STANDARD WROUGHT AUSTENITIC STAINLESS STEELS

A PRACTICAL GUIDE TO THE USE OF NICKEL-CONTAINING ALLOYS

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Nickel Institute

communications@nickelinstitute.org
www.nickelinstitute.org

Standard wrought austenitic stainless steels

Wrought austenitic stainless steels combine a useful combination of outstanding corrosion and heat resistance with good mechanical properties over a wide temperature range. Available in virtually all mill forms and relatively easy to fabricate by conventional means, they are widely used for chemical, petroleum, pollution abatement, food processing and transportation equipment.

This manual covers only those wrought austenitic stainless steels currently standardized by the American Iron and Steel Institute (AISI). In addition to these grades, however, numerous proprietary grades are available. These so-called "specialty" stainless steels, while not covered herein, may be superior to the standard grades in some respects. For example, while standard grades are essentially nonmagnetic materials in the annealed condition, most grades will become slightly magnetic upon cold working. On the other hand, some specialty grades remain nonmagnetic even after severe cold working. Thus, one should not limit the selection of wrought austenitic stainless steels to those included herein, but rather, should inquire of producers for the best grade, standard or specialty, for a particular use.

Types, forms, finishes, uses and costs

Standard wrought austenitic stainless steels are generally classified into two groups: the chromium-nickel AISI 300 series type and the chromium-nickel-manganese 200 series type. The "300" series grades are by far the most widely used. The low-nickel "200" grades are used much less frequently. Compositions and distinguishing characteristics of the various grades are given in Table 1.

Chromium-nickel grades

Type 301 is noted for its high rate of work hardening, providing high strength and adequate ductility in the form of integrally stiffened panels for railroad cars, trucks and trailers. Although its chromium content is slightly less than other 300 grades, it still provides considerable corrosion protection. In addition, it is also used for automotive and aircraft parts, conveyor belts, jewelry, kitchen utensils, fasteners and many other products.

302 is a general purpose stainless steel of slightly higher chromium content and finds use for acid storage, food and petroleum processing equipment, appliance and aircraft parts, hospital ware, kitchen utensils and architectural trim. 302B has a higher silicon content for greater high temperature oxidation resistance and is useful for heating elements, radiant tubes and heat treating fixtures.

303 and 303Se are "free-machining" versions of 302 stainless, the former being preferred for heavier cuts, the latter for lighter cuts and where hot working or cold heading also may be involved. Both are somewhat less corrosion resistant than 302, but are widely used for screw machine parts. In general, 303Se provides the better machined finish.

304 and 304L are low carbon and extra low carbon modifications respectively of 302. Low carbon content restricts carbide precipitation during welding and thus both grades are widely used for welded applications. 304N contains a small amount of nitrogen to provide greater strength than 302 at just a small sacrifice in ductility and minimum effect on corrosion resistance. 305 has a slightly higher nickel content than 302 and 304 to reduce the rate of work hardening. It is used for parts requiring severe forming operations such as deep drawn, spun, stamped or cold headed parts. UNS (Unified Numbering System)-S30430 has an even lower work hardening rate and is used for severe cold heading applications.

308 has somewhat higher chromium content, and thus is more corrosion resistant, than the above grades. Because of its higher alloy content, it is widely used for welding rods to compensate for alloying elements that may be lost during welding. Other uses include furnace parts, valves and oil refinery equipment.

309, 309S, 310, 310S and 314 have still higher chromium and nickel contents and have exceptional corrosion and heat resistance. 309S and 310S are low carbon grades for greater resistance to carbide precipitation during welding. They also have higher creep strength than all other standard austenitic grades, with the possible exception of 347 and 348. 314 has a higher than normal silicon content for further resistance to oxidation. Its resistance to scaling is superior to that of 310, but its relatively high silicon content causes embrittlement upon prolonged exposure at temperatures of 1200-1500 F (922-1089 K). However, this embrittlement, evident only at or near room temperature, is not harmful unless parts are subject to shock stresses at low temperatures, and it can be removed by thermal treatments. These high alloy grades are commonly used for chemical and oil refinery equipment, heaters and heat exchangers, radiant tubes, heat treating fixtures, furnace parts and turbine components.

316, 316L, 316F, 316N, 317, 317L, 321 and 329 stainless steels are characterized by additions of molybdenum, molybdenum and nitrogen (316N), or titanium (321) for improved properties. 316, for example, is more corrosion and creep resistant than 302 and 304 types. Like other low carbon grades, 316L provides greater resistance to carbide precipitation during welding. 316F has relatively high phosphorus and sulfur contents for better machinability while 316N contains a small amount of nitrogen for greater strength. 317 and 317L are somewhat more corrosion and heat resistant than 316 types and also have high creep strength. Both 316 and 317 type stainless steels are widely used for chemical, food, oil, pulp, paper, pharmaceutical and photographic processing equipment.

321 stainless is titanium-stabilized and provides increased resistance to intergranular corrosion of welds. Applications cover the gamut of high temperature equipment, from furnace parts and boiler casings to exhaust manifolds and oil refinery equipment subject to heating in the normal stainless steel carbide precipitation range.

329, a high chromium, low nickel, austenitic/ferritic stainless steel, is similar to 316 types in general corrosion resistance, but is more resistant to stress corrosion cracking, and is also age hardenable. 330 stainless is a high nickel, normal chromium, high silicon stainless featuring good resistance

1 Nominal composition and characteristics of standard (AISI) wrough austenitic stainless steels[a]

AISI Grade	Composition, %[b] Cr	Ni	C	Mn	Si	P	S	Other	Distinguishing Characteristics
201	16-18	3.5-5.5	0.15	5.5-7.5	1.0	0.060	0.030	0.25N	Low nickel version of 301. High work hardening rate
202	17-18	4-6	0.15	7.5-10	1.0	0.060	0.030	0.25N	General purpose low nickel version of 302
205	16.5-18	1-1.75	0.12-0.25	14-15.5	1.0	0.060	0.030	1-1.75Mo	Lower work hardening rate than 202.
301	16-18	6-8	0.15	2.0	1.0	0.045	0.030	—	High work hardening rate
302	17-19	8-10	0.15	2.0	1.0	0.045	0.030	—	General purpose grade
302B	17-19	8-10	0.15	2.0	2-3	0.045	0.15[c]	—	More scale resistant than 302
303	17-19	8-10	0.15	2.0	1.0	0.20	0.030	0.60Mo[d]	Free machining version of 302 for heavier cuts
303Se	17-19	8-10	0.15	2.0	1.0	0.20	0.06	0.15Se[c]	Free machining version of 302 for lighter cuts and cold working
304	18-20	8-10.5	0.08	2.0	1.0	0.045	0.030	—	Low carbon version of 302 to inhibit carbide precipitation during welding
304L	18-20	8-12	0.03	2.0	1.0	0.045	0.030	—	Extra low carbon version of 302 for further restriction of carbide precipitation during welding
304N	16-18	10-14	0.08	2.0	1.0	0.045	0.030	0.10-0.16N	Nitrogen increases strength without significantly affecting ductility or corrosion resistance
S30430[e]	17-19	8-10	0.08	2.0	1.0	0.045	0.030	3-4Cu	Lower work hardening rate than 305; facilitate severe cold heading
305	17-19	10.5-13	0.12	2.0	1.0	0.045	0.030	—	Low work hardening
308	19-21	10-12	0.08	2.0	1.0	0.045	0.030	—	Higher corrosion and heat resistance; used for welding filler metals to compensate for alloy loss in welding
309	22-24	12-15	0.20	2.0	1.0	0.045	0.030	—	High temperature strength, heat and corrosion resistance.
309S	22-24	12-15	0.08	2.0	1.0	0.045	0.030	—	Low carbon version of 309 for welded applications
310	24-26	19-22	0.25	2.0	1.5	0.045	0.030	—	Stronger, more scale resistant than 309 at elevated temperatures
310S	24-26	19-22	0.08	2.0	1.5	0.045	0.030	—	Low carbon version of 310 for welded applications
314	23-26	19-22	0.25	2.0	1.5-3.0	0.045	0.030	—	More scale resistant than 310
316	16-18	10-14	0.08	2.0	1.0	0.045	0.030	2.0-3.0Mo	More corrosion resistant than 302 and 304; high creep strength
316F	16-18	10-14	0.08	2.0	1.0	0.20	0.10[c]	1.75-2.50Mo	Better machining and non-seizing characteristics than 316
316L	16-18	10-14	0.03	2.0	1.0	0.045	0.030	2.0-3.0Mo	Extra low carbon version of 316 to restrict carbide precipitation during welding
316N	16-18	10-14	0.08	2.0	1.0	0.045	0.030	2-3Mo, 0.1-0.16N	Nitrogen increases strength without significantly affecting ductility or corrosion resistance
317	18-20	11-15	0.08	2.0	1.0	0.045	0.030	3.0-4.0Mo	More corrosion and creep resistant than 316
317L	18-20	11-15	0.03	2.0	1.0	0.045	0.030	3.0-4.0Mo	Extra low carbon version of 317 to restrict carbide pecipitation during welding
321	17-19	9-12	0.08	2.0	1.0	0.045	0.030	5 x C Ti[e]	Stabilized for welded applications subject to severe corrosion and for service at 800-1600 F (700-1144 K)
329	25-30	3-6	0.10	2.0	1.0	0.040	0.030	1.0-2.0Mo	Austenitic/ferritic structure; can be age hardened. More resistant to stress corrosion than 316
330	17-20	34-37	0.08	2.0	0.75-1.5	0.040	0.030	—	Good resistance to carburization, heat and thermal shock
347	17-19	9-13	0.08	2.0	1.0	0.045	0.030	10 x C Cb + Ta[c]	Similar to 321
348	17-19	9-13	0.08	2.0	1.0	0.045	0.030	10 x C Cb + Ta[c], 0.1 Ta[f]; 0.20C[b]	Similar to 321, 347
384	15-17	17-19	0.08	2.0	1.0	0.045	0.030	—	Lower work hardening rate than 304

[a] Source: American Iron and Steel Institute. [b] Balance iron. Single values are maximum values unless otherwise noted. [c] Minimum. [d] Optional. [e] Unified Numbering System designation. [f] Maximum.

to carburization, heat and thermal shock.

347 and 348 are similar to 321 in composition except for the use of columbium and tantalum, rather than titanium, for stabilization. They also have higher creep strength than 321. Both grades find uses for welded structures, radiant tubes, aircraft exhaust manifolds, pressure vessels, expansion joints, heat exchangers and oil refinery equipment.

384 has a lower rate of work hardening than 304 and is used for severe cold heading and other cold forming applications. Typical applications include bolts, rivets, screws and instrument parts.

Chromium-nickel-manganese grades

201 and 202 stainless steels are commonly referred to as the low nickel equivalents of 301 and 302. 201 became prominent as a substitute for 301 during the Korean war because of the nickel shortage and has since become accepted on its own merits rather than just as a substitute material.

In the annealed condition, 201 is stronger and somewhat less ductile than 301, while 202 is stronger and slightly more ductile than 302. In general, these low nickel grades are suitable for similar applications as 301 and 302, but they are used less frequently.

205 is the low nickel equivalent of 305. Like the latter, it has a low rate of work hardening which makes it useful for deep spun or drawn parts.

Shapes and sizes

Standard wrought austenitic stainless steels are available in virtually all mill forms, including sheet, strip, foil, plate, bar, rod, tubing, wire, extrusions, rolled sections, forgings and fasteners. While all grades are not available in all forms, many grades are available in a broad cross section of mill products. Several of the steels also are used as facing materials for clad metals.

Finishes

Standard wrought austenitic stainless steels can be supplied in a variety of standard finishes. These finishes may vary somewhat with mill product. For example, thin gages are generally smoother than thick gages. Continuous products such as coils differ in color from hand mill products, and polished finishes on 200 and 300 series grades may differ slightly in color. In addition to the following standard finishes, various proprietary decorative finishes are also available from stainless steel producers.

Sheet finishes include:

No. 1—a dull finish produced by hot rolling, annealing and descaling. It is used where a smooth finish is not required.

No. 2D—a dull finish produced similarly, but preferred for deep drawing applications because of its lubricant retention characteristics.

No. 2B—a bright, cold-rolled finish produced similarly except for final light cold rolling on polished rolls. It is a general purpose finish commonly used for all applications except severely deep drawn shapes.

Bright annealed—a highly reflective finish produced by cold rolling and maintained by annealing in a controlled atmosphere furnace.

No 3—an intermediate polished finish used where a semifinished, polished surface is needed and where further finishing will follow fabrication.

No. 4—a bright, machine-polished finish with a visible grain which prevents mirror reflection.

No. 6—a dull satin finish, less reflective than No. 4, produced by tampico brushing the No. 4 finish in an abrasive/oil medium.

No. 7—a highly reflective finish obtained by buffing a finely ground surface without removing grit lines.

No. 8—a mirror polish finish produced by polishing with progressively finer abrasives, followed by extensive buffing with fine rouges. The finish is essentially free of grit lines.

Strip is normally supplied in three mill finishes: No. 1, which approximates the No. 2D sheet finish; No. 2, which approximates the No. 2B sheet finish; and bright annealed, which is similar to the bright annealed sheet finish.

Bar is generally available in six finishes: A—with scale; B—rough turned; C—pickled or sand blast and pickled; D—cold drawn or cold rolled; E—centerless ground; F—polished. Annealed or otherwise heat treated bar is supplied in any of these finishes; hot worked bar is supplied in A, B or C; and bar which is annealed and cold worked to high strength is supplied in finishes D, E or F.

Wire is available in the following finishes:

Oil or grease drawn—a special bright finish.

Diamond drawn—a very bright finish generally limited to fine wire sizes.

Copper coated—a special finish providing lubrication for spring coiling or cold heading operations.

Tinned—a tin coating to facilitate soldering.

Lead coated—a special lubricating finish useful for spring coiling.

Finishes for tubing include: dull and smooth, white pickled, ground finishes up to 500 grit, rouge polished and tumbled.

Cost

In general, base prices for standard wrought austenitic stainless steels range from $0.50-1.60/lb ($1.10-3.52/kg) depending on grade and mill form. The widely used 304, and 302, are about $0.53/lb ($1.17/kg) in sheet and strip, and $0.63/lb ($1.39/kg) in bar. The more highly alloyed 309 and 310 are roughly $1.13/lb ($2.49/kg) and $1.38/lb ($3.04/kg) respectively in bar form. Molybdenum-bearing 316 and stabilized grades 321 and 347 are somewhat intermediate in cost: about $0.87/lb ($1.91/kg), $0.71/lb ($1.56/kg) and $1.10/lb ($2.42/kg) respectively in sheet and strip; $0.88/lb ($1.94/kg), $0.86/lb ($1.89/kg), $0.93/lb ($2.05/kg) respectively in bar form. Low carbon grades are more expensive than their normal carbon counterparts. For example, 304L costs about $0.61/lb ($1.34/kg) in sheet and strip, and $0.69/lb ($1.52/kg) in bar. Wire is more expensive than either sheet, strip or bar products: $0.93/lb ($2.05/kg) for 304L, $1.31/lb ($2.88/kg) for 310, $1.18/lb ($2.60/kg) for 316L and $1.50 ($3.30/kg) for 317L. Prices may vary slightly amongst producers.

Engineering properties

Room temperature tensile properties and hardness of annealed standard wrought austenitic stainless steels are given in Table 2. High temperature properties are shown in Tables 3 and 4 while low temperature properties are given in Table 5.

Room temperature strength

In the annealed condition, the steels have tensile strengths in the range of 75,000-120,000 psi (517-827 MPa) ultimate and 30,000-80,000 psi (207-552 MPa) yield, with elongations of 35-70%. For many grades, tensile strengths vary somewhat with mill form. The large difference between ultimate and yield strengths is characteristic of austenitic stainless steels and is one of the reasons for their excellent formability. In general, all grades can be strengthened appreciably by cold work. And although cold working reduces ductility considerably, ductility is still adequate for many applications. For example, cold working 201 or 301 sheet and strip to the ½-hard temper increases tensile strengths to a minimum of 150,000 psi (1034 MPa) ultimate and 110,000 psi (758 MPa) yield while elongation is reduced to a minimum of 10-15%.

In compression, yield strengths of the steels in the annealed condition are about equal to tensile yield strengths. However, due to the inherent toughness of the steels, overloading in compression usually will cause permanent set rather than brittle failure. Ultimate shear strengths are about 50-75% of ultimate tensile strengths and ultimate bearing strengths are generally 50% greater than ultimate tensile strengths.

Fatigue strength increases with tensile strength and hardness. In general, endurance limits for annealed austenitic stainless steels are 35-45% of ultimate tensile strengths. Notches considerably reduce the fatigue strength of cold worked material, but have little effect on the fatigue strength of annealed material.

2 Room temperature mechanical properties of annealed standard (AISI) wrought austenitic stainless steels

Grade	Form[a]	Ten str, 1000 psi (MPa)	Yld str,[b] 1000 psi (MPa)	Elong (in 2 in.), %	Hardness, Rb (Bhn)
201	S, s, T	115 (793)	55 (379)	55	90
202	S, s, T	105 (724)	55 (379)	55	90
205	P	120 (827)	69 (476)	58	98
301	S, s	110 (758)	40 (276)	60	85
	P	105 (724)	40 (276)	55	(165)
	T	105 (724)	40 (276)	50	95
302	S, s	90 (621)	40 (276)	50	85
	P	90 (621)	35 (241)	60	(150)
	B	85 (586)	35 (241)	60	(150)
	T	85 (586)	35 (241)	50	85
302B	S, s	95 (655)	40 (276)	55	85
	P, B	90 (621)	40 (276)	50	85
	T	85 (586)	35 (241)	50	95
303, 303Se	B, W	90 (621)	35 (241)	50	76
	T	80 (552)	38 (262)	53	76
304	S, s	84 (579)	42 (290)	55	80
	P	82 (565)	35 (241)	60	(149)
	B	85 (586)	35 (241)	60	(149)
	T	85 (586)	35 (241)	50	80
	W	90 (621)	35 (241)	60	83
304L	S, s	81 (558)	39 (269)	55	79
	P	79 (545)	33 (228)	60	(143)
	T	78 (538)	34 (234)	55	75
304N	S	90 (621)	48 (331)	50	85
	B	90 (621)	42 (290)	55	(180)
S30430	W	73 (503)	31 (214)	70	70
	W[d]	81 (558)	55 (379)	—	—
305	S, s	85 (586)	38 (262)	50	80
	P	85 (586)	35 (241)	55	—
	T	80 (552)	36 (248)	56	80
	W	85 (586)	74 (510)	60	77
308	S, s, T	85 (586)	35 (241)	50	80
	P	85 (586)	30 (207)	55	(150)
	B	85 (586)	30 (207)	55	80
	W[d]	95 (655)	60 (414)	50	—
309, 309S	S, s, T	90 (621)	45 (310)	45	85
	P	95 (655)	40 (276)	45	(170)
	B	95 (655)	40 (276)	45	83
	W[d]	105 (724)	70 (483)	35	98
310, 310S	S, s, T[e]	95 (655)	45 (310)	45	85
	P	95 (655)	45 (310)	50	(170)
	B	95 (655)	45 (310)	50	89
	W[d]	105 (724)	75 (517)	30	98
314	S	100 (690)	50 (345)	40	85
	P, B	100 (690)	50 (345)	45	(180)
316	S, s	84 (579)	42 (290)	50	79
	P	82 (565)	36 (248)	55	(149)
	B	80 (552)	30 (207)	60	78
	T	85 (586)	35 (241)	50	85
	W	80 (552)	30 (207)	60	78
316F	S	85 (586)	38 (262)	60	85
	B	82 (565)	35 (241)	57	(143)
316L	S, s	81 (558)	42 (290)	50	79
	P	81 (558)	34 (234)	55	(146)
	T	80 (552)	35 (241)	55	78
316N	S	90 (621)	48 (331)	48	85
	B	90 (621)	42 (290)	55	(180)
317	S, s	90 (621)	40 (276)	45	85
	P, B	85 (586)	40 (276)	50	(160)
	T	85 (586)	35 (241)	40	85
317L	S	86 (593)	38 (262)	55	85
	P	85 (586)	35 (241)	55	80
	T	86 (593)	50 (345)	55	—
321	S, s	90 (621)	35 (241)	45	80
	P	85 (586)	30 (207)	55	(160)
	B	85 (586)	35 (241)	55	(150)
	T	85 (586)	35 (241)	50	80
	W[d]	95 (655)	65 (448)	40	89
329	s, B	105 (724)	80 (552)	25	(230)
330	S, s	80 (552)	38 (262)	40	—
	P	90 (621)	38 (262)	45	80
	B	85 (586)	42 (290)	45	80
347, 348	S, s	95 (655)	40 (276)	45	85
	P	90 (621)	35 (241)	50	(160)
	B	90 (621)	35 (241)	50	(160)
	T	85 (586)	35 (241)	45	85
	W[d]	100 (690)	70 (483)	40	95
384	W	75 (517)	35 (241)	55	70

[a] B = bar, P = plate, S = sheet, s = strip, T = tubing, W = wire. [b] At 0.2% offset. [d] Soft temper. [e] Composition of 310 tubing varies slightly from AISI standard grade composition (see ASTM A213).

Hardness, toughness, rigidity

As shown in Table 2, the hardness of annealed standard wrought austenitic stainless steels ranges from 70-98 Rb. Cold working increases hardness appreciably—to 25 Rc for ¼-hard 301 and 43 Rc for extra hard 301, for example. As with strength properties, hardness varies somewhat with mill form.

In the annealed condition, these steels are among the toughest of metals with Izod impact strengths in the range of 85-120 ft·lb (115-163 J). Cold working markedly reduces toughness. For example, the impact strength of 302 cold rolled to an ultimate tensile strength of 165,000 psi (1138 MPa) is 50 ft·lb (68 J). Additional cold rolling to 225,000 psi (1551 MPa) ultimate, reduces impact strength to 17 ft·lb (23 J).

The tensile modulus of elasticity of most of the steels is 28,000,000 psi (193,060 MPa). However, 309, 309S, 310 and 310S are slightly more rigid, having a tensile modulus of 29,000,000 psi (199,955 MPa). Modulus of rigidity, or shear modulus, is about 11,000,000 psi (75,845 MPa). Cold working reduces tensile modulus to some extent, especially in the longitudinal grain direction. For example, cold rolling 301 stainless to the full hard temper reduces tensile modulus in this direction by as much as 3,000,000 psi (20,685 MPa).

Electrical, magnetic and thermal properties

The physical properties of standard wrought austenitic stainless steels are quite similar for all grades.

Virtually all grades have a density of 0.29 lb/cu in (8027 kg/cu m). 201, 202 and 329 are just slightly lighter: 0.28 lb/cu in. (7750 kg/cu m).

Electrical resistivity ranges from 69-78 microhm·cm (69×10^{-8} - 78×10^{-8} ohm·m) at room temperature with 309, 309S, 310 and 310S having the highest resistivities and 201 and 202 the lowest. Resistivity rises with increasing temperature; from about 50-60 microhm·cm (50×10^{-8} - 60×10^{-8} ohm·m) at —400 F (33 K) to 107-120 microhm·cm (107×10^{-8} - 120×10^{-8} ohm·m) at 1200 F (922 K).

Although standard wrought austenitic stainless

3 High temperature tensile and rupture strengths of annealed standard (AISI) wrought austenitic stainless steels

Property	Grade 201	202	301	302	303	304	305	309	310	316[a]	321	347[b]
Ten str[c], 1000 psi (MPa)												
800 F (700 K)	76 (524)	77 (531)	68 (469)	60 (414)	60 (414)	60 (414)	64 (441)	79 (545)	78 (538)	72 (496)	67 (462)	65 (448)
1000 F (811 K)	70 (482)	72 (496)	58 (400)	56 (386)	56 (386)	56 (386)	58 (400)	70 (483)	73 (503)	68 (469)	58 (400)	60 (414)
1200 F (922 K)	48 (331)	55 (379)	41 (283)	45 (310)	45 (310)	45 (310)	47 (324)	53 (365)	60 (414)	56 (386)	47 (324)	51 (352)
1300 F (978 K)	—	—	—	35 (241)	35 (241)	35 (241)	40 (276)	44 (303)	51 (352)	48 (331)	39 (269)	43 (296)
1400 F (1033 K)	27 (186)	31 (214)	29 (200)	30 (207)	30 (207)	30 (207)	24 (165)	39 (269)	42 (290)	40 (276)	32 (221)	35 (241)
1500 F (1089 K)	20 (138)	24 (165)	16 (110)	22 (152)	22 (152)	22 (152)	20 (138)	27 (186)	30 (207)	30 (207)	24 (165)	26 (179)
1600 F (1144 K)	—	—	—	18 (124)	18 (124)	18 (124)	—	21 (145)	23 (159)	25 (172)	18 (124)	21 (145)
1700 F (1200 K)	—	—	—	12 (83)	12 (83)	12 (83)	15 (103)	15 (103)	18 (124)	18 (124)	15 (103)	—
1900 F (1311 K)	—	—	—	6 (41)	6 (41)	6 (41)	—	8 (55)	10 (69)	—	—	10 (69)
Yld str,[c] 1000 psi (MPa)												
800 F (700 K)	26 (179)	28 (193)	20 (138)	24 (165)	24 (165)	24 (165)	—	42 (290)	27 (186)	27 (186)	29 (200)	30 (207)
1000 F (811 K)	23 (159)	25 (172)	18 (124)	22 (152)	22 (152)	22 (152)	—	36 (248)	24 (165)	25 (172)	27 (186)	28 (193)
1200 F (922 K)	20 (138)	22 (152)	15 (103)	18 (124)	18 (124)	18 (124)	—	31 (214)	22 (152)	23 (159)	23 (158)	24 (165)
1300 F (978 K)	—	—	—	16 (110)	16 (110)	16 (110)	—	27 (186)	21 (145)	22 (152)	21 (145)	22 (152)
1400 F (1033 K)	18 (124)	19 (131)	14 (97)	14 (97)	14 (97)	14 (97)	—	25 (172)	20 (138)	21 (145)	18 (124)	20 (138)
1500 F (1089 K)	15 (103)	16 (110)	9 (62)	12 (83)	12 (83)	12 (83)	—	21 (145)	19 (131)	18 (124)	15 (103)	18 (124)
1600 F (1144 K)	—	—	—	10 (69)	10 (69)	10 (69)	—	18 (124)	17 (117)	11 (76)	11 (76)	13 (90)
Rup str (1000 hr), psi (MPa)												
1000 F (811 K)	—	—	—	37 (255)	—	37 (255)	—	—	32 (221)	—	42 (290)	49 (338)
1100 F (866 K)	—	—	—	25 (172)	—	25 (172)	—	—	25 (172)	37 (255)	30 (207)	35 (241)
1200 F (922 K)	22 (152)	25 (172)	—	17 (117)	—	17 (117)	—	19 (131)	18 (124)	24 (165)	18 (124)	23 (159)
1300 F (978 K)	—	—	—	10 (69)	—	10 (69)	—	12 (83)	13 (90)	16 (110)	11 (76)	14 (97)
1400 F (1033 K)	—	—	—	7 (48)	—	7 (48)	—	8 (55)	8 (55)	10 (69)	7 (48)	8 (55)
1500 F (1089 K)	4 (28)	4 (28)	—	4 (28)	—	4 (28)	—	4 (28)	6 (41)	7 (48)	4 (28)	4 (28)
1600 F (1144 K)	—	—	—	3 (21)	—	3 (21)	—	3 (21)	4 (28)	3 (21)	—	—
Rup str (10,000 hr), psi (MPa)												
1000 F (811 K)	—	—	—	27 (186)	—	27 (186)	—	—	27 (186)	—	34 (234)	39 (269)
1100 F (866 K)	—	—	—	18 (124)	—	18 (124)	—	—	18 (124)	28 (193)	21 (145)	27 (186)
1200 F (922 K)	—	—	—	11 (76)	—	11 (76)	—	13 (90)	13 (90)	17 (117)	12 (83)	18 (124)
1300 F (978 K)	—	—	—	6 (41)	—	6 (41)	—	7 (48)	8 (55)	10 (69)	6 (41)	11 (76)
1400 F (1033 K)	—	—	—	4 (28)	—	4 (28)	—	4 (28)	5 (34)	7 (48)	3 (21)	6 (41)
1500 F (1089 K)	—	—	—	3 (21)	—	3 (21)	—	3 (21)	3 (21)	4 (28)	2 (14)	3 (21)

[a] Properties of 317 somewhat similar. [b] Properties of 348 somewhat similar.
[c] About 30 min. at temperature.

steels are considered nonmagnetic, this is essentially true only for annealed material. Most grades will become slightly magnetic upon cold working. In the annealed condition, magnetic permeability is usually less than 1.02 in a field strength of 200 oersteds. Grades least affected by cold working are 205, 305 and S30430.

Standard wrought austenitic stainless steels have a melting range of 2500-2650 F (1644-1728 K). Specific heat at 32-212 F (273-373 K) is 0.12 Btu/lb·F (502 J/kg·K) for almost all grades. Thermal conductivity at 212 F (373 K) is 9.2-9.4 Btu·ft/hr·sq ft·F (15.9-16.3 W/m·K) for most grades, 8.8-9 Btu·ft/hr·sq ft·F (15.2-15.6 W/m·K) for 308, 309 and 309S, 8.2 Btu·ft/hr·sq ft·F (14.2 W/m·k) for the less conductive 310 and 301S, and increases with increasing temperatures. Mean coefficient of thermal expansion, which also rises with increasing temperatures, is in the range of 8.3×10^{-6} in./in./F (14.9×10^{-6} m/m/K) to 10.4×10^{-6} in./in./F (18.7×10^{-6} m/m/K) at 32-212 F (273-373 K). Specific heat, thermal conductivity and thermal expansivity decrease sharply at cryogenic temperatures.

High temperature mechanical properties

The high temperature tensile and rupture strengths of annealed standard wrought austenitic stainless steels are shown in Table 3. Creep strengths and maximum service temperatures for scale resistance are given in Table 4.

In general, these steels have adequate strength for use up to about 1800 F (1255 K) and sufficient heat resistance for nonstructural use to as high as 2000 F (1366 K). The higher alloy grades such as 309, 310, 316, 317, 347 and 348 provide the greater strength and creep resistance at high temperatures.

Like strength properties, rigidity also declines with increasing temperatures. For example, the tensile modulus of 300 series grades falls to about 26,000,000 psi (179,270 MPa) at 500 F (533 K), 23,000,000 psi (158,585 MPa) at 1000 F (811 K), and 18,000,000 psi (124,110 MPa) at 1500 F (1089 K). Similarly, shear modulus is about 10,000,000 psi (68,950 MPa) at 500 F (533 K), 8,700,000 psi (599,865 MPa) at 1000 F (811 K) and 7,200,000 psi (49,644 MPa) at 1500 F (1089 K).

Low temperature mechanical properties

The strength of annealed austenitic stainless steels increases significantly with decreasing temperatures. Although ductility decreases, a sufficient amount is retained even at cryogenic temperatures. And while Izod impact strength declines for some grades, it remains essentially constant for 302, 304 and 321 stainless steels. Thus, these steels are widely used for the low temperature storage of liquefied gases. Nominal low temperature tensile properties and impact strengths of the steels are shown in Table 5.

Rigidity also increases with decreasing temperatures, although not as markedly as tensile strengths. At cryogenic temperatures, tensile modulus is about 2,000,000-3,000,000 psi (13790-20685 MPa) greater than at room temperature. Limited data on fatigue strength at sub-zero temperatures indicate that endurance limits rise as temperatures decrease.

4 Creep strength and scaling temperature of annealed standard (AISI) wrought austentic stainless steels

Grade	Creep strength (for 1% elongation 10,000 hr), 1000 psi (MPa)			Scaling temp,[a] F (K)	
	1000 F (811 K)	1200 F (922 K)	1500 F (1089 K)	Continuous service	Intermittent service
201	—	—	—	1550 (1116)	1450 (1061)
202	—	—	—	1550 (1116)	1450 (1061)
301	19 (131)	8 (55)	1.8 (12)	1650 (1172)	1500 (1089)
302	20 (138)	7.5 (52)	1.5 (10)	1650 (1172)	1500 (1089)
302B	—	7 (48)	1 (6.9)	1750 (1228)	1600 (1144)
303, 303Se	16.5 (114)	6.5 (45)	0.7 (4.8)	1650 (1172)	1400 (1033)
304, 304L	20 (138)	7.5 (52)	1.5 (10)	1650 (1172)	1550 (1116)
305	19 (131)	8 (55)	2 (14)	1650 (1172)	—
308	—	—	—	1700 (1200)	1550 (1116)
309, 309S	16.5 (114)	10 (69)	3 (21)	1950 (1339)	1850 (1283)
310, 310S	33 (228)	15 (103)	3 (21)	2050 (1394)	1900 (1311)
314	20 (138)	7.5 (52)	2.5 (17)	—	—
316, 316L	25 (172)	11.6 (80)	2.4 (17)	1650 (1172)	1550 (1116)
317	23 (159)	11.2 (77)	2.0 (14)	1700 (1200)	1600 (1144)
321	18 (124)	9 (62)	1.5 (10)	1650 (1172)	1550 (1116)
347, 348	32 (221)	16 (110)	2 (14)	1650 (1172)	1550 (1116)

[a] Maximum temperature in air.

5 Nominal low temperature mechanical properties of annealed standard (AISI) wrought austentic stainless steels

Grade	Temp, F (K)	Ten str, 1000 psi (MPa)	Yld str, 1000 psi (MPa)	Elong, (in 2 in.), %	Izod imp str, ft·lb (J)
202	70 (294)	100 (690)	55 (379)	55	110-120 (149-162)
	−100 (200)	145 (1000)	95 (655)	38	—
	−300 (89)	200 (1379)	150 (1034)	15	42-120 (57-162)
	−423 (20)	220 (1517)	170 (1172)	5	—
301	−70 (294)	105 (724)	40 (276)	60	110 (149)
	−80 (211)	195 (1345)	50 (345)	40	110 (149)
	−320 (78)	275 (1896)	75 (517)	30	110 (149)
302	70 (294)	94 (648)	37 (255)	68	110 (149)
	−80 (211)	161 (1110)	50 (345)	57	110 (149)
	−320 (78)	219 (1510)	68 (469)	46	110 (149)
	−423 (20)	250 (1724)	125 (862)	41	—
303, 303Se	70 (294)	100 (690)	40 (276)	67	85 (115)
	−80 (211)	162 (1117)	40 (276)	40	106 (144)
	−320 (78)	235 (1620)	37 (255)	35	125 (169)
	452 (4.3)	267 (1841)	—	30	—
304, 304L	70 (294)	95 (655)	35 (241)	65	110 (149)
	−80 (211)	170 (1172)	34 (234)	39	110 (149)
	−320 (78)	221 (1524)	39 (269)	40	110 (149)
	−423 (20)	243 (1675)	50 (345)	40	110 (149)
310, 310S	70 (294)	86 (593)	37 (255)	55	110 (149)
	−80 (211)	100 (690)	40 (276)	55	110 (149)
	−320 (78)	152 (1048)	74 (510)	54	85 (115)
	−423 (20)	176 (1213)	108 (745)	56	—
316, 316L	70 (294)	85 (586)	37 (255)	65	110 (149)
	−80 (211)	118 (814)	44 (303)	57	110 (149)
	−320 (78)	185 (1276)	75 (517)	59	—
	−423 (20)	210 (1448)	84 (579)	52	—
321	70 (294)	89 (614)	37 (255)	62	110 (149)
	−80 (211)	130 (896)	45 (310)	57	117 (159)
	−320 (78)	208 (1434)	64 (441)	44	110 (149)
	−423 (20)	238 (1641)	92 (634)	35	—
347, 348	70 (294)	93 (641)	38 (262)	55	110 (149)
	−80 (211)	130 (896)	45 (310)	57	110 (149)
	−320 (78)	200 (1379)	47 (324)	43	95 (129)
	−423 (20)	228 (1572)	55 (379)	39	60 (81)

Corrosion resistance

As their name implies, corrosion resistance is the most notable characteristic of stainless steels. Although no material is completely resistant to corrosion in all environments, standard wrought austenitic stainless steels are among the most corrosion resistant of materials.

The steels are generally cathodic, or passive, in the galvanic series. Thus galvanic corrosion usually will occur in the metal or alloy with which the steels are coupled. However, the steels can become active in certain environments and be severely attacked, and dissimilar metals need not be involved. Galvanic corrosion also may stem from dissimilar solutions, similar solutions of different concentration, similar solutions at different temperatures, different surface treatments or surface irregularities, and different rates of aeration, agitation or flow. Such conditions are apt to be found in heat exchangers and chemical processing equipment, and obviously should be avoided if possible. Galvanic corrosion rates also vary with electrolytes, attack being more severe in acid solutions, or in solutions capable of high ionization, than in basic solutions. While the latter are capable of high ionization, attack is usually inhibited by the insolubility of the alloy constituents.

Some austenitic stainless steels are prone to intergranular corrosion due to carbide precipitation if heated in the 800-1500 F (700-1089 K) temperature range either in service or during welding or stress relieving. Low carbon grades are effective in suppressing attack during welding or stress relieving, but not in service at sensitizing temperatures. However, the compositionally stabilized grades, 321, 347 and 348, are far less susceptible to intergranular corrosion in service at these temperatures, although these grades also can be attacked in certain environments such as boiling or fuming nitric acid.

The steels are also susceptible to stress corrosion in certain media such as hot chloride solutions, steam and steam condensate, high temperature water, strong hot caustic solutions, severe industrial atmospheres, pickling baths, dyes, acetic acid, blood serum and certain food products. However, attack often can be avoided by proper design, which prevents local concentrations of harmful media, and by stress relieving.

Urban and rural atmospheres have essentially no effect on the appearance of the steels, but sulfur-bearing industrial and severe marine atmospheres may cause staining. In marine atmospheres, 309 and 310 type stainless steels are more stain resistant than 301, 302, 303, 304, 321 and 347. However, molybdenum-bearing 316 and 317 are particularly resistant to staining in both marine and sulfur-bearing industrial atmospheres.

Austenitic stainless steels are only slightly attacked by fresh waters, including relatively polluted lake and river waters. They are also resistant to high purity water, mine waters and high velocity sea water.

The steels also have excellent resistance to high temperature oxidation. As shown in Table 4, all grades can resist temperatures of up to 1450-1550 F (1061-1116 K) without scaling, and some grades, such as the high-chromium 309 and 310 are scale resistant to temperatures as high as 1850-2050 F (1283-1394 K). High-chromium 329 and high-silicon grades also are noted for superior oxidation resistance. 314, for example, is said to be more scale resistant than 310, but high silicon contents cause embrittlement upon prolonged exposure at 1200-1500 F (922-1089 K). The steels also have good resistance to oxidation by steam at temperatures up to about 1600 F (1144 K).The presence of sulfur, as in sulfur dioxide, hydrogen sulfide, molten sulfur or sulfur vapor, accelerates high temperature corrosion.

Standard wrought austenitic stainless steels are generally resistant to hydrogen and most carburizing gases. They are also resistant to dry chlorine and dry hydrogen chloride to temperatures of about 600 F (589 K), and to fluorine to about 480 F (522 K). However, the steels are severely attacked by pure ammonia at 1000 F (811 K) and hydrogen fluoride above 900 F (755 K).

The steels also resist liquid sodium at 950 F (783 K) and sodium-potassium at 1600 F (1144 K), but are sensitive to contamination by oxygen and carbonaceous materials in liquid sodium. Although they are also resistant to lithium up to 600 F (589 K) and thallium to 1200 F (922 K), they are attacked by many other liquid metals, including lead, aluminum, zinc, mercury, antimony, bismuth, cadmium and tin.

Austenitic stainless steels are resistant to some acids, but are attacked by others. While they are resistant to strong nitric acid solutions up to slightly above the boiling point, attack accelerates rapidly at higher temperatures and at concentrations over 80%. White or red fuming nitric acid is extremely corrosive, but severity can be markedly reduced by small additions of hydrofluoric acid in solutions. High-chromium, high-nickel grades have the best resistance.

Hydrochloric acid in virtually all concentrations attacks all grades. Chlorine water containing hydrochloric and hypochlorous acids and dissolved chlorine causes rapid pitting. Hot, dilute hydrofluoric is also very aggressive, but hydrobromic and hydroiodic acids are less corrosive. Substantially anhydrous acids are not particularly aggressive.

While aerated solutions of sulfuric acid at low temperature are not corrosive, hot or unaerated solutions of relatively high concentrations will cause attack. Sulfurous acid is not normally aggressive to the steels, but the presence of sulfates or chlorides will cause attack. Warm solutions containing both sulfuric and sulfurous acids also can be harmful.

304 and 316 stainless steels are only mildly attacked by phosphoric acid solutions up to 20% concentration at temperatures up to boiling, and in all concentrations up to about 125 F (325 K); however, attack accelerates at higher concentrations and temperatures. All but very dilute (1% or less) solutions of chromic acid attack all austenitic stainless steels, but boric acid is not generally aggressive. And, although the steels are resistant to most organic compounds, including alcohols, aldehydes, esters, ketones and aromatic and aliphatic hydrocarbons,

they can be attacked by organic acids at certain concentrations and temperatures.

Standard wrought austenitic stainless steels also are attacked by acetic acid at high concentrations and temperatures, but resist all concentrations at ambient temperatures. Chloroacetic and formic acids are even more aggressive, but butyric acid is less corrosive and citric acid is somewhat intermediate in its corrosivity. Fatty acids such as tall oil are corrosive at elevated temperatures to most grades, but 316 and 317 are relatively resistant. Naphthenic acids also will attack some grades, molybdenum-bearing grades being the most resistant. Lactic and oxalic acids are not harmful at room temperature, but cause attack at elevated temperatures. Phenol is generally harmless, except in the vapor phase, and phthalic anhydride is also relatively noncorrosive.

The steels are resistant to most soils; however, aggressive soils can cause pitting. Molybdenum-bearing grades are again the most resistant.

The steels also are resistant to most food products. They also are nontoxic and provide protection against contamination, discoloration, flavor alteration, formation of sediments and loss of nutritional value. However, some foods, including mayonnaise, catsup, vinegar salt dressings and boiling sugar-salt brines can cause slight pitting.

Processing and fabrication

Standard wrought austenitic stainless steels are readily forged, formed, machined, brazed, soldered and welded, but certain precautions are required in these and other fabrication processes.

Forging

The steels can be readily forged, but require about 25% more blows than ordinary carbon steels. Also, the steels should not be heated directly with an open flame since scaling or carburization with a consequent loss in corrosion resistance is apt to occur. Muffle or semi-muffle furnaces with accurate heat controls are generally best.

Preheating at 1500-1600 F (1089-1144 K) is important, but may be omitted for sections under 1 in. (25.4 mm) thick. Required time at temperature is about twice that of plain carbon steels. Recommended starting temperatures for forging are given in Table 6. Initial blows should be light, then progressively harder, then light again as temperature drops. In the finish forging range, usually 1600-1700 F (1144-1200 K), but 1700-1800 F (1200-1255 K) for 309, 310 and 314 grades, only sizing rather than forming should be done. Forgings should be trimmed hot and restruck, then cooled rapidly, taking precautions from exposure to dirt, oil or grease.

Forming

Annealed sheet and strip can be cold formed to minimum bend radii equal to or less than gage thickness. Minimum bend radii for cold worked stock are one-half to three times gage thickness depending on temper, gage and degree of bend.

Annealed tubing can be formed to minimum bend radii of two to six times o.d. Rotating die bending with internal tube support produces the tightest bends. Tube ends can be flanged, flared or beaded.

Annealed sheet also can be readily deep drawn to dish or box shapes. Most grades work harden appreciably and intermittent anneals may be required. 205, S30430 and 305 work harden the least and are often preferred for severe draws. In general, parts can be formed in a single draw if the required blank area is not more than four times the punch area, and punch and die radii are at least six times gage thickness. The preferred finish for draw forming stock is No. 2D. In drawing, heavy body type lubricants of high film strength are generally preferred.

Machining

Annealed standard austenitic stainless steels are tough rather than hard and tend to seize and gall in machining. Thus they are more difficult to ma-

6 Melting, forging, annealing and stress relieving temperatures of standard (AISI) wrought austenitic stainless steels

Grade	Melting range, F (K)	Initial forging temp, F (K)	Annealing temp, F (K)	Stress relieving ann temp, F (K)
201, 202	—	2100-2250 (1422-1505)	1850-2050 (1283-1394)	—
205	—	2250 (1505)	1950 (1339)	—
301, 302	2250-2590 (1505-1694)	2100-2300 (1422-1533)	1850-2050 (1283-1394)	400-750 (478-672)
302B	2500-2550 (1644-1672)	2050-2250 (1394-1505)	1850-2050 (1283-1394)	—
303, 303Se	2550-2590 (1672-1694)	2100-2350 (1422-1560)	1850-2050 (1283-1394)	400-750 (478-672)
304, 304L	2550-2650 (1672-1728)	2100-2300 (1422-1533)	1850-2050 (1283-1394)	400-750 (478-672)
304N, S30430	2550-2650 (1672-1728)	2100-2300 (1422-1533)	1850-2050 (1283-1394)	—
305	2550-2650 (1672-1728)	2100-2300 (1422-1533)	1850-2050 (1283-1394)	—
308	2550-2590 (1672-1694)	2100-2300 (1422-1533)	1850-2050 (1283-1394)	—
309, 309S	2550-2650 (1672-1728)	2050-2250 (1394-1505)	1900-2050 (1311-1394)	—
310, 310S	2550-2650 (1672-1728)	2000-2250 (1366-1505)	1900-2100 (1311-1422)	400-750 (478-672)
314	—	1900-2050 (1311-1394)	2100 (1422)	—
316, 316L	2500-2550 (1644-1672)	2100-2300 (1422-1533)	1850-2050 (1283-1394)	400-750 (478-672)
316F	2500-2550 (1644-1672)	2200 (1478)	2000 (1366)	—
316N	2500-2550 (1644-1672)	2100-2300 (1422-1533)	1850-2050 (1283-1394)	—
317	2500-2550 (1644-1672)	2100-2300 (1422-1533)	1850-2050 (1283-1394)	—
317L	2500-2550 (1644-1672)	2250 (1505)	1900-2000 (1311-1366)	—
321	2550-2600 (1672-1700)	2100-2300 (1422-1533)	1750-2050 (1228-1394)	400-750[a] (478-672)
329	—	2000 (1366)	1750-1800 (1228-1255)	—
330	2550-2600 (1672-1700)	2100-2150 (1422-1450)	1950-2150 (1339-1450)	—
347, 348	2550-2600 (1672-1700)	2100-2300 (1422-1533)	1850-2050 (1283-1394)	400-750[a] (478-672)
384	2550-2650 (1672-1728)	2100-2250 (1422-1505)	1900-2100 (1311-1422)	—

[a] Stabilizing temperature, 1550-1650 F (1116-1172 K).

chine than plain carbon steels. They also work harden rapidly and thus cutting tools should not be permitted to dwell. In general 303, 303Se and 316F have the best machinability. Both oil- and water-base cutting fluids are used as lubricants, the former for heavy cuts and the latter for light cuts.

Heat treating

In general, annealing and stress relieving are the only heat treating operations used in the fabrication of austenitic stainless steels. Recommended temperatures for both operations are shown in Table 6.

In annealing, the low side of the recommended range is generally used for low carbon grades, while the high side is used for normal carbon grades. As in heating for forging, muffle or semi-muffle furnaces are preferred and heating in an open flame is not recommended. A slightly oxidizing furnace atmosphere is preferred to provide the best finish after pickling. Subsequent quenching should be rapid, with water quenching generally preferred, especially for heavy sections. However, rapid air cooling also can be used. Stabilized grades—321, 347 and 348—are more completely stabilized at the lower temperatures of the recommended range, but maximum ductility is achieved with the higher temperatures. A "stabilize anneal," generally required only if these grades will be subject to severe corrosion, involves heating at 1600-1650 F (1144-1172 K) for one hour per inch of thickness followed by water or rapid air quenching.

Stress relieving is generally performed at temperatures of 400-750 F (478-672 K), but temperatures as high as 1700 F (1200 K) can be used for greater effect. However, the 800-1500 F (700-1089 K) range should be avoided for unstabilized grades.

Descaling, pickling and passivating

Surface scale from oxidation can be removed from the steels by mechanical or chemical means, including wet and dry blasting, brushing, tumbling or salt bath descaling, the latter being the most effective for large, high volume parts. Salt bath descaling is performed in molten salts at about 700-900 F (644-755 K), and must be followed by pickling in the following solutions: 1) 10% by volume sulfuric acid, with or without an inhibitor, at 150-180 F (339-344 K); 2) 50% by volume hydrochloric acid, with or without inhibitor, at 150-160 F (339-344 K); 3) either of the above followed by immersion in a solution of 10% nitric acid and 2% hydrofluoric acid at 120 F (322 K). The first solution reacts rather slowly, the second is considerably faster, and the third is usually used to remove the last traces of scale retained after the first treatment.

Parts must be water rinsed after descaling and between pickling operations. To avoid hydrogen or acid embrittlement during or after pickling, parts not in the annealed condition should be stress relieved prior to pickling and "baked" at 250-300 F (394-422 K) for one to two hours after pickling.

Once the protective oxide film of the steels is removed in fabrication ,the steels should be passivated to remove contaminating films and particles from the surface and to restore original corrosion resistance. Passivating is done by immersion in a 20% by volume nitric acid solution at 120-150 F (322-339 K) for about 30 min followed by rinsing in clear running water and drying. If required, this should be the last operation in fabrication.

Joining

In addition to mechanical fastening, standard wrought austenitic stainless steels may be joined by brazing, soldering or welding.

Brazing can be readily accomplished, but the major problem is that unstabilized grades are prone to intergranular attack when heated in the 800-1500 F(700-1089 K) range. To minimize this effect, brazing cycles for susceptible grades should be as short as possible or braze temperatures should be well above the heat sensitizing range. Stabilized grades (321, 347 and 348), however, can be brazed with virtually no danger of impairing corrosion resistance.

Prior to brazing, parts should be especially clean and essentially free of internal stresses to preclude stress corrosion cracking by molten filler metals. Choice of filler metal depends upon service temperatures to be encountered. Boron-copper compositions are useful for temperatures up to 500 F (533 K), boron-silver to 800 F (700 K), chromium-nickel-manganese types for 800-1000 F (700-811 K), and boron-nickel filler metals containing gold or palladium for still higher temperatures. Brazing without fluxes can be done in vacuum or in atmospheres of dry hydrogen, argon or helium. If fluxes are used, flux residues must be removed quickly and thoroughly after brazing to prevent corrosion.

The steels also can be soldered, using, for example, tin-lead filler metals. Fluxes are required to break down the protective oxide film and permit wetting. Again, fluxes are quite corrosive and residues must be removed soon after soldering.

Except for free-machining grades (303, 303Se, 316F), which because of their greater sulfur or selenium contents have a tendency for porosity or weld cracking, all of the standard wrought austenitic stainless steels have good weldability. The problem with the other grades, except stabilized grades, is that of carbide precipitation during welding which can cause subsequent intergranular corrosion. However, the use of low carbon grades 304L, 316L and 317L minimizes this problem to a large extent.

All grades can be welded by shielded metal arc methods. Shielding is necessary to prevent chromium loss from the weld metal by oxidation. In welding unstabilized grades or grades of normal carbon content, carbide precipitation can be reduced by using low heat input and ample heat sink capacity to remove heat from the workpiece. Gas tungsten arc welding is generally preferred for flat stock and can be used for thicknesses ranging from foil to 1-in. (25.4-mm) plate. It also can be used for tubing and formed parts. Gas metal arc can be used for thicknesses from 0.125-1 in. (3.18-25.4 mm). Submerged arc welding is preferred for thick plate and heavy sections. Other applicable welding processes are electron beam and electrical resistance welding.

John A. Vaccari, Executive Editor