304/304L

Stainless Steel: Austenitic (Chromium-Nickel)

INTRODUCTION

304 (S30400), 304L (S30403), stainless steels are variations of the 18 percent chromium – 8 percent nickel austenitic alloy, the most familiar and most frequently used alloy in the stainless steel family. These alloys may be considered for a wide variety of applications where one or more of the following properties are important:

1. Resistance to corrosion
2. Prevention of product contamination
3. Resistance to oxidation
4. Ease of fabrication
5. Excellent formability
6. Beauty of appearance
7. Ease of cleaning
8. High strength with low weight
9. Good strength and toughness at cryogenic temperatures
10. Ready availability of a wide range of product forms

Each alloy represents an excellent combination of corrosion resistance and fabricability. This combination of properties is the reason for the extensive use of these alloys which represent nearly one half of the total U.S. stainless steel production. 304 alloy represents the largest volume followed by 304L alloy. The 18-8 stainless steels, principally 304 and 304L alloys, are available in a wide range of product forms including sheet, strip, foil and plate. The alloys are covered by a variety of specifications and codes relating to, or regulating, construction or use of equipment manufactured from these alloys for specific conditions. Food and beverage, sanitary, cryogenic, and pressure-containing applications are examples.

Past users of 302 stainless are generally now using 304 alloy since AOD technology has made lower carbon levels more easily attainable and economical. There are instances, such as in temper rolled products, when 302 alloy is preferred over 304 since the higher carbon permits meeting of yield and tensile strength requirements while maintaining a higher level of ductility (elongation) versus that of the lower carbon 304. 304L alloy is used for welded products which might be exposed to conditions which could cause intergranular corrosion in service.

TYPICAL COMPOSITION

Chemistries per ASTM A240:

Element	Percentage by Weight Maximum Unless Range is Specified			
		304	304L	
Carbon		0.07	0.030	
Manganese		2.00	2.00	
Phosphorus		0.045	0.045	
Sulfur		0.030	0.030	
Silicon		0.75	0.75	
Chromium		17.5 19.5	17.5 19.5	
Nickel		8.0 10.5	8.0 12.0	
Nitrogen		0.10	0.10	

SPECIFICATIONS & CERTIFICATES

Because of the extensive use of these austenitic stainless steels, and their broad specification coverage, the following list of specifications is representative, but not complete.

Product Form	Specification	
	ASTM	ASME
Plate, Sheet and Strip	A 240	SA-240
Seamless and/or Welded Tubing	A 249/A 249M (304, 304L, 305 only), A 269/ A269M (304, 304L only), A554	SA-249/SA-249M (304, 304L only)
Seamless and/or Welded Pipe	A 312/A 312M, A 409/A 409M (304, 304L only)	SA-312/SA-312M,SA-409/SA- 409M (304, 304L only)
Bar, Wire	A 276, A 478, A 479/A 479M (302, 304, 304L only)	SA-479/SA-479M (302, 304, 304L only)
Billet, Forgings	A 314, A 473	
Flanges, Fittings	A 182/A 182M, A 403/A 403M (304, 304L only)	SA-182/SA-182M, SA-403/SA- 403M (304, 304L only)

In Section II, Part D of the ASME Boiler and Pressure Vessel Code, 304 alloy is assigned allowable stresses for a variety of product forms to maximum use temperatures of 1500°F (816°C). 304L alloy coverage includes fewer product forms with lower allowable stresses to maximum use temperature of 800°F (426°C).

All of the grades are accepted for use in food preparation and storage by the National Sanitation Foundation and for contact with dairy products by the Dairy and Food Industries Supply Association – Sanitary Standards Committee and are standard materials used in each industry. Similarly, 304 and 304L alloys are standard materials of construction in the brewery industry.

PHYSICAL PROPERTIES

Density:
0.285 lb/in^3 (7.90 g/cm^3)

Modulus of Elasticity in Tension:
29 x 10^6 psi (200 GPa)

Linear Coefficient of Thermal Expansion:

Temperature Range		Coefficients	
°F	°C	in/in/°F	cm/cm/°C
68 - 212	20 - 100	9.2 x 10^{-6}	16.6 x 10^{-6}
68 - 1600	20 - 870	11.0 x 10^{-6}	19.8 x 10^{-6}

Linear Coefficient of Thermal Expansion

Temperature Range		Btu/hr•ft•°F	W/m•K
°F	°C		
212 932	100 500	9.4 12.4	16.3 21.4

The overall heat transfer coefficient of metals is determined by factors in addition to the thermal conductivity of the metal. The ability of the 18-8 stainless grades to maintain clean surfaces often allows better heat transfer than other metals having higher thermal conductivity.

Specific Heat

°F	°C	Btu/lb/°F	J/kg•K
32 - 212	0 - 100	0.12	500

Magnetic Permeability

The 18-8 alloys are generally non-magnetic in the annealed condition with magnetic permeability values typically less than 1.02 at 200H. As illustrated below, permeability values will vary with composition and will increase with cold work. The following data are illustrative:

Percent Cold Work	Magnetic Permeability			
		304	304L	
0		1.005	1.015	
10		1.009	1.064	
30		1.163	3.235	
50		2.291	8.480	

Melting Range

°F	°C
2,550 - 2,590	1,399 - 1,421

Electrical Resistivity

Temperature		Microhm-in	Microhm-cm
°F	°C		
68	20	28.3	72
212	100	30.7	78
392	200	33.8	86
752	400	39.4	100
1112	600	43.7	111
1472	800	47.6	121
1652	900	49.6	126

MECHANICAL PROPERTIES

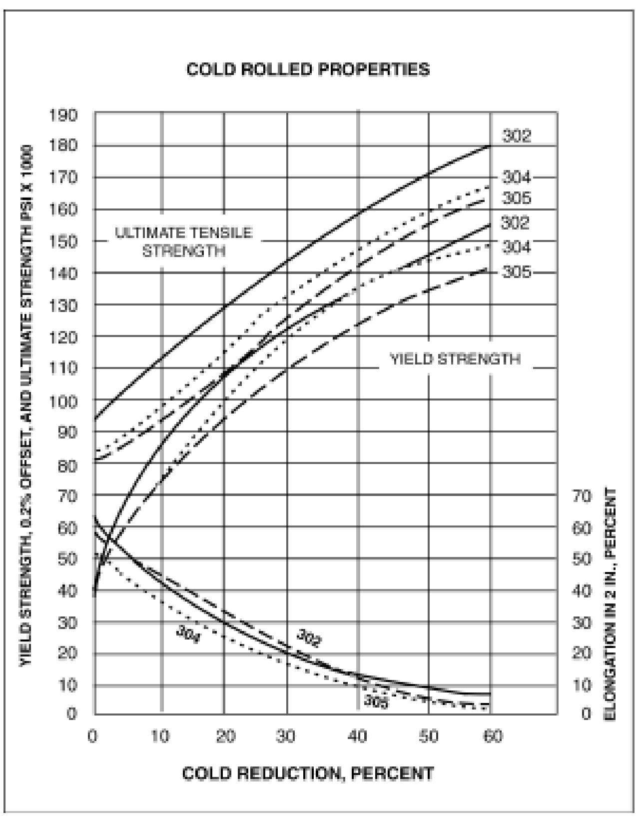
Room Temperature Mechanical Properties

Minimum mechanical properties for annealed 304, and 304L austenitic stainless steel plate, sheet and strip as required by ASTM specifications A 240 and ASME specification SA-240 are shown below.

Property	Minimum Mechanical Properties Required by ASTM A 240, and ASME SA-240	
	304	304L
0.2% Offset Yield Strength, psi Mpa	30,000 205	25,000 170
Ultimate Tensile Strength, psi Mpa	75,000 515	70,000 485
Percent Elongation in 2 in. or 51 mm	40.0	40.0
Hardness, Max., Brinell RB	201 92	201 92

Effect of Cold Work

Deformation of the 18-8 alloys at room or slightly elevated temperatures produces an increase in strength accompanied by a decrease in elongation value. A portion of this increase in strength is caused by partial transformation of austenite to martensite during deformation. As shown by the permeability data, the 304 and 304L alloys are more prone to martensite formation. Strengthening during deformation is, therefore, more pronounced in the leaner compositions. Typical data are shown below.

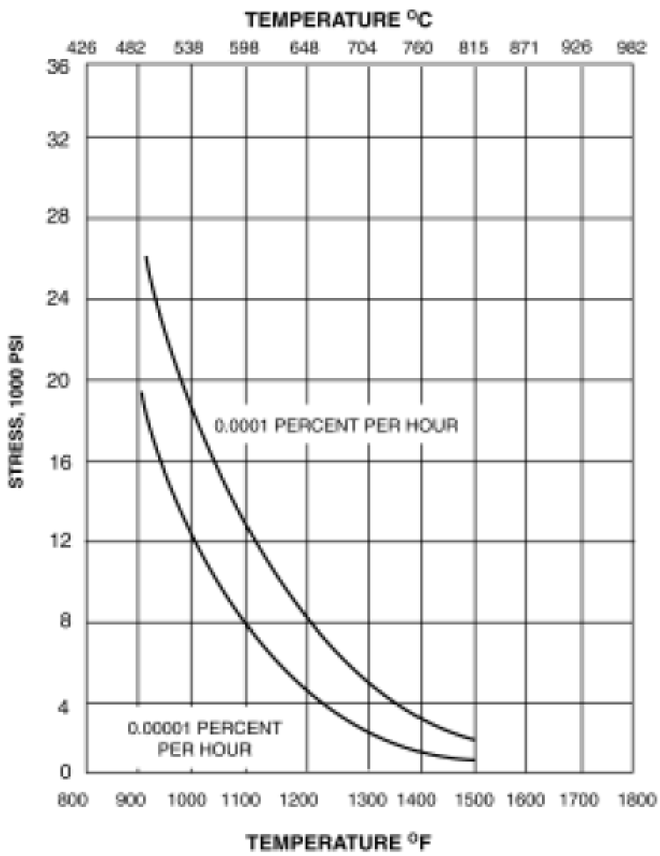


Low and Elevated Temperature Properties

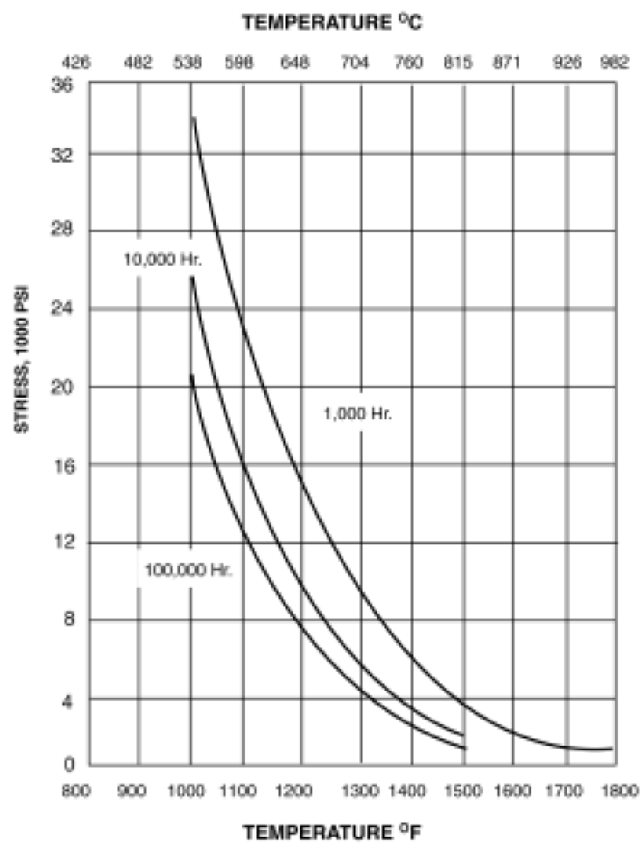
Typical short time tensile property data for low and elevated temperatures are shown below. At temperatures of 1000°F (538°C) or higher, creep and stress rupture become considerations. Typical creep and stress rupture data are also shown below.

Test Temperature		0.2% Yield Strength		Tensile Strength		Elongation
°F	°C	psi	(MPa)	psi	(MPa)	Percent in 2" or 51 mm
-423	-253	100	690	250	1725	25
-320	-196	70	485	230	1585	35
-100	-79	50	345	150	1035	50
70	21	35	240	90	620	60
400	205	23	160	70	485	50
800	427	19	130	66	455	43
1200	650	15,5	105	48	330	34
1500	815	13	90	23	160	46

CREEP STRENGTH
ANNEALED STAINLESS
ATI 302™, ATI 304™, ATI 305™



STRESS RUPTURE STRENGTH
ANNEALED STAINLESS
ATI 302™, 304™, 305™



Impact Resistance

The annealed austenitic stainless steels maintain high impact resistance even at cryogenic temperatures, a property which, in combination with their low temperature strength and fabricability, has led to their use in handling liquified natural gas and other cryogenic environments. Typical Charpy V-notch impact data are shown below.

Temperature		Charpy V-Notch Energy Absorbed	
°F	°C	Foot - pounds	Joules
75	23	150	200
-320	-196	85	115
-425	-254	85	115

Fatigue Strength

The fatigue strength or endurance limit is the maximum stress below which material is unlikely to fail in 10 million cycles in air environment. The fatigue strength for austenitic stainless steels, as a group, is typically about 35 percent of the tensile strength. Substantial variability in service results is experienced since additional variables influence fatigue strength. As examples – increased smoothness of surface improves strength, increased corrosivity of service environment decreases strength.

CORROSION RESISTANCE

General Corrosion

304, and 304L austenitic stainless steels provide useful resistance to corrosion on a wide range of moderately oxidizing to moderately reducing environments. The alloys are used widely in equipment and utensils for processing and handling of food, beverages and dairy products. Heat exchangers, piping, tanks and other process equipment in contact with fresh water also utilize these alloys. Building facades and other architectural and structural applications exposed to non-marine atmospheres also heavily utilize the 18-8 alloys. In addition, a large variety of applications involve household and industrial chemicals.

The 18 to 19 percent of chromium which these alloys contain provides resistance to oxidizing environments such as dilute nitric acid, as illustrated by data for 304 below.

% Nitric Acid	Temperature		Corrosion Rate	
	°F	°C	Mils/Yr	mm/a
10	300	149	5.0	0.13
20	300	149	10.1	0.25
30	300	149	17.0	0.43

Other laboratory data for 304 and 304L alloys in the table below illustrate that these alloys are also resistant to moderately aggressive organic acids such as acetic, and reducing acids such as phosphoric. The 9 to 11 percent of nickel contained by these 18-8 alloys assists in providing resistance to moderately reducing environments. The more highly reducing environments such as boiling dilute hydrochloric and sulfuric acids are shown to be too aggressive for these materials. Boiling 50 percent caustic is likewise too aggressive.

General Corrosion in Boiling Chemicals					
Boiling Environment		Corrosion Rate, Mils/Yr (mm/a)			
		304		304L	
20% Acetic Acid,	Base Metal Welded*	0.1 1.0	(<0.01) (0.03)	0.1 0.1	(<0.01) (<0.01)
45% Formic Acid,	Base Metal Welded*	55 52	(1.4) (1.3)	15 19	(0.4) (0.5)
10% Sulfamic Acid,	Base Metal Welded*	144 144	(3.7) (3.7)	50 57	(1.3) (1.4)
1% Hydrochloric,	Base Metal Welded	98 112	(2.5) (2.8)	85 143	(2.2) (3.6)
20% Phosphoric Acid,	Base Metal Welded	<1.0 <1.0	(<0.03) (<0.03)	- -	- -
65% Nitric Acid,	Base Metal Welded	9.2 9.4	(0.2) (0.2)	8.9 7.4	(0.2) (0.2)
10% Sulfuric Acid,	Base Metal Welded	445 494	(11.3) (12.5)	662 879	(16.8) (22.3)
50% Sodium Hydroxide	Base Metal Welded	118 130	(3.0) (3.3)	71 87	(1.8) (2.2)

*Autogenous weld on base metal sample.

In some cases, the low carbon 304L alloy may show a lower corrosion rate than the higher carbon 304 alloy. The data for formic acid, sulfamic acid and sodium hydroxide illustrate this. Otherwise, the 304, and 304L alloys may be considered to perform equally in most corrosive environments. A notable exception is in environments sufficiently corrosive to cause intergranular corrosion of welds and heat-affected zones on susceptible alloys. The 304L alloy is preferred for use in such media in the welded condition since the low carbon level enhances resistance to intergranular corrosion.

Intergranular Corrosion

Exposure of the 18-8 austenitic stainless steels to temperatures in the 800°F to 1500°F (427°C to 816°C) range may cause precipitation of chromium carbides in grain boundaries. Such steels are "sensitized" and subject to intergranular corrosion when exposed to aggressive environments. The carbon content of 304 alloy may allow sensitization to occur from thermal conditions experienced by autogenous welds and heat-affected zones of welds. For this reason, the low carbon 304L alloy is preferred for applications in which the material is put into service in the as-welded condition. Low carbon content extends the time necessary to precipitate a harmful level of chromium carbides, but does not eliminate the precipitation reaction for material held for long times in the precipitation temperature range.

Intergranular Corrosion Tests		
ASTM A 262 Evaluation Test	Corrosion Rate, Mils/Yr (mm/a)	
	304	304L
Practice B Base Metal Welded	20 (0.5) Intergranular 23 (0.6) Corrosion	20 (0.5) 20 (0.5)
Practice E Base Metal Welded	No Fissures on Bend Some Fissures on Weld (unacceptable)	No Fissures No Fissures
Practice A Base Metal Welded	Step Structure Ditched (unacceptable)	Step Structure Step Structure

Stress Corrosion Cracking

The 304 and 304L and alloys are the most susceptible of the austenitic stainless steels to stress corrosion cracking (SCC) in halides because of their relatively low nickel content. Conditions which cause SCC are: (1) presence of halide ions (generally chloride), (2) residual tensile stresses, and (3) temperatures in excess of about 120°F (49°C). Stresses may result from cold deformation of the alloy during forming, or by roller expanding tubes into tubesheets, or by welding operations which produce stresses from the thermal cycles used. Stress levels may be reduced by annealing or stress relieving heat treatments following cold deformation, thereby reducing sensitivity to halide SCC. The low carbon ATI 304L material is the better choice for service in the stress relieved condition in environments which might cause intergranular corrosion.

Halide (Chloride) Stress Corrosion Tests		
Test	U-Bend (Highly Stressed) Samples	
	304, 304L	
42% Magnesium Chloride, Boiling	Base Metal Welded	Cracked 1 to 20 hours Cracked; ½ to 21 hours
33% Lithium Chloride, Boiling	Base Metal Welded	Cracked 24 to 96 hours Cracked; 18 to 90 hours
26% Sodium Chloride, Boiling	Base Metal Welded	Cracked 142 to 1004 hours Cracked; 300 to 500 hours
40% Calcium Chloride, Boiling	Base Metal	Cracked 144 Hours -
Ambient Temperature Seacoast Exposure	Base Metal Welded	No Cracking No Cracking

The above data illustrate that various hot chloride solutions may cause failure after differing lengths of time. The important thing to note is that failure eventually occurs under these conditions of chloride presence, high stresses and elevated temperatures.

Pitting/Crevice Corrosion

The 18-8 alloys have been used very successfully in fresh waters containing low levels of chloride ion. Although 304 tubing has been used in power plant surface condenser cooling water with as much as 1000 ppm chloride, this performance can only result from careful cleaning of the tubes during use and care to avoid stagnant waters from remaining in contact with the tube. Generally, 100 ppm chloride is considered to be the limit for the 18-8 alloys, particularly if crevices are present. Higher levels of chloride might cause crevice corrosion and pitting. For the more severe conditions of higher chloride levels, lower pH and/or higher temperatures, alloys with higher molybdenum content such as 316 alloy should be considered. Interestingly, 304 and 304L stainless steels pass the 100 hour, 5 percent neutral salt spray test (ASTM B117) with no rusting or staining of samples. However, 304 stainless building exteriors exposed to salt mists from the ocean are prone to pitting and crevice corrosion accompanied by severe discoloration. The 18-8 alloys are not recommended for exposure to marine environments.

WELDABILITY

The austenitic stainless steels are considered to be the most weldable of the high-alloy steels and can be welded by all fusion and resistance welding processes. The 304 and 304L alloys are typical of the austenitic stainless steels.

Two important considerations in producing weld joints in the austenitic stainless steels are: 1) preservation of corrosion resistance, and 2) avoidance of cracking. A temperature gradient is produced in the material being welded which ranges from above the melting temperature in the molten pool to ambient temperature at some distance from the weld. The higher the carbon level of the material being welded, the greater the likelihood that the welding thermal cycle will result in the chromium carbide precipitation which is detrimental to corrosion resistance. To provide material at the best level of corrosion resistance, low carbon material (304L) should be used for material put in service in the welded condition. Alternately, full annealing dissolves the chromium carbide and restores a high level of corrosion resistance to the standard carbon content materials.

Weld metal with a fully austenitic structure is more susceptible to cracking during the welding operation. For this reason, 304, and 304L alloys are designed to resolidify with a small amount of ferrite to minimize cracking susceptibility.

If filler metal is required, ATI 308 (20% Cr-11% Ni) alloy is generally used. This enriched composition avoids martensite which might otherwise form in multipass welds. Chemistry is controlled to allow a small amount of ferrite in the deposit to limit hot cracking tendency.

309 alloy (23% Cr – 13.5% Ni) or nickel-base filler metals are used in joining the 18-8 austenitic alloys to carbon steel.

HEAT TREATMENT

The austenitic stainless steels are heat treated to remove the effects of cold forming or to dissolve precipitated chromium carbides. The surest heat treatment to accomplish both requirements is the solution anneal which is conducted in the 1850°F to 2050°F range (1010°C to 1121°C). Cooling from the anneal temperature should be at sufficiently high rates through 1500-800°F (816°C – 427°C) to avoid reprecipitation of chromium carbides. These materials cannot be hardened by heat treatment.

CLEANING

Despite their corrosion resistance, stainless steels need care in fabrication and use to maintain their surface appearance even under normal conditions of service.

In welding, inert gas processes are used. Scale or slag that forms from welding processes is removed with a stainless steel wire brush. Normal carbon steel wire brushes will leave carbon steel particles in the surface which will eventually produce surface rusting. For more severe applications, welded areas should be treated with a descaling solution such as a mixture of nitric and hydrofluoric acids and these should be subsequently washed off.

For material exposed in inland, light industrial or milder service, minimum maintenance is required. Only sheltered areas need occasional washing with a stream of pressurized water. In heavy industrial areas, frequent washing is advisable to remove dirt deposits which might eventually cause corrosion and impair the surface appearance of the stainless steel.

Stubborn spots and deposits like burned-on food can be removed by scrubbing with a nonabrasive cleaner and fiber brush, a sponge or pad of stainless steel wool. The stainless steel wool will leave a permanent mark on smooth stainless steel surfaces. Many of the uses of stainless steel involve cleaning or sterilizing on a regular basis. Equipment is cleaned with specially designed caustic soda, organic solvent or acid solutions such as phosphoric or sulfamic acid (strongly reducing acids such as hydrofluoric or hydrochloric may be harmful to these stainless steels).

Cleaning solutions need to be drained and stainless steel surfaces rinsed thoroughly with fresh water.

Design can aid cleanability. Equipment with rounded corners, fillets and absence of crevices facilitates cleaning as do smooth ground welds and polished surfaces.

SURFACE FINISHES

A range of surface finishes is available. These are designated by a series of numbers.

Number 1 Finish – is hot rolled annealed and descaled. It is available in plate and sheet and is used for functional applications where a smooth decorative finish is not important.

Number 2D Finish – is a dull finish produced by cold rolling, annealing and descaling. This finish is favorable for the retention of lubricants in drawing or forming operations and is preferred for deep drawn and formed parts.

Number 2B Finish – is a brighter finish than 2D. It is produced much like the 2D finish except that the final cold rolling is done with smooth polished rolls. This is a general purpose finish used for all but severe cold forming. Because it is smoother as produced, it is more readily polished than 1 or 2D finishes.

Number 2BA Finish – is a very smooth finish produced by cold rolling and bright annealing. A light pass using highly polished rolls produces a glossy finish. A 2BA finish may be used for lightly formed applications where a glossy finish is desired in the as formed part.

Polished finishes – a variety of ground finishes is available.

Because special equipment or processes are used to develop these finishes, not all finishes are available.