Specification Sheet: Alloy 316/316L
(UNS S31600, S31603) W. Nr. 1.4401, 1.4404

An Austenitic Stainless Steel Containing Molybdenum Which is More Corrosion Resistant than the Conventional 304/304L Stainless Steel

Alloy 316/316L (UNS S31600/S31603) is a chromium-nickel-molybdenum austenitic stainless steel developed to provide improved corrosion resistance to Alloy 304/304L in moderately corrosive environments. It is often utilized in process streams containing chlorides or halides. The addition of molybdenum improves general corrosion and chloride pitting resistance. It also provides higher creep, stress-to-rupture and tensile strength at elevated temperatures.

It is common practice for 316L to be dual certified as 316 and 316L. The low carbon chemistry of 316L combined with an addition of nitrogen enables 316L to meet the mechanical properties of 316.

Alloy 316/316L resists atmospheric corrosion, as well as, moderately oxidizing and reducing environments. It also resists corrosion in polluted marine atmospheres. The alloy has excellent resistance to intergranular corrosion in the as-welded condition. Alloy 316/316L has excellent strength and toughness at cryogenic temperatures.

Alloy 316/316L is non-magnetic in the annealed condition, but can become slightly magnetic as a result of cold working or welding. It can be easily welded and processed by standard shop fabrication practices.

Standards

ASTM ..... A 240
ASME ..... SA 240
AMS 5524/5507
QQ-S 766

Applications

- Chemical and Petrochemical Processing — pressure vessels, tanks, heat exchangers, piping systems, flanges, fittings, valves and pumps
- Food and Beverage Processing
- Marine
- Medical
- Petroleum Refining
- Pharmaceutical Processing
- Power Generation — nuclear
- Pulp and Paper
- Textiles
- Water Treatment

Chemical Analysis

Weight % (all values are maximum unless a range is otherwise indicated)

Element	316	316L
Chromium	16.0 min.–18.0 max.	16.0 min.–18.0 max.
Nickel	10.0 min.–14.0 max.	10.0 min.–14.0 max.
Molybdenum	2.00 min.–3.00 max.	2.00 min.–3.00 max.
Carbon	0.08	0.030
Manganese	2.00	2.00
Phosphorous	0.045	0.045
Sulfur	0.03	0.03
Silicon	0.75	0.75
Nitrogen	0.1	0.1
Iron	Balance	Balance

Physical Properties

Density
0.285 lbs/in^3
7.90 g/cm^3

Specific Heat
0.11 BTU/lb-°F (32–212°F)
450 J/kg-°K (0–100°C)

Modulus of Elasticity
29.0 x 10^6 psi
200 GPa

Thermal Conductivity 212°F (100°C)
10.1 BTU/hr/ft^2/ft/°F
14.6 W/m-°K

Melting Range
2450–2630°F
1390–1440°C

Electrical Resistivity
29.1 Microhm-in at 68°F
74 Microhm-cm at 20°C

Mean Coefficient of Thermal Expansion

Temperature Range			
°F	°C	in/in/°F	cm/cm °C
68–212	20–100	9.2 x 10^{-6}	16.6 x 10^{-6}
68–932	20–500	10.1 x 10^{-6}	18.2 x 10^{-6}
68–1832	20–1000	10.8 x 10^{-6}	19.4 x 10^{-6}

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Mechanical Properties

At Room Temperature

	Typical*	ASTM	
		Type 316	Type 316L
0.2% Offset Yield Strength, ksi	44	30 min.	25 min.
Ultimate Tensile Strength, ksi	85	75 min.	70 min.
Elongation in 2 inches, %	56	40 min.	40 min.
Reduction in Area, %	69	—	—
Hardness, Rockwell B	81	95 max.	95 max.

**0.375 inch plate*

Corrosion Resistance

	Composition (Weight Percent)				CCT[2]	CPT[3]
ALLOY	Cr	Mo	N	PRE_N[1]	°F (°C)	°F (°C)
Type 304	18.0	—	0.06	19.0	<27.5 (<-2.5)	— —
Type 316	16.5	2.1	0.05	24.2	27.5 (-2.5)	59 (15.0)
Type 317	18.5	3.1	0.06	29.7	35.0 (1.7)	66 (18.9)
SSC-6MO	20.5	6.2	0.22	44.5	110 (43.0)	149 (65)

[1] *Pitting Resistance Equivalent, including Nitrogen, PREN = Cr + 3.3Mo + 16N*
[2] *Critical Crevice Corrosion Temperature, CCCT, based on ASTM G-48B (6% $FeCl_3$ for 72 hr, with crevices*
[3] *Critical Pitting Temperature, CPT, based on ASTM G-48A (6% $FeCl_3$ for 72 hr)*

Lowest Temperature (°F) at Which the Corrosion Rate Exceeds 5 mpy

CORROSION ENVIRONMENT	Type 316L	Type 304	2205 (UNS S32205)	2507
0.2% Hydrochloric Acid	>Boiling	>Boiling	>Boiling	>Boiling
1% Hydrochloric Acid	86	86p	185	>Boiling
10% Sulfuric Acid	122	—	140	167
60% Sulfuric Acid	<54	—	<59	<57
96% Sulfuric Acid	113	—	77	86
85% Phosphoric Acid	203	176	194	203
10% Nitric Acid	>Boiling	>Boiling	>Boiling	>Boiling
65% Nitric Acid	212	212	221	230
80% Acetic Acid	>Boiling	212p	>Boiling	>Boiling
50% Formic Acid	104	≥50	194	194
50% Sodium Hydroxide	194	185	194	230
83% Phosphoric Acid + 2% Hydrofluoric Acid	149	113	122	140
60% Nitric Acid + 2% Hydrochloric Acid	>140	>140	>140	>140
50% Acetic Acid + 50% Acetic Anhydride	248	>Boiling	212	230
1% Hydrochloric Acid + 0.3% Ferric Chloride	77p	68p	113ps	203ps
10% Sulfuric Acid + 2000ppm Cl- + N_2	77	—	95	122
10% Sulfuric Acid + 2000ppm Cl- + SO_2	<<59p	—	<59	104
WPA1, High Cl- Content	≤50	<<50	113	203
WPA2, High F- Content	≤50	<<50	140	167

ps = pitting can occur
ps = pitting/crevice corrosion can occur

WPA	P_2O_5	Cl^-	F^-	H_2SO_4	Fe_2O_3	Al_2O_3	SiO_2	CaO	MgO
1	54	0.20	0.50	4.0	0.30	0.20	0.10	0.20	0.70
2	54	0.02	2.0	4.0	0.30	0.20	0.10	0.20	0.70

In most applications Alloy 316/316L has superior corrosion resistance to Alloy 304/304L. Process environments that do not corrode Alloy 304/304L will not attack this grade. One exception, however, is in highly oxidizing acids such as nitric acid where stainless steels containing molybdenum are less resistant. Alloy 316/316L performs well in sulfur containing service such as that encountered in the pulp and paper industry. The alloy can be used in high concentrations at temperatures up to 120°F (38°C).

Alloy 316/316L also has good resistance to pitting in phosphoric and acetic acid. It performs well in boiling 20% phosphoric acid. The alloy can also be used in the food and pharmaceutical process industries where it is utilized to handle hot organic and fatty acids in an effort to minimize product contamination.

Alloy 316/316L performs well in fresh water service even with high levels of chlorides. The alloy has excellent resistance to corrosion in marine environments under atmospheric conditions.

The higher molybdenum content of Alloy 316/316L assures it will have superior pitting resistance to Alloy 304/304L in applications involving chloride solutions, particularly in an oxidizing environment.

In most instances, the corrosion resistance of Alloys 316 and 316L will be roughly equal in most corrosive environments. However, in environments that are sufficiently corrosive to cause intergranular corrosion of welds and heat-affected zones Alloy 316L should be used because of its low carbon content.

Fabrication Data

Alloy 316/316L can be easily welded and processed by standard shop fabrication practices.

Hot Forming

Working temperatures of 1700–2200°F (927–1204°C) are recommended for most hot working processes. For maximum corrosion resistance, the material should be annealed at 1900°F (1038°C) minimum and water quenched or rapidly cooled by other means after hot working.

Cold Forming

The alloy is quite ductile and forms easily. Cold working operations will increase the strength and hardness of the alloy and might leave it slightly magnetic.

Welding

Alloy 316/316L can be readily welded by most standard processes. A post weld heat treatment is not necessary.

Machining

Alloy 316/316L is subject to work hardening during deformation and is subject to chip breaking. The best machining results are achieved with slower speeds, heavier feeds, excellent lubrication, sharp tooling and powerful rigid equipment.

Operation / Tool / Lubrication			CONDITIONS					
			Depth-mm	Depth-in	Feed-mm/t	Feed-in/t	Speed-m/min	Speed-ft/min
Turning	High Speed Steel	Cutting Oil	6	.23	0.5	.019	11–16	36.1–52.5
			3	.11	0.4	.016	18–23	59.1–75.5
			1	.04	0.2	.008	25–30	82–98.4
	Carbide	Dry or Cutting Oil	6	.23	0.5	.019	70–80	229.7–262.5
			3	.11	0.4	.016	85–95	278.9–312.7
			1	.04	0.2	.008	100–110	328.1–360.9
			Depth of cut-mm	Depth of cut-in	Feed-mm/t	Feed-in/t	Speed-m/min	Speed-ft/min
Cutting	High Speed Steel	Cutting Oil	1.5	.06	0.03–0.05	.0012–.0020	16–21	52.5–68.9
			3	.11	0.04–0.06	.0016–.0024	17–22	55.8–72.2
			6	.23	0.05–0.07	.0020–.0027	18–23	59–75.45
			Drill ø mm	Drill ø in	Feed-mm/t	Feed-in/t	Speed-m/min	Speed-ft/min
Drilling	High Speed Steel	Cutting Oil	1.5	.06	0.02–0.03	.0008–.0012	10–14	32.8–45.9
			3	.11	0.05–0.06	.0020–.0024	12–16	39.3–52.5
			6	.23	0.08–0.09	.0031–.0035	12–16	39.3–52.5
			12	.48	0.09–0.10	.0035–.0039	12–16	39.3–52.5
					Feed-mm/t	Feed-in/t	Speed-m/min	Speed-ft/min
Milling Profiling	High Speed Steel	Cutting Oil			0.05–0.10	.002–.004	10–20	32.8–65.6

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