LION® nickel-chromium-iron alloy 601 (UNS N06601/W.Nr. 2.4851) is a general-purpose engineeringmaterial for applications that requi and corrosion. resistance to heat An outstanding characteristic of LION alloy 601 is its resistance to high-temperature oxidation. The alloy also has good resistance to aqueous corrosion, has high mechanical strength, and is readily formed, machined and welded. The limiting chemical composition of LION alloy 601 is listed in Table 1. The composition is a face-centered-cubic solid solution with a high degree of metallurgical stability. The alloy's nickel base, in conjunction with substantial chromium content, provides resistance to many corrosive media and high-temperature environments. Oxidation resistance is further enhanced by the aluminum content.

The properties of LION alloy 601 make it a material of broad utility in such fields as thermal processing, chemical processing, pollution control, aerospace, and power generation.

Alloy 601 is a standard material of construction for various types of thermal-processing equipment. Industrial-heating applications include baskets, trays, and fixtures for annealing, carburizing, carbonitriding, nitriding and other heat-treating operations. In industrial furnaces, the alloy is used for radiant tubes, muffles, retorts, flame shields, strand-annealing tubes, woven-wire conveyor belts, chain curtains, burner nozzles, and electrical resistance heating elements. Other thermal-processing applications are thermocouple protection tubes, furnace-atmosphere generators, and infrared radiant screens.

Chemical-processing applications for alloy 601 include process heaters, condenser tubes in sour-water strippers, and insulating cans in ammonia reformers. The alloy is also used for combustor components and catalyst grid supports in equipment for nitric acid production.

In petrochemical processing, the alloy is used for catalyst regenerators and air preheaters in the manufacture of high-density polyethylene.

In pollution-control applications, LION alloy 601 is used for thermal reactors in exhaust systems of gasoline engines and for combustion chambers in solid-waste incinerators.

In the power-generation field, alloy 601 is used for superheater tube supports, grid barriers, and ash-handling systems.

The alloy is also used for jet-engine igniters and for combustion-can liners, diffuser assembles, and containment rings in gas turbines for aircraft, industrial, and vehicular applications.

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

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

Physical Constants and Thermal Properties

Some physical constants for LION alloy 601 are listed in Table 2. Thermal and electrical properties at room and elevated temperatures are given in Table 3. Values shown for thermal conductivity were calculated from measurements of electrical resistivity. Specific-heat values were calculated from chemical composition.

Thermal-expansion coefficients were determined on a Leitz dilatometer; values were corrected for expansion of the quartz specimen holder. Each coefficient listed is the average coefficient over the indicated temperature range.

The effect of temperature on the modulus of elasticity of alloy 601 is shown in Table 4. The data were obtained by the dynamic method. The values listed for Poisson's ratio were calculated from moduli of elasticity.

All data reported for physical constants and thermal properties were determined for annealed material.

Table 2 - Physical Constants

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

LION® alloy 601

Mechanical Properties

LION alloy 601 has good mechanical strength. Nominal mechanical-property ranges for various products are shown in Table 5. As indicated by those values, the strength level exhibited by the alloy varies with the form and condition of the material.

The optimum condition for alloy 601 depends on the type of application and the service temperature involved. In general, the solution-treated condition is used for rupture-limited applications (temperatures of about 1000°F (540°C) and higher). The annealed condition is normally used for tensile-limited applications (temperatures below about 1000°F (540°C)).

Tensile Properties

LION alloy 601 has high tensile properties at room temperature and retains much of its strength at elevated temperatures.

Typical room-temperature tensile properties of annealed material are listed in Table 6. Values are shown for both hot-finished and cold-rolled material annealed at different temperatures.

Table 3 - Thermal Properties of LION alloy 601

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

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

Table 4 - Modulus of Elasticity

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

[a]Calculated from modulus of elasticity.

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

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

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

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

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

[a]Annealing time varied with section size.

Room-temperature tensile properties of rod and bar in the hot-finished condition are given in Table 7. The tests were performed on longitudinal specimens from midway between the center and surface of the piece.
Table 8 gives room-temperature properties of various product forms in the solution-treated condition.

Tensile properties of hot-finished rod annealed at 2000°F (1090°C) are given for temperatures to 1000°F (540°C) in Table 9. The test specimens were from 0.625-in. (16-mm) rod having a room-temperature hardness of 80 Rb.

High-temperature properties of solution-treated (2100°F) (1150°C) material are shown in Figure 1. The tests were performed on specimens from 0.625-in. (16-mm) diameter rod. Room-temperature hardness of the material was 81 Rb.

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

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

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

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

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

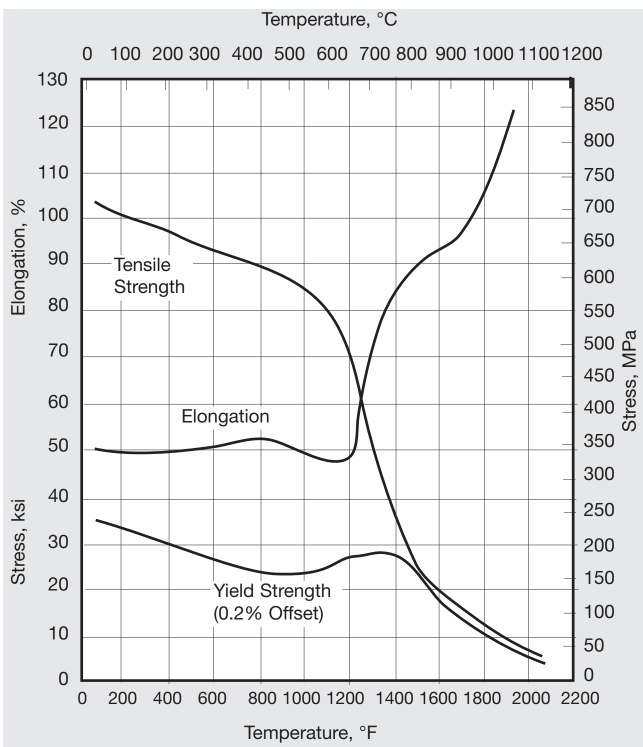

Figure 1. High-temperature tensile properties of solution-treated (2100°F) (1150°C) hot-finished rod.

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

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

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

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

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

Impact Strength

LION alloy 601 is not embrittled by extended exposure to high temperatures. Table 10 shows the impact strength of the alloy after long-time exposure to temperatures from 1000 to 1600°F (540 to 870°C). The specimens retained relatively high impact strengths even after 1000 hr of exposure. The material tested was solution-treated 0.625-in. (16-mm) diameter hot-finished rod.

The results of Charpy V-notch impact tests on hot-finished rod in the annealed and solution-treated conditions are given in Table 11. Tensile properties of the material tested are also shown.

Table 11 - Impact Strength of Hot-Finished Rod

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

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

Fatigue Strength

The rotating-beam fatigue strength of LION alloy 601 in two conditions is shown in Figure 2. As indicated by the curves, annealed material has higher fatigue strength than solution-treated material.

The data for annealed material in Figure 2 were determined on 0.500-in. (13-mm) diameter hot-finished rod given an annealing treatment of 1800°F (980°C)/1 hr, A.C. The material had a hardness of 89 Rb, a grain size of ASTM 8, and the following tensile properties:

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

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

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

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

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

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

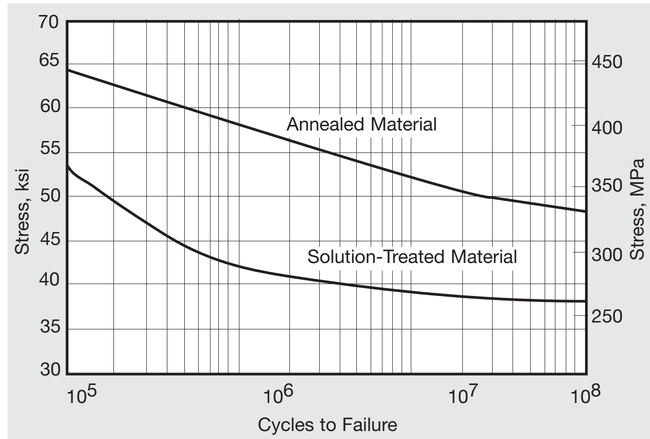

Figure 2. Rotating-beam fatigue strength at room temperature.

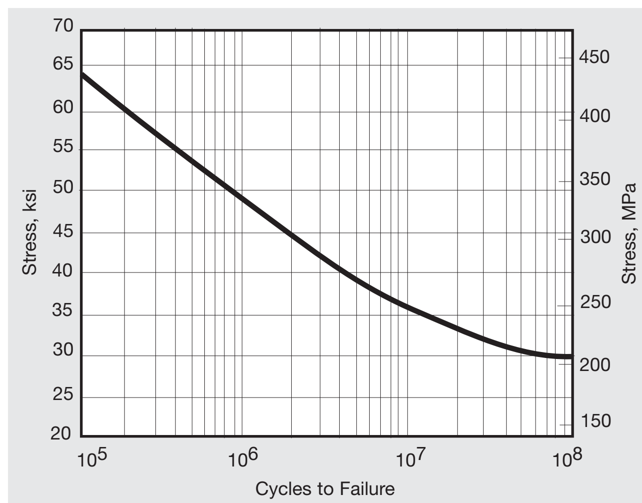

Figure 3. Room-temperature fatigue strength of annealed (1900°F) (1040°C) cold-rolled sheet.

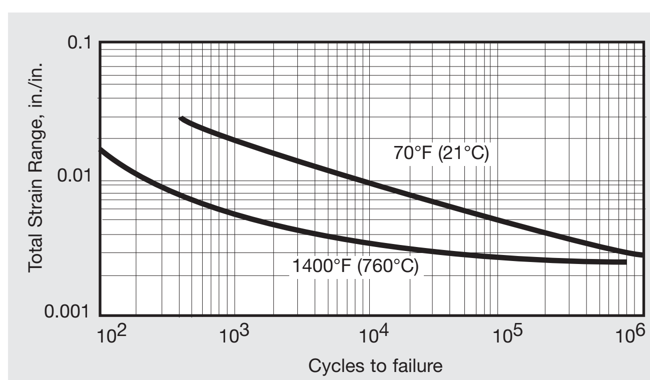

Figure 4. Low-cycle fatigue strength of LION alloy 601.

Creep and Rupture Properties

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

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

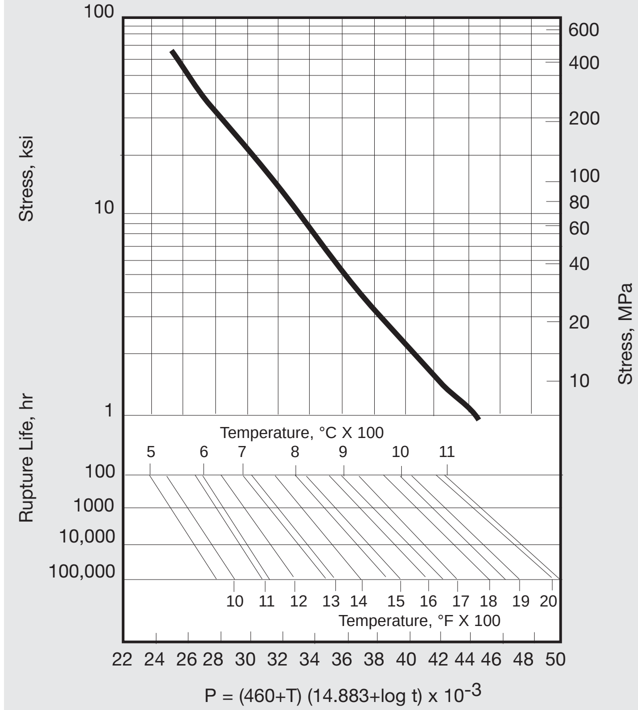

Figure 5. Larson-Miller parameter plot of rupture strength of solution-treated (2100°F) (1150°C) LION alloy 601. In the parameter, T is temperature in °F, and t is time in hours.

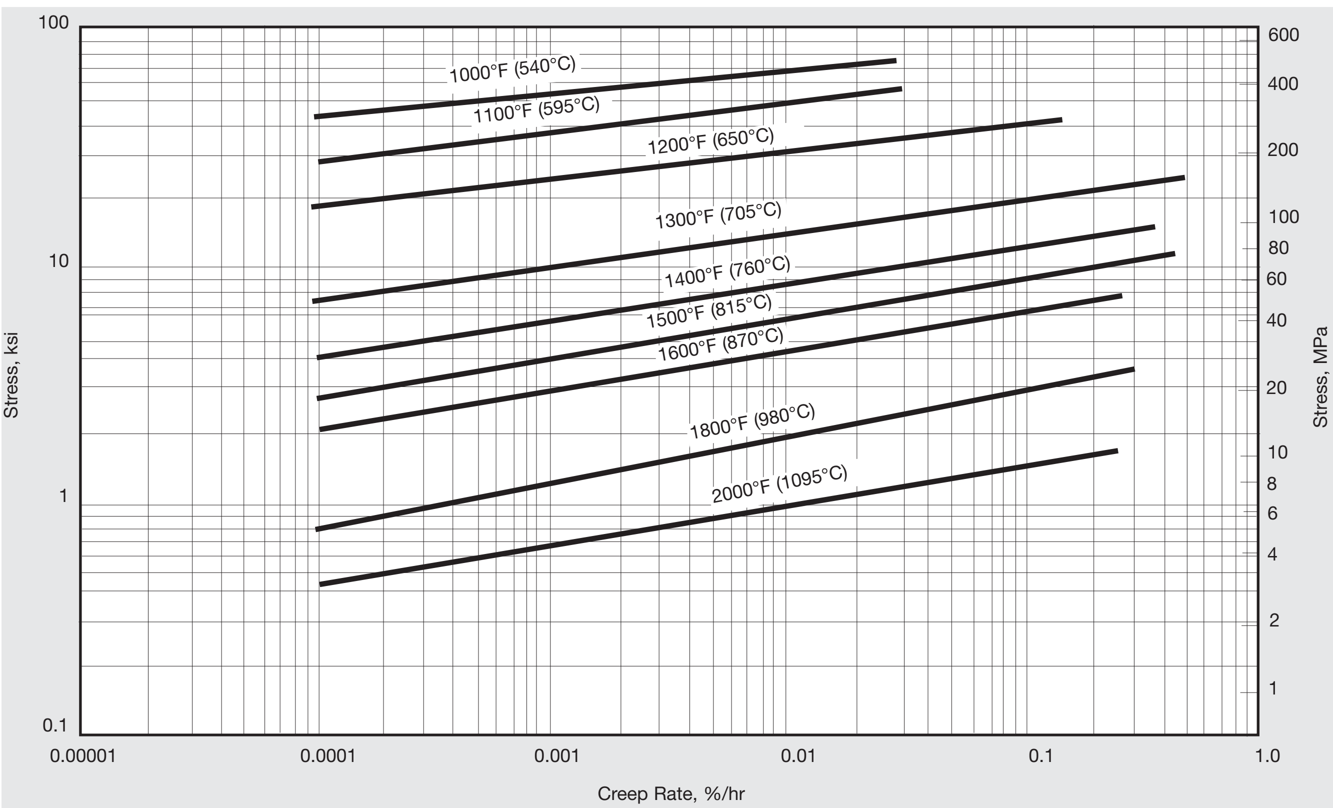

Figure 6. Typical creep strength of solution-treated (2100°F) (1150°C) LION alloy 601.

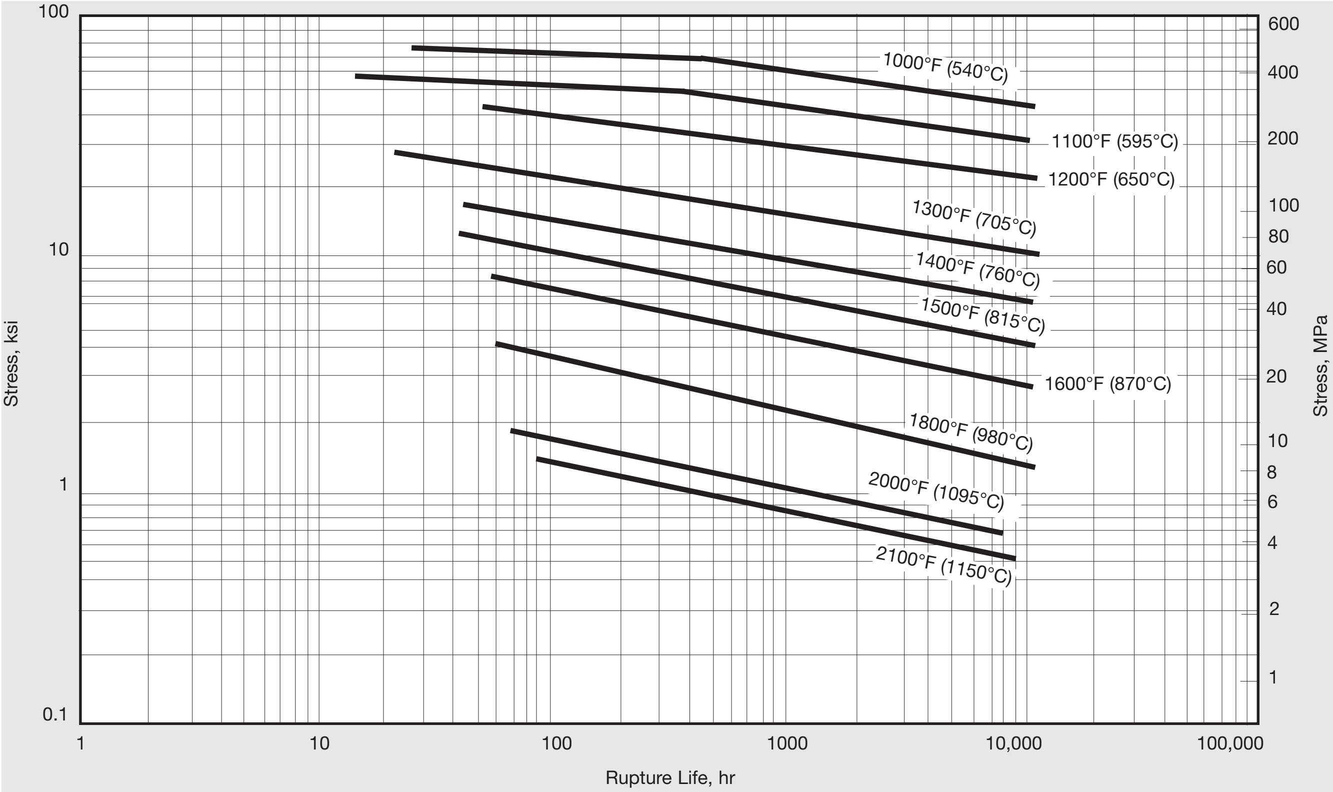

Figure 7. Typical rupture strength of solution-treated (2100°F) (1150°C) LION alloy 601.

Microstructure

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

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

Corrosion Resistance

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

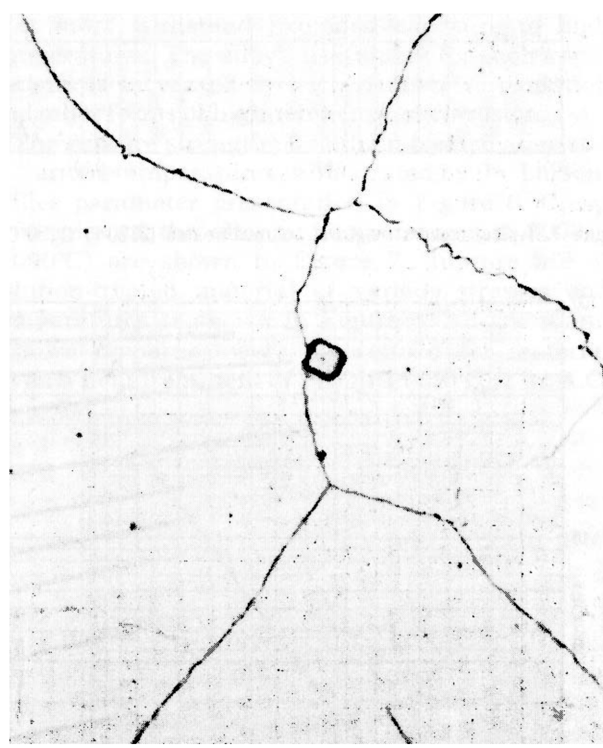

Figure 8. Typical microstructure of solution-treated hot-finished rod. 500X. Etchant: 5% Nital electrolytic.

Oxidation

LION alloy 601 has exceptional resistance to oxidation at high temperatures. The alloy forms a protective oxide coating that resists scaling even under the severe conditions of cyclic exposure to temperature.

Figure 9 compares the performance of LION alloy 601 with the behavior of other oxidation-resistant materials in a cyclic oxidation test at 2000°F (1095°C). The specimens were subjected to cycles of exposure to 2000°F(1095°C) for 15 min and rapid cooling in air for 5 min. Weight change was determined periodically throughout the test.

The resistance of alloy 601 to oxidation at temperatures of 2100°F (1150°C) and 2200°F (1200°C) is illustrated in Figures 10 and 11. The data were derived from tests in which the specimens were exposed to temperature for ten consecutive 50-hr periods. After each exposure period, the specimens were cooled to room temperature, brushed lightly to remove loose oxide, and then weighed to determine weight change.

The superior oxidation resistance of LION alloy 601 is related to the amounts of nickel, chromium, and aluminum in the alloy. During high-temperature exposure, those elements form an extremely protective and adherent oxide film on the surface of the material. In addition, a slight amount of internal oxidation occurs and provides a higher chromium content in the surface oxide. The protective oxide layer is illustrated in Figures 12 and 13, which are unetched photomicrographs of the cross-sections of specimens exposed to high temperatures.

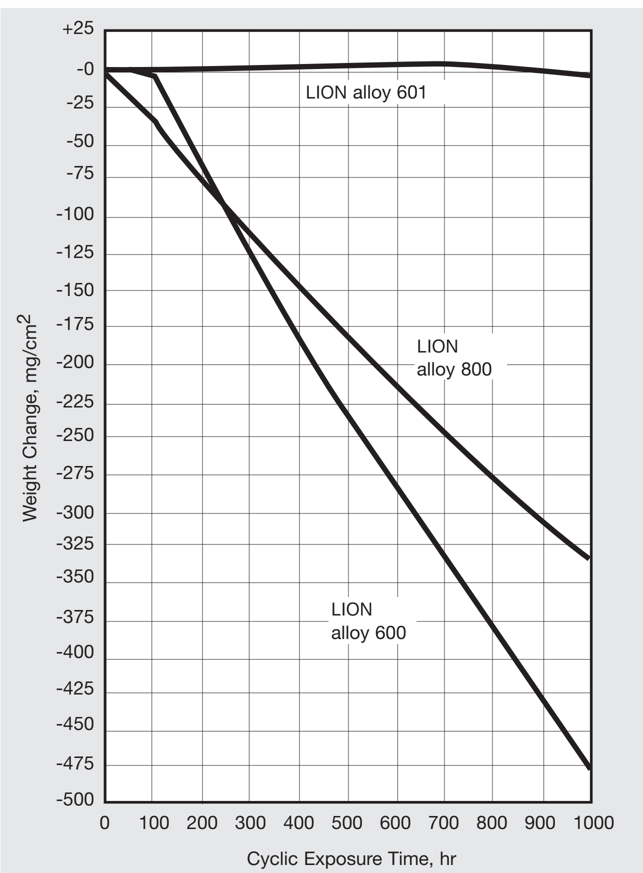

Figure 9. Results of cyclic oxidation tests at 2000°F (1095°C). Cycles consisted of 15 min heating and 5 min cooling in air.

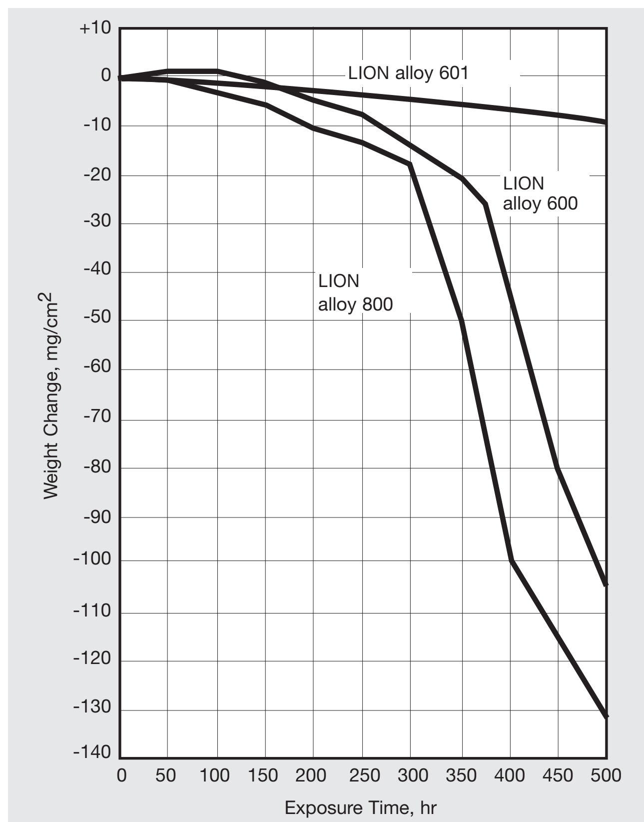

Figure 10. Results of oxidation tests at 2100°F (1150°C). Test cycles consisted of 50 hr at exposure temperature followed by air-cooling to room temperature.

Carburization

LION alloy 601 has good resistance to carburization. Tables 13 and 14 give the results of gas carburization tests performed at three different temperatures. The weight-gain measurements indicate the amount of carbon absorbed by the specimens during the exposure periods.

Alloy 601 also has good resistance to carbonitriding environments. Table 15 gives the results of tests performed in a gas mixture of 5% ammonia, 2% methane, and 93% hydrogen at 2000°F (1095°C).

Sulfidation

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

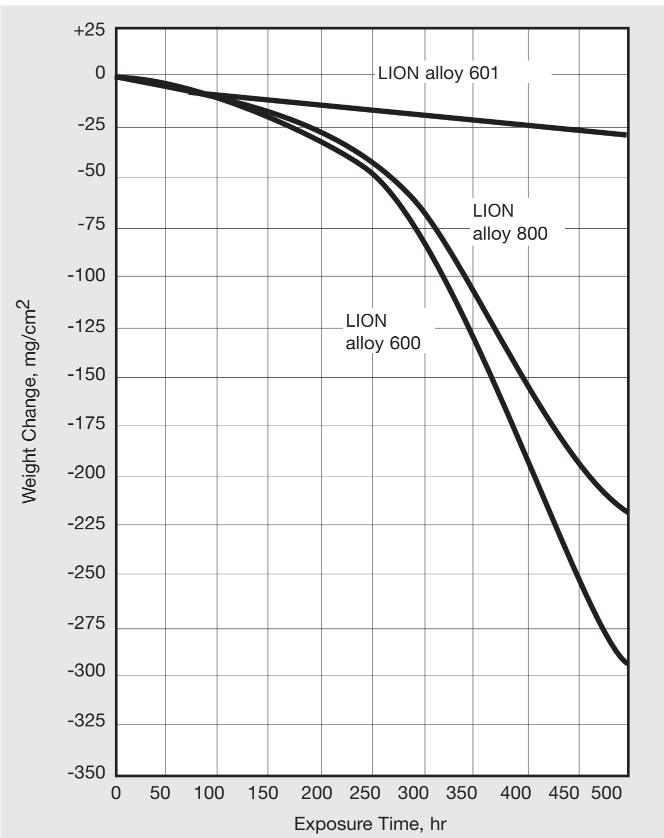

Figure 11. Results of oxidation tests at 2200°F (1205°C). Test cycles consisted of 50 hr at exposure temperature followed by air-cooling to room temperature.

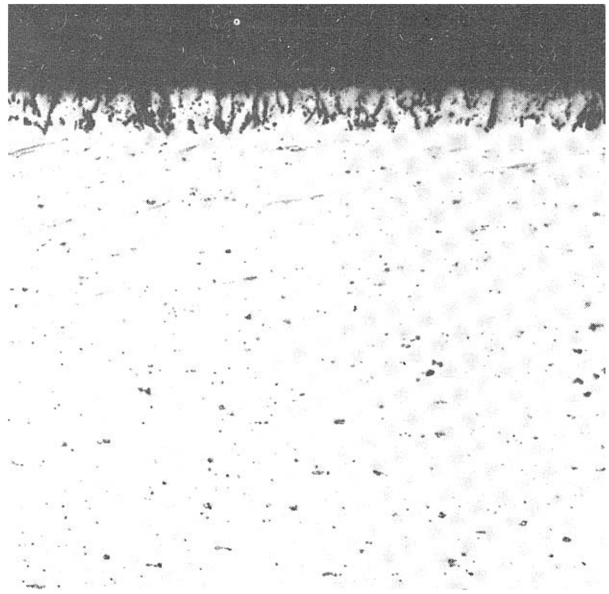

Figure 12. Oxide layer on specimen exposed to 2100°F (1150°C) for 500 hr. 75X. Unetched.

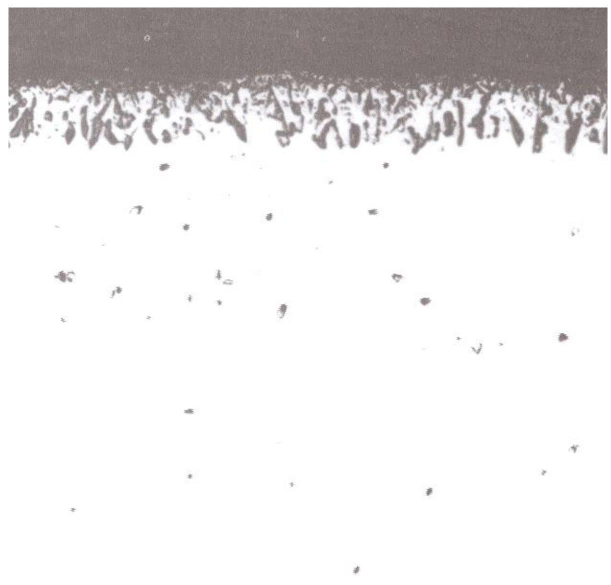

Figure 13. Oxide layer on specimen exposed to 2200°F (1205°C) for 500 hr. 75X. Unetched.

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

Alloy	Weight Gain in 100 hr, mg/cm²	
	1700°F (925°C)	1800°F (980°C)
LION alloy 600	2.66	-
LION alloy 601	2.72	4.32
LION alloy 800	4.94	11.6

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

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

Alloy	Weight Gain in 25 hr, mg/cm²
LION alloy 600	2.78
LION alloy 601	3.67
LION alloy 800	5.33

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

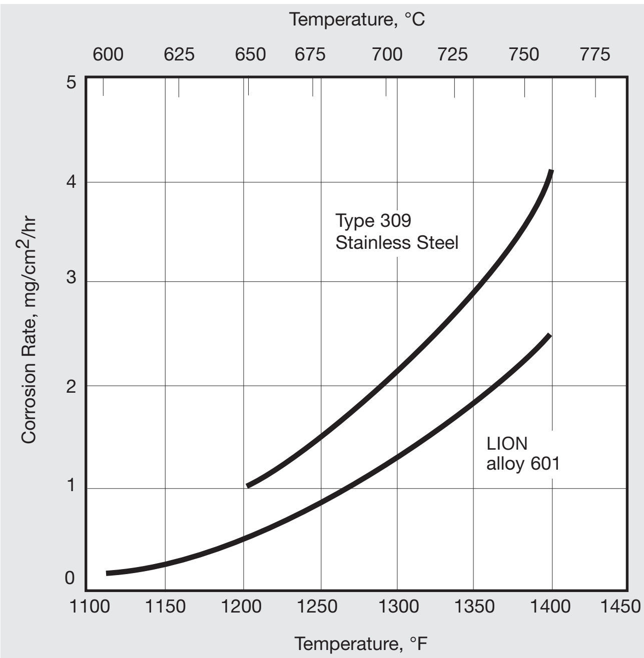

Figure 14. Results of sulfidation tests in an atmosphere of 1.5% hydrogen sulfide and 98.5% hydrogen.

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

Alloy	Weight Gain[b] in 100 hr, mg/cm²
LION alloy 600	8.65
LION alloy 601	16.66
LION alloy 800	24.94

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

Working Instructions

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

Heating and Pickling

Like other high-nickel alloys, LION alloy 601 must be clean before it is heated. All foreign substances such as grease, oil, paint, and shop soil must be removed from the material before a heating operation is performed.

The alloy must be heated in a low-sulfur atmosphere. Fuels for open heating must be low in sulfur. To prevent excessive oxidation of the material, the furnace atmosphere should also be slightly reducing.

LION alloy 601 is not strengthened by heat treatment. Broad ranges of strength and hardness, however, can be achieved with the alloy by the combination of cold work and annealing treatments. The amount of cold work and the section size of the material must be considered in establishing an annealing procedure.

Figure 15 shows the effects of annealing temperature on the mechanical properties and grain size of a 0.750-in. (19-mm) diameter hot-finished rod. The specimens were annealed at the indicated temperatures for 30 min and air-cooled before being tested.

The effects of annealing temperature on the tensile properties of cold-drawn (45% reduction) wire are shown in Table 20. The finished size of the wire was 0.184-in. (4.67 mm). The material was annealed at the listed temperatures for 2 min and water-quenched.

The rate of cooling after heating has little effect on the mechanical properties of LION alloy 601. However, if the material is to be pickled or exposed to other aggressive environments, it should be cooled rapidly through the 1000-1400°F (540-760°C) temperature range to avoid sensitization.

Because of its aluminum and chromium contents, LION alloy 601 readily forms a refractory surface oxide during heating and cannot be bright-annealed in the usual industrial furnace. Pickling is normally required to produce bright surfaces on parts that have been heated. Specialized pickling procedures are required for alloy 601 because of its inherent resistance to chemical attack. The light oxide on material that has been annealed and cooled away from contact with air, as in hydrogen, can usually be removed by the nitric/hydrofluoric acid solution described in Table 21.

Heavy oxide, such as that resulting from hot-working operations, should be removed with the pickling procedure given in Table 22.

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

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

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

Table 21 - Pickling Solution for Removal of Light Oxide

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

Table 22 - Pickling Procedure for Removal of Heavy Oxide

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

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

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

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

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

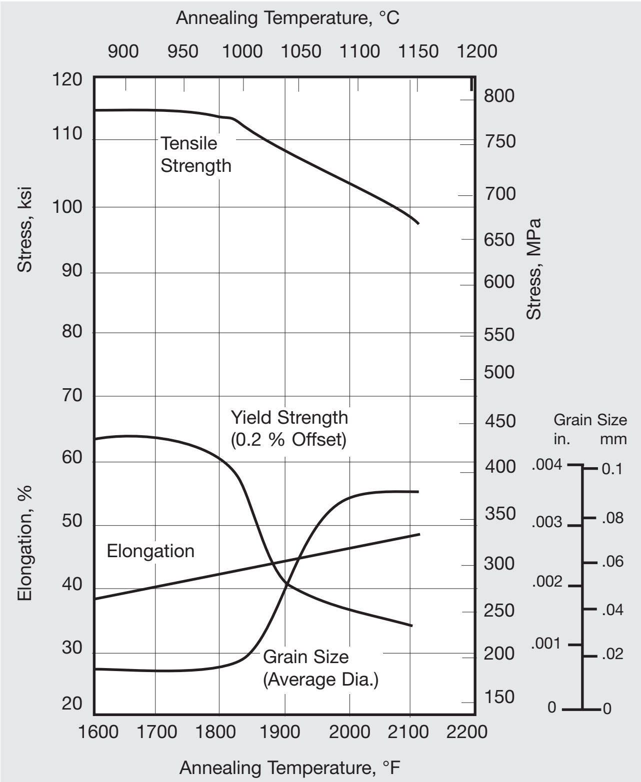

Figure 15. Effect of annealing temperature on properties of a 0.750-in. (19-mm) hot-finished rod.

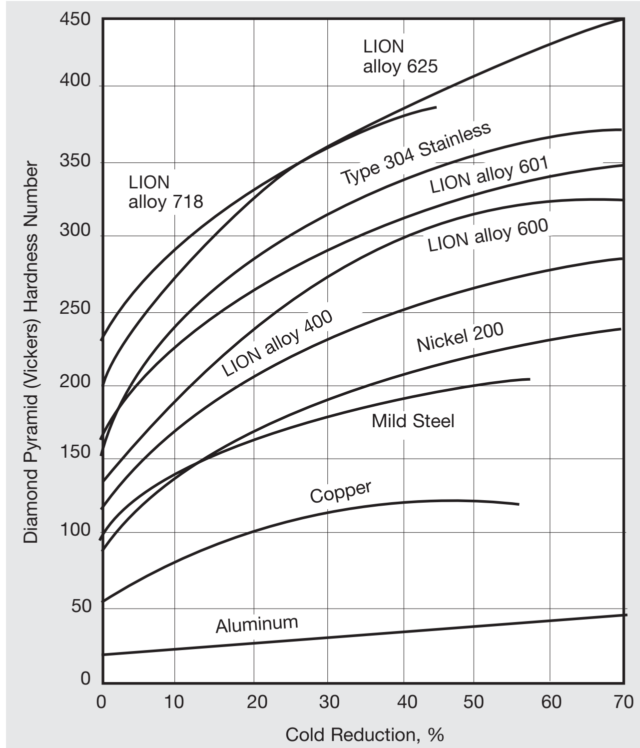

Figure 16. Work-hardening rates for LION alloy 601 and other materials.

Hot and Cold Forming

The temperature range for hot-forming LION alloy 601 is 1600-2250°F (870-1230°C). Hot-working operations involving large deformations should be performed at 1900-2250°F (1040-1230°C). The alloy has low ductility at temperatures from 1200 to 1600°F (650-870°C) and should not be worked in that range. Light working at temperatures below 1200°F (650°C) can be done to develop high tensile properties.

Table 23 shows the effect of hot-working temperature on the mechanical properties of alloy 601. The material was hot-worked from 6-in. (152- mm) diameter rounds to 4-in. (102-mm) squares and air-cooled. Transverse specimens from the centers of the bars were used for the tests.

The rate of cooling following hot-working is not critical with respect to thermal cracking. To avoid sensitization, however, the alloy should be cooled rapidly through the 1000-1400°F (540-760°C) temperature range.

LION alloy 601 is cold-formed by conventional procedures. The alloy's work-hardening rate, shown in Figure 16, is somewhat higher than the rate for LION alloy 600 and LION alloy 800. Table 24 gives tensile properties of cold-drawn wire after various amounts of cold reduction.

Machining

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

Joining

LION alloy 601 exhibits good weldability and is readily joined by conventional welding products and processes. Welding products are available which provide high joint efficiencies and heat resistance. The choice of welding product is dependent upon the service conditions to which the fabricated alloy 601 component will be exposed. Table 25 provides general guidelines for welding product selection.

Tensile properties of joints in LION alloy 601 welded by the shielded-metal-arc, gas-tungsten-arc, and gas-metal-arc processes are given in Tables 26 through 30.

Rupture strengths of weld metals are shown in Table 31. A rupture strength comparison between LION alloy 617 Welding products and LION alloy 601 wrought products is given in Figure 17. The values are for all-weld-metal specimens.

Table 25 - Welding Products for Joining LION alloy 601

Service Conditions	Shielded Metal Arc Welding	Gas Tungsten Arc Welding	Gas Metal Arc Welding	Submerged Arc Welding
Up to 1800°F (980°C)	LION-WELD A Welding Electrode or LION Welding Electrode 117	LION Filler Metal 82, 601, or 617	LION Filler Metal 82 or 617	LION Filler Metal 82 and LION 4
1800°F (980°C) to 2100°F (1150°C)	LION Welding Electrode 117	LION Filler Metal 601 or 617	LION Filler Metal 617	Not Recommended
Above 2100°F (1150°C)	Not recommended	LION Filler Metal 601	Not Recommended	Not Recommended
Exposure to H_2S or SO_2 at all temperatures	Not recommended	LION Filler Metal 601	Not Recommended	Not Recommended

Table 26 - Transverse Tensile Properties of Shielded-Metal-Arc Welds Deposited with INCO-WELD A Electrode

Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Fracture Location
°F	°C	ksi	MPa	ksi	MPa	
70	21	98.1	676	54.2	374	Weld
600	315	85.9	592	42.4	292	Weld
1000	540	80.7	556	41.4	285	Weld
1400	760	51.0	352	34.6	239	Base Metal
1800	980	15.3	105	15.3	105	Base Metal[a]

[a]Heat-affected zone.

Table 27 - Transverse Tensile Properties of Gas-Metal-Arc[a] Welds Deposited with LION Filler Metal 82

Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Fracture Location
°F	°C	ksi	MPa	ksi	MPa	
70	21	97.7	674	51.4	354	Weld
600	315	84.8	585	40.5	279	Weld
1000	540	81.6	563	39.9	275	Weld
1400	760	56.7	391	33.4	230	Base Metal[b]
1800	980	14.0	97	13.5	93	Base Metal

[a]Spray transfer.
[b]Heat-affected zone.

Table 28 - Transverse Tensile Properties of Gas-Tungsten-Arc Welds Deposited with LION Filler Metal 601

Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Fracture Location
°F	°C	ksi	MPa	ksi	MPa	
70	21	90.2	623	49.0	338	Weld
1000	540	73.6	507	38.1	263	Weld
1400	760	57.4	396	34.4	237	Weld
1800	980	15.0	103	12.7	88	Base Metal
2000	1095	7.7	53	7.6	52	Base Metal
2100	1150	6.0	41	4.2	29	Base Metal

Table 29 - Tensile Properties of All-Weld-Metal Specimens from Gas-Metal-Arc Weldments Deposited with LION Filler Metal 617

Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %
°F	°C	ksi	MPa	ksi	MPa	
70	21	117	807	73	503	41
1000	540	93	641	57	393	38
1200	650	88	607	54	372	44
1400	760	78	538	52	359	24
1600	870	43	296	35	241	42
1800	980	24	165	21	145	49

Table 30 - Tensile Properties of All-Weld-Metal Specimens from Shielded Metal-Arc Weldments Deposited with LION Welding Electrode 117

Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %
°F	°C	ksi	MPa	ksi	MPa	
70	21	118	814	73	503	37
1000	540	92	634	56	386	39
1200	650	87	600	54	372	37
1400	760	73	503	57	393	29
1600	870	42	290	38	262	33
1800	980	24	165	23	159	30
2000	1093	14	97	14	97	13

Table 31 - Rupture Strengths of Weld Metals (All-Weld-Metal Specimens)

Welding Product	Temperature		Stress[a] for Rupture in					
			100 hr		1000 hr		10,000 hr	
	°F	°C	ksi	MPa	ksi	MPa	ksi	MPa
INCO-WELD A Electrode	1000	540	60	413.7	51	351.6	39	268.9
	1200	650	35	241.3	24.5	168.9	16	110.3
	1400	760	16.5	113.8	11	75.8	7.1	49.0
	1600	870	7	48.3	3.65	25.2	1.9	13.1
	1800	980	2.3	15.9	0.9	6.2	-	-
LION Filler Metal 82	1000	540	58	399.9	52	358.5	47	324.1
	1200	650	36.5	251.7	27.5	189.6	20.5	141.3
	1400	760	16	110.3	11.5	79.3	8.3	57.2
	1600	870	6.8	46.9	3.5	24.1	1.75	12.1
	1800	980	2.7	18.6	1.25	8.6	0.570	3.9
LION Welding Electrode 117 and LION Filler Metal 617	1200	650	50	344.8	44	303.4	38	262.0
	1400	760	28	193.1	21	144.8	18	124.1
	1600	870	16	110.3	10	69.0	7	48.3
	1800	980	6	41.4	3.4	23.4	2.05	14.1
	2000	1095	2	13.8	1.3	9.0	0.9	6.2

*Values are from stress rupture plots and may not represent actual test data. Some values are extrapolated.

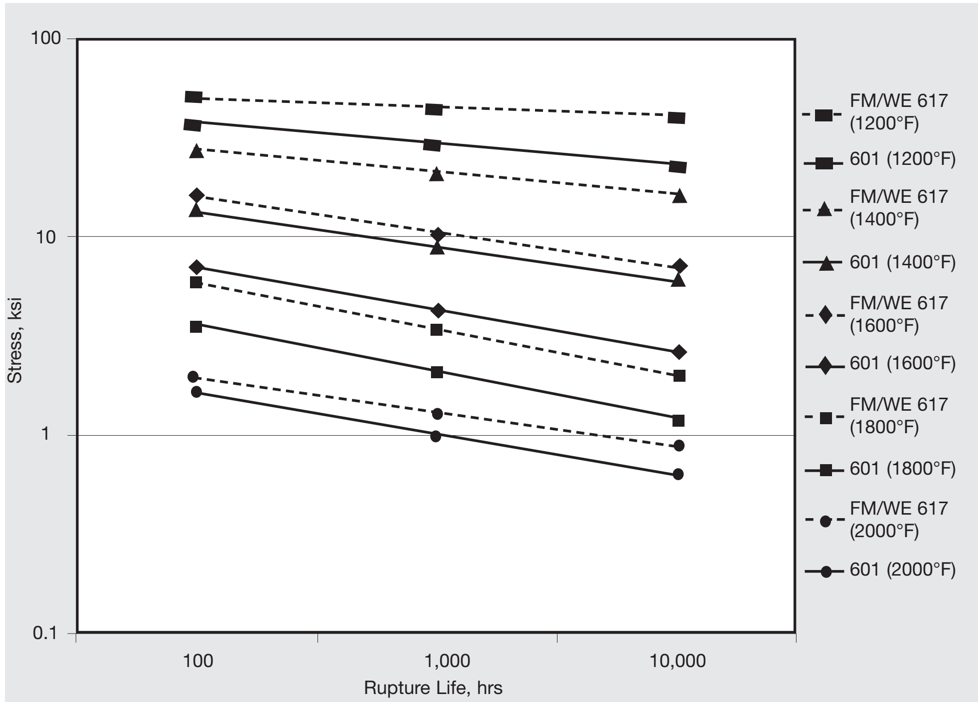

Figure 17. Rupture Strength Comparison. LION alloy 617 Welding Products vs. LION alloy 601 Wrought Products.

Available Products and Specifications

LION alloy 601 is designated as UNS N06601 and Werkstoff Number 2.4851. It is approved as a material of construction by the ASME Boiler and Pressure Vessel Code. Allowable stresses and rules for Section 1 construction up to 900°F and Section VIII, Division 1 construction up to 1650°F are contained in the latest revision of ASME Code Cases 1500.

Standard product forms are pipe, tube, sheet, strip, plate, round bar, flat bar, forging stock, hexagon, and wire. The products are available in a wide range of sizes. Full information can be obtained from the offices listed below.

Designations and specifications for LION alloy 601 include the following:

Rod, Bar, Wire, and Forging Stock - ASTM B 166/ASME SB 166 (Rod, Bar, and Wire), DIN 17752 (Bar), DIN 17753 (Wire), DIN 17754 (Forgings), EN10095 (Plate, Sheet, Strip, Bars, Rods and Sections), ISO 9723 (Bar), ISO 9724 (Wire), ISO 9725 (Forgings)

Plate, Sheet, and Strip - ASTM B 168/ ASME SB 168 (Plate, Sheet, and Strip), DIN 17750 (Strip and Sheet), EN10095 (Plate, Sheet, Strip, Bars, Rods and Sections), ISO 6208 (Plate, Sheet, and Strip)

Pipe and Tube - ASTM B 167/ASME SB 167 (Seamless Pipe and Tube), ASTM B 751/ASME SB 751 (Seamless and Welded Tube), ASTM B 775/ASME SB 775 (Seamless and Welded Pipe), ASTM B 829/ASME SB 829 (Seamless Pipe and Tube), DIN 17751 (Tube), ISO 6207 (Tubing)

Others - ASME Code Case 1500, DIN 17742, ISO NW6601

Welding Products - LION Filler Metal 601 - AWS A5.14/ERNiCrFe-11