Specification Sheet: Alloy 276 (UNS N10276)

A Nickel-Base Alloy with Resistance in a Wide Range of Aggressive Media

Alloy 276 (UNS N10276) is a nickel-molybdenum-chromium-iron-tungsten alloy which is among the most corrosion resistant alloys currently available. The high molybdenum content imparts resistance to localized corrosion such as pitting. The low carbon minimizes carbide precipitation during welding to maintain resistance to intergranular attack in heat-affected zones of welding joints.

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

Alloy 276 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.

Applications

- Chemical and petrochemical processing
- Flue gas desulfurization
- Pulp and paper equipment
- Industrial and municipal waste equipment
- Air pollution control

Standards

ASTM...............B 575

ASME...............SB 575

General Corrosion

Alloy 276 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. Alloy 276 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.

Alloy 276 is used in wet chlorine service where it is one of the few materials able to resist this very aggressive environment. Alloy 276 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 Alloy 276 compared to that of Alloy 316 in the “Green Death” simulated scrubber solution.

Green Death Solution (Boiling)	Corrosion Rate, MPY (mm/a)	
	Type 316	Alloy 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 Alloy 276 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 Alloy 276 to that of three other alloys in the 10% (Ferric Chloride • 6% H_2O) solution per ASTM Procedure G-48.

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

*Generally considered beyond the stability 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 Results & Test Time (Hours) Alloy 316	6% Moly	Alloy 625	Alloy 276
42% Magnesium Chloride (Boiling)	Fail (24 hours)	Mixed (1000 hours)	Resist (1000 hours)	Resist (1000 hours)
33% Lithium Chloride (Boiling)	Fail (100 hours)	Resist (1000 hours)	Resist (1000 hours)	Resist (1000 hours)
26% Sodium Chloride (Boiling)	Fail (300 hours)	Resist (1000 hours)	Resist (1000 hours)	Resist (1000 hours)

Chemical Analysis

Typical Analysis (Weight %)

C	Mn	P	S	Si	Cr	Ni	Mo	W	V	Co	Fe
0.006	0.150	0.005	0.002	0.03	15.50	Balance*	16.0	3.50	0.15	0.10	6.00

*By difference

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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 Minimum
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 2100ºF (1150ºC) and water quenched.

Temperature ºF	Temperature ºC	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

Impact Resistance

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

Physical Properties

Linear Coefficient of Thermal Expansion

Average from 70ºF 70ºF (21ºC) to ºF	ºF (ºC) ºC	Linear Coefficient of Expansion 10^{-6}in/in/°F	Linear Coefficient of Expansion 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

Thermal Conductivity

Temperature ºF	Temperature ºC	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

Density
0.321 lb/in^3
8.90 g/cm^3

Specific Gravity
8.90

Specific Heat
0.102 Btu/lb/°F
425 Joules/kg/°K

Magnetic Permeability
1.02

Electrical Resistivity
130 microhm-cm at 70ºF (21ºC)

Elastic Modulus 70ºF (21ºC)
29.8 x 10^6 psi (205 GPa)

Formability

Alloy 276 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 the need for intermediate anneals if the cold deformation is extensive.

Welding

Alloy 276 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.

Post-Weld Heat Treatment

For most corrosive service applications, Alloy 276 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 Alloy 276 to itself.

If there is a requirement to join Alloy 276 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 Alloy 276 mill products are furnished in the solution heat-treated condition. This consists of heating in the 1900º-2100°F (1040º-1150°C) range and rapidly cooling. Alloy 276 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 Alloy 276.

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.