TECHNICAL DATA
BLUE SHEET

Stainless Steel
Type 316Ti

Austenitic Stainless Steel (UNS S31635)

GENERAL PROPERTIES

Allegheny Ludlum Type 316Ti (UNS S31635) is a titanium stabilized version of Type 316 molybdenum-bearing austenitic stainless steel. It is also known as DIN/EN designation No. 1.4571. The Type 316 alloys are more resistant to general corrosion and pitting/crevice corrosion than the conventional chromium-nickel austenitic stainless steels such as Type 304. They also offer higher creep, stress-rupture and tensile strength at elevated temperature. Type 316 stainless steel can be susceptible to sensitization – the formation of grain boundary chromium carbides at temperatures between approximately 900 and 1500 °F (425 to 815 °C) – which can result in rapid corrosion. Reduced carbon Type 316L is resistant to sensitization; however, extended exposures in this temperature range will eventually result in sensitization of even the low carbon grade. Resistance to sensitization is achieved in Type 316Ti with titanium additions to stabilize the structure against chromium carbide precipitation, which is the source of sensitization. This stabilization is achieved by an intermediate-temperature heat treatment, during which the titanium reacts with carbon to form titanium carbides. This significantly reduces susceptibility to sensitization in service by limiting the formation of chromium carbides. Thus, the alloy can be used for extended periods at elevated temperatures without compromising its corrosion resistance. Like Types 316 and 316L, the Type 316Ti alloy also offers excellent resistance to general corrosion and pitting/crevice corrosion.

SPECIFICATION COVERAGE

Type 316Ti is included in ASTM A 240 for plate, sheet, and strip products.

COMPOSITION (Weight percents)

Element	Minimum	Maximum*
Chromium	16.0	18.0
Molybdenum	2.00	3.00
Nickel	10.0	14.0
Manganese		2.00
Phosphorus		0.045
Sulfur		0.030
Silicon		0.75
Carbon		0.08
Nitrogen		0.10
Titanium	5 x %(C+N)	0.70
Iron	balance	

*** ASTM Specification A 240**

PHYSICAL PROPERTIES

Property	Value	Units
Density at 72°F (22°C)	8.00 0.289	g/cm^3 lb/in^3
Melting Range	2450 °F – 2630 °F	1345 °C – 1440 °C
Thermal Conductivity at 212 °F (100°C)	8.4 14.6	BTU/hr·ft·°F W/m·K
Thermal Expansion coefficient at 68-212°F (20-100°C)	9.2 16.5	μ in/in/°F μ m/m/°C
Thermal Expansion coefficient at 68-932°F (20-500°C)	10.1 18.2	μ in/in/°F μ m/m/°C
Thermal Expansion coefficient at 68-1832°F (20-1000°C)	10.8 19.5	μ in/in/°F μ m/m/°C

Data are typical and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those shown herein.

Type 316Ti is a single phase austenitic (face centered cubic) stainless steel at all temperatures up to the melting point. The alloy can not be hardened by heat treatment. The alloy is nonmagnetic in the annealed condition. Its magnetic permeability is typically less than 1.02 at 200 H (Oersteds). Permeability values for cold deformed material vary with composition and the amount of cold deformation, but are usually higher than that for annealed material.

MECHANICAL PROPERTIES

Typical Room Temperature properties

Property	Typical Value	ASTM A 240
Yield Strength 0.2% offset	36ksi 248 MPa	30 ksi* 205 MPa*
Ultimate Tensile Strength	90 ksi 620 MPa	75 ksi* 515 MPa*
Elongation in 2" (51 mm)	54%	40%*
Hardness	76 HRB	217 Brinell** 95 HRB**

* minimum, ** maximum

Typical Elevated Temperature Properties

Test Temperature (°F/ °C)	Yield Strength[1] ksi (MPa)	Tensile Strength ksi (MPa)	Elongation[2] (%)
200 / 93	30.2 (208)	75.2 (518)	39.5
400 / 204	26.0 (179)	66.0 (455)	28.0
600 / 316	23.1 (159)	64.2 (443)	26.0
800 / 427	21.2 (146)	62.7 (433)	25.0
1000 / 538	21.0 (145)	61.3 (423)	23.0
1200 / 649	21.1 (146)	54.4 (375)	19.5
1400 / 760	21.1 (146)	37.9 (261)	23.0
1600 / 871	16.2 (112)	22.5 (155)	48.0
1800 / 982	8.0 (55)	11.3 (78)	41.0

[1] 0.2% Offset
[2] In 2-inch gauge length

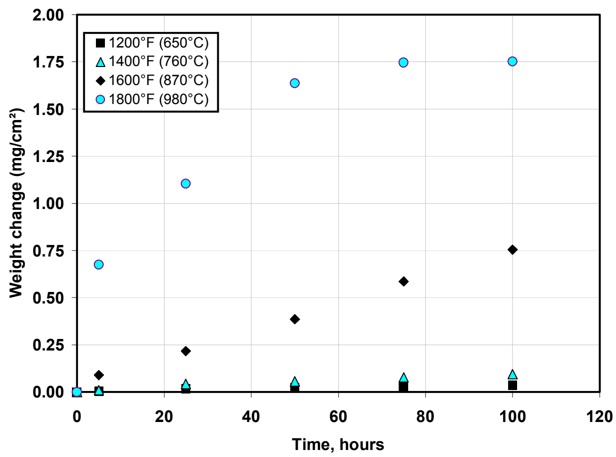
Fatigue Resistance

The fatigue strength or endurance limit is the maximum stress below which a material is unlikely to fail in 10 million cycles in an air environment. For austenitic stainless steels as a group, the fatigue strength is typically about 35 percent of the tensile strength. However, substantial variability in service results is experienced since additional variables such as corrosive conditions, type of loading and mean stress, surface condition, and other factors affect fatigue properties. For this reason, no definitive endurance limit value can be given which is representative of all operating conditions.

OXIDATION RESISTANCE

Type 316Ti alloy exhibits excellent resistance to oxidation and a low rate of scaling in air atmospheres at temperatures up to 1600-1650°F (870-900°C). Weight change vs. time data for exposure of Type 316Ti to air over a range of temperatures may be seen in the following figure. The performance of Type 316Ti is slightly inferior to that of Type 304 stainless steel, which has slightly higher chromium content (18% vs. 16% for Type 316Ti). The rate of oxidation is greatly influenced by the atmosphere encountered in service and by operating conditions. For this reason, no data can be presented that is applicable to all service conditions.

Like other molybdenum bearing alloys, Type 316Ti is subject to catastrophic oxidation at high temperatures in stagnant air atmospheres, such as in the heat treatment of closely packed items. This occurs due to the formation of low melting molybdenum trioxide (MoO_3), which reacts with the alloy causing deep pitting and metal loss. When air is allowed to circulate, the MoO_3 will evaporate from the metal surface and excessive oxidation is avoided.



Weight change vs. time for Type 316Ti exposed to various temperatures in air.

CORROSION PROPERTIES

General Corrosion Resistance

The molybdenum bearing grades such as Types 316 and 316Ti stainless steels are more resistant to atmospheric and other mild types of corrosion than the 18Cr-8Ni stainless steels. In general, media that do not corrode 18-8 stainless steels will not attack the molybdenum-containing grades. One known exception is highly oxidizing acids such as nitric acid to which the molybdenum bearing stainless steels are less resistant. Types 316 and 316Ti are considerably more resistant than any of the other chromium-nickel types to solutions of sulfuric acid. Where condensation of sulfur-bearing gases occurs, these alloys are much more resistant than other types of stainless steels. In sulfuric acid solutions, the acid concentration has a strong influence on the rate of attack.

Pitting Corrosion

Resistance of austenitic stainless steels to pitting and/or crevice corrosion in the presence of chloride or other halide ions is enhanced by higher chromium (Cr) and molybdenum (Mo) content. A relative measure of pitting resistance is given by the PRE (Pitting Resistance Equivalent) calculation, where:

$$PRE = Cr + 3.3Mo$$

The PRE of Type 316Ti (23.0) is higher than that of Type 304 (PRE =19.0), reflecting the better pitting resistance which Type 316Ti offers due to its Mo content. Type 304 stainless steel is considered to resist pitting and crevice corrosion in waters containing up to about 100 ppm chloride. Type 316Ti alloy on the other hand, due to its Mo-content, will handle waters with up to about 2000 ppm chloride. This alloy is not recommended for use in seawater (~19,000 ppm chloride). Type 316Ti alloy is considered adequate for some applications that are exposed to salt spray. Type 316Ti stainless steel exhibits no evidence of corrosion in the 100-hour, 5% salt spray (ASTM B117) test.

Intergranular Corrosion

Type 316 stainless steel is susceptible to precipitation of chromium carbides in grain boundaries when exposed to temperatures in the 800°F to 1500°F (425°C to 815°C) range. Such "sensitized" steels are subject to intergranular corrosion when exposed to aggressive environments. Type 316L alloy is available to avoid the hazard of intergranular corrosion. Type 316L provides resistance to intergranular attack even after short periods of exposure in the 800-1500°F (425-815°C) temperature range. Stress relieving treatments falling within these limits can be employed without affecting the corrosion resistance of the metal. Accelerated cooling from higher temperatures for the "L" grades is not needed when very heavy or bulky sections have been annealed. Type 316Ti possesses the same mechanical properties as the corresponding higher-carbon Type 316, and offers resistance to intergranular corrosion. Although the short duration heating encountered during welding or stress relieving does not produce susceptibility to intergranular corrosion, continuous or prolonged exposure at 800-1200°F (422-650°C) can produce sensitization of Type 316Ti (and of Type 316L).

The combined influences of molybdenum and titanium reduce the resistance of Type 316Ti stainless steel to highly oxidizing environments including the nitric acid environment of the ASTM A 262 practice C "Huey" test and the ferric sulfate environment of the ASTM A 262 Practice B "Streicher" test. However, testing in the less oxidizing ASTM A 262 Practice F test (Copper-Copper Sulfate-50% Sulfuric Acid environment) has demonstrated the resistance of Type 316Ti stainless steel to sensitization.

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Stress Corrosion Cracking

Austenitic stainless steels are susceptible to stress corrosion cracking (SCC) in halide environments. Although the Type 316, 316L and 316Ti alloys are more resistant to SCC than the 18 Cr-8 Ni alloys, they still are quite susceptible. Conditions that produce SCC are:

(1) Presence of halide ion (generally chloride),
(2) Residual tensile stresses, and
(3) Temperature in excess of about 140°F (60°C).

Stresses result from cold deformation or thermal cycles during welding. Annealing or stress relieving heat treatments may be effective in reducing stresses, thereby reducing sensitivity to halide SCC. Although the stabillized Type 316Ti and low carbon "L" grades offer no advantage as regards SCC resistance, they are better choices for service in the stress relieved condition in environments which might cause intergranular corrosion.

FABRICATION AND WELDING

Fabrication

The austenitic stainless steels, including the Type 316Ti alloy, are routinely fabricated into a variety of shapes ranging from the very simple to very complex. These alloys are blanked, pierced, and formed on equipment essentially the same as used for carbon steel. The excellent ductility of the austenitic alloys allows them to be readily formed by bending, stretching, deep drawing and spinning. However, because of their greater strength and work hardenability, the power requirements for the austenitic grades during forming operations are considerably greater than for carbon steels. Attention to lubrication during forming of the austenitic alloys is essential to accommodate the high strength and galling tendency of these alloys.

Annealing

The austenitic stainless steels are provided in the mill-annealed condition ready for use. Heat treatment may be necessary during or after fabrication to remove the effects of cold forming or to dissolve precipitated chromium carbides resulting from thermal exposures. For the Type 316Ti alloy the solution anneal is accomplished by heating in the 1900-2150°F (1040-1175°C) temperature range followed by air cooling or a water quench, depending on section thickness. For maximum resistance to sensitization, Type 316Ti should be given a stabilizing heat treatment at 1550-1650°F (845-900°C) to precipitate titanium carbides and prevent the precipitation of chromium carbides during lower temperature exposure. Type 316Ti cannot be hardened by heat treatment.

Welding

The austenitic stainless steels are considered the most weldable of the stainless steels. They are routinely joined by all fusion and resistance welding processes. Two important considerations for weld joints in these alloys are (1) avoidance of solidification cracking, and (2) preservation of corrosion resistance of the weld and heat-affected zones. Type 316Ti stainless steel often is welded autogenously. If filler metal must be used for welding Type 316Ti, it is advisable to utilize the low carbon Types 316L or E318 filler metals. Contamination of the weld region with copper or zinc should be avoided, since these elements can form low melting point compounds, which in turn can create weld cracking.

Stabilized austenitic stainless steels, such as Type 316Ti, can be attacked by intergranular corrosion under certain special conditions after welding. One such condition results in what is known as "knifeline attack." This manifests itself as a very narrow band of severe corrosion adjacent to a weld. This occurs when the metal adjacent to the weld is heated to a high temperature (greater than 2100°F) so that the titanium carbides are dissolved, and then subsequently exposed to temperatures in the sensitizing region (800°–1500°F; 425°C–815°C). At these temperatures, the rate of formation of titanium carbides is sluggish, and the free carbon reacts with chromium to form grain boundary carbides in the heat affected zone.