Technical Data Sheet

ATI 601™

Nickel-base Alloy

(UNS N06601)

INTRODUCTION

ATI 601™ alloy (UNS Designation N06601) is an austenitic nickel-chromium-iron alloy designed for both heat and corrosion resistance. As compared to ATI 600 alloy (UNS Designation N06600), the ATI 601 alloy has, in addition to increased chromium, an aluminum content which together provide outstanding resistance to oxidation. In addition, ATI 601 alloy has good resistance to environments containing carbon and sulfur and this alloy also resists aqueous corrosion.

The ATI 601 alloy is used in aerospace applications, for heat and chemical processing equipment, and in power generation, pollution control and heat treating applications.

Forming, machining and welding properties are similar to those of stable austenitic stainless steels.

PRODUCT FORMS

ATI 601 alloy is available in plate, sheet and strip form, in the annealed or solution-treated condition.

SPECIFICATIONS & CERTIFICATES

The ATI 601 alloy is covered by only a few specifications, as shown in the table below.

	SPECIFICATON		
PRODUCT FORM	ASTM	ASME	AMS
Sheet, Strip and Plate	B168	SB-168	5870
Bars, Forgings and Rings			5715
Rod, Bar and Wire	B166	SB-166	
Seamless Pipe and Tubing	B163	SB-163	
Seamless Pipe and Tubing	B167	SB-167	
Welded Pipe	B474		
Finned Tube	B924		
Fittings	B366		

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TYPICAL ANALYSIS

Element	Wt. Percent
Carbon	0.05
Manganese	0.50
Sulfur	0.005
Silicon	0.25
Chromium	23.0
Nickel	60.5
Iron	14.1
Aluminum	1.35
Copper	0.25

PHYSICAL PROPERTIES

Density
0.291 lb/in^3
8.05 g/cm^3

Specific Gravity
8.05

Magnetic Permeability
1.02

Specific Heat

32-212°F	0.11 Btu/lb/°F
(0-100°C)	460 Joules/kg•K

Linear Coefficient of Thermal Expansion

Average From 80°F (27°C) to F°(°C)		Linear Coefficient of Thermal Expansion*	
°F	°C	10^{-6}in/in/°F	10^{-6}cm/cm/°C
80	27	6.10	11.0
200	93	7.60	13.7
400	204	8.01	14.4
600	316	8.11	14.6
800	427	8.30	14.9
1000	538	8.50	15.3
1200	649	8.87	16.0
1400	760	9.19	16.5
1600	871	9.51	17.1
1800	982	9.82	17.7
2000	1093	10.18	18.3

*80 F value measured from -320 F to 80 F;
others from 80 F temperature shown.

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Temperature	Elastic Properties			
°F (°C)	Tension Modulus		Torsion Modulus	
	10^6 psi	(GPa)	10^6 psi	(GPa)
70 (21)	29.9	(205)	11.8	(81)
200 (93)	29.4	(200)	11.5	(80)
400 (204)	28.5	(195)	11.1	(76)
600 (316)	27.6	(190)	10.7	(74)
800 (427)	26.6	(185)	10.2	(70)
1000 (538)	25.4	(175)	9.7	(67)
1200 (649)	24.2	(170)	9.1	(63)
1400 (760)	22.5	(155)	8.3	(57)
1600 (871)	20.6	(140)	7.5	(51)
1800 (982)	18.4	(125)	6.6	(45)
2000 (1093)	16.1	(110)	5.7	(39)

OXIDATION RESISTANCE

The ATI 601 alloy has outstanding resistance to oxidation and scaling at high temperatures. Figure 1 shows its performance in a severe test consisting of cycles of alternate exposure to 2000°F for 15 minutes and cooling at room temperature for 5 minutes. The fact that there is very little loss in weight indicates the alloy's ability to retain a protective oxide coating under conditions of cyclic oxidation. To emphasize the effectiveness of ATI 601 alloy in such an environment, data are also included for three other materials with well demonstrated oxidation resistance. These three alloys are: 22 Cr-18.5 Fe-9.0 Mo-1.5 Co-0.6 W-balance, Ni 50-50 Cr and alloy 702. ATI 601 alloy shows a significant improvement over alloy 702 which has found usage for applications requiring outstanding oxidation resistance.

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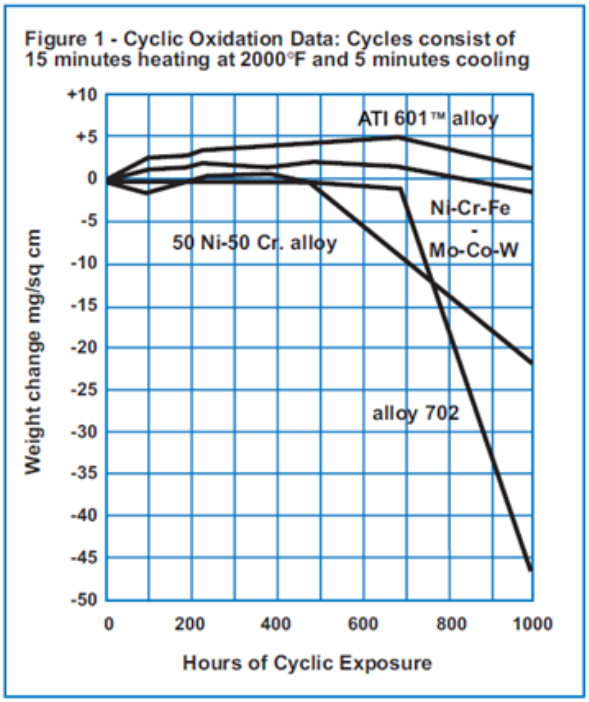
Figure 1 - Cyclic Oxidation Data: Cycles consist of 15 minutes heating at 2000°F and 5 minutes cooling



ATI 601 alloy also displays greater resistance to cyclic oxidation than Types 309, 310 or 330 when tested at 2000°F for 15 minutes heating and 5 minutes cooling as shown in figure 2 below.

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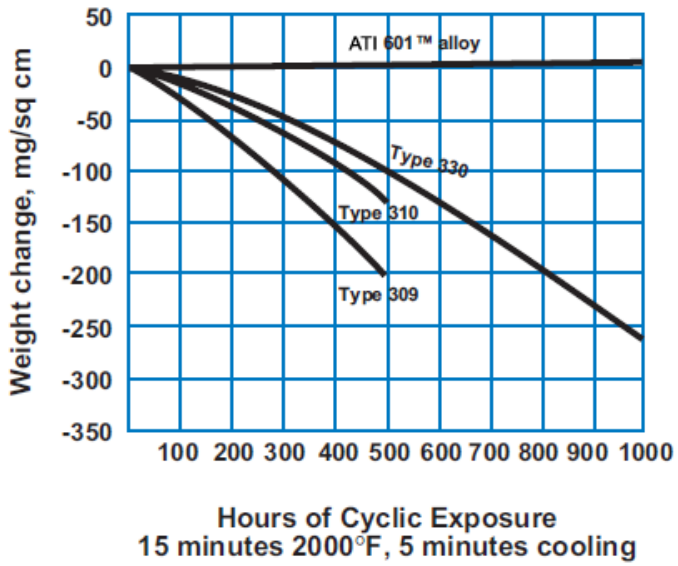
Figure 2 - Cyclic Oxidation Data: Cycles consist of 15 minutes heating at 2000°F and 5 minutes cooling



Laboratory tests have further shown that ATI 601 alloy joints, which are gas-tungsten-arc-welded, have oxidation resistance at 2000°F equivalent to that of the base metal.

ATI 601 alloy owes its high oxidation resistance to the formation of a tenacious oxide film which forms upon exposure to elevated temperatures. This film layer is keyed to the metal surface by a uniform network of internally penetrating oxide. In static tests at 2000°F, this network formed to a depth of 0.002 inches during the first 100 hours of exposure. The thickness and structure of the protective oxide layer remained unchanged for the balance of the 1,000 hours of the test.

The 2000°F cyclic oxidation test also was used to demonstrate the alloy's resistance to warping. Sample strips, 0.050 x 0.750 x 3 inches of ATI 601 alloy were only mildly distorted during the 1,000 hours of exposure. On the other hand, similar samples of ATI 600™ alloy completely disintegrated.

Because of the high nickel content of the alloy, sufficiently aggressive sulfidizing conditions will cause sulfidation.

CORROSION RESISTANCE

The high nickel content of the ATI 601 alloy provides good resistance to moderate levels of reducing conditions. The nickel content of the alloy renders the alloy extremely resistant to chloride stress corrosion cracking.

Similarly, the chromium content of ATI 601 alloy provides resistance to weak oxidizing environments. The ATI 601 alloy is relatively unaffected by the majority of neutral and alkaline solutions.

MECHANICAL PROPERTIES

ATI 601 alloy has good mechanical strength at room temperature and retains much of its strength at elevated temperatures. Mechanical properties are influenced by prior heat treatment with 2100°F (1149°C) solution-treated material less strong than 1800°F (982°C) annealed material.

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Typical room temperature mechanical properties of the ATI 601 alloy are shown below:

Property	1800° (982°C) Anneal	2100°F (1149°C) Solution Treated
Yield Strength psi (MPa)	64,000 (440)	36,000 (250)
Tensile Strength psi (MPa)	115,000 (790)	97,000 (670)
Elongation (% in 2 in.)	45	55
% Reduction in Area	60	55
Hardness (Rb)	80	70
Charpy Impact Strength Ft. - Lbs. (Joules)	110 (150)	130 (175)

Short-time Elevated Temperature Tensile Properties
The following table illustrates the short-time tensile properties of annealed ATI 601 alloy:

Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation (% in 2")
°F	(°C)	psi	(MPa)	psi	(MPa)	
400	(204)	60,000	(415)	109,000	(750)	45
800	(427)	52,000	(360)	102,000	(705)	44
1000	(538)	48,000	(330)	90,000	(620)	44
1200	(649)	41,000	(280)	60,000	(415)	45
1400	(760)	26,000	(180)	34,000	(235)	70
1600	(871)	15,000	(105)	18,000	(125)	120

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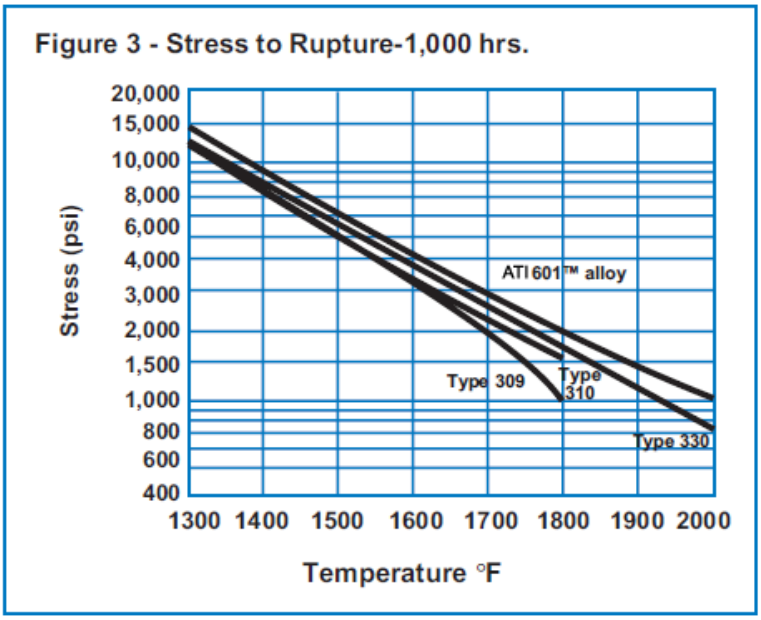
Stress Rupture
Stress rupture data below illustrates that solutiontreated ATI 601 alloy has superior performance when compared with austenitic steels such as Types 309, 310, and 330.



COLD FORMING

ATI 601 alloy exhibits the excellent cold forming characteristics normally associated with chromium-nickel stainless steels. The high nickel content prevents the austenite-to-martensite transformation which can occur when Types 301 or 304 stainless steels are cold formed. The alloy has a lower workhardening rate than Types 301 or 304 and can be used in multiple draw-forming operations where relatively large amounts of deformation occur between anneals.

If a solution treatment is conducted on the ATI 601 alloy to produce a relatively large grain size for elevated temperature properties, extensive forming produces a rough surface generally characterized by an "orange peel" appearance. This surface feature is produced by the large grain size and is usually not considered detrimental to the properties of the material.

WELDABILITY

The ATI 601 alloy can be joined by the standard resistance and fusion welding processes used for stainless steels. A number of welding rods and wires, including matching filler, are commercially available for joining ATI 601 alloy to itself and other materials.

INCO-WELD®* A or 182 Electrode are used for the shielded-metal-arc process and INCONEL®* 82 or matching filler are used for gas-metal-arc or gastungsten- arc processes. The optimum filler should be chosen with knowledge of the service conditions to which the joint will be exposed.

Since the reactive element aluminum is important in determining properties of the alloy and since the alloy forms a tightly adhering oxide which can be removed only by grinding, inert gas shielding is desirable.

* Registered trademark of Special Metals Corporation

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HEAT TREATMENT

The ATI 601 alloy is non-hardenable by thermal treatments. The alloy can only be strengthened by cold working.
Like other nickel-base alloys, ATI 601 alloy should be clean before heat treating is conducted. Low sulfur heat treating environments are necessary.

Annealing is conducted to soften the material after cold working operations. Softening begins at 1600°F (871°C) and can be conducted to about 2100°F (1149°C). At about 1850°F (1010°C) rapid grain growth occurs.

Low temperature anneal should be conducted for low temperature applications (1000°F [540°C]), while better creep resistance for high temperature applications (greater than 1000°F) results from the large grain size produced by solution treatment in the 2100°F (1149°C) range.

Slow cooling produces approximately the same hardness in ATI 601 alloy as quenching. For applications involving aqueous corrosion resistance, quenching is used to avoid sensitization.

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