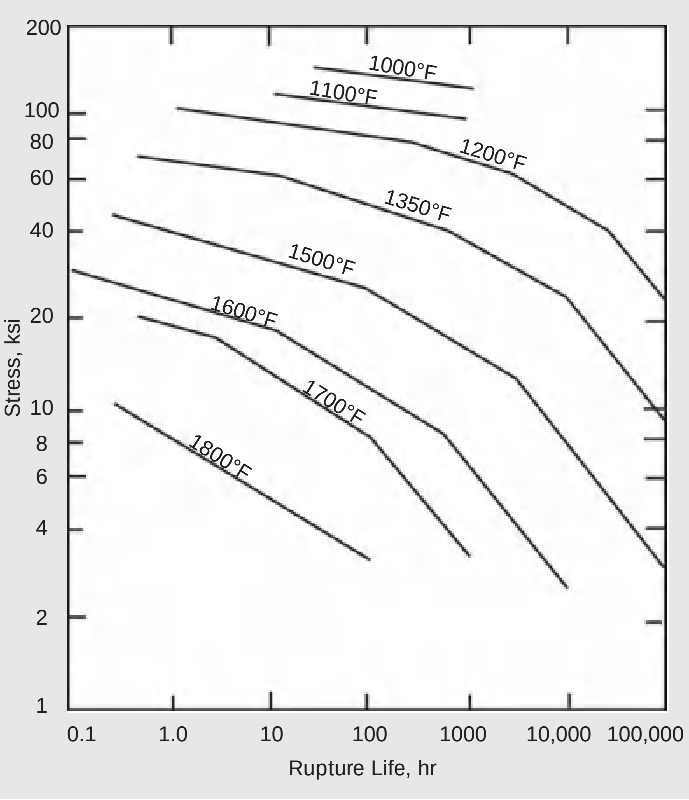

Figure 15. Rupture life of bar triple-heat-treated (2100°F/2 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.).

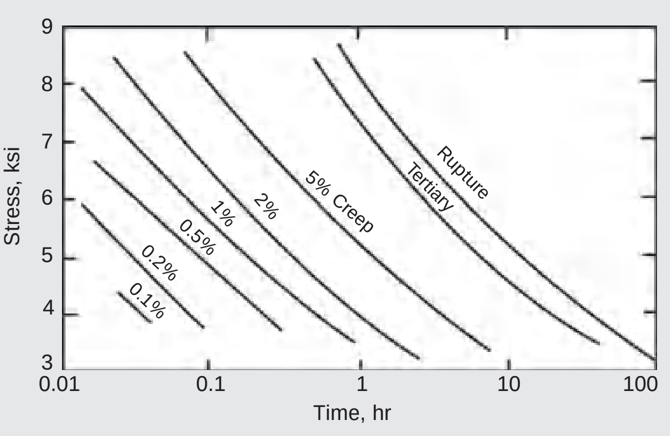

Figure 16. Creep properties at 1800°F of bars triple-heat-treated (2100°F/4 hr, A.C., + 1550°F/24 hr, A.C., +1300°F/20 hr, A.C.).

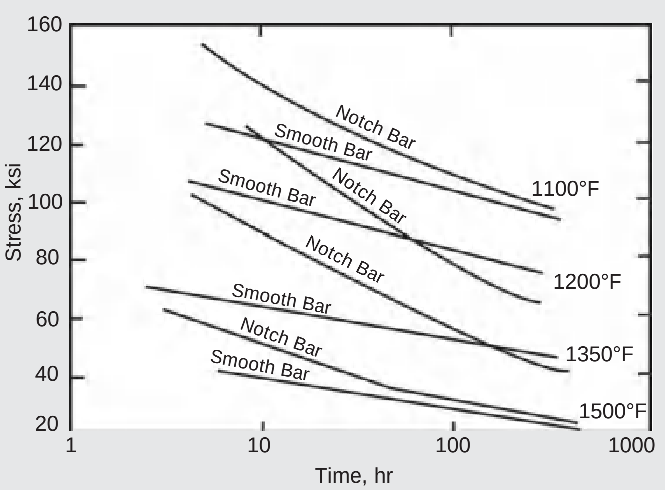

Figure 17. Rupture life of bar triple-heat-treated (2100°F/2 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.).

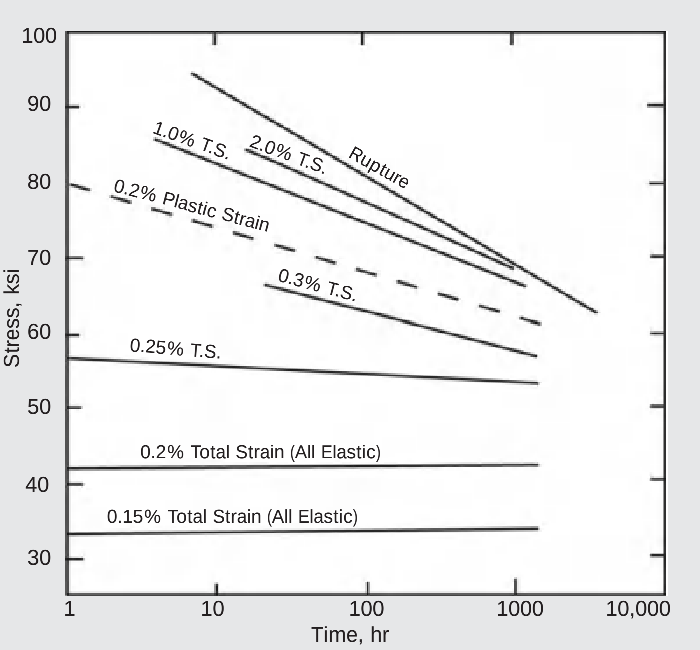

Figure 18. Rupture strength at 1200°F of triple-heat-treated bar (2100°F/4 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.).

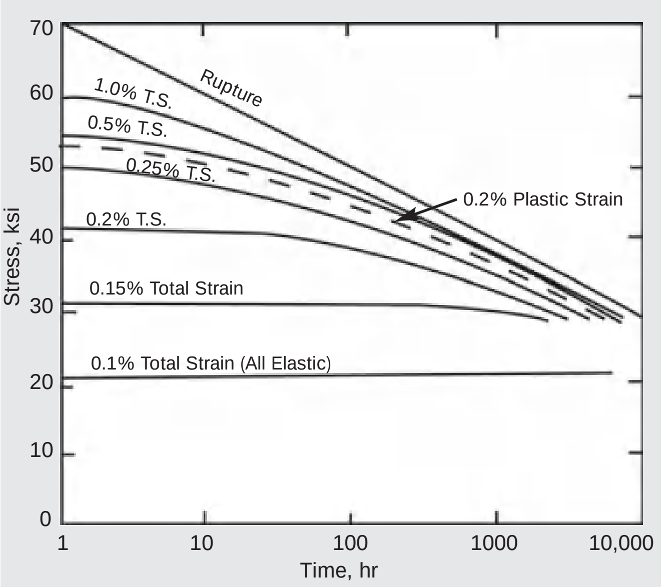

Figure 19. Rupture strength at 1350°F of triple-heat-treated bar (2100°F/4 hr, A.C., +1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.).

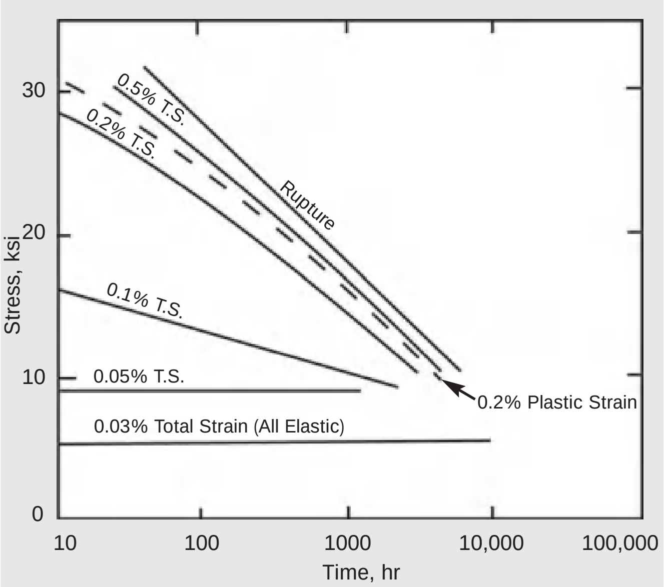

Figure 20. Rupture strength at 1500°F of triple-heat-treated bar (2100°F/4 hr, A.C., +1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.).

Sheet, Strip and Plate

High Strength to 1300°F – Constant-Temperature Precipitation-Treated Material

For high strength at high temperatures and high relaxation resistance, LION alloy X-750 sheet, strip, and plate (which are furnished in the annealed condition) are given the following one-step precipitation treatment:

1300°F/20 hr, A.C.

This precipitation treatment is described by AMS Specification 5542 which requires the following room-temperature properties:

Typical tensile properties of annealed sheet from room temperature to 1600°F are shown in Table 17. Table 18 gives high-temperature properties of cold-rolled annealed sheet which had been precipitation-treated.

Cryogenic tensile properties, including notch tensile strength, of annealed and precipitation-treated sheet are given in Table 19. Table 20 contains similar data for 67% cold-rolled sheet.

Form and Size, in.	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elonga-tion in 2 in., %	Hardness, Rc
Annealed Condition				
Strip				
Under 0.010	140 max.	–	–	–
0.010 to 0.025, excl.	130 max.	–	20 min.	–
0.025 & over	As agreed upon between purchaser & vendor			
Sheet				
0.010 to 0.024, incl.	140 max.	–	30 min.	–
Over 0.024-0.125, incl.	130 max.	60 max.	40 min.	–
Over 0.125-0.250, incl.	130 max.	65 max.	40 min.	–

Form and Size, in.	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elonga-tion in 2 in., %	Hardness, Rc
After Precipitation Treating (1300°F/20 hr, A.C.)				
Strip				
Under 0.010	150 min.	–	–	30 min. (0.005 & over)
0.010 to 0.025, excl.	155 min.	–	15 min.	30 min.
0.025 & over	155 min.	–	15 min.	30 min.
Sheet				
0.010 to 0.025, incl.	165 min.	105 min.	20 min.	32 min.
Plate				
0.187 to 4.000, excl.	155 min.	100 min.	20 min.	30 min.

Table 17 - High-Temperature Tensile Properties of Cold-Rolled Annealed Sheet (0.062-in.)

Temperature, °F	Tensile Strength, ksi	Yield Strength, (0.2% offset), ksi	Elongation, %
Room	110.0	46.5	51
900	100.5	35.0	55
1000	91.0	35.0	55
1200	83.0	54.5	23
1350	77.0	67.5	6
1500	57.0	32.0	11
1600	35.0	27.5	45

Table 18 - High-Temperature Tensile Properties of Cold-Rolled Annealed Sheet (0.050-in.) Precipitation-Treated 1300°F/20 hr, A.C.

Temperature, °F	Tensile Strength, ksi	Yield Strength, (0.2% offset), ksi	Elongation, %
Room	177.0	122.5	27.0
400	167.0	112.0	30.0
800	151.0	107.0	33.0
1000	154.0	112.0	26.0
1100	135.0	105.5	10.5
1200	123.0	105.5	6.0
1300	110.0	100.0	3.5
1500	80.3	76.4	11.0

Table 19 - Low-Temperature Tensile Properties of Annealed Sheet (0.063-in.) Precipitation-Treated 1300°F/20 hr, A.C.

Temperature, °F	Orientation °F	Tensile Strength ksi	Yield Strength ksi	Elongation %	Notched Tensile Strength ksi [1]	Ratio, Notched /Unnotched T.S.
78	Longitudinal	174	118	25.5	168	0.97
78	Transverse	174	118	25.0	168	0.97
-100	Longitudinal	189	122	30.0	174	0.92
-100	Transverse	–	–	–	175	–
-320	Longitudinal	214	130	31.0	184	0.86
-320	Transverse	212	130	30.0	184	0.87
-423	Longitudinal	233	134	30.0	199	0.85
-423	Transverse	234	139	31.0	201	0.86

[1] K_t = 6.3.

Table 20 - Notch Tensile Strength of Cold-Rolled (67%) and Precipitation-Treated (1300°F/20 hr) Sheet (Longitudinal Tests)

Temperature, °F	Tensile Strength, ksi	Yield Strength, (0.2% offset), ksi	Sharp-Edge Notch Tensile Strength, ksi	Ratio, Sharp-Edge Notch Tensile/T.S.
Room	245.0	233.0	180.0	0.7
-423	310.0	266.0	202.0	0.65

Table 21 - Compressive Properties of Annealed Sheet Precipitation-Treated 1300°F/20 hr.

Orientation	Tensile Properties			Compressive Properties	
	Tensile Strength, ksi	Yield Strength (0.2% offset),ksi	Elongation, %	Yield Strength (0.2% offset),ksi	Modulus of Elasticity, 10^3 ksi
			0.062-in.		
Longitudinal	170.5	116.0	26.5	121.0	29.7
Transverse	166.0	116.0	28.0	122.5	30.5
			0.125-in.		
Longitudinal	179.5	124.0	26.0	127.0	30.4
Transverse	180.0	128.0	26.0	130.0	31.0

Table 22 - Room-Temperature Shear Properties of 0.062-in. Sheet Annealed and Precipitation-Treated (1300°F/20 hr, A.C.)

Orientation °F	Tensile Properties		Hardness, Rc	Shear Strength[1], ksi	
	Tensile Strength, ksi	Yield Strength (0.2% offset),ksi		Single Shear	Double Shear
Longitudinal	165.0	115.0	36	123.5	111.0
	170.5	116.0	–	–	111.5
	171.5	116.0	36	125.0	112.5
	–	–	–	–	112.0
Transverse	166.0	116.0	36	123.0	112.5
	172.0	114.5	–	–	111.5
	175.0	122.0	35	122.5	113.0
	–	–	–	–	113.0
Average[2]	170.0	116.6	36	123.5	112.1

[1] Single-shear specimen. Double-shear specimens were machined from shoulders of single-shear specimen after testing.

[2] Ratio, single-shear strength/tensile strength, 0.725; double-shear strength/tensile strength, 0.66.

Figure 21 compares tensile and crack-propagation properties of precipitation-treated sheet from -200° to 1000°F. These data show that alloy X-750 is quite notch-insensitive over this wide temperature range.

Room-temperature compressive properties of annealed and precipitation-treated sheet of varying thickness are shown in Table 21. Shear strength of annealed and precipitation-treated sheet at room temperature and -423°F is in Tables 22 and 23. Table 24 shows some data on bearing strength, resistance to sheet tearing, at room and elevated temperatures.

Room-temperature fatigue strength of cold-rolled, annealed, and precipitation-treated sheet is shown in Figure 22. Figure 23 illustrates Gerber and modified Goodman diagrams, which show the limiting values of combined alternating and steady stresses for annealed and precipitation-treated sheet. Table 25 shows the superiority of alloy X-750's notch fatigue strength over that of other materials at cryogenic temperature. Other fatigue-strength data at room temperature are in Figure 24.

Rupture life of cold-rolled annealed sheet under various test conditions is shown in Table 26, and a Larson-Miller parameter plot in Figure 25.

Table 23 - Low-Temperature Shear Strength of Cold-Rolled Annealed Sheet (0.25-in.) Precipitation-Treated 1300°F/20 hr, A.C.

Temperature, °F	Tensile Strength, ksi	Shear Strength, ksi	Ratio, Shear Strength/ Tensile Strength
Room	175.1	118.0	0.674
-423	253.3	152.8	0.603

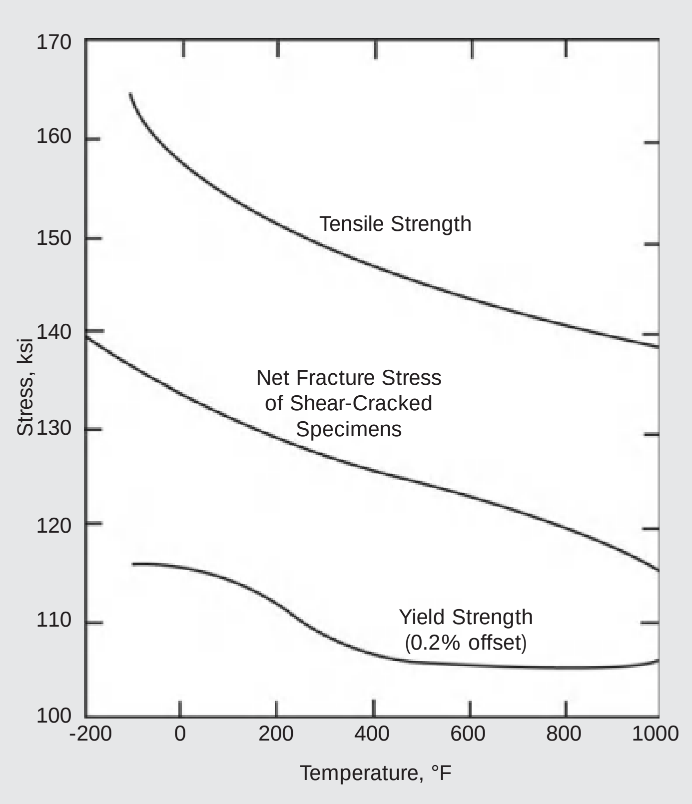

Figure 21. Crack-propagation properties of 0.064-in. sheet precipitation-treated 1300°F/20 hr showing notch insensitivity. (Net fracture stress is obtained by dividing the ultimate load by the original net supporting area.)

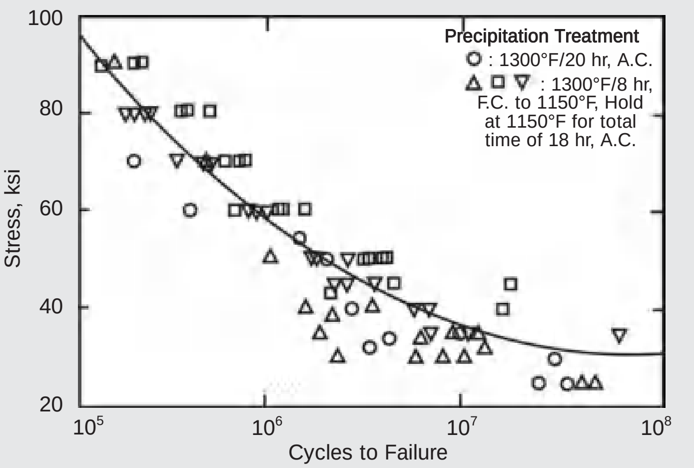

Figure 22. Fatigue strength of cold-rolled annealed sheet (Krouse tests, completely reversed bending).

Table 24 - Bearing Strength of Annealed and Precipitation-Treated Sheet[1]

Distance from Pin Centerline to Edge	Test Temper-ature, °F	Bearing		Ratio of Bearing	
		Yield Strength (0.2% offset),[2]ksi	Ultimate Strength,[3] ksi	Yield Strength/ Tensile Yield Strength	Ultimate Strength/ Tensile Strength
1.5 x Pin Dia.	80	175	258	1.63	1.57
	900	165	213	1.71	1.57
	1200	152	170	1.66	1.54
	1600	69	71.5	2.66	1.93
2.0 x Pin Dia.	80	222	338	2.08	2.06
	900	218	274	2.26	2.02
	1200	175	217	1.91	1.99
	1600	70	72	2.69	1.94

[1] Precipitation treatment: 1300°F/20 hr, A.C. Sheet specimens–8 in. long, 1 in. wide, 0.062 in. thick. Pin–0.250 in. dia.

[2] 2.0% of pin dia.

[3] Tearing out hole.

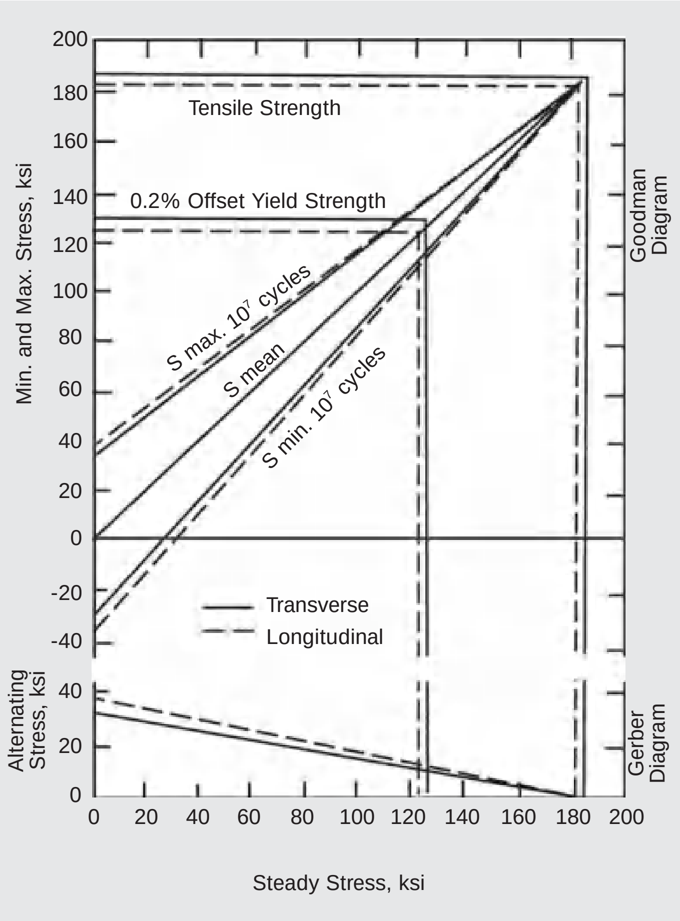

Figure 23. Effect of combining alternating and constant stresses on fatigue strength (S) of 0.060-gage, cold-rolled, annealed, and precipitation-treated (1300°F/20 hr) sheet (test made at room temperature).

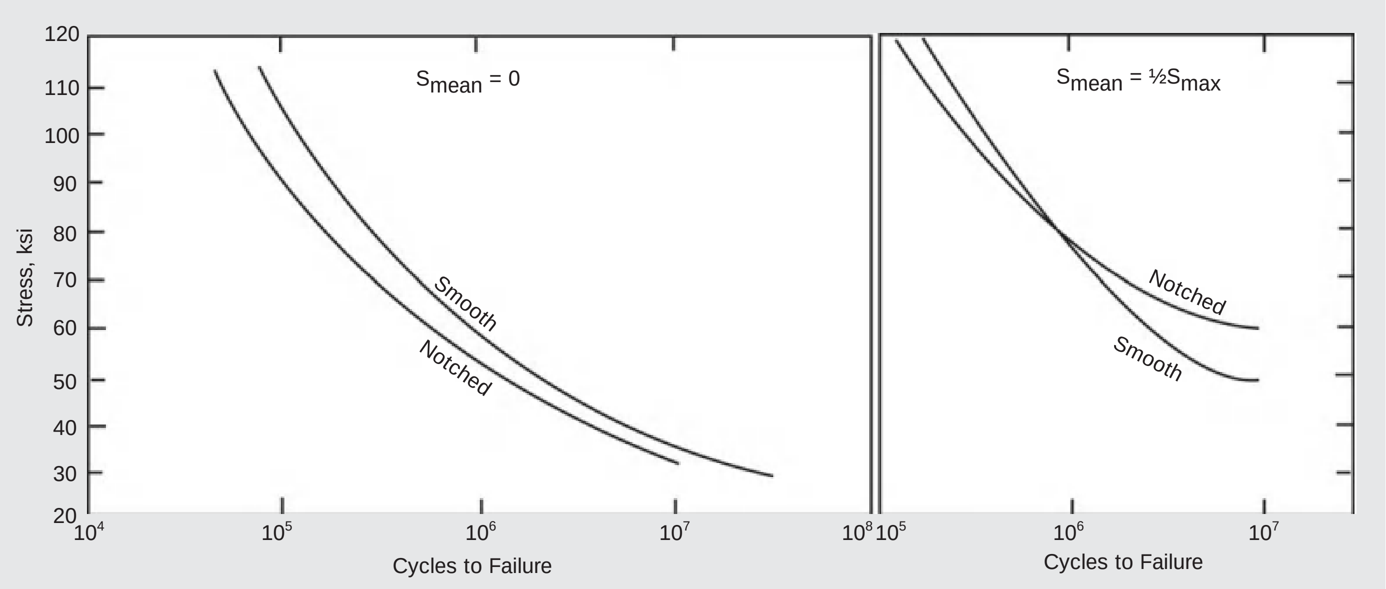

Figure 24. Fatigue strength of smooth and notched specimens of cold-rolled annealed sheet precipitation-treated 1300°F/20 hr (transverse specimens).

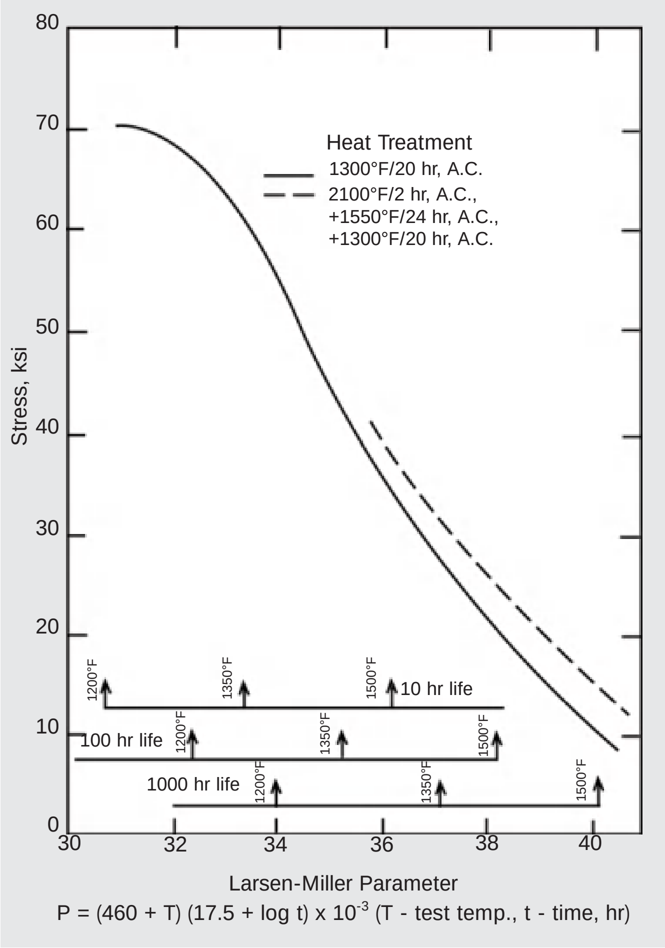

Figure 25. Rupture life of cold-rolled, annealed, and precipitation-treated sheet.

Table 25 - Low-Temperature Notch Fatigue Strength[1] of Sheet

Material	Fatigue Strength (10^6 Cycles), ksi		
	-110°F	-320°F	-423°F
LION alloy X-750	60	64	67
301 Stainless Steel	31	44	–
70/30 Brass	36	39	49
1075 Plain Carbon Steel	44	29	30
2800 (9% Ni) Steel	46	37	37
6 Al - 4V Titanium alloy	32	27	37
347 Stainless Steel	47	50	67
Nickel 200	18	21	37
LION alloy K-500	43	48	48
LION alloy 600	40	40	47
Berylco 25 - AT (Be-Cu)	33	39	43
Berylco 25 - ½HT (Be-Cu)	35	47	45
NI-SPAN-C alloy 902	46	45	57
17-7 PH (RH950) Stainless Steel	32	45	57

[1] K_t = 3.1. Specimens tested in fully reversed bending.

Table 26 - Rupture Life of Cold-Rolled, Annealed, and Precipitation-Treated (1300°F/20 hr, A.C.) Sheet

Thickness, in.	Test Conditions, °F/ksi	Rupture Life, hr
0.031	1200/70	21.5
		17.0
	1350/40	42.8
		49.5
	1500/20	40.4
		43.9
0.093	1200/70	72.3
		98.9
	1350/40	130.4
		116.8
	1500/20	63.7
		77.6

Sheet, Strip and Plate

High Strength to 1300°F – Furnace-Cool Precipitation-Treated Material

For high strength at high temperatures and high relaxation resistance, but also higher tensile properties to about 1300°F, LION alloy X-750 sheet, strip, and plate (which are furnished in the annealed condition) are given a furnace-cool precipitation treatment: 1300°F/8 hr, F.C. to 1150°F, hold at 1150°F for total precipitation treating time of 18 hr, A.C.

This heat treatment is described by AMS Specification 5598 which requires the following room-temperature properties:

Form and Size, in.	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elonga-tion in 2 in., %	Hardness, Rc
Annealed Condition				
Strip				
Up to 0.010, excl.	140 max.	–	–	–
0.010 to 0.025, excl.	135 max.	–	18 min.	–
0.025 & over	As agreed upon between purchaser & vendor			
Sheet				
0.010 to 0.024, incl.	135 max.	75 max.	30 min.	–
Over 0.024-0.250, incl.	135 max.	75 max.	35 min.	–

Form and Size, in.	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elonga-tion in 2 in., %	Hardness, Rc
After Precipitation Treating				
Strip				
Up to 0.010, excl.	155 min.	–	–	30 min. (0.005 & over)
0.010 & over	160 min.	–	12 min.	30 min.
Sheet				
0.010 to 0.250, incl.	170 min.	115 min.	18 min.	32 min.
Plate				
0.187 to 4.000, excl.	160 min.	105 min.	18 min.	30 min.

In comparison to the 1300°F/20 hr, A.C., treatment, furnace-cool precipitation treating results in increases in tensile strength and yield strength which extend to about 1300°F. It decreases ductility but not significantly. There is little difference in stress-rupture properties at 1200°, 1350°, and 1500°F produced by the two treatments. Typical high-temperature tensile properties of annealed and furnace-cool precipitation-treated sheet are shown in Table 27. Rupture life at 1200°, 1350°, and 1500°F is in Table 28. See Table 29 for room-temperature impact properties.

Table 27 - High-Temperature Tensile Properties of Cold-Rolled Annealed 0.050-in. Sheet Precipitation-Treated 1350°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Precipitation-Treating Time of 18 hr, A.C.

Temperature, °F	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elongation, %
Room	186.5	132.0	25.0
400	176.5	123.0	25.0
800	162.0	120.0	29.5
1000	155.0	116.0	25.0
1100	145.0	116.5	9.0
1200	132.5	113.0	4.2
1300	115.0	103.5	3.0
1500	82.0	77.2	12.0

Table 28 - Rupture Life of Cold-Rolled, Annealed, and Precipitation-Treated (1350°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Precipitation-Treating Time of 18 hr, A.C.) Sheet

Thickness, in.	Test Conditions, °F/ksi	Rupture Life, hr
0.031	1200/70	24.6
		16.8
	1350/40	43.6
		58.2
	1500/20	55.5
		49.9
0.093	1200/70	83.6
		103.0
	1350/40	131.8
		118.3
	1500/20	76.5
		83.2

Table 29 - Charpy Impact Strength of Hot-Rolled Plate Annealed (1800°F/1 hr) and Precipitation-Treated (1350°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Precipitation-Treating Time of 18 hr, A.C.)

Size, in.	Impact Strength, ft-lb	
	V-Notch	Keyhole Notch
½ x 48 x 96	47.5	31
¾ x 48 x 120	50.5	35
1 x 36 x 96	40.5	26
1¼ x 37 x 82	34	24
2 x 48 x 120	48.5	28.5

Sheet, Strip and Plate

Other Precipitation Treatments

Properties that are approximately equivalent to those attained with the 1300°F/20 hr treatment can be developed in a shorter time by using the following shorter furnace-cool precipitation treatment:

1400°F/1 hr, F.C. to 1150°F, Hold at 1150°F for total precipitation-treating time of 6 hr, A.C.

Although improvements in rupture properties can be gained in rod and forging products by triple heat treatment (2100°F/2-4 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.), it is not usually practical to apply it to sheet. If heat-treated after fabrication, components would be likely to sag or become distorted during exposure to 2100°F. If heat-treated before fabrication, forming operations would nullify benefits gained. The improvements in rupture properties from triple heat treatment without consideration for these negative factors are shown in Figure 25.

Seamless Tubing

For high strength to 1300°F, LION alloy X-750 seamless tubing (cold-drawn, annealed) is given the following precipitation treatment:

1300°F/20 hr, A.C.

This heat treatment is described by AMS Specification 5582, which requires that heat-treated material have the following minimum properties:

Tensile strength................................155 ksi
Yield strength (0.2% offset).............100 ksi
Elongation in 2 in.
    Strip specimen.....................15%
    Full tube specimen.............20%
Rupture life (1350°F/45 ksi)............23 hr

Wire for Springs

For best service from LION alloy X-750 springs, a temper and heat treatment must be selected that will develop the properties required for the application under consideration. Wire and strip used for helical and flat springs are usually produced in two tempers: No. 1 Temper, which represents material that has been cold-reduced about 15 to 20% after the final process anneal; and Spring Temper, which represents material that has been cold-reduced approximately 30 to 65% after the final process anneal. Some springs are also made from hot-finished material.

Design stresses for helical and flat springs are shown in Table 30. This table may be used as a guide for selection of the appropriate temper and heat treatment for the intended service temperature. As temperatures decrease below room temperature, strength and modulus will increase; therefore, if specific test data at cryogenic temperatures are not available, springs for service at these temperatures may be safely designed based on room-temperature properties.

Table 30 - Design Stresses for Springs at Elevated Temperatures[1]

Temper	Method of Coiling	Thermal Treatment,[2] °F/hr	Maximum Stress, ksi, for Temperature, °F																
			Up to 400	400-450	450-500	500-550	550-600	600-650	650-700	700-750	750-800	800-850	850-900	900-950	950-1000	1000-1050	1050-1100	1100-1150	1150-1200
HELICAL SPRINGS																			
No. 1	Cold	1350/16	70	70	70	70	70	70	70	70	70	60-70[3]	50-55[3]	45-50[3]	40-45[3]	25-30[3]	–	–	–
No. 1 (>3/8 in.)	Hot	1350/16	70	70	70	70	70	70	70	65-70[3]	60-65[3]	55-60[3]	50-55[3]	45-50[3]	40-45[3]	25-30[3]	–	–	–
Spring	Cold	1200/4	100	100	100	90	90	85	85	–	–	–	–	–	–	–	–	–	–
Spring	Cold	2100/2+1550/24+ 1300/20	55	55	55	55	55	55	55	55	55	55	55	55	55	50	50	40	30
FLAT SPRINGS																			
No. 1	–	1300/16	100	100	100	100	100	100	100	100	100	90	80	70	60	–	–	–	–
Spring	–	1300/16	120	120	120	110	110	105	100	–	–	–	–	–	–	–	–	–	–
Spring	–	2100/2+1550/24+ 1300/20	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	40	30
Hot-Finished	–	1625/24+1300/20	90	90	90	80	80	80	80	60	60	60	60	60	60	–	–	–	–
Hot-Finished	–	2100/2+1550/24+ 1300/20	60	60	60	60	60	60	60	60	60	60	60	60	60	–	–	–	–

[1] Data based on stress to produce 5% relaxation in 7 days. Helical springs, because of their configuration, are loaded in shear, and design stresses are based on maximum shearing stress. The design of flat springs, however, normally involves tensile stresses; therefore, values for flat springs do not consider shear strength.

[2] After coiling or fabrication.

[3] Use lower value for minimum rate of relaxation and higher value where some initial relaxation and a higher rate of relaxation can be tolerated.

Wire for alloy X-750 helical springs covered by AMS Specifications is described in Table 31.

Some typical room-temperature properties of wire in various conditions are shown in Table 32, and shear properties in Table 33.

No. 1 Temper wire is hardened only a small degree by the cold reduction it has undergone, but its rigidity is sufficient to permit uniform coiling on automatic machines. Spring-Temper wire has been cold-worked to the extent that the load-carrying capacity of springs made from it has been significantly raised. Thus, increased cold work gives higher strength and higher working stresses but only up to service temperatures approaching the stress-relieving temperatures.

Spring-Temper wire has a greater proportional limit but not greater resistance to relaxation at moderate temperatures. For instance, a No. 1 Temper spring, precipitation-treated 1350°F/16 hr, loaded at 70 ksi, relaxed only 3% in 500 hr at 800°F, whereas an identical spring, made of Spring-Temper wire and also precipitation-treated 1350°F/16 hr, relaxed 12%. This difference in relaxation is believed to be the effect of a difference in residual stresses brought about by cold work.

Therefore, for maximum strength from cryogenic temperatures up to about 700°F, the Spring-Temper condition, precipitation-treated 1200°F/4 hr, is

Table 31 - Specifications for Spring Wire

Temper	Heat Treat-ment, °F/hr, A.C.	Service Temp., °F	AMS Specification		
			No.	Size, in. (inclusive)	Min. Tensile Strength, ksi
No. 1	1350/16	Up to 1000	5698	Up to 0.025	155
				Over 0.025-0.500	165
Spring	1200/4	Up to 700	5699	0.012 to 0.250	220
				Over 0.250-0.418	200
				Over 0.418-0.500	180
Spring	2100/2+	900 - 1200	5699	0.012-0.250	150
	1550/24+			Over 0.250-0.500	145
	1300/20				

Table 33 - Room-Temperature Shear Properties of Springs

Temper	Solution Treatment, °F/hr	Precipitation Treatment, °F/hr	Proportional Limit (Shear), ksi	Shear Modulus, 10^3 ksi
Spring	2100/2, A.C.	1550/24,A.C. +1300/20, A.C.	67.5	11.1
Spring	2100/1, A.C.	1400/4, A.C.	54.0	11.1
Spring	None	1350/16, A.C.	93.5	11.2
No. 1	None	1350/16, A.C.	90.5	9.9

Table 32 - Room-Temperature Properties of Wire

Condition	Tensile Strength, ksi		Yield Strength (0.2% Offset), ksi		Proportional Limit (0.2% Offset), ksi		Elongation in 2 in., %		Modulus of Elasticity, 10^3 ksi	
	Diameter, in.		Diameter, in.		Diameter, in.		Diameter, in.		Tension	Torsion
	0.020	0.229	0.020	0.229	0.020	0.229	0.020	0.229		
No. 1 Temper										
As-Drawn	139	145	68	119	40	56	30.0	24	30.6	11.3
1950°F/15 min. W.Q.	120	110	43	42	34	24	34.0	53	31.0	11.3
2100°F/2 hr, W.Q. + 1550°F/24 hr + 1300°F/20 hr, A.C.	158	166	93	101	65	64	13.0	14	30.2	11.7
1350°F/16 hr, A.C.	202	204	141	159	93	91	16.0	16	31.2	11.6
1200°F/4 hr, A.C.	178	176	109	136	77	81	25.0	19	30.4	11.7
Spring Temper										
As-Drawn	269	–	233	–	137	–	1.6	–	26.0	10.2
1950°F/15 min, W.Q.	130	–	51	–	37	–	33.0	–	–	11.0
2100°F/2 hr, W.Q. + 1550°F/24 hr + 1300°F/20 hr, A.C.	154	–	104	–	81	–	8.0	–	30.8	11.2
1300°F/16 hr, A.C.	274	–	268	–	168	–	1.0	–	31.6	12.2
1200°F/4 hr, A.C.	298	–	293	–	173	–	1.0	–	31.0	11.9

recommended. For greatest relaxation resistance (up to about 900°F), No. 1 Temper, directly precipitation-treated (1350°F/16 hr) springs are preferable.

For service from about 900° to 1200°F, springs should be made of Spring-Temper material solution-treated plus stabilization-treated plus precipitation-treated (2100°F/2 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.). Material given this triple-heat-treatment will have a lower proportional limit but maximum relaxation resistance at 900° - 1200°F under stresses less than the proportional limit. The reason for its superior relaxation resistance stems from cold working. A high percentage of the cold work on a wire that has been reduced 15% (No. 1 Temper) will be on its periphery; during solution treating grains will grow in the area that was cold-worked. On the other hand, wire cold-reduced 30-65% will be cold-worked throughout and uniform-size grains will grow throughout its cross section. In general, the relaxation strength is greater for wire with a uniform coarse grain structure. (See the section on Working Instructions for the effect of solution-treating conditions on grain size of wire.)

The relaxation of springs cold-coiled from No. 1 Temper wire precipitation-treated at 1350°F/16 hr and that of springs cold-coiled from Spring-Temper wire and triple-heat-treated (2100°F/2 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.) are shown in Figures 26 and 27. Long-time relaxation of Spring-Temper, triple-heat-treated springs at 1000°, 1100°F, 1200°F, and 1300°F is shown in Figures 28-31. Although all these relaxation data were derived from tests on helical springs, they would be applicable to flat springs under the same conditions. In these tests, relaxation is the reduction of load necessary to maintain the spring at a constant height.

In fabricating springs for low-temperature service, they may be cold-pressed after precipitation treating to moderately increase load-carrying capacity. This process adds additional cold work. Cold-pressing of springs for high-temperature service is not beneficial; it increases the cold work and hence relaxation is increased. Heat loading or prestressing at temperature is beneficial to helical springs for high-temperature applications. Prestressing is done by clamping the spring under a load that is about 10% higher than the maximum working load, putting the assembly in a furnace at a temperature of about 100°F higher than the maximum service temperature, and holding for 1 hr.

Springs must be protected from sagging during triple heat treatment, especially the 2100°F solution treatment. This is done by placing the spring on an arbor which makes a snug fit with its inside diameter.

Another criterion in the design of flat springs is the fatigue strength of the material. Fatigue strength can be used in conjunction with design stresses to establish the actual limiting stress. For instance, Figure 32 shows the room-

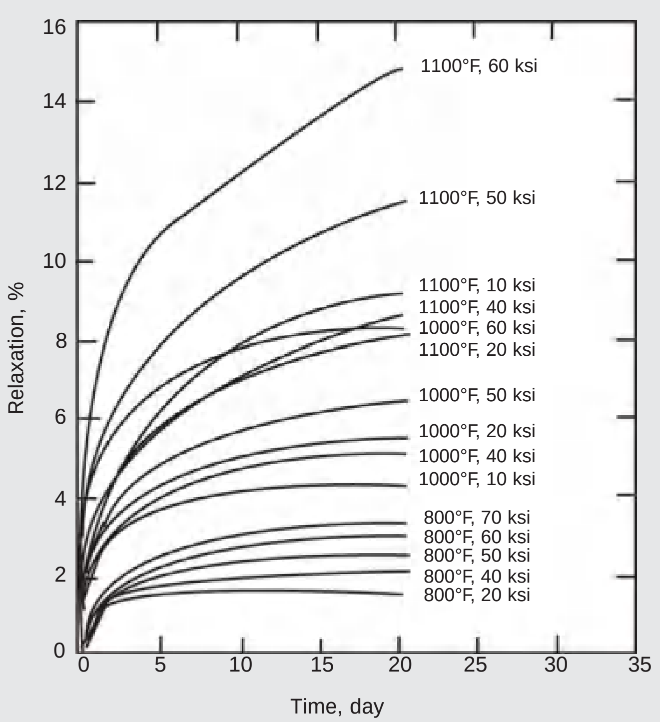

Figure 26. Relaxation of springs cold-coiled from No. 1 Temper wire (precipitation-treated at 1350°F/16 hr).

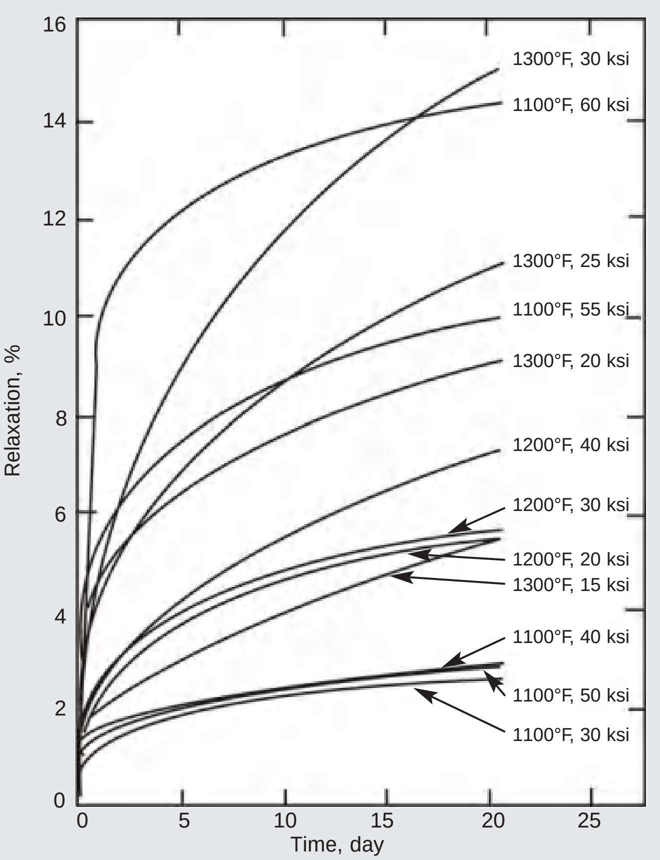

Figure 27. Relaxation of springs cold-coiled from triple-heat-treated Spring Temper wire (2100°F/2 hr, A.C., +1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.).

temperature fatigue strength of Spring-Temper strip precipitation-treated 1300°F/20 hr. If a spring is required to have a life of 2,000,000 cycles, the design stress of 120 ksi shown in Table 30 must be reduced to 70 ksi (from Figure 32). (Although the precipitation treatments are slightly different, the data may be interpreted on this basis with sufficient accuracy.) Fatigue data for other conditions shown earlier under “Mechanical Properties” may be used in the same way.

For torsion wires, internal friction (damping decrement in torsional oscillation) is an important factor. The damping decrement in torsion is given for various conditions of heat treatment in Table 34. This table also gives modulus of rigidity data for wire sizes other than those shown in Table 32.

After heat treatment, alloy X-750 springs will have a thin oxide coating. This oxide is beneficial in aiding resistance to many corrosive environments and need not be removed. Pickling after precipitation treating may cause an acid attack on the grain boundaries or result in pitting. Removing the oxide by mechanical means lowers relaxation resistance.

When possible, springs should be used with the oxide on. If they must be cleaned, treatment in a reducing bath (sodium hydride) followed by water quenching and rinsing gives a good surface.

Table 34 - Effect of Heat Treatment on Modulus of Rigidity and Damping Decrement in Torsion of Cold-Drawn Wire (All results from torsion pendulum at about 1 cps)

Size, in.	Condition	Modulus of Rigidity, 10^3 ksi	Damping Decrement in Torsion x 10^{-4}
0.037	No.1 Temper	10.50	12.30
0.037	No. 1 Temper+1350°F/16 hr	10.95	6.01
0.037	No. 1 Temper+2100°F/2 hr, A.C.+ 1550°F/24 hr, A.C.+1300°F/20 hr, A.C.	11.91	10.06
0.149	1900°F+C.D.15%+1350°F/16 hr, A.C.	11.21	9.12
0.149	2000°F+C.D.15%+1350°F/16 hr, A.C.	11.24	7.16
0.149	1900°F+C.D.15%+2100°F/2 hr, A.C.,+ 1550°F/24 hr, A.C.,+1300°F/20 hr,A.C.	11.77	6.66
0.149	2000°F+C.D.15%+2100°F/2 hr, A.C.+ 1550°F/24 hr, A.C.+1300°F/20 hr, A.C.	11.80	4.79
0.149	2100°F+C.D.15%+2100°F/2 hr, A.C.+ 1550°F/24 hr, A.C.+1300°F/20 hr, A.C.	11.80	4.75
0.149	Annealed + 65% Reduction	10.07	8.89

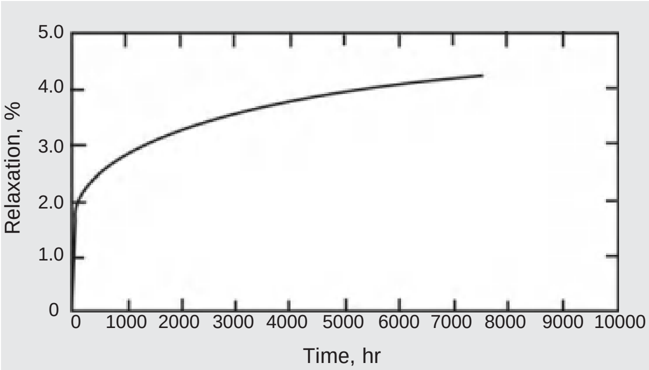

Figure 28 - Relaxation at 1000°F vs time of Spring-Temper, triple-heat-treated springs. (Stresses corrected for curvature; modulus corrected for temperature.) Loaded at 60 ksi.

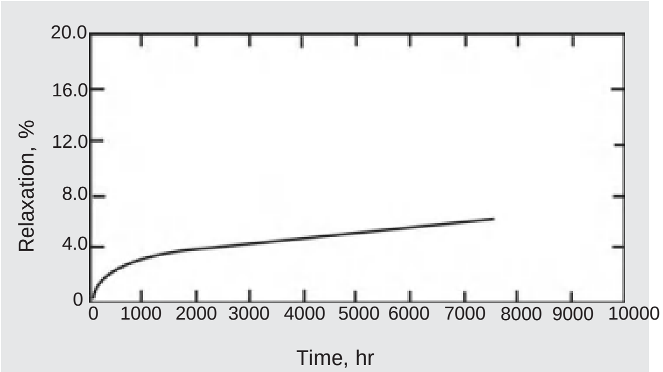

Figure 29 - Relaxation at 1100°F of Spring-Temper, triple-heat-treated springs. (Stresses corrected for curvature; modulus corrected for temperature.) Loaded at 50 ksi.

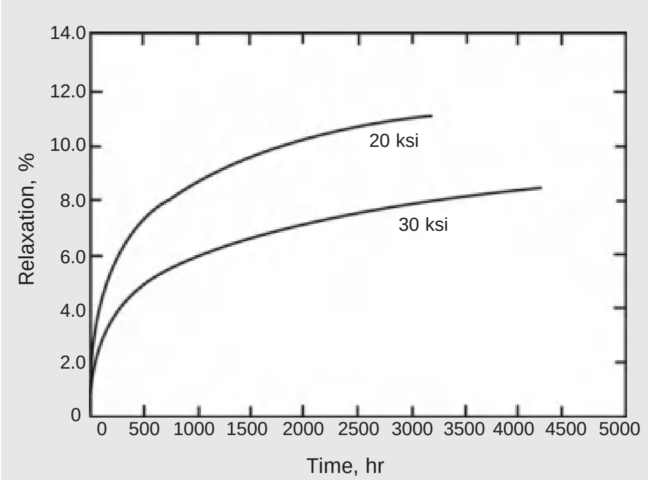

Figure 30 - Relaxation at 1200°F vs time of Spring-Temper, triple-heat-treated springs. (Stresses corrected for curvature; modulus corrected for temperature.)

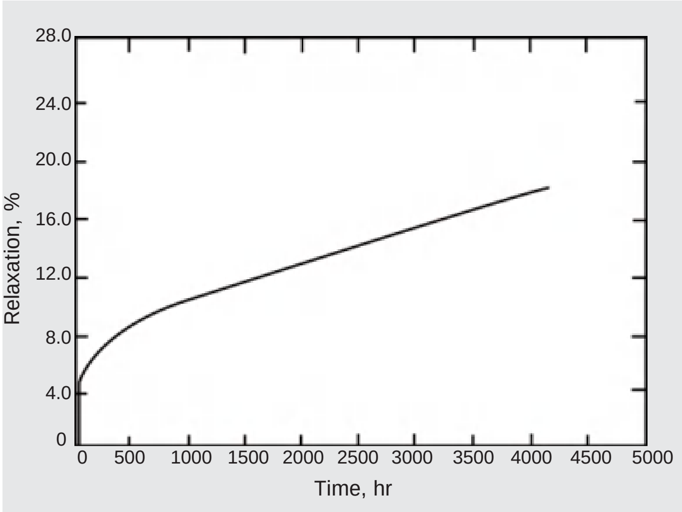

Figure 31 - Relaxation at 1300°F of Spring-Temper, triple-heat-treated springs. (Stresses corrected for curvature; modulus corrected for temperature.) Loaded at 20 ksi.

Corrosion Resistance

LION alloy X-750 is resistant to a wide variety of industrial corrosives under both oxidizing and reducing conditions. It resists oxidation and attack by other high-temperature corrosion mechanisms.

In hot corrosion tests for automotive applications, weight loss after exposure for 100 hours in 90% Na_2SO_4 + 10% NaCl mixture in air was about 5%. Samples precoated with sodium chloride (by dipping in a hot saturated salt solution), suspended in a furnace at 1700°F and exposed for 100 hr to a moving gas stream of air containing 1% SO_2 exhibited a corrosion penetration of approximately 0.007 in.

An interesting feature of this alloy is its high resistance to chloride-ion stress-corrosion cracking even in the fully precipitation-hardened condition. Standard U-bend specimens of precipitation-hardened material (hardness, 33 R_c) showed no signs of cracking when exposed to boiling 42% magnesium chloride for 30 days.

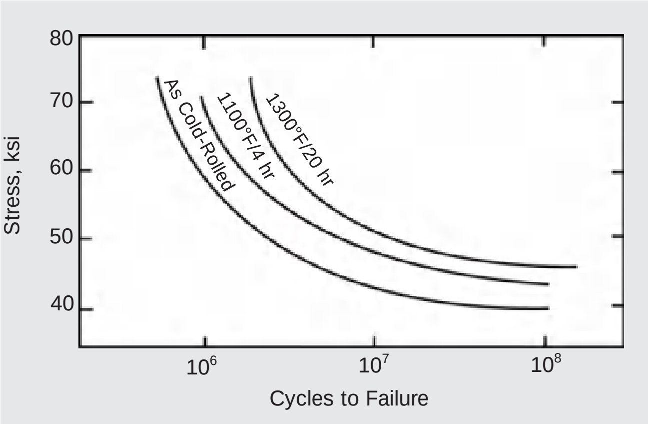

Figure 32 - Fatigue strength of cold-rolled Spring-Temper strip (tested in completely reversed bending at room temperature).

Metallography

LION alloy X-750, which contains aluminum and titanium, is made precipitation-hardenable by the combination, during heat treatment, of these elements with nickel to form gamma prime (γ’), the intermetallic compound Ni_3 (Al, Ti).

When alloy X-750 is solution-treated at 2100°F, the number of dislocations and crystal defects are reduced, and γ’ and soluble carbides go into solution. For best results, the material should be in a fairly heavily worked condition prior to the treatment to ensure rapid and complete recrystallization. Once the material has been solution-treated, it should not be subjected to any cold work since it will generate new dislocations and thus impair rupture properties.

Creep resistance of alloy X-750 stems from the uniform dispersion of intragranular γ’; whereas rupture properties are more closely related to grain-boundary area microstructure. During the 1550°F/24 hr stabilization treatment of the triple heat treatment, fine γ’ appears in the grain interiors and $M_{23}C_6$ is precipitated in the grain boundary; adjacent to the grain boundary is a zone denuded of γ’. On precipitation treating (1300°F/20 hr), γ’ has precipitated in this denuded zone. γ’ particles arrest the motion of moving dislocations, thereby increasing tensile and creep-rupture properties.

During $M_{23}C_6$ transformation at 1550°F, the carbon is essentially stabilized, without leaving chromium-depleted areas at the grain boundaries. This stabilization improves the resistance of nickel-chromium alloys to attack by certain corrosive media.

By lowering the precipitation temperature from 1350°F to 1150°F, as described for certain specific heat treatments, additional γ’ can be caused to nucleate in smaller particles, increasing the hardening effect and thereby improving tensile properties.

Working Instructions

Heating and Pickling

Heating: General procedures and precautions for heating LION alloy X-750 either in preparation for hot working or for achievement . To avoid thermal cracking, localized heating is not recommended. The entire part should be heated to the hot-working temperature.

Alloy X-750 should be air-cooled after heating. Liquid quenching is not recommended, particularly for large sections or complex parts because it can set up stresses that may cause thermal cracking during subsequent heating. Very large sections may require furnace cooling.

The heat treatments most often used for alloy X-750 have been identified in the section on Mechanical Properties. Hardnesses developed by some of these treatments are shown in Table 35.

The effect of various high-temperature thermal treatments on grain size of wire is shown in Figure 33.

When heated at intermediate temperatures (in the range of about 900° to 1600°F), LION alloy X-750, like other precipitation-hardenable alloys, is hardened rather than softened. If annealed or solution-treated alloy X-750 is placed in service in this temperature range (although this is not usually done), the alloy will harden and contract slightly. In addition, ductility is lowered if alloy X-750 is exposed in this range under stress. Hardness developed by precipitation-treating alloy X-750 at various times and temperatures is shown in Figure 34. Optimum schedules for precipitation hardening are given in the section on Mechanical Properties. Depending on end use, material can be precipitation-treated in the solution-treated, annealed, hot-worked, or cold-worked condition. For service below about 1100°F, in some cases higher strength is obtained by combining some cold work with precipitation treating.

Effect of precipitation-treating conditions on room-temperature properties of annealed sheet (Figure 35) shows that of the conditions studied a treatment of 1300°F/20 hr develops highest strength. Figure 36 deals with the furnace-cool precipitation treatment. It shows that the rate of cooling from 1350°F to 1150°F is of no significance providing total aging time is 18 hr.

Heat treatments used in conjunction with welding alloy X-750 are discussed later under “Joining”.

Table 35 - Effect of Heat Treatment on Hardness of Hot-Finished Products

Condition	Hardness	
	BHN	Rockwell
As-Rolled or As-Forged	228-298	20C-32C
Hot-Worked+1300°F/24 hr, A.C.	313-400	34C-44C
2100°F/2 hr, A.C.	140-277	77B-29C
2100°F/2 hr+1550°F/24 hr, A.C.	200-277	13C-29C
2100°F/2 hr+1550°F/24 hr, A.C.+ 1300°F/20 hr, A.C.	262-340	26C-37C
1625°F/24 hr, A.C.	200-298	13C-32C
1625°F/24 hr, A.C.+1300°F/20 hr, A.C.	302-363	32C-40C
1800°F/1 hr, A.C.+1350°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Time of 18 hr, A.C.	–	32C-42C

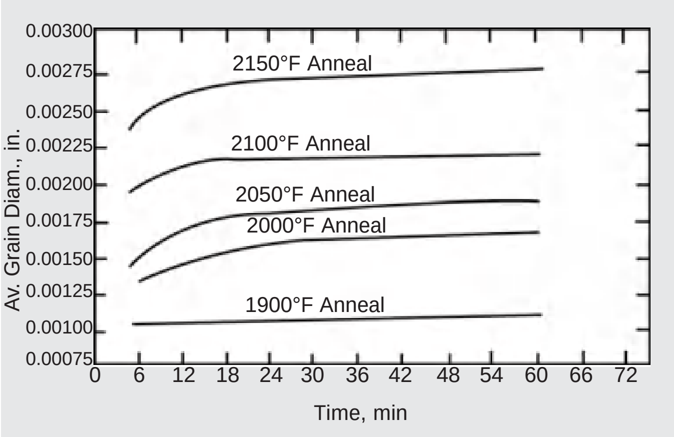

Figure 33. Effect of high-temperature thermal treatments on grain size of wire.

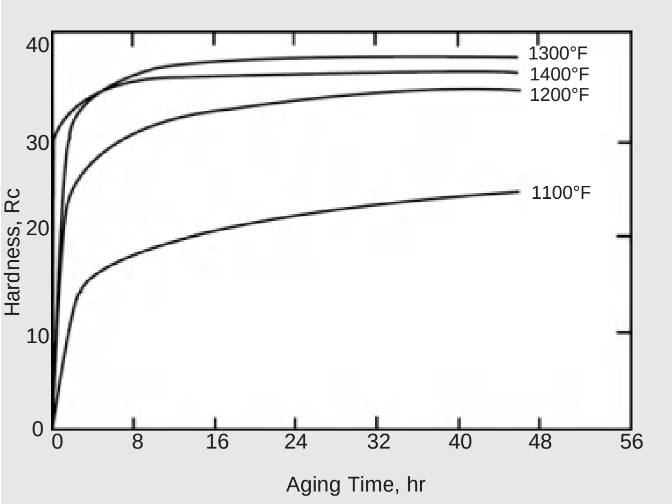

Figure 34. Effect of precipitation-hardening conditions on hardness of solution-treated (2100°F) material.

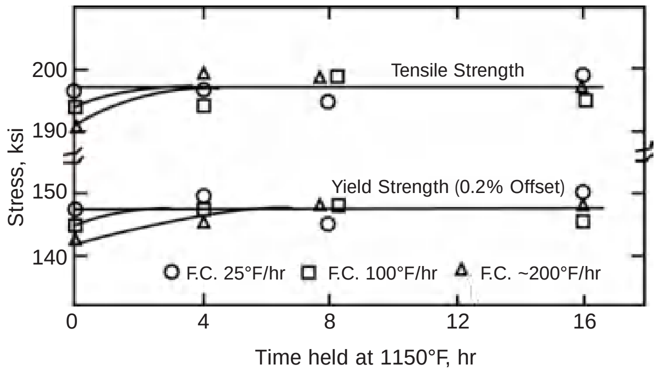

Figure 36. Effect of precipitation-treating procedures on room-temperature tensile properties of 7/8-in. diameter hot-rolled bar (heat treatment: 1800°F/1 hr, A.C., + 1350°F/8 hr, F.C. to 1150°F).

Pickling: Heat-treated LION alloy X-750, like nickel-chromium alloys in general, forms oxide films even when heated and cooled in atmospheres that keep other types of alloys bright. (It can be bright-annealed only in very dry hydrogen or argon, or in a vacuum.) Oxide or scale is therefore the usual surface condition for pickling.

Pretreatment in a fused salt bath is strongly recommended for most effective removal of scale.

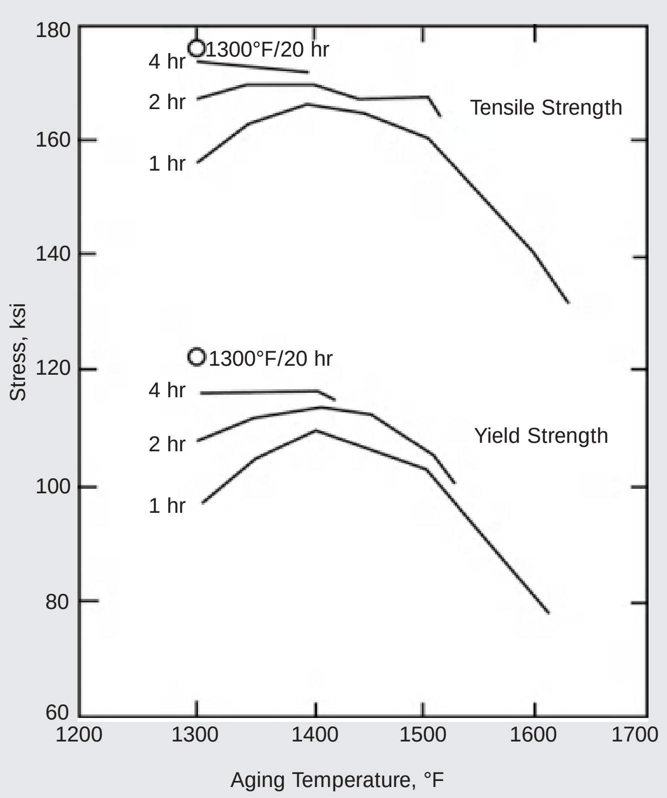

Figure 35. Effect of precipitation-treating conditions on room-temperature tensile properties of annealed sheet.

A nitric-hydrofluoric acid pickling bath, however, can be employed directly for removal of some types of scale. LION alloy X-750 is subject to intergranular attack in this solution, particularly if the alloy is in the precipitation-hardened condition. Time in bath should be kept to a minimum. Bath temperature is critical; maximum temperature should not exceed 125°F. The pickling tank must be properly ventilated because the fumes are toxic. For appropriate pickling procedures refer to the “Fabricating” publication mentioned above.

Scale can be successfully mechanically removed by barrel tumbling, fine-grit and vapor blasting.

Fabricating

LION alloy X-750 is readily fabricated by processes common to industry. Procedures and tools must be selected that will be appropriate for its high strength and characteristic strain-hardening rates. Care must be taken to ensure that material is in the condition recommended for a specific operation.

Hot Forming: Sufficiently powerful equipment is important when hot-forming alloy X-750 because of its resistance to deformation.

The recommended temperature range for hot working alloy X-750 is 1800°-2200°F range. All heavy hot working should be done above 1900°F. Forgings can be finished with some light reduction in the 1800°-1900°F range. Below 1800°F the metal is stiff and hard to move, and attempts to work it may cause splitting.

Steam hammers are well suited for working LION alloy X-750 since the work can be handled rapidly with a minimum of chilling. When the alloy is forged on presses, the metal is in contact with the dies or blocks for a relatively long time, and the surface layers may be chilled to temperatures below the correct hot-working range. The work should be reheated as often as may be needed to maintain uniform temperature throughout the piece and to avoid rupture arising from localized chilling.

Approximately 20% final reduction should be done below 2000°F to ensure meeting the requirements of AMS 5667, 5670, 5671, and 5747.

Cold Forming: LION alloy X-750 is successfully cold-formed by a variety of processes. Its relatively rapid strain-hardening rate (the effect of cold work on hardness) is shown in Figure 37. To guard against rupturing, care must be taken to incorporate sufficient anneals when a forming operation consists of successive reductions.

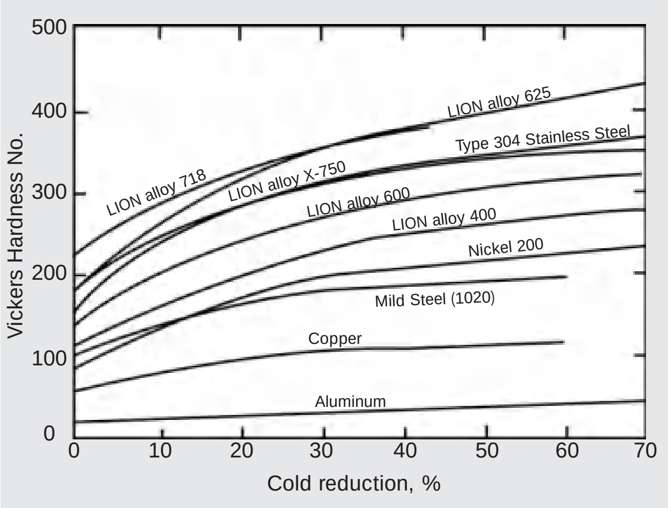

Figure 37. Effect of cold work on hardness.

Machining

LION alloy X-750 is machined at practical and economical rates.

Because of precipitation-hardened alloy X-750's high strength and hardness, rough machining is usually done before precipitation hardening. Finish machining then follows precipitation treating. Precipitation hardening relieves machining stresses; therefore, allowance must be made for possible warpage. A slight permanent contraction takes place during precipitation treating, but precipitation-treated material has good dimensional stability. Accurate dimensions and a good finish will result from following these practices.

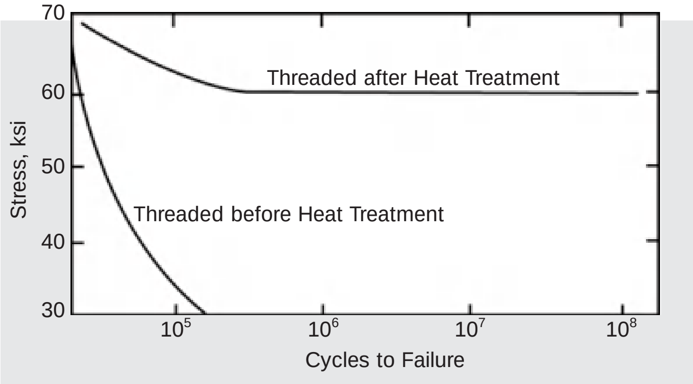

Figure 38. Effect of sequence of threading and heat treatment (1625°F/4 hr, A.C. + 1300°F/16 hr, A.C.) operations on fatigue strength of bolts (hot-rolled 5/8-in. diameter rod) at 1100°F.

Wire Drawing and Bolt Manufacture

LION alloy X-750 wire is process-annealed at 1900°F. About 40% cold reduction before re-annealing is preferable. Hot heading or hot upsetting is best done at 1800° to 2000°F. Generally, the wire is heated by induction or resistance and then fed into the die for forming.

Various coatings are often applied to alloy X-750 to avoid sticking and seizing in the dies. Lead is commonly used in cold drawing, and copper for cold heading and for spring manufacture. Where lead may be prohibited in certain applications (including nuclear), oxalates may be used. The coatings may be applied by either batch or continuous processes. For effective coating, the wire should have an extremely clean pickled or etched surface.

In difficult forming or coiling jobs, success has been attained with chlorinated paraffin used in conjunction with copper-coated wire.

During the cold upsetting of copper-coated wire, it is often drawn through a soap and lime mixture to add extra lubricating qualities to the surface.

It is essential to remove all lead coatings prior to heat treatment or high-temperature service to prevent subsequent diseasing and cracking. The copper coating also must be removed before heat treatment to prevent copper dilution at the surface and loss of mechanical properties. A 15-20% nitric acid bath is the most common method for removing lead or copper.

Depending on the properties required, bolts may be threaded either before or after heat treatment. If threading is done prior to precipitation treating, tool and die wear will be reduced and manufacture will be generally facilitated; however, strength will be greater by threading after precipitation treating. A comparison of the effects on fatigue strength of threading before or after precipitation treating is shown in Figure 38.

Joining

Welding processes recommended for alloy X-750 are gas-tungsten-arc, plasma-arc, electron-beam, resistance, and pressure-oxyacetylene welding.

In welding LION alloy X-750 by the gas-tungsten-arc process, LIONFiller Metal 718 is used. Joint efficiencies are nearly 100% at room temperature and 80% at 1300°-1500°F, based on the results of stress-rupture tests. Typical tensile properties of welded plate from -423° to 1500°F are shown in Figure 39.

Alloy X-750 should be in the annealed or solution-treated condition prior to welding. It is possible to weld it when it is in the precipitation-treated condition, but neither the weld or the heat-affected zone should be subsequently precipitation-treated or exposed to service temperatures within the precipitation-hardening temperature range because of the danger of parent-metal cracking. If alloy X-750 has been precipitation-hardened and then welded and is expected to be exposed to precipitation-treating temperatures during service, the weldment should be annealed or solution-treated and re-precipitation-treated. In all cases, care must be taken during assembling and welding to minimize high stresses.

Alloy X-750 weldments should be solution-treated prior to precipitation treating. Rate of heating of the weldment up to temperature must be fast and uniform to keep to a minimum time of exposure to temperatures in the precipitation-hardening range. The most practical means of obtaining the rapid heating rate is to charge the fabricated part to a preheated furnace.

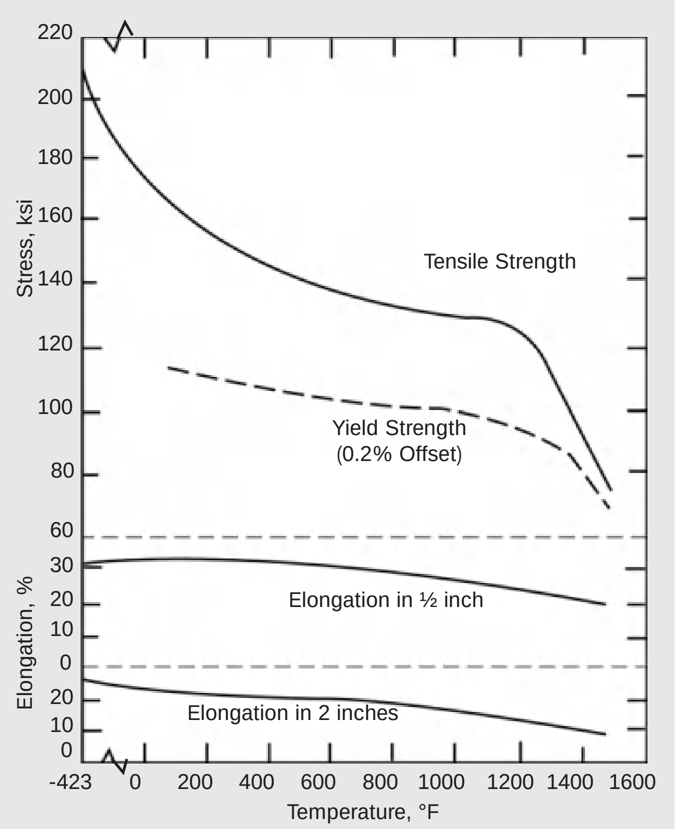

Figure 39. Tensile properties of welded ¾-in. plate. Welded by gas tungsten-arc process. Double U-groove butt weld. Postweld heat treatment, 1925°F/1 hr, A.C.+1300°F/20 hr.

Sometimes preweld heat treatments will be beneficial – in cases where material to be welded is in restraint or if the weldment is complex, and especially if the assembly is too complicated for carrying out a postweld anneal. Two preweld treatments that have been proved effective are:

1. 1550°F/16 hr, A.C.
2. 1950°F/1hr, F.C. at a rate of 25°-100°F/hr to 1200°F, A.C.

Repair welding of parts that have been in service should be followed by solution treating (heating rapidly through the precipitation-hardening range) and re-precipitation treating.

Interbead or interlayer cleaning must be provided to remove the oxide films that form during welding. (Complete protection of the weld metal by gas-shielded processes is difficult to achieve.) If these films are not removed periodically, they can become sufficiently heavy to interfere with proper fusion and reduce joint strength. Power wire brushing serves only to polish the oxide surface; the weld bead must be abrasive-blasted or -ground. Frequency of cleaning depends on how much oxide has accumulated. All grit must be removed before welding is resumed.

LION alloy X-750 may be brazed by conventional procedures using many of the commercial brazing alloys. Precipitation treating, if desired, must take place after brazing; therefore, an alloy should be selected that melts above precipitation-treating temperatures. Nickel-base brazing alloys are particularly useful with alloy X-750.

Alloy X-750 is readily joined by spot, projection, seam, and flash resistance welding processes. Equipment must be of adequate capacity. In general, alloy X-750 is resistance-welded in the annealed or solution-treated condition.

Available Products and Specifications

LION alloy X-750 is designated as UNS N07750 and W. Nr. 2.4669. The alloy is stated in NACE MR-01-75. Available product forms are sheet, strip, plate, round bar, flat bar, forging stock, hexagon, wire, tubing and extruded section.

Specifications include the following:

Rod, Bar and Forging Stock - ASTM B 637/ASME SB 637; ISO 9723-9725; SAE AMS 5667-5671 and 5747; EN 10269.

Plate, Sheet and Strip - ISO 6208, SAE AMS 5542 and 5598.

Wire - BS HR 505, SAE AMS 5698 and 5699.