LION® (nickel-chromium-iron) alloy 600 (UNS N06600/W.Nr. 2.4816) is a standard engineering material for applications which require resistance to corrosion and heat. The alloy also has excellent mechanical properties and presents the desirable combination of high strength and good workability.

The limiting chemical composition of LION alloy 600 is shown in Table 1. The high nickel content gives the alloy resistance to corrosion by many organic and inorganic compounds and also makes it virtually immune to chloride-ion stress-corrosion cracking. Chromium confers resistance to sulfur compounds and also provides resistance to oxidizing conditions at high temperatures or in corrosive solutions. The alloy is not precipitation hardenable; it is hardened and strengthened only by cold work.

The versatility of LION alloy 600 has led to its use in a variety of applications involving temperatures from cryogenic to above 2000°F (1095°C).

The alloy is used extensively in the chemical industry for its strength and corrosion resistance. Applications include heaters, stills, bubble towers and condensers for processing of fatty acids; evaporator tubes, tube sheets and flaking trays for the manufacture of sodium sulfide; and equipment for handling abietic acid in the manufacture of paper pulp.

The alloy's strength and oxidation resistance at high temperatures make it useful for many applications in the heat-treating industry. It is used for retorts, muffles, roller hearths and other furnace components and for heat-treating baskets and trays.

In the aeronautical field, LION alloy 600 is used for a variety of engine and airframe components which must withstand high temperatures. Examples are lockwire, exhaust liners and turbine seals.

LION alloy 600 is used in the electronic field for such parts as cathode-ray tube spiders, thyratron grids, tube support members and springs.

The alloy is a standard material of construction for nuclear reactors. It has excellent resistance to corrosion by high-purity water, and no indication of chloride-ion stress-corrosion cracking in reactor water systems has been detected. For nuclear applications, the alloy is produced to exacting specifications and is designated LION alloy 600T.

Table 1 - Limiting Chemical Composition, %

Nickel (plus Cobalt)	72.0 min.
Chromium	14.0-17.0
Iron	6.00-10.00
Carbon	0.15 max.
Manganese	1.00 max
Sulfur	0.015 max.
Silicon	0.50 max.
Copper	0.50 max.

Physical Constants and Thermal Properties

Some physical constants of LION alloy 600 are given in Table 2. Thermal properties at low and high temperatures are listed in Table 3.

The modulus of elasticity in tension at various temperatures is shown in Table 4.

Measurements of total hemispherical emissivity and total normal emissivity are shown in Table 5.

The values for physical constants and thermal properties reported here are typical but are not suitable for specification use.

Table 2 - Physical Constants

Density, lb/in^3	0.306
Mg/m^3	8.47
Melting Range, °F	2470-2575
°C	1354-1413
Specific Heat, Btu/lb-°F	0.106
J/kg-°C	444
Electrical Resistivity, ohm-circ mil/ft	620
µΩ-m	1.03
Curie Temperature, °F	-192
°C	-124
Permeability at 200 oersted (15.9 kA/m)	1.010

Mechanical Properties

As indicated by the nominal mechanical properties listed in Table 6, a broad range of strength and hardness is obtainable with LION alloy 600, depending on form and condition. In the annealed condition, the alloy exhibits moderate yield strengths of 25,000 to 50,000 psi (172 to 345 MPa). Yield strengths in that range, combined with elongations of 55 to 35%, permit the alloy to be fabricated with little difficulty. Heavily cold-worked material, however, can have tensile strengths as high as 220,000 psi (1517 MPa).

Values for properties reported in this publication are typical but are not suitable for specification purposes unless stated as minimum or maximum.

Table 3 - Thermal Properties

Temperature	Coefficient of Expansion[a]	Electrical Resistivity	Thermal Conductivity	Specific Heat
°F	10^{-6}in/in•°F	ohm•circ•mil/ft	Btu•in/ft^2•h•°F	Btu/lb•°F
-250	6.0	-	86	0.073
-200	6.3	-	89	0.079
-100	6.7	-	93	0.090
70	5.8	620	103	0.106
200	7.4	625	109	0.111
400	7.7	634	121	0.116
600	7.9	644	133	0.121
800	8.1	657	145	0.126
1000	8.4	680	158	0.132
1200	8.6	680	172	0.140
1400	8.9	680	186	0.145
1600	9.1	686	200	0.149
1800	9.3	698	-	-
2000	-	704	-	-
°C	µm/m•°C	µΩ•m	W/m•°C	J/kg•°C
-150	10.9	-	12.5	310
-100	11.7	-	13.1	352
-50	12.3	-	13.6	394
20	10.4	1.03	14.9	444
100	13.3	1.04	15.9	465
200	13.8	1.05	17.3	486
300	14.2	1.07	19.0	502
400	14.5	1.09	20.5	519
500	14.9	1.12	22.1	536
600	15.3	1.13	23.9	578
700	15.8	1.13	25.7	595
800	16.1	1.13	27.5	611
900	16.4	1.15	-	628

[a]Mean coefficient of linear expansion between 70°F (21°C) and temperature shown except that the room-temperature value was measured from -320°F (-196°C).

Table 5 - Emissivity

	Temperature, °F (°C)					
	600 (315)	900 (480)	1200 (650)	1500 (815)	1800 (980)	2000 (1090)
Total Hemispherical Emissivity	0.69	0.72	0.76	0.79	0.82	-
Total Normal Emissivity As-Rolled and Oxidized[a]	-	0.85	0.87	0.90	0.95	0.98
Sand-Blasted and Oxidized[b]	-	0.86	0.90	0.93	0.96	0.97

[a]Oxidized by heating 13 min in air at 2000°F (1090°C).
[b]Oxidized by heating 15 min at 1500°F (815°C), 15 min at 1800°F (980°C), and 15 min at 2100°F (1150°C).

Table 4 - Modulus of Elasticity

Temperature	Young Modulus	Shear Modulus	Poisson's Ratio
°F	10^3 ksi	10^3 ksi	
72	31.1	11.72	0.327
200	30.5	11.56	0.319
400	29.7	11.32	0.312
600	28.8	11.02	0.307
800	27.8	10.68	0.301
1000	26.7	10.29	0.297
1200	25.5	9.83	0.297
1400	24.3	9.24	0.315
1600	22.8	8.58	0.329
1800	21.0	7.85	0.338
°C	GPa	GPa	Poisson's Ratio
22	214	80.8	0.324
100	210	79.6	0.319
200	205	78.0	0.314
300	199	76.2	0.306
400	193	74.2	0.301
500	187	71.9	0.300
600	180	69.2	0.301
700	172	65.9	0.305
800	164	62.1	0.320
900	154	57.9	0.330
1000	143	53.4	0.339

Tensile Properties

Nominal room-temperature tensile-property ranges of material in standard forms and conditions are given in Table 6.

Table 7 lists room-temperature tensile properties of hot-rolled rod annealed at various temperatures. Tensile properties of a rod forged to a 31% reduction at 1600°F (870°C) are given for the as-forged condition and after various annealing treatments in Table 8. Room-temperature properties of 0.875-in. (22-mm) thick hot-rolled plate are listed in Table 9.

Table 10 shows the tensile properties of a cold-drawn, 0.750-in. (19-mm) dia. rod. The table also shows the effect of annealing on the properties of cold-drawn material. The tensile properties of cold-drawn tubing are given for the as-drawn and annealed conditions in Table 11.

Table 6 - Typical Mechanical-Property Ranges[a]

Form and Condition	Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Hardness, Rockwell
	ksi	MPa	ksi	MPa		
Rod and Bar						
Cold-Drawn						
Annealed	80-100	550-690	25-50	170-345	55-35	65-85B
As-Drawn	105-150	725-1035	80-125	550-860	30-10	90B-30C
Hot-Finished						
Annealed	80-100	550-690	30-50	205-345	55-35	65-85B
Hot-Finished	85-120	585-830	35-90	240-620	50-30	75-95B
Plate						
Hot-Rolled						
Annealed	80-105	550-725	30-50	205-345	55-35	65-85B
As-Rolled	85-110	580-760	35-65	240-450	50-30	80-95B
Sheet						
Cold-Rolled						
Annealed	80-100	550-690	30-45	205-310	55-35	88B max.
Hard	120-150	830-1035	90-125	620-860	15-2	24C min.
Strip						
Cold-Rolled						
Annealed	80-100	550-690	30-45	205-310	55-35	84B max.
Spring Temper	145-170	1000-1170	120-160	830-1100	10-2	30C min.
Tube and Pipe						
Hot-Finished						
Hot-Finished	75-100	520-690	25-50	170-345	55-35	-
Annealed	75-100	520-690	25-50	170-345	55-35	-
Cold-Drawn						
Annealed	80-100	550-690	25-50	170-345	55-35	88B max.
Wire[b]						
Cold-Drawn						
Annealed	80-120	550-830	35-75	240-520	45-20	-
No. 1 Temper	105-135	725-930	70-105	480-725	35-15	-
Spring Temper	170-220	1170-1520	150-210	1035-1450	5-2	-

[a]Values shown are composites for various product sizes and therefore are not suitable for specification purposes.
[b]Properties shown are for sizes 0.0625- to 0.250-in. (1.6 to 6.4 mm) dia. Properties for other sizes may vary from these.

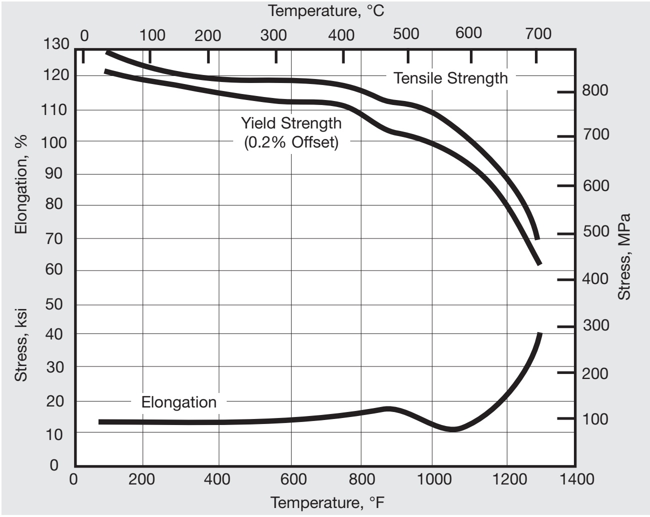

Figure 1. High-temperature tensile properties of cold-drawn bar.

High-temperature tensile properties of cold-drawn bar are shown in Figure 1.

Tensile properties of cold-drawn (20% reduction) rod at cryogenic temperatures are shown in Figure 2.

Brinell hardness readings on hot-rolled material at elevated temperatures are given in Figure 3.

Short-time, high-temperature tensile data for annealed rod and plate are plotted in Figures 4 and 5.

Table 7 - Room-Temperature Tensile Properties of Hot-Rolled Rod

Heat Treatment[a]		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Reduction of Area, %	Hardness, R_b
°F/1 hr	°C/1 hr	ksi	MPa	ksi	MPa			
As-rolled	As-rolled	97.5	672.3	44.5	306.8	46.0	68.0	86
1600	870	95.6	659.1	41.1	283.3	44.0	66.0	85
1700	925	95.6	659.1	41.0	282.7	45.0	46.5	84
1800	980	90.5	624.0	30.4	209.6	49.0	69.5	75
1900	1040	86.5	596.4	20.5	141.3	55.0	71.5	70
2000	1090	86.3	595.0	24.2	166.9	55.0	71.5	70
2100	1150	84.5	582.6	24.0	165.5	57.5	69.5	69

[a]Air-cooled after all treatments.

Table 8 - Room-Temperature Properties of Forged[a] Rod

Heat Treatment[b]		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Hardness, R_b
°F/1 hr	°C/1 hr	ksi	MPa	ksi	MPa		
As-forged	As-forged	99.0	682.6	58.0	399.9	35	91
1300	705	100.5	692.9	61.0	420.6	34	92
1400	760	97.5	672.3	57.0	393.0	31	89
1500	815	98.5	679.2	57.0	393.0	33	91
1600	870	102.0	703.3	62.0	427.5	32	93
1700	925	102.5	706.7	41.5	286.1	39	88

[a]31% reduction, finished at 1600°F (870°C).
[b]Air-cooled after all treatments.

Table 9 - Room-Temperature Properties of Hot-Rolled Plate

Heat Treatment[a]		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Reduction of Area, %	Hardness, R_b
°F/1 hr	°C/1 hr	ksi	MPa	ksi	MPa			
As-rolled	As-rolled	99.0	682.6	50.2	346.1	42.0	55.5	87
1600	870	98.0	675.7	48.0	331.0	40.0	55.0	87
1700	925	98.5	679.2	49.4	340.6	40.5	58.0	84
1800	980	92.7	639.2	28.9	199.3	49.0	63.0	75
1900	1040	91.0	627.4	27.5	189.6	51.0	65.0	73
2000	1090	89.8	619.2	26.7	184.1	52.5	66.5	72
2100	1150	84.5	582.6	23.5	162.0	58.0	65.0	68

[a]Air-cooled after all treatments.

Table 10 - Room-Temperature Properties of Cold-Drawn Rod

Heat Treatment		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Reduction of Area, %	Hardness, Rockwell
°F/1 hr	°C/1 hr	ksi	MPa	ksi	MPa			
As-drawn	As-drawn	123.5	851.5	118.5	817.1	16.0	55	28C
1200	650	134.0	923.9	113.0	779.4	20.0	51	23C
1300	705	148.0	1020.5	100.0	689.5	22.0	52	99B
1400	760	118.3	815.7	90.4	623.3	23.5	53	97B
1500	815	99.4	685.4	40.0	275.8	42.0	61	76B
1600	870	99.2	684.0	39.7	273.7	43.0	63	77B

Table 11 - Room-Temperature Properties of Cold-Drawn Tubing[a]

Heat Treatment		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Hardness, Rockwell
°F/1 hr	°C/1 hr	ksi	MPa	ksi	MPa		
As-drawn	As-drawn	144.0	992.9	132.8	915.7	8.0	34C
1200	650	143.5	989.4	124.0	855.0	17.5	32C
1300	705	131.5	906.7	108.2	746.0	18.0	30C
1400	760	103.0	710.2	41.5	286.1	41.0	88B
1500	815	100.3	691.6	39.7	273.7	42.0	83B
1600	870	100.5	692.9	40.5	279.2	43.0	83B

[a]0.625-in. (15.9-mm) OD x 0.075-in. (1.9-mm) wall.

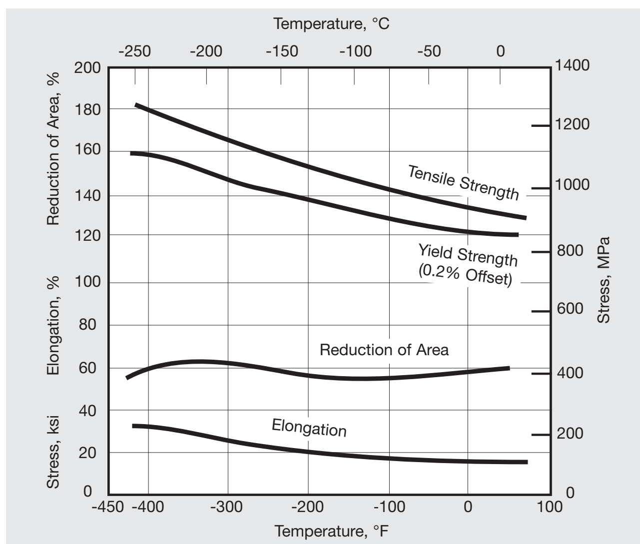

Figure 2. Low-temperature tensile properties of cold-drawn rod.

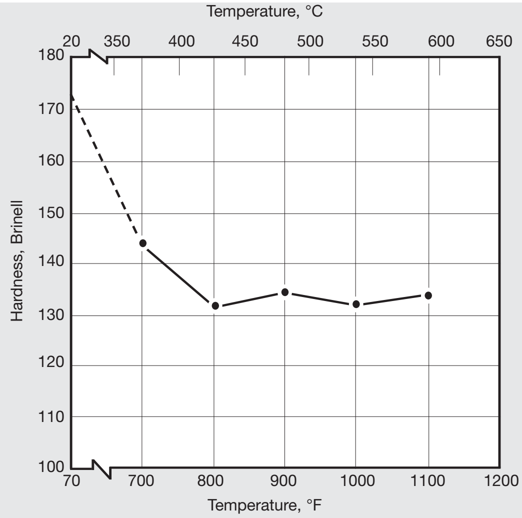

Figure 3. Hot hardness of hot-rolled material.

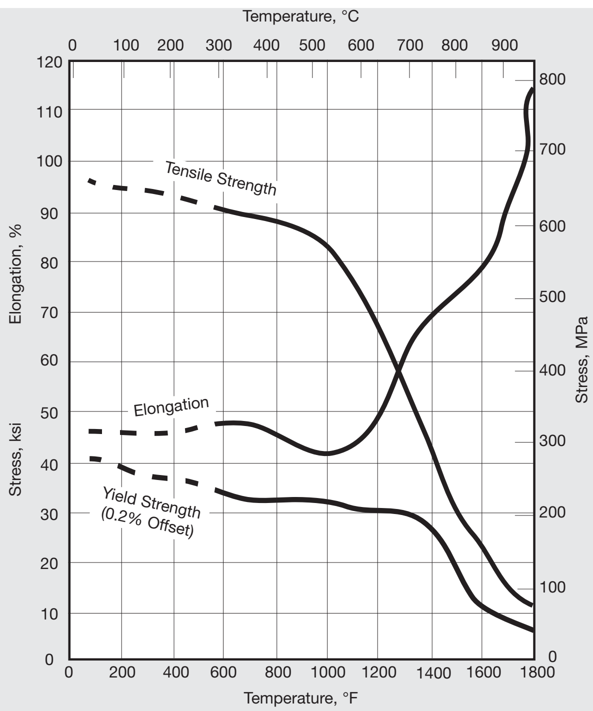

Figure 4. High-temperature tensile properties of annealed, 1600°F (870°C)/1 hr, hot-rolled rod.

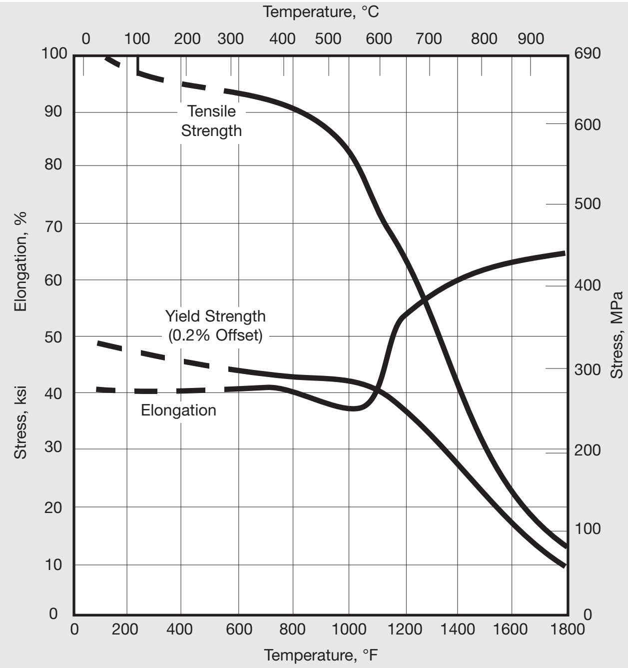

Figure 5. High-temperature tensile properties of annealed, 1600°F (870°C)/1 hr, hot-rolled plate.

Impact Strength and Ductility

LION alloy 600 has good impact strength at room temperature and retains virtually all of that strength at low temperatures; there is no tough-to-brittle transition with decreasing temperature. Impact-strength values (Charpy keyhole) for ½-in. (13-mm)- thick plate at room and low temperatures are shown in Table 12. Additional room-temperature values are listed in Table 13.

Impact-strength values at elevated temperatures are given for annealed and cold-drawn material in Table 14.

Table 12 - Impact Strength (Charpy Keyhole) of Plate

Orientation	Temperature		Impact Strength[a]	
	°F	°C	ft-lb	J
Transverse	70	21	63.5	86.1
	-110	-79	65.5	88.8
	-320	-196	60.8	82.4
Longitudinal	70	21	61.7	83.7
	-110	-79	67.0	90.8
	-320	-196	61.3	83.1

[a]Values are the average of three tests.

Table 13 - Room-Temperature Impact Strength of Rod

Condition	Impact Strength			
	Izod Notch		Charpy U-Notch	
	ft•lb	J	ft•lb	J
Cold-Drawn	>120	>163	230	312
Cold-Drawn, Annealed	70-100	95-136	151	205
Hot-Rolled	>120	>163	230	312
Hot-Rolled, Annealed	100-120	136-163	-	-

Table 14 - Impact Strength (Charpy V-Notch) at Elevated Temperatures

Temperature		Impact Strength			
		Annealed		Cold-Drawn	
°F	°C	ft•lb	J	ft•lb	J
70	21	180	244	114	155
800	430	187	254	84	114
1000	540	160	217	86	116
1200	650	160	217	104	141
1400	760	154	209	163	221

Shear properties

Shear-strength values for cold-rolled sheet and strip in three tempers are listed in Table 15.

Table 15 - Shear Strength of Cold-Rolled Sheet and Strip

Temper	Shear Strength		Tensile Strength		Hardness, Rockwell
	ksi	MPa	ksi	MPa	
Annealed	60.8	419.2	85.0	586.1	71 B
Half-Hard	66.3	456.8	98.8	681.2	98 B
Full-Hard	82.4	568.1	152.2	1049.5	31 C

Fatigue Strength

The room-temperature fatigue strength of material in various conditions is shown in Table 16. The data were obtained from rotating-beam tests using polished specimens.

The fatigue strength of LION alloy 600 at elevated temperatures is shown in Figure 6. The tests were performed on material having the following room-temperature mechanical properties:

Tensile strength	106 ksi	(730 MPa)
Yield strength (0.2% offset)	52 ksi	(360 MPa)
Elongation	39%	
Reduction of Area	68.6%	

Low-cycle fatigue data for annealed rod are given for room and elevated temperatures in Table 17. Low-cycle data for forgings in two conditions are shown in Table 18. The values in Table 18 were obtained from material having two different carbon contents and with varying amounts of hot-cold work. These variables had no apparent effect on the cyclic-strain behavior.

Figure 7 and 8 illustrate the effect of grain size and mechanical properties on the room-temperature fatigue strength of forgings. The material tested was from one melt, but was forged by different practices to produce the four conditions described in Table 19. Rotating-beam (10,000 cycles/min) and high-strain, low-cycle (675 cycles/hr) fatigue tests were performed at room temperature on material in each of the four conditions. The results indicate that grain size and mechanical properties have no appreciable effect on low-cycle fatigue strength (Figure 7). However, those variables do affect high-speed, rotating-beam fatigue properties. The best room-temperature, rotating-beam fatigue strength (Figure 8) is obtained with fine-grained hard material.

Table 16 - Room-Temperature Fatigue Strength

Condition	Fatigue Strength (10^8 Cycles)		Tensile Strength		Average Endurance Ratio
	ksi	MPa	ksi	MPa	
Annealed	39.0	268.9	85-114	586.1-786.0	0.39
Hot-Rolled	40.5	279.2	87-129.5	600.0-892.9	0.41
Cold-Drawn	45.0	310.3	112.5-202	775.7-1393	0.32
Cold-Drawn, Stress-Equalized[a]	52.5	361.0	121.5-173	837.7-1193	0.34

[a]525°F (274°C) 3 hr.

Table 17 - Low-Cycle[a] Fatigue of Annealed Rod

Temperature		Reversed Strain, %, to Cause Failure In		
°F	°C	10,000 Cycles	50,000 Cycles	100,000 Cycles
75	24	±0.36	±0.21	±0.18
200	93	±0.43	±0.21	±0.18
400	204	±0.58	±0.26	±0.20
600	316	±0.52	±0.23	±0.18

[a]550 cycles/hr.

Table 18 - Room-Temperature Low-Cycle[a] Fatigue of Forgings

Material Condition	Reversed Strain, %, to Cause Failure In		
	1000 Cycles	10,000 Cycles	50,000 Cycles
As-Forged	±1.25	±0.50	±0.35
Stress-Relieved 1400°F (760°C)/4 hr	±1.25	±0.47	±0.27

[a]675 cycles/hr.

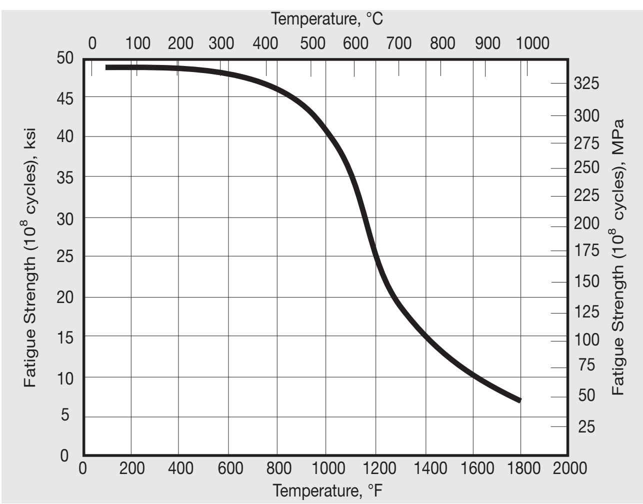

Figure 6. Rotating-beam fatigue strength (10^8 cycles) of cold-drawn, annealed rod at elevated temperatures.

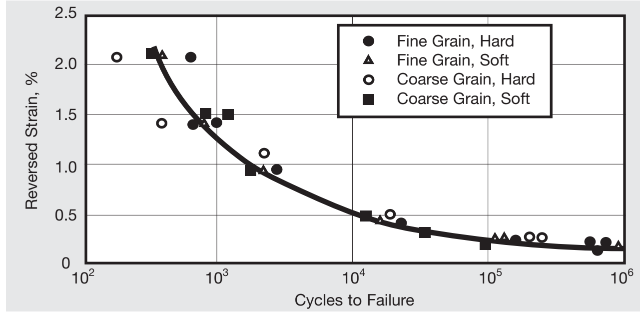

Figure 7. Low-cycle fatigue strength of forgings in four conditions.

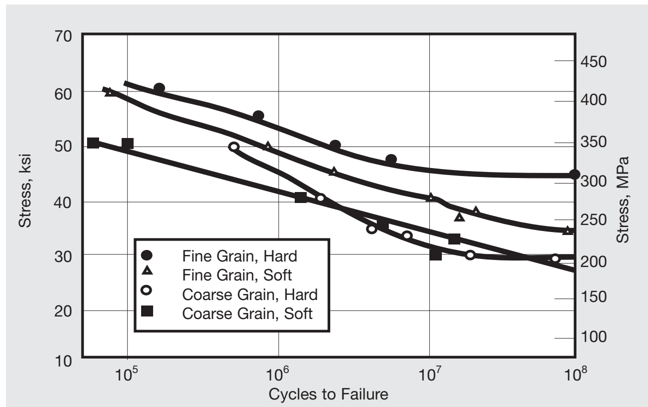

Figure 8. Rotating-beam fatigue strength of forgings in four conditions.

Creep and Rupture Properties

Creep properties of LION alloy 600 in two conditions are shown for temperatures to 2100°F (1150°C) in Table 20. Figure 9 gives creep rates for hot-rolled material at intermediate temperatures.

Rupture properties for material in various conditions are presented in Table 21. The rupture life of hot-rolled material at temperatures of 1000° to 1300°F (540° to 705°C) is shown in Figure 10.

LION alloy 600 does not embrittle after long exposure to high temperatures. The room-temperature mechanical properties of specimens of cold-drawn rod after creep testing are listed in Tables 22 and 23.

Table 19 - Room-Temperature Properties of Material Forged by Four Different Practices

Condition	Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Reduction of Area, %	Hardness, R_b	Grain Size	
	ksi	MPa	ksi	MPa				in.	mm
Fine Grain, Hard	103.0	710	64.6	445	35.0	60.3	93.0	0.0028[a]	0.0711
Fine Grain, Soft	92.0	634	40.5	279	44.0	61.0	83.5	0.0028[a]	0.0711
Coarse Grain, Hard	102.0	703	74.7	515	28.0	56.7	94.0	0.006-0.02[b]	0.152-0.51[b]
Coarse Grain, Soft	86.4	596	32.7	225	61.7	50.7	76.5	0.006-0.02[b]	0.152-0.51[b]

[a]Average diameter.
[b]Mixed grain size.

Table 20 - Creep Properties

Temperature		Stress for a Secondary Creep Rate of:							
		0.01%/1000 hr				0.1%/1000 hr			
		Cold-Drawn, Annealed[a]		Solution-Treated[b]		Cold-Drawn, Annealed[a]		Solution-Treated[b]	
°F	°C	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
800	427	30.00	206.9	-	-	40.00	275.8	-	-
900	482	18.00	124.1	-	-	28.00	193.1	-	-
1000	538	6.10	42.1	-	-	12.50	86.2	-	-
1100	593	3.40	23.4	-	-	6.80	46.9	-	-
1200	649	2.20	15.2	-	-	-	-	-	-
1300	704	1.40	9.7	4.00	27.6	-	-	5.00	34.5
1400	760	0.97	6.7	3.50	24.1	-	-	-	-
1500	816	0.66	4.6	2.80	19.3	-	-	3.20	22.1
1600	871	0.45	3.1	1.70	11.7	0.88	6.1	2.00	13.8
1700	927	-	-	0.81	5.6	-	-	1.10	7.6
1800	982	0.34	2.3	0.35	2.4	0.56	3.9	0.56	3.9
2000	1093	0.16	1.1	0.16	1.1	0.27	1.9	0.27	1.9
2100	1149	0.10	0.7	0.10	0.7	0.17	1.2	0.17	1.2

[a]1750°F (954°C)/3 hr, A.C
[b]2050°F (1121°C)/2 hr, A.C.

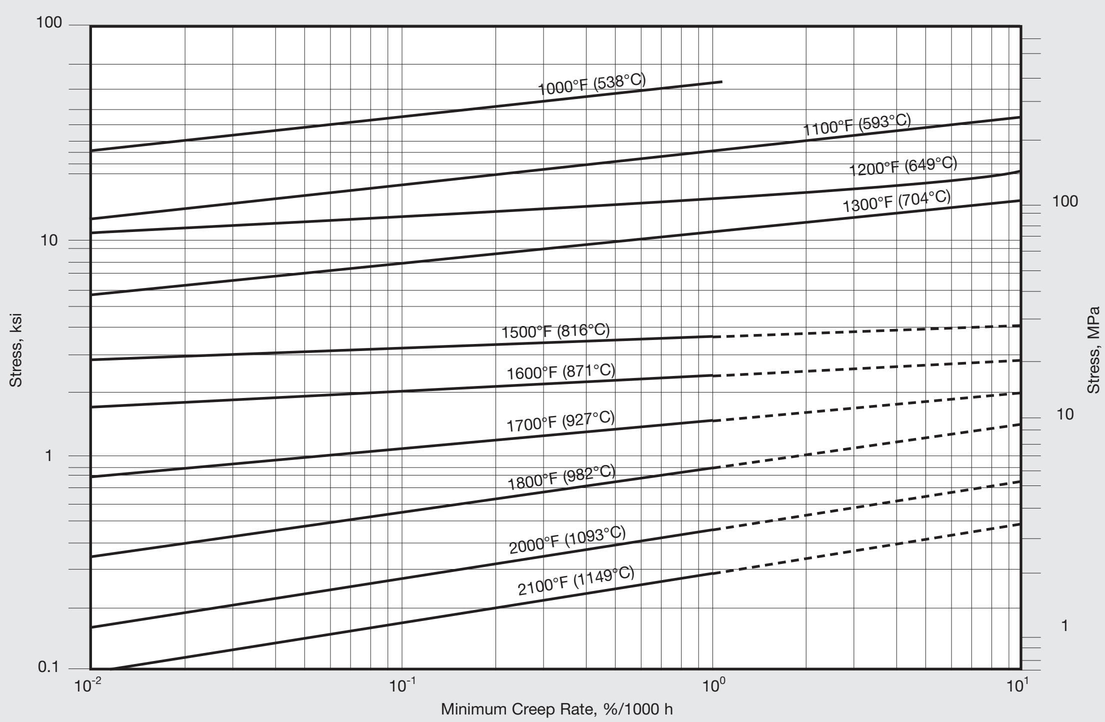

Figure 9. Creep rates of plate in the as-hot-rolled condition (1000°F-1300°F (538°C-704°C) data) and in the hot-rolled and solution-annealed (2050°F (1121°C)/2 h) condition (1500°F-2000°F (816°C-1093°C) data).

Table 21 - Rupture Properties

Temperature		Stress[a] to Produce Rupture in									
		10 hr		100 hr		1,000 hr		10,000 hr		100,000 hr	
°F	°C	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
Cold-Drawn, Annealed at 1750°F (954°C)/3 hr, A.C.											
100	538	74.00	510.2	50.00	344.8	34.00	234.4	**23.00**	**158.6**	**16.00**	**110.3**
1200	649	34.00	234.4	23.00	158.6	14.50	100.0	**9.40**	**64.8**	**6.00**	**41.4**
1400	760	13.00	89.6	8.40	57.9	5.60	38.6	**3.60**	**24.8**	**2.40**	**16.5**
1600	871	7.50	51.7	4.80	33.1	3.00	20.7	**1.90**	**13.1**	**1.20**	**8.3**
1800	982	4.40	30.3	2.80	19.3	1.80	12.4	1.15	7.9	**0.73**	**5.0**
2000	1093	2.10	14.5	1.40	9.7	**0.92**	**6.3**	**0.62**	**4.3**	**0.42**	**2.9**
Hot-Rolled, Annealed at 1650°F (899°C)/2 hr											
1350	732	20.00	137.9	13.50	93.1	9.20	63.4	**6.40**	**44.1**	**4.40**	**30.3**
1600	871	8.10	55.8	5.30	36.5	**3.50**	**24.1**	**2.20**	**15.2**	**1.50**	**10.3**
1800	982	4.40	30.3	2.80	19.3	1.80	12.4	1.15	7.9	**0.73**	**5.0**
2000	1093	2.10	14.5	1.40	9.7	**0.92**	**6.3**	**0.62**	**4.3**	**0.40**	**2.8**
Solution-Treated at 2050°F (1121°C)/2 hr, A.C.											
1350	732	19.00	131.0	14.00	96.5	9.80	67.6	**7.00**	**48.3**	**5.00**	**34.5**
1500	816	11.50	79.3	8.00	55.2	5.60	38.6	**4.00**	**27.6**	**2.80**	**19.3**
1600	871	8.00	55.2	5.30	36.5	**3.50**	**24.1**	**2.30**	**15.9**	**1.50**	**10.3**
1800	982	4.40	30.3	2.80	19.3	1.80	12.4	1.15	7.9	**0.73**	**5.0**
2000	1093	2.10	14.5	1.40	9.7	**0.92**	**6.3**	**0.62**	**4.3**	**0.40**	**2.8**
2100	1149	1.60	11.0	1.10	7.6	-	-	-	-	-	-

[a]Values in bold are extrapolated.

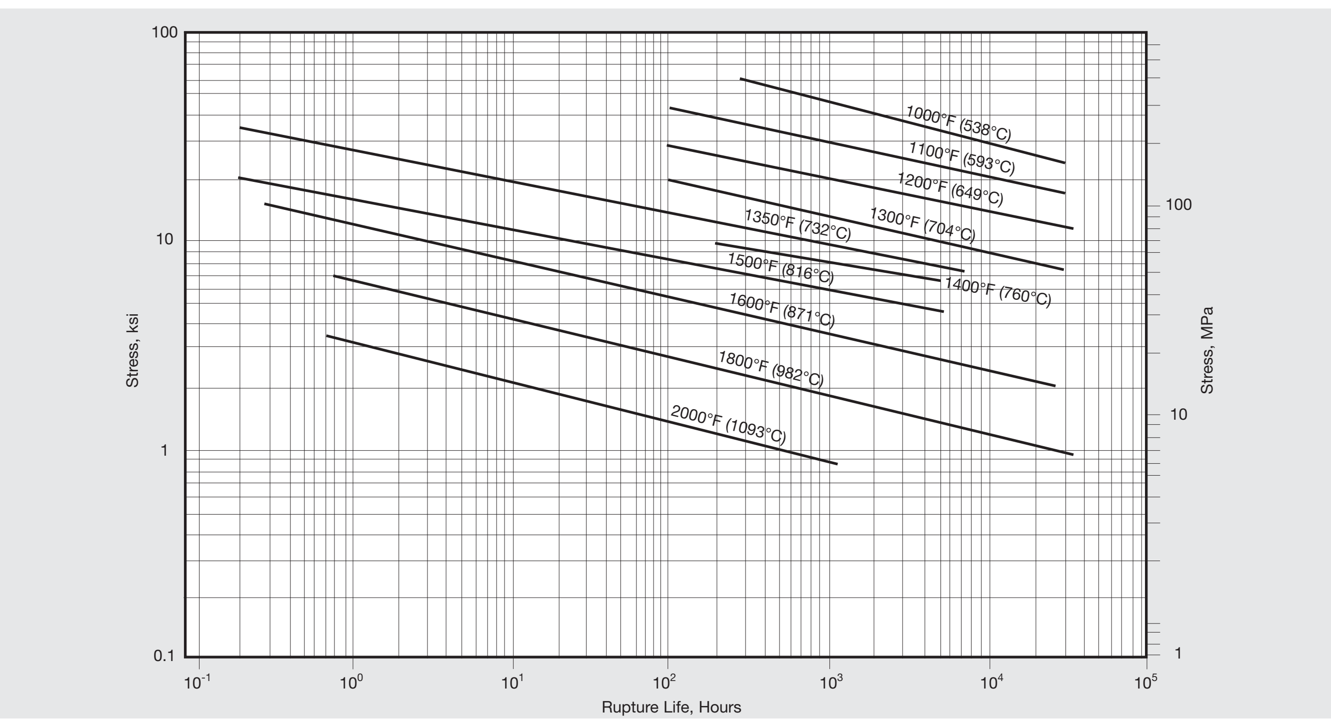

Figure 10. Rupture life of plate in the as-hot-rolled condition (1000°F-1300°F (538°C-704°C) data) and in the hot-rolled and solution-annealed (2050°F (1121°C)/2h) condition (1350°F-2000°F (732°C-1093°C) data).

Table 22 - Room-Temperature Mechanical Properties of Creep-Test Specimens[a]

Conditions of Creep Test					Room-Temperature Properties						
Temperature		Stress		Duration, hr	Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Reduction of Area, %	Hardness, R_b
°F	°C	ksi	MPa		ksi	MPa	ksi	MPa			
80	27	0	0	0	97.30	670.9	35.60	245.5	41	66	79
800	427	50.00	344.8	1945	101.00	696.4	60.30	415.8	40	65	90
800	427	30.00	206.9	1874	96.80	667.4	40.80	281.3	43	64	80
900	482	40.00	275.8	1508	98.00	675.7	57.80	398.5	46	66	90
900	482	30.00	206.9	1900	96.50	665.4	39.40	271.7	44	67	80
900	482	20.00	137.9	1969	96.30	664.0	39.40	271.7	45	65	80
1000	538	20.00	137.9	264	96.60	666.1	40.80	281.3	44	64	80
1000	538	15.00	103.4	2159	95.50	658.5	36.60	252.4	43	65	80
1000	538	10.00	69.0	1942	93.70	646.1	36.70	253.0	44	65	80
1100	593	10.00	69.0	576	98.20	677.1	40.40	278.6	43	65	80
1100	593	5.00	34.5	1602	94.50	651.6	35.10	242.0	43	65	80
1100	593	2.50	17.2	2205	96.60	666.1	35.80	246.8	42	65	80

[a]Cold-drawn rod, annealed 1750°F (954°C)/3 hr, A.C.

Table 23 - Room-Temperature Impact Strength of Creep-Test Specimens[a]

Conditions of Creep Test					Room-Temperature Properties		
Temperature		Stress		Duration, hr	Modified[b] Izod Impact Strength		Hardness, R_b
°F	°C	ksi	MPa		ft•lb	J	
80	27	0	0	0	94-95	127-129	79
800	427	40	275.8	1861	76-78	103-106	80
900	482	30	206.9	1617	90-96	122-130	80
900	482	15	103.4	1876	97-98	132-133	80
1000	538	20	137.9	582	85	115	80
1000	538	5	34.5	2022	87-89	118-121	80
1100	593	5	34.5	1850	101-109	137-148	80

[a]Cold-drawn rod, annealed 1750°F (954°C)/3 hr, A.C.
[b]See text.

Corrosion Resistance

The composition of LION alloy 600 enables it to resist a variety of corrosives. The chromium content of the alloy makes it superior to commercially pure nickel under oxidizing conditions, and its high nickel content enables it to retain considerable resistance under reducing conditions. The nickel content also provides excellent resistance to alkaline solutions.

The alloy has fair resistance to strongly oxidizing acid solutions. However, the oxidizing effect of dissolved air alone is not sufficient to insure complete passivity and freedom from attack by air-saturated mineral acids and certain concentrated organic acids.

Stress-Corrosion Cracking

Austenitic chromium-nickel stainless steels sometimes fail catastrophically by stress-corrosion cracking. This type of failure is generally associated with an environment containing chlorides as well as with stress, water, dissolved oxygen, and other factors. The tendency of austenitic alloys to crack transgranularly in chloride solutions decreases as the nickel content of the alloy is increased. LION alloy 600, with a minimum nickel content of 72%, is virtually immune to chloride-ion stress-corrosion cracking.

LION alloy 600 is subject to stress-corrosion cracking in high-temperature, high-strength caustic alkalies. Material for such service should be fully stress-relieved at 1650°F/1 hr or 1450°F/4 hr (900°C/1 hr or 790°C/4 hr) prior to use, and operating stresses should be kept to a minimum.

Stress-corrosion cracking may occur also in the presence of mercury at elevated temperatures. The recommendations given for caustic-alkali service should be followed if the alloy is used in an application which involves contact with mercury at high temperatures.

Microstructure

LION alloy 600 is a stable, austenitic solid-solution alloy. The only precipitated phases present in the microstructure are titanium nitrides, titanium carbides (or solutions of those two compounds commonly called cyanonitrides), and chromium carbides.

Titanium nitrides and carbides are visible in polished microspecimens at magnifications of 50X or greater. They appear as small, randomly dispersed, angular-shaped inclusions. The color varies from orange-yellow for the nitride to gray-lavender for the carbide. These nitrides and cyanonitrides are stable at all temperatures below the melting point and are unaffected by heat treatment.

At temperatures between 1000° and 1800°F (540° and 980°C), chromium carbides precipitate out of the solid solution. Precipitation occurs both at the grain boundaries and in the matrix. Because of the grain-boundary precipitation, the corrosion behavior of LION alloy 600 is similar to that of other austenitic alloys in that the material can be made susceptible to intergranular attack in some aggressive media (sensitized) by exposure to temperatures of 1000° to 1400°F (540° to 760°C). At temperatures above 1400°F (760°C) the predominant carbide is Cr_7C_3. Below 1400°F (760°C) the $Cr_{23}C_6$ carbide is also present.

High-Temperature Applications

LION alloy 600 is widely used in the furnace and heat-treating fields for retorts, boxes, muffles, wire belts, roller hearths, and similar parts which require resistance to oxidation and to furnace atmospheres. The alloy is the standard material for nitriding containers because of its resistance to nitrogen at high temperatures.

The alloy's resistance to oxidation and scaling at 1800°F (980°C) is shown in Figure 11. The weight-loss determinations used to obtain the curves in Figure 11 indicate the ability of a material to retain a protective oxide coating under conditions of cyclic exposure to the temperature.

LION alloy 600 has good resistance to carburization. Table 24 gives the results of tests in high-temperature carburizing atmospheres.

LION alloy 600 resists attack by sulfur compounds at moderate temperatures, but it is subject to sulfidation in high-temperature, sulfur-containing environments. Molybdenum disulfide, a lubricant sometimes used to aid parts assembly, should not be used if the material will be subsequently exposed to temperatures above 800°F (427°C).

Table 24 - Gas Carburization Tests (100 h) in Hydrogen/2% Methane

Alloy	Weight Gain, mg/cm^2	
	1700°F (925°C)	2000°F (1095°C)[a]
LION alloy 600	2.66	12.30
LION alloy 601	2.72	16.18
LION alloy 800HT	4.94	21.58
Type 330 Stainless Steel	6.42	24.00

[a]Atmosphere also contained 5% argon.

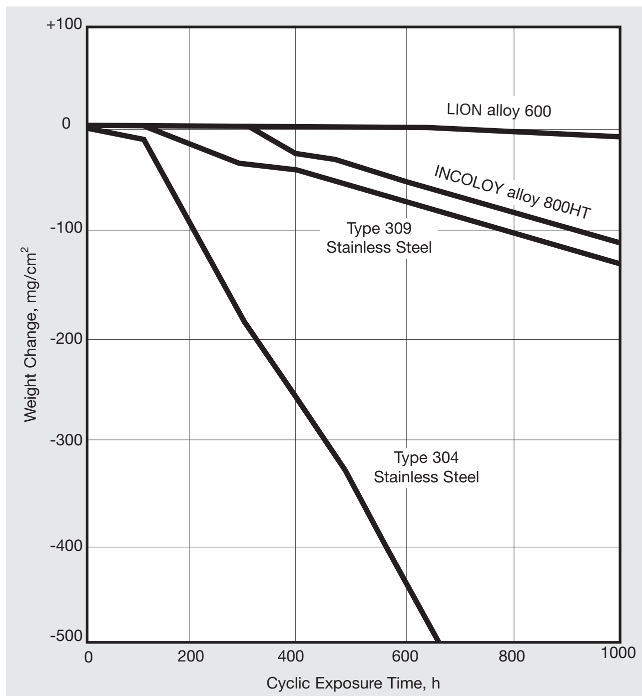

Figure 11. Results of cyclic oxidation tests at 1800°F (980°C). Cycles were 15 minutes of heating and 5 minutes of cooling in air.

Working Instructions

LION alloy 600 is readily fabricated by either hot or cold working and can be joined by standard welding, brazing, and soldering processes. Although the alloy can be hardened and strengthened only by cold work, a wide range of mechanical properties can be obtained in finished parts by combining cold work and thermal treatments.

Heat Treatment

The behavior of the alloy during heating is governed by a number of interacting variables: amount of cold work, grain size, chemical composition, and dimensions of the material. Consequently, times and temperatures for heat treatment are usually experimentally determined.

In general, an annealing treatment of about 1850°F/15 min (1010°C/15 min) will produce soft material. Brief exposure to 1900°F (1040°C) will give soft material without producing a coarse grain structure. Grain growth does not occur until the alloy is heated to about 1800°F (980°C). At that temperature, the finely dispersed carbide particles in the alloy’s microstructure, which inhibit grain growth, begin to coalesce. Solution of the carbides begins at about 1900°F (1040°C). Treatment for 1 to 2 hr at 2000° to 2100°F (1090° to 1150°C) dissolves the carbides completely and results in increased grain size. This solution treatment is beneficial in obtaining maximum creep and rupture strength.

In general, material with a fine grain structure is preferred because it has better corrosion resistance and higher tensile, fatigue and impact strength. Fine-grain material is preferred for all low-temperature applications, most intermediate temperature applications, and those high-temperature applications which require resistance to shock and corrosion.

Grain size is dependent on processing. Hot-rolled products will usually have a small grain size because they are finished at relatively low temperatures. Annealing has little effect on the grain size of hot-rolled material. Cold-drawn or cold-rolled material, in either the cold-worked or annealed condition, will have a small grain size. Solution treatment will produce a coarse grain structure in either hot-worked or cold-worked material.

The time and temperatures required for recrystallization of cold-worked material vary widely, depending on the amount of cold work and the specific composition. Table 25 shows times and temperatures required for recrystallization of fine-grain sheet after various amounts of cold reduction.

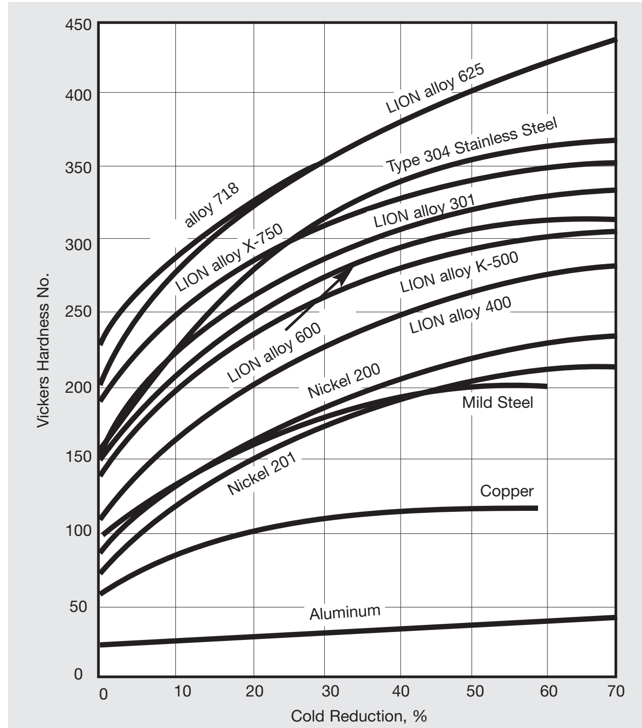

Figure 12. Work-hardening rates of LION alloy 600 and other metals.

Heating and Pickling

LION alloy 600, like all nickel-base alloys, must be clean before it is heated and must be heated in a sulfur-free atmosphere. Furnace atmosphere for forging or open annealing should be slightly reducing to prevent excessive oxidation.

The rate of cooling after heating has little effect on the mechanical properties of LION alloy 600. However, the alloy is subject to carbide precipitation in the 1000° to 1400°F (540 to 760°C) temperature range and should be rapidly cooled through that range if the material is to be pickled or used in an environment requiring freedom from sensitization.

The alloy can be bright-heated only in very dry hydrogen or in a vacuum and usually must be pickled if a bright surface is required.

Hot and Cold Forming

The normal hot-working temperature range for LION alloy 600 is 1600° to 2250°F (870° to 1230°C). Heavy hot work should be done between 1900° and 2250°F (1040° and 1230°C); light work can be continued down to 1600°F (870°C). The alloy has low ductility at temperatures between 1200° and 1600°F (650° and 870°C) and should not be worked in that range. High tensile properties can be developed in the material by careful working at temperatures below 1200°F (650°C).

LION alloy 600 is cold-formed by the standard processes used for steel and stainless steel. The rate of work hardening, as shown by Figure 12 is greater than that of mild steel but less than the rate of Type 304 stainless steel.

Table 25 - Effect of Cold Work on Recrystallization Temperature of Cold-Rolled, Fine-Grain Sheet

Cold Reduction, %	Temperature Required for Recrystalization in							
	15 min		30 min		60 min		120 min	
	°F	°C	°F	°C	°F	°C	°F	°C
5	1775	968	1750	954	1700	927	1700	927
10	1650	899	1600	871	1550	843	1550	843
20	1525	829	1475	802	1425	774	1425	774
50	1350	732	1325	718	1275	691	1275	691
80	1250	677	1225	663	1200	649	1200	649

Machining

LION alloy 600 is slightly more machinable than Type 304 stainless steel and slightly less machinable than Type 303 free-machining stainless steel.

The alloy is best handled on heavy-duty equipment using cutting tools large and heavy enough to withstand the loads and to quickly dissipate the heat generated. Tools must be sharp and have the proper geometry.

Welding

LION alloy 600 is readily joined by conventional welding processes. Welding materials for joining alloy 600 are LION Welding Electrode 182 for shielded metal-arc welding*, LIONFiller Metal 82 for gas tungsten-arc and gas metal-arc welding, and LIONFiller Metal 82 and LION 4 Submerged Arc Flux for the submerged-arc process.

Table 26 compares thermal-expansion rates of weld metals with those of wrought alloy 600. Impact-strength values for all-weld-metal deposits of LIONWelding Electrode 182 are listed in Table 27.

Room-temperature tensile properties of welds made with LIONFiller Metal 82 and Welding Electrode 182 are given in Table 28. High-temperature tensile properties of welds made with those materials are shown in Figures 13 and 14. Stress-rupture properties of weld metals are given in Table 29.

Welds made with LIONWelding Electrode 182 may have decreased ductility after extended exposure to temperatures of 1000° to 1400°F (540° to 760°).

*For maximum stress-rupture properties in shielded metal-arc welds at temperatures above 1200°F (650°C), LION-WELD A Electrode is recommended.

Table 26 - Thermal Expansion of Weld Metals

Material	Mean Linear Expansion[a]									
	10^{-6} in/in-°F					µm/m-°C				
	200°F	300°F	400°F	500°F	600°F	93°C	149°C	204°C	260°C	316°C
LION alloy 600	7.4	-	7.7	-	7.9	13.3	-	13.9	-	14.2
LION Filler Metal 82	6.7	7.2	7.6	7.8	7.9	12.1	13.0	13.7	14.0	14.2
LION Welding Electrode 182	7.6	8.0	8.1	8.2	8.3	13.7	14.4	14.6	14.8	14.9

[a]From 70°F (21°C) to temperature shown.

Table 27 - Impact Strength (Charpy Keyhole) of LIONWelding Electrode 182 Deposited Weld Metal

Temperature		Impact Strength[a]	
°F	°C	ft•lb	J
70	21	48.8	66.2
-110	-79	46.5	63.0
-320	-196	42.2	57.2

[a]Values at 70°F (21°C) and -110°F (-79°C) are the average of three tests; value at -320°F (-196°C) is the average of two tests.

Table 28 - Room-Temperature Tensile Properties of All-Weld-Metal Deposits

Welding Material	Tensile Strength		Yield Strength (0.2% Offset)		Elongation in 1.25 in. (31.75 mm), %
	ksi	MPa	ksi	MPa	
LIONFiller Metal 82 [a]	96.20	663.3	57.10	393.7	45
LIONWelding Electrode 182 [a]	92.40	637.1	55.10	379.9	44
LIONWelding Electrode 182 [b]	98.80	681.2	61.40	423.4	40

[a]0.505-in. (12.83 mm)-dia. specimen.
[b]0.252-in. (6.40-mm)-dia. specimen.

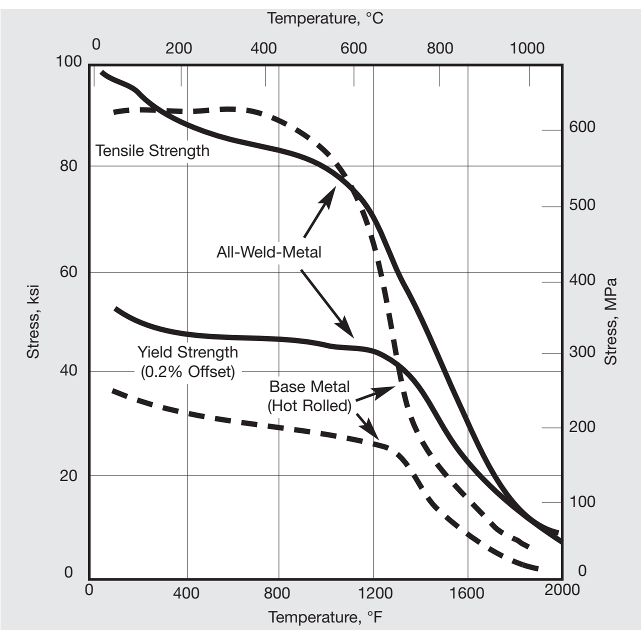

Figure 13. High-temperature tensile properties of welds made with LION FIller Metal 82.

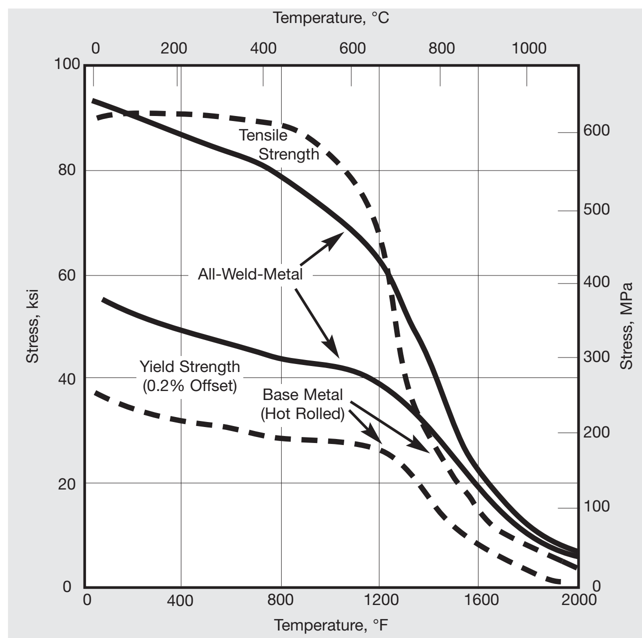

Figure 14. High-temperature tensile properties of welds made with LION Welding Electrode 182.

Table 29 - Rupture Strength of All-Weld-Metal Deposits

Welding Material	Temperature		Stress[a] to Produce Rupture in					
			100 hr		1000 hr		10,000 hr	
	°F	°C	ksi	MPa	ksi	MPa	ksi	MPa
LION Filler Metal 82	1000	538	58.00	399.9	**52.00**	**358.5**	**47.00**	**324.1**
	1200	649	36.50	251.7	27.50	189.6	**20.50**	**141.3**
	1400	760	16.00	110.3	11.50	79.3	**8.30**	**57.2**
	1600	871	6.80	46.9	3.50	24.1	**1.75**	**12.1**
	1800	982	2.70	18.6	1.25	8.6	**0.57**	**3.9**
LION Welding Electrode 182	1000	538	53.00	365.4	50.00	344.8	**41.00**	**282.7**
	1200	649	34.00	234.4	22.50	155.1	**14.50**	**100.0**
	1350	732	13.50	93.1	8.20	56.5	4.90	33.8
	1500	816	7.00	48.3	4.00	27.6	2.25	15.5
	1600	871	4.00	27.6	2.15	14.8	1.15	7.9
	1800	982	1.70	11.7	0.82	5.7	**0.41**	**2.8**
LION-WELD A Electrode	1000	538	60.00	413.7	51.00	351.6	**39.00**	**268.9**
	1200	649	35.00	241.3	24.50	168.9	**16.00**	**110.3**
	1400	760	16.50	113.8	11.00	75.8	**7.10**	**48.9**
	1600	871	7.00	48.3	3.65	25.2	**1.90**	**13.1**
	1800	982	2.30	15.9	0.90	6.2	-	-

[a]Values in bold are extrapolated.

Available products and specifications

LION alloy 600 is designated as UNS N06600 and Werkstoff Number 2.4816. The alloy is approved under the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers. It is approved under Section I (Power Boilers), Section III (Nuclear Vessels), and Section VIII (Pressure Vessels). Allowable design stresses are found in Section II, Part D. Section I coverage is provided by Code Case 1827.

Standard product forms are pipe, tube, sheet, strip, plate, round bar, flat bar, forging stock, hexagon, wire and extruded section. The products are available in a wide range of sizes. Full information is available from the offices listed on the back cover.

Rod, Bar, Wire and Forging Stock - ASTM B 166/ASME SB 166, ASTM B 564/ASME SB 564, ASME Code Cases 1827 and N-253, SAE/AMS 5665 and 5687, BS 3075NA14 and 3076NA14, DIN 17752, 17753 and 17754, ISO 9723, 9724, and 9725, MIL-DTL-23229, QQ-W-390.

Plate, Sheet and Strip - ASTM B 168/ASME SB 168, ASTM B 906/ASME SB 906, ASME Code Cases 1827 and N-253, SAE/AMS 5540, BS 3072NA14 and 3073NA14, DIN 17750, ISO 6208, EN 10095, MIL-DTL-23228.

Pipe and Tube - ASTM B 167/ASME SB 167, ASTM B 163/ASME SB 163, ASTM B 516/ASME SB 516, ASTM B 517/ASME SB 517, ASTM B 751/ASME SB 751, ASTM B 775/ASME SB 775, ASTM B 829/ASME SB 829, ASME Code Cases 1827, N-20, N-253, and N-576, SAE/AMS 5580, DIN 17751, ISO 6207, MIL-DTL-23227

Other - ASTM B 366/ASME SB 366, DIN 17742, ISO 4955A, AFNOR NC15Fe