Technical Data Sheet

ATI 276™

Nickel-base Alloy

(UNS N10276)

INTRODUCTION

ATI 276™ alloy (UNS Designation N10276) is a nickel-molybdenum-chromium-iron-tungsten alloy which is among the most corrosion resistant of alloys currently available. The ATI 276 alloy is widely used in the severest environments encountered in the chemical and petrochemical processing, flue gas desulfurization, pulp and paper and other specialized fields. Design of the alloy allows a high level of corrosion resistance to be retained even in the welded condition.

ATI 276™ alloy also has good high temperature strength and moderate oxidation resistance although the alloy will eventually form embrittling high temperature precipitates.

ATI 276™ alloy has been available for several years and has been used in ASME Boiler and Pressure Vessel related construction. The alloy is covered in ASME Section VIII Divisions 1 and 2, in numerous product forms.

The alloy is readily fabricated by welding using techniques similar to those used for austenitic stainless steels and other nickel base alloys. Precautions are advisable during fabrication because raising the low carbon and silicon contents of the material may adversely affect important properties.

PRODUCT FORMS

The ATI 276 alloy is furnished as plate, sheet and strip. In all forms, the material is furnished in the solution-annealed condition.

SPECIFICATIONS & CERTIFICATES

ATI 276™ alloy is covered by the following widely published specifications:

ASTM B574 ASME SB574	Bar Products
ASTM B575 ASME SB575	Plate, Sheet and Strip
ASTM B619 ASME SB619	Welded Pipe
ASTM B622 ASME SB622	Seamless Tubing
ASTM B626 ASME SB626	Welded Tubing
ASTM B366 ASME SB366	Wrought Corrosion Resistant Fittings - CR HC 276 Wrought ANSI Pressure Fittings - WPHC276
AWS A 5.14 ASME SA 5.14	Welding Wire (ER NiCrMo-4)
AWS A 5.11 ASME SA 5.11	Covered Electrodes (E NiCrMo-4)

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TYPICAL COMPOSITION

Element	Weight Percent
Carbon	0.006
Manganese	0.150
Phosphorus	0.005
Sulfur	0.002
Silicon	0.03
Chromium	15.50
Nickel	Balance*
Molybdenum	16.0
Tungsten	3.50
Vanadium	0.15
Cobalt	0.10
Iron	6.00

* By Difference

CORROSION RESISTANCE

Corrosion test data were generated on ATI melted and worked materials. The data are typical, but should not be used for specification purposes. Similarly, in any unfamiliar environment, sample testing is advisable.

Test Environment (Boiling)	Corrosion Rate, Mils per Year (mm/a)						
	Type 316		AL-6XN®		Altemp® 625	ATI 276™	
	Base Metal Sample	Welded Sample (.080" Thick)	Base Metal Sample	Welded Sample (.047" Thick)	Base Metal Sample	Base Metal Sample	Welded Sample (.048" Thick)
20% Acetic Acid	0.12 (0.003)	0.12 (0.003)	0.14 (0.0036)	0.07 (0.0018)	0.30 (0.0076)	0.50 (0.013)	0.24 (0.006)
45% Formic Acid	10.92 (0.277)	10.32 (0.262)	4.55 (0.116)	5.61 (0.142)	5.0 (0.13)	2.76 (0.07)	1.92 (0.049)
10% Oxalic Acid	40.08 (1.02)	39.00 (0.991)	10.92 (0.277)	10.80 (0.274)	6.0 (0.15)	11.28 (0.29)	10.20 (0.259)
20% Phosphoric Acid	**0.20** (**<0.01**)	6.12 (0.155)	0.26 (0.007)	0.25 (0.006)	0.36 (0.01)	0.36 (0.01)	0.24 (0.006)
10% Sulfamic Acid	63.60 (1.62)	62.16 (1.58)	29.57 (0.751)	14.98 (0.381)	4.80 (0.12)	2.64 (0. 07)	2.40 (0.061)
10% Sulfuric Acid	**636** (**16.2**)	**641** (**16.3**)	84.4 (2.14)	92.3 (2.34)	25.3 (0.64)	13.92 (0.35)	19.80 (0.503)
10% Sodium Bisulfate	41.64 (1.06)	41.64 (1.06)	23.96 (0.609)	13.56 (0.344)	3.96 (0.10)	2.64 (0.07)	2.16 (0.055)

General Corrosion

ATI 276™ alloy is one of the most universally corrosion resistant materials available. The alloy is used in a range of environments from moderately oxidizing to strongly reducing. ATI 276 alloy does not have sufficient chromium content to be useful in the most strongly oxidizing environments like hot, concentrated nitric acid. The alloy is established in a number of chemical process environments especially where mixed acids are involved. One application is in the more corrosive area of flue gas desulfurization systems, such as outlet ducting.

The following table illustrates the comparative performance of various alloys to that of ATI 276 alloy in a variety of laboratory corrosion test solutions. All welding performed by the autogenous GTAW process.

ATI 276 alloy is used in wet chlorine service where it is one of the few materials able to resist this very aggressive environment.

ATI 276 alloy is used in coal burning electric utility flue gas scrubbers where it is among the most corrosion resistant of materials. The following chart illustrates the excellent resistance of ATI 276 alloy compared to that of Type 316 in the "Green Death" simulated scrubber solution:

Green Death Solution (Boiling)	Corrosion Rate, MPY (mm/a)	
	Type 316	ATI 276™
7% Sulfuric Acid 3% Hydrochloric Acid 1% Cupric Chloride 1% Ferric Chloride	Destroyed	26.5 (0.67)

Pitting and Crevice Corrosion

The chromium, molybdenum and tungsten content of ATI 276™ alloy produces such a high level of pitting corrosion resistance that the alloy is considered inert to seawater and is used in many seawater, brine, and high chloride environments, even at strong acid pH values.

The following table illustrates the performance of ATI 276™ alloy to that of three other alloys in the 10% (Ferric Chloride+6% H_2O) solution per ASTM Procedure G-48, Practice B.

Alloy	Temperature of Onset of Crevice Corrosion Attack	
	°F	°C
Type 316	27	2.5
AL-6XN®	113	45
Altemp® 625	113	45
AL 276™	140*	60*

*Generally considered beyond the stability limit of the Ferric Chloride solution.

Chloride Stress Corrosion

The high level of nickel and molybdenum provides extreme resistance to chloride stress corrosion cracking.

Test Solution	Alloy Tested as U-Bend Samples Result and Test Time (Hours)			
	Type 316	AL-6XN®	Altemp® 625	ATI 276™
42% Magnesium Chloride (boiling)	Fail (24 Hours)	Mixed (1000 Hrs)	Resist (1000 Hrs)	Resist (1000 Hrs)
33% Lithium Chloride (boiling)	Fail (100 Hrs)	Resist (1000 Hrs)	Resist (1000 Hrs)	Resist (1000 Hrs)
26% Sodium Chloride (boiling)	Fail (300 Hrs)	Resist (1000 Hrs)	Resist (1000 Hrs)	Resist (1000 Hrs)

Corrosion Resistance - Independent Laboratory Study

To determine that ATI 276™ alloy, as is currently produced by ATI, has the same excellent corrosion resistance characteristics as the originally developed alloy, corrosion testing was conducted by an independent laboratory; namely, Corrosion Testing Laboratories, Inc. (CTL) of Wilmington, Delaware.

Sample coupons from three separate heats of ATI 276 alloy, melted and processed material were tested in three corrosive solutions. Coupons were tested in the mill annealed and pickled condition for all three solutions. Butt welded coupons were also tested in Solution 3 which represents a test designed to simulate the anticipated service conditions encountered in the processing of nuclear waste.

Results of this independent corrosion study, as detailed in the three following tables, verify that ATI 276 alloy is equal in corrosion resistance to that of the originally developed alloy and is deemed satisfactory for service environments where this alloy is specified. Heat codes as maintained by Corrosion Testing Laboratories, Inc. for ATI's material are used in the following three tables:

Solution 1: ASTM G28-85, Practice A

This test represents a standard corrosion acceptance test conducted by many major chemical processors and government agencies to screen for resistance to susceptibility to intergranular attack. Industry recognized corrosion rate criteria, which differentiates material susceptible to IGA from that resistant to attack, is 480 mils per year maximum. The corrosion rates tabulated below demonstrate that ATI 276 alloy possesses excellent resistance to IGA.

Test Environment (Boiling) G28-85, Practice A 24 hrs	Uniform Corrosion Rate (MPY) - Mill Annealed and Pickled Condition		
	ATI 276™ Alloy		
	Heat ACO .062" thick	Heat ACV .250" thick	Heat ADB .266" thick
Ferric Sulfate, 50% Sulfuric Acid	250	200	220

Solution 2: ASTM G28, Practice B

This test solution also represents an acceptance test that determines susceptibility to intergranular attack. This test is useful for determining whether the correct material in the proper metallurgical condition (void of secondary phase precipitates) has been supplied. Rates over 60 mils per year would constitute undesirable material. Results are tabulated below, and again, corrosion rates verify the excellent resistance of ATI 276™ alloy to intergranular attack.

Test Environment (Boiling) G28-85, Practice B 24 hrs	Uniform Corrosion Rate (MPY) - Mill Annealed and Pickled Condition		
	ATI 276™ Alloy		
	Heat ACO .062" thick	Heat ACV .250" thick	Heat ADB .266" thick
23% Sulfuric Acid 1.2% Hydrochloric Acid 1.0% Ferric Chloride 1.0% Cupric Chloride	45	43	48

Solution 3:

The "3 B-2 Solution" contains 0.25% chloride as sodium chloride, 0.03% fluoride as sodium fluoride, 0.003% iodide as sodium iodide, 0.08% sulfate as sodium sulfate, 0.10% nitrate as sodium nitrate and 0.10% mercury as mercuric chloride. The pH is adjusted to 2.2 using sulfuric acid. The test is run at the boiling point of the solution for 10 days. This solution simulates anticipated service conditions in the processing of nuclear waste in a vitrification melter off-gas line and condensate storage tank located at the U.S. Department of Energy's Savannah River Plant, Aiken, South Carolina. Over 1,000 tons of UNS N10276 alloy have been supplied as the material of construction for this project based upon the alloy passing this test with corrosion rates of less than 1.5 mils per year and limited susceptibility to crevice corrosion (i.e., less than 1 mil [0.025 mm] in this ten day test). Again, ATI 276 alloy, demonstrated excellent corrosion resistance as the following table shows:

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Uniform Corrosion Rates (MPY) "3 B-2 Solution"			
Heat	**Coupon Thickness**	**Mill Annealed and Pickled**	**Welded***
ACO	0.062"	0.0	0.0
ACV	0.250"	0.1 CC 0.020 mm	0.0
ADB	0.266"	0.2	0.1

CC - 0.020 mm = crevice corrosion to a depth of 0.020 mm in a 10 day test

*Butt welded with added filler metal of AWS Er Ni Cr Mo - 4 by Standard GTAW process

PHYSICAL PROPERTIES

Density

0.321 lb/in^3

8.90 g/cm^3

Specific Gravity

8.90

Magnetic Permeability

1.02

Specific Heat

0.102 Btu/lb/°F

425 Joules/kg/°K

Electrical Resistivity

130 microhm-cm at 70°F (21°C)

Elastic Modulus 70°F (21°C)

29.8 x 106 psi (205 GPa)

Linear Coefficient of Thermal Expansion			
Average from 70°F 70°F (21°C) to °F (°C)		Linear Coefficient of Expansion	
°F	°C	10^{-6}in/in/°F	10^{-6}cm/cm/°C
200	93	6.2	11.2
400	204	6.7	12.0
600	316	7.1	12.8
800	427	7.3	13.2
1000	538	7.4	13.4

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Temperature °F	Temperature °C	Thermal Conductivity Btu/h•ft•°F	Thermal Conductivity W/m•K
-270	-168	4.2	7.3
-100	73	5.0	8.7
70	21	5.9	10.2
200	93	6.4	11.0
400	204	7.5	13.0
600	316	8.7	15.1
800	427	9.8	17.0
1000	538	11.0	19.0

MECHANICAL PROPERTIES

Room temperature mechanical properties are generally specified as follows:

Minimum Properties (ASTM B 575)

0.2% Yield Strength Minimum psi (MPa)	Ultimate Tensile Strength Minimum psi (MPa)	Elongation (% in 2") Minimum	Hardness Rb Maximum
41,000 (283)	100,000 (690)	40	100

Hardness measurement is taken for information only. Typical short time tensile properties as a function of temperature are listed below. Material tested was annealed at 2100°F (1150°C) and water quenched.

Temperature °F	Temperature °C	0.2% Yield Strength Ksi	0.2% Yield Strength (MPa)	Tensile Strength Ksi	Tensile Strength (MPa)	Elongation (% in 2")
-320	-196	82	(565)	140	(965)	45
150	101	70	(480)	130	(895)	50
70	21	60	(415)	115	(790)	50
200	93	55	(380)	105	(725)	50
400	204	50	(345)	103	(710)	50
600	316	46	(315)	98	(675)	55
800	427	42	(290)	95	(655)	60
1000	538	39	(270)	93	(640)	60

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Cold Working
The strength of the material may be increased by cold deformation. Typical room temperature properties of sheet and strip versus percent cold reduction are shown below:

Percent Cold Reduction	0.2% Yield Strength ksi (MPa)	Tensile Strength ksi (MPa)	Elongation (% in 2")
0	60 (415)	115 (790)	50
10	90 (620)	129 (890)	40
20	125 (860)	145 (1,000)	30
30	155 (1,070)	168 (1,160)	15
40	180 (1,240)	194 (1,340)	10
50	195 (1,345)	210 (1,450)	7

Impact Resistant
Charpy V-Notch impact strength of full thickness (10 mm) samples taken from annealed plate are listed below. Samples welded with matching filler may be expected to show ductile impact properties over the same temperature range, but the values may be lower due to the nature of the weld.

Test Temperature		Charpy V-Notch Impact Strength	
°F	°C	ft-lbs	Joules
-320	-196	180	245
70	21	240	325
392	200	240	325

FORMABILITY

ATI 276™ alloy is capable of being formed like the standard austenitic stainless steels. The material is considerably stronger than conventional austenitic stainless steels and consequently requires higher loads to cause the material to deform. During cold working, the material work hardens more rapidly than austenitic stainless steels. The combination of high initial strength and work hardening rate may necessitate need for intermediate anneals if the cold deformation is extensive.

WELDABILITY

ATI 276™ alloy has welding characteristics similar to the austenitic stainless steels. When selecting a welding method, techniques that minimize degradation of corrosion resistance should be used. Methods such as gas tungsten-arc welding (GTAW), gas metal-arc (GMAW), shielded metal-arc (coated electrode), or resistance welding do minimal damage to corrosion resistance of the weld and heat affected zone. Oxyacetylene welding should not be used because of probable carbon pick-up from the acetylene flame. Submerged arc fluxes containing carbon or silicon should not be used because they will similarly cause pick-up. Minimum level of heat input consistent with suitable penetration should be conducted to avoid hot cracking.

Weld Joints
Selection of weld joint type should be commensurate with good welding practices as set forth in the ASME Boiler and Pressure Vessel Code.

Edge Preparation
Machine tool beveling is the preferred way to obtain correct fit-up. Shearing will produce work hardening at the edges making it advisable to grind sheared edges back before welding.

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Post Weld Heat Treatment
For most corrosive service applications, ATI 276™ alloy may be used in the welded condition. For most severe service, the material should be solution heat treated for optimum resistance to corrosion.

Weld Wire and Filler
Matching wire and filler metal are available for welding ATI 276™ alloy to itself.

If there is a requirement to join ATI 276™ alloy to materials such as other nickel-base alloys or stainless steels, and if the welds will be exposed to a corrosive environment, the welding electrodes or weld wire should be comparable in corrosion resistance to the more noble alloy.

HEAT TREATMENT

All ATI 276™ alloy mill products are furnished in the solution heat-treated condition. This consists of heating in the 1900 to 2100°F (1040 - 1150°C) range and rapidly cooling. ATI 276™ alloy should be cooled from solution heat-treatment temperatures to black in two minutes or less for optimum corrosion resistance.

Stress relief heat treatments are not effective and full anneal should be conducted where stress relief heat treatment of other materials would be considered.

Material to be heat treated should be clean and free of grease, oils and other potential sources of carbon.

DESCALING AND CLEANING

Clean surface is required to obtain the optimum corrosion resistance of the ATI 276™ alloy. Surface oxides formed during anneal or welding tend to deplete chromium very close to the scale-base metal interface. For this reason, acid treatments which remove surface metal under scaled surfaces are necessary for optimum corrosion resistance. The alloy content of the material makes descaling difficult. Stainless wire brushing or grit blasting is advisable, followed by immersion in a mixture of nitric and hydrofluoric acids and a thorough water rinse.