Nickel-Chrome Alloy Inconel 601 (UNS N06601)


Inconel 601 is a Nickel-Chromium alloy that offers good heat and corrosion resistance. It provides resistance to high temperature oxidation up to 2200oF and has high temperature strength and good ductility in prolong service applications. Great aqueous corrosion resistance, high mechanical strength and is easily produced, machined and welded. It is widely used in aerospace, power production, thermal processing, chemical treatment and land base gas turbine engines.

Alloy 601 offers adequate resistance to heat and corrosion due to oxidation and other media at the high temperature limits. It resists the aqueous corrosion and offers suitable mechanical strength. It can be easily formed. Alloy 601 offers good welding character.

Chemical Composition

Aluminum (Al)	1.4 %
Carbon (C)	0.05 %
Chromium (Cr)	22.5 %
Copper (Cu)	<= 1.0 %
Iron (Fe)	14 %
Manganese (Mn)	0.3 %
Nickel (Ni)	61.5 %
Silicon (Si)	0.2 %
Sulfur (S)	<= 0.015 %

Physical Properties

Density	8.11 g/cc or 0.293 lb/in^3
Ultimate Tensile Strength	620 MPa at 550oC or 89900 psi at 1020oF
	760 MPa at 23oC or 110000 psi at 73.4oF
Yield Strength	450 MPa at strain 0.200 % or 65300 psi at strain 0.200 %

	330 MPa at strain 0.200 % at temperature 550oC or 47900 psi at strain 0.200 % at temperature 1020oF
Elongation	42% or 32% at temperature 550oC
Electrical Resistivity	0.000119 ohm-cm
Magnetic permeability	1.003
Curie temperature	-196oC or -321oF
Linear coefficient of thermal expansion	13.75 micro-m/m oC at 20oC to 100oC or 7.639 micro-in/inch-oF at temperature 68oF to 212oF
Specific heat capacity	0.448 J/g-oC or 0.107 BTU/lb/oF
Thermal conductivity	11.2 W/m-K or 77.7 BTU-in/hr-ft2-oF
Melting Point	1360oC to 1411oC or 2480oF to 2572oF
Solidus temperature	1360oC or 2480oF
Liquidus temperature	1411oC or 2572oF

Mean Coefficient of Thermal Expansion

oF	oC	10^{-6} in/in-°F	µm/m-°C
80 of to 200 of	27 oC to 100 oC	7.60 x 10^{-6} in/in-°F	13.75 µm/m-°C
80 of to 400 of	27 oC to 200 oc	8.01 x 10^{-6} in/in-°F	14.36 µm/m-°C
80 of to 600 of	27 oC to 300 oC	8.11 x 10^{-6} in/in-°F	14.58 µm/m-°C
80 of to 800 of	27 oC to 400 oC	8.30 x 10^{-6} in/in-°F	14.83 µm/m-°C
80 of to 1000 of	27 oC to 500 oC	8.50 x 10^{-6} in/in-°F	15.19 µm/m-°C
80 of to 1200 of	27 oC to 600 oC	8.87 x 10^{-6} in/in-°F	15.62 µm/m-°C
80 of to 1400 of	27 oC to 700 oC	9.19 x 10^{-6} in/in-°F	16.11 µm/m-°C
80 of to 1600 of	27 oC to 800 oC	9.51 x 10^{-6} in/in-°F	16.67 µm/m-°C
80 of to 1800 of	27 oC to 900 oC	9.82 x 10^{-6} in/in-°F	17.24 µm/m-°C
80 of to 2000 of	27 oC to 1000 oC	10.18 x 10^{-6} in/in-°F	17.82 µm/m-°C

Mechanical Properties

Inconel alloy 601 offers excellent mechanical strength. The strengthening scale offered by alloy 601 varies with the variation in the alloy forms and conditions. The particular condition depends on the type of operation and temperature. Basically, the solution processed alloy is used in the crack oriented operations at the high temperatures up to 1000oF.

Alloy form	Condition	Tensile strength		Yield strength		Elongation %	Hardnes, HB
601 Rod	Annealed	80 to 115 ksi	550 to 790 MPa	30 to 60 ksi	205 to 415 MPa	70 to 40 %	60 to 80
601 Sheet	Annealed	85 to 100 ksi	585 to 690 MPa	30 to 50 ksi	205 to 345 MPa	55 to 35 %	65 to 80
601 Plate	Annealed	80 to 100 ksi	550 to 690 MPa	30 to 45 ksi	205 to 310 MPa	65 to 45 %	60 to 75

The annealed Inconel 601 is implemented in the operations that need high tensile strength. It retains its strength and other features even at the elevated temperatures.

Creeping Strength of Inconel 601

Inconel 601 introduces superior creep rupturing strength and is extensively utilized in the apparatus that operate under high temperatures for extended periods. It is significantly used for these purposes as it offers excellent resistance to oxidation and other kinds of corrosion conditions at the elevated temperatures. The cracking strength of alloy solution processed at the various temperature ranges is demonstrated by the Larson Miller parameter.

The creep and rupture strengths of alloy are concluded at the heat processing temperature about 2100oF or 1150oC for one hour. The transverse specimen with the hardness of 86 Rb and the grain size of ASTM 8 are utilized for evaluation. The tensile characters are Yield strength 59.5 ksi, Tensile Strength, 111 ksi, and Elongation, 36%.

Inconel 601 Creep Rupture Strength for 1000 hours

Operation temperature, 1000 hours	Psi	Mpa
1200 oF or 650 oC	28,000 Psi	195 Mpa
1400 oF or 760 oC	9100 Psi	63 Mpa
1600 oF or 870 oC	4300 Psi	30 Mpa
1800 oF or 980 oC	2100 Psi	14 Mpa
2000 oF or 1095 oC	1000 Psi	7 Mpa

Corrosion Resistance

Inconel alloy 601 has described the full fledge unavailability of embrittling intermetallic forms like sigma. The content of nickel and chromium in Inconel 601 in combination with the concentration of aluminum offers the superior resistance to corrosion at the high temperatures. The excellent features of alloy are its resistance to oxidation at the high temperatures about 2200oF or 1200oC. The concentration of chromium and aluminum offers exclusive spaling resistance during the cyclic thermal work.

Alloy 601 offers excellent resistance to oxidation at the high temperatures. It creates the protective oxide layer that inhibits scaling in the rigorous environments of cyclic exposure to the temperature. The alloy offers extensive resistance to cyclic oxidation at the temperature of 2000oF or 1095oC. It is subjected in the cyclic exposure to 2000oF or 1095oC for 15 minutes and quick air cooling for five minutes. The difference in the weight is noticed regularly.

The excellent resistance to oxidation provided by alloy 601 is based on the concentration of nickel, aluminum and chromium. At the elevated temperature, these elements produce the secured oxide layer on the material's surface. Moreover the minor internal oxidation offers more chromium concentration in the surface oxide. **Inconel 601 alloy** also offers excellent resistance to carburization.

Average Corrosion rate in various acidic media

Media	Test time, days	Corrosion Rate	
		Mpy	mm/yr
Acetic Acid (10%)	7	<0.1 mpy	<0.002 mm/y
Acetic Acid (10%)+			
-Sodium Chloride (0.5%)	30	2.18 mpy	0.554 mm/y
Acetic Acid (10%)+			
-Sulfuric Acid (0.5%)	7	45.7 mpy	1.161 mm/y
Alum (5%)	7	28.6 mpy	0.726 mm/y
Aluminum Sulfate (5%)	7	<0.1 mpy	<0.002 mm/y
Ammonium Chloride (5%)	30	0.1 mpy	0.002 mm/y
Ammonium Hydroxide (5%)	7	Nil	Nil
Ammonium Hydroxide (10%)	7	Nil	Nil
Ammonium Sulfate (5%)	7	0.1 mpy	0.002 mm/y
Barium Chloride (10%)	30	0.1 mpy	0.002 mm/y
Calcium Chloride (5%)	30	0.1 mpy	0.002 mm/y
Chromic Acid (5%)	7	3.6 mpy	0.091 mm/y
Citric Acid (10%)	7	<0.1 mpy	<0.002 mm/y
Copper Sulfate (10%)	7	Nil	Nil
Ferric Chloride (5%)	7	354 mpy	8.99 mm/y
Ferrous Ammonium			
-Sulfate (5%)	7	Nil	Nil
Lactic Acid (10%)	7	36.4 mpy	0.925 mm/y
Methanol	7	Nil	Nil
Oxalic Acid (5%)	7	23.8 mpy	0.605 mm/y
Oxalic Acid (10%)	7	52.2 mpy	1.326 mm/y
Potassium Ferricyanide (5%)	7	Nil	Nil
Sodium Bisulfite (5%)	7	<0.1 mpy	<0.002 mm/y
Sodium Carbonate (5%)	7	Nil	Nil
Sodium Chloride (10%)	30	0.2 mpy	0.005 mm/y
Sodium Chloride (20%)	30	0.3 mpy	0.008 mm/y
Sodium Hypochlorite (1%)	7	3.5 mpy	0.089 mm/y
Sodium Hypochlorite (5%)	7	<6.9 mpy	0.175 mm/y
Sodium Sulfate (5%)	7	Nil	Nil
Sodium Sulfate (10%)	7	<0.1 mpy	<0.002 mm/y
Sulphurous Acid (6%)	7	56.2 mpy	1.427 mm/y
Tartaric Acid (20%)	7	21.8 mpy	0.554 mm/y
Zinc Chloride (10%)	7	0.1 mpy	0.002 mm/y

Fabrication

Inconel 601 is easily forged, machined and welded by following the standard processes. The unnecessary materials like grease, oil and dust should be eradicated from the material prior to heating.

Alloy 601 is heated in the conditions of lower concentration of sulfur. The fuel for open heating should include minor sulfur content. In order to avoid the massive oxidation of alloy, the furnace conditions should be reduced slowly. Inconel 601 alloy is not strengthened by heat processing. The wide range of forces and hardness can be obtained from it by the mixture of cold processing and annealing. The impact of annealing temperature on the tensile strength of cold treated Inconel alloy is shown in the below table:

Annealing Temperature °F	Tensile Strength, ksi	Yield Strength, ksi	Elongation%
1750	174.0	166.0	5
1800	114.0	56.5	32
1850	113.5	53.5	34
1900	105.0	43.0	37
1950	107.0	41.0	36
2000	104.0	43.0	39

The presence of aluminum and chromium offers capability to Inconel 601 alloy to produce the refractory surface oxide while heating that cannot be annealed in the commercial furnaces. The pickling is essential to produce the bright layers on the alloy sections that are heated. The specialized pickling processes are essential for alloy 601 due to its resistance to the chemical processes. The light oxide on the material that are annealed and cooled in absence of air can be eradicated by the nitric or hydrochloric acid solution.

Hot Forging of Inconel 601

The temperature of hot forging of **Inconel 601 alloy** is 1600 to 2250oF or 870-1230oC. The hot processing operations that consist of wider distortions should be conducted at temperature of 1900oF to 2250oF or 1040oC to 1230oC. Alloy 601 has low ductile nature at higher temperature of 1200 to 1600oF or 650-870oC so it is not recommend to process in this temperature range. Minor processing is done at temperature lower than 1200oF or 650oC to obtain the high tensile strength.

Inconel 601 alloy is cold treated by following the traditional methods. Its toughening rate is slightly more than the alloy 600 and alloy 800. Following table shows the tensile character of cold drawn alloy subsequent to different amounts of cold reduction.

Cold reduction Temp. °F	Tensile Strength-ksi	Yield Strength-ksi	Elongation,%
45	174.0	166.0	5
68	192.0	185.0	4
77.5	197.0	183.0	4
83	202.0	193.0	3

Welding of Inconel 601

Inconel 601 alloy obtains the superior welding character and it is easily connected by following the traditional welding products and methods. The welding forms are introduced

with the higher joint efficiency and resistance to heat. The choice of welding form is based on the service conditions that are followed to produce the Inconel alloy parts for exposure.

Available Forms

Wire, Mesh, Strip, Foil, Plate, Sheet, Pipe, Tubing, Bars, Rod, Flanges