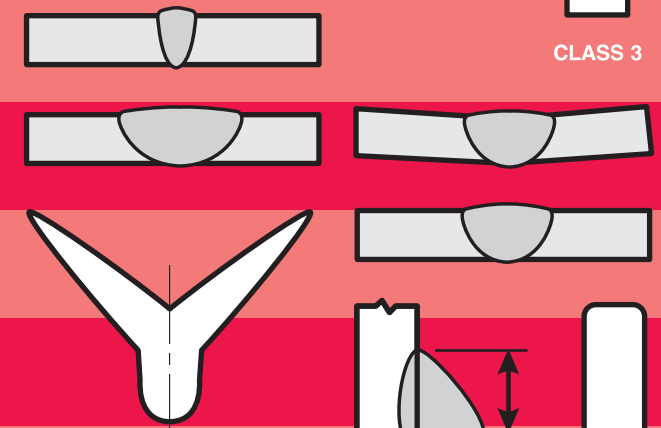
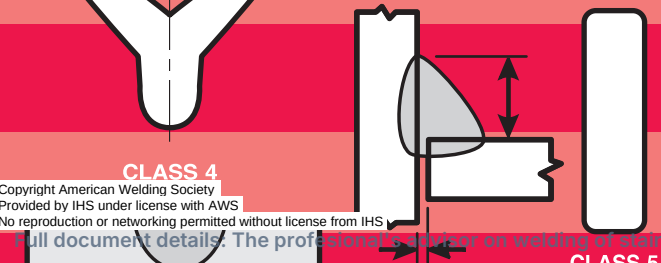






The Professional's Advisor on Welding of Stainless Steels

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Basic Safety Precautions

Burn Protection. Molten metal, sparks, slag, and hot work surfaces are produced by welding, cutting, and allied processes. These can cause burns if precautionary measures are not used. Workers should wear protective clothing made of fire-resistant material. Pant cuffs, open pockets, or other places on clothing that can catch and retain molten metal or sparks should not be worn. High-top shoes or leather leggings and fire-resistant gloves should be worn. Pant legs should be worn over the outside of high-top shoes. Helmets or hand shields that provide protection for the face, neck, and ears, and a head covering to protect the head should be used. In addition, appropriate eye protection should be used.

Electrical Hazards. Electric shock can kill. However, it can be avoided. Live electrical parts should not be touched. The manufacturer's instructions and recommended safe practices should be read and understood. Faulty installation, improper grounding, and incorrect operation and maintenance of electrical equipment are all sources of danger.

All electrical equipment and the workpiece should be grounded. The workpiece lead is not a ground lead. It is used only to complete the welding circuit. A separate connection is required to ground the workpiece. The workpiece should not be mistaken for a ground connection.

Fumes and Gases. Many welding, cutting, and allied processes produce fumes and gases which may be harmful to health. Avoid breathing the air in the fume plume directly above the arc. Do not weld in a confined area without a ventilation system. Use point-of-welding fume removal when welding galvanized steel, zinc, lead, cadmium, chromium, manganese, brass, or bronze. No container should be presumed to be clean or safe. Do not weld or cut on any container, including piping, until it has been examined by, cleaned under the supervision of, and rendered safe by qualified personnel.

Compressed Gas Cylinders. Keep caps on cylinders when not in use. Make sure that gas cylinders are chained to a wall or other structural support. Do not weld on cylinders.

Radiation. Arc welding may produce ultraviolet, infrared, or light radiation. Always wear protective clothing and eye protection to protect the skin and eyes from radiation. Shield others from light radiation from your welding operation.

AWS recommends a personal copy of *Arc Welding Safely*, *Fire Safety in Welding and Cutting*, *Recommended Safe Practices for the Preparation for Welding and Cutting of Containers and Piping*, and *Safety in Welding, Cutting, and Allied Processes*.

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Abbreviation Quick Reference

Ag	Silver	**Mo**	Molybdenum
Al	Aluminum	**N**	Nitrogen
Ar	Argon	**Nb**	Niobium
B	Boron	**Ni**	Nickel
Be	Beryllium	**O**	Oxygen
C	Carbon	**P**	Phosphorus
Cd	Cadmium	**S**	Sulfur
Co	Cobalt	**Se**	Selenium
CO_2	Carbon Dioxide	**Si**	Silicon
Cr	Chromium	**Sn**	Tin
Cu	Copper	**Ta**	Tantalum
Fe	Iron	**Ti**	Titanium
He	Helium	**V**	Vanadium
La	Lanthanum	**W**	Tungsten
Li	Lithium	**Zn**	Zinc
Mg	Magnesium	**Zr**	Zirconium
Mn	Manganese		

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Chapter 1—Definitions

The terms in this chapter are common words used in dealing with welding of stainless steels. See the latest revision of AWS A3.0, *Standard Welding Terms and Definitions*, for the standard terms used in the welding industry. Some other terms and definitions are standard metallurgical and corrosion terms from ASM International and the National Association of Corrosion Engineers (NACE).

Air carbon arc cutting (CAC-A)—A carbon arc cutting process variation that removes molten metal with a jet of air.

Austenite—A nonmagnetic phase of steel with a face-centered cubic (FCC) structure.

Austenitic stainless steel—A stainless steel that contains chromium, nickel, and sometimes manganese, which produce austenite.

Autogenous weld—A fusion weld made without filler metal.

Base metal—The metal or alloy that is welded.

Buttering—A surfacing variation that deposits surfacing metal on one or more surfaces to provide metallurgically compatible weld metal for the subsequent completion of the weld.

Carbon arc cutting (CAC)—An arc cutting process that uses a carbon electrode.

Carburizing flame—A reducing oxyfuel gas flame in which there is an excess of fuel gas, resulting in a carbon-rich zone extending around and beyond the cone.

Cold crack—A crack which develops after solidification is complete.

Corrosion—The deterioration of a metal by chemical or electrochemical reaction with its environment.

Consumable insert—Filler metal that is placed at the joint root before welding, and is intended to be completely fused into the joint root to become part of the weld.

Crater crack—A crack formed in the crater or end of a weld bead, typically a form of a hot crack.

Crevice corrosion—Corrosion caused by the concentration of corrodent along crevices.

Defect—A discontinuity or discontinuities that by nature or accumulated effect (for example total crack length) render a part or product unable to meet minimum applicable standards or specifications. The term designates rejectability.

Delayed crack—A nonstandard term for cold crack caused by hydrogen embrittlement.

Dilution—The change in chemical composition of a welding filler metal caused by the admixture of the base metal or previous weld metal in the weld bead.

Discontinuity—An interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect.

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Duplex stainless steel—A stainless steel that contains chromium plus other alloying elements, designed to produce a duplex structure at room temperature of a mixture of austenite and ferrite, austenite and martensite, etc.

Electrode—A component of the electrical circuit that terminates at the arc, molten conductive slag, or base metal.

Electron beam welding (EBW)—A welding process that produces fusion (coalescence) with a concentrated beam, composed primarily of high-velocity electrons, impinging on the joint.

Ferrite—A magnetic phase of steel with a body-centered cubic (BCC) structure.

Ferrite number (FN)—An arbitrary, standardized value designating the ferrite content of an austenitic stainless steel weld metal.

Ferritic stainless steel—A stainless steel that contains chromium (and often molybdenum), which produce ferrite.

Filler metal—The metal or alloy to be added in making a welded joint.

Flux cored arc welding (FCAW)—An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding gas from a flux contained within the tubular electrode, with or without additional shielding from an externally supplied gas.

Fusion welding—Any welding process that uses fusion of the base metal to make the weld.

Fusion zone—The area of base metal melted as determined on the cross section of a weld.

Gas metal arc welding (GMAW)—An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas.

Gas tungsten arc welding (GTAW)—An arc welding process that uses an arc between a tungsten electrode (nonconsumable) and the weld pool. The process is used with shielding gas.

Heat-affected zone (HAZ)—The portion of the base metal whose mechanical properties or microstructure have been altered by the heat of welding.

Heliarc welding—A nonstandard term for gas tungsten arc welding.

Hot crack—A crack formed at temperatures near the completion of solidification.

Hydrogen crack—Another term for cold crack.

Inert gas—A gas that normally does not combine chemically with materials.

Intergranular corrosion—Corrosion occurring along grain boundaries, with little attack on the surrounding grains.

Interpass temperature—In a multipass weld, the temperature of the weld area between weld passes.

Laser beam cutting (LBC)—A thermal cutting process that severs metal by locally melting or vaporizing with the heat from a laser beam.

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Laser beam welding (LBW)—A welding process that produces fusion (coalescence) with the heat from a laser beam impinging on the joint.

Martensite—A hard, brittle phase of steel with a body-centered tetragonal (BCT) structure.

Martensitic stainless steel—A stainless steel that contains chromium and carbon, which produce martensite.

MIG Welding—A nonstandard term for gas metal arc welding.

Oxidizing flame—An oxyfuel gas flame in which there is an excess of oxygen, resulting in an oxygen-rich zone extending around and beyond the cone.

Oxyfuel gas cutting (OFC)—A group of oxygen cutting processes that use heat from an oxyfuel gas flame.

Oxyfuel welding (OFW)—A group of welding processes that produces fusion (coalescence) of workpieces by heating them with an oxyfuel gas flame.

Passivation—The changing of a chemically active surface of stainless steel to a much less reactive state. Formation of a chromium-rich oxide layer, which is passive to corrosion or further oxidation.

Pitting corrosion—Localized corrosion occurring in the form of cavities or pits.

Plasma arc cutting (PAC)—An arc cutting process that uses a constricted arc and removes the molten metal with a high-velocity jet of ionized gas issuing from the constricting orifice.

Plasma arc welding (PAW)—An arc welding process that uses a constricted arc between a nonconsumable electrode and the weld pool (transferred arc) or between the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained from the ionized gas issuing from the torch, which may be supplemented by an auxiliary source of shielding gas.

Postheating (Postweld heat treatment)—The application of heat to an assembly after welding.

Precipitation-hardening stainless steel—A stainless steel that contains chromium plus other alloying elements designed to produce a hardened structure by precipitation of constituents. The main structure can be austenite, ferrite, or martensite.

Preheat—The heat applied to the base metal to attain and maintain preheat temperature.

Resistance welding (RW)—A group of welding processes that produces fusion (coalescence) of the faying surfaces with the heat obtained from resistance of the workpieces to the flow of the welding current in a circuit of which the workpieces are a part, and by the application of pressure.

Sensitization—In austenitic stainless steels, precipitation of chromium carbides along grain boundaries in the temperature range of 800–1500°F (427–816°C), which leaves the grain boundaries depleted of chromium and susceptible to intergranular corrosion.

Shielded metal arc welding (SMAW)—An arc welding process with an arc between a covered electrode and the weld pool. The process is used

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with shielding from the decomposition of the electrode covering and with filler metal from the electrode.

Stabilized stainless steels—Stainless steels that contain niobium, tantalum and/or titanium, which form carbides that are more stable than chromium carbides, thus avoiding sensitization.

Stainless steel—Steels that contain a minimum of 10.5–12% chromium, depending on classification.

Stick electrode welding—A nonstandard term for shielded metal arc welding.

Stress-corrosion cracking (SCC)—Failure of metals by cracking under combined action of corrosion and stress, residual or applied.

Submerged arc welding (SAW)—An arc welding process that uses an arc or arcs between a bare metal electrode or electrodes and the weld pool. The arc and molten metal are shielded by a blanket of granular flux on the workpieces. The process is used with filler metal from the electrode and sometimes from a supplemental source (such as the flux).

TIG welding—A nonstandard term for gas tungsten arc welding.

Weld (arc)—A localized coalescence (fusion) of metals produced by heating the metals to the welding temperature, with or without the use of filler metals.

Welding rod—A form of welding filler metal, normally packaged in straight lengths, that does not conduct the welding current.

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Chapter 2—Introduction to Stainless Steels and Types of Stainless Steels

What are Stainless Steels?

Stainless steels are steels (iron-based alloys) that contain a minimum of approximately 10.5 wt.% chromium (sometimes classified as containing no less than 12 wt.% chromium). With more than this amount of chromium, stainless steels are very resistant to corrosion and oxidation in specific environments. These steels are properly called corrosion-resistant steels, or "CRES," as called for on some older drawings and material lists.

Just as chromium plating provides protection for steel, the chromium in stainless steels provides corrosion resistance. The chromium causes a "passive" chromium-rich oxide layer to form on the surface of the steel. This is an invisible layer that adheres to the surface of the steel. Unlike plated or painted steel, if stainless steel is scratched, the passive chromium oxide reforms in air, thus protecting the steel from corrosion or oxidation.

Types of Stainless Steels

The American Iron and Steel Institute (AISI) classifications for stainless steels are:

AISI Classification Series	Major Alloying Elements
200 Series	Cr-Ni-Mn
300 Series	Cr-Ni
400 Series	Cr

The five major types or classifications of stainless steels are:

Classification	AISI Series
Austenitic	200 and 300 Series
Ferritic	Some of the 400 Series
Martensitic	Some of the 400 Series
Duplex	
Precipitation-Hardening	

Each type is described by the metallurgical structure present at room temperature.

Most stainless steel base metals are available in various forms, including:

(1) Wrought
- Plate, sheet
- Pipe, tube
- Bar, wire
- Forgings

(2) Cast

Note: The 500 series of steels are technically heat-resistant steels, not corrosion-resistant, because they contain less than 10.5% chromium. However, they are often classified with the corrosion-resistant base metals and filler metals.

In the following tables, the stainless steels are listed by their AISI type (e.g., 304). The tables also list the Unified Numbering System (UNS) numbers for the various stainless steels. The UNS numbers include an "S" for wrought stainless steel. The number typically includes the common type

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number, such as UNS S30400 for Type 304; S30403 for Type 304L, etc. Some of the superaustenitic stainless steels are actually classified as nickel alloys and have UNS "N" designations (see Table 2-3). Cast stainless steels have a UNS "J" designation.

Austenitic Stainless Steels

The majority of stainless steels used are austenitic stainless steels, which contain approximately 16–25 wt.% chromium and 7–35 wt.% nickel. The 300 series austenitics are iron-chromium-nickel alloys, while the 200 series also contain manganese and nitrogen to replace some of the nickel. These steels are named for the face-centered cubic (FCC) structure that is present at room temperature, called *austenite*. Some properties of these stainless steels (with some exceptions) include:

(1) Nonmagnetic.
(2) Best general corrosion resistance.
(3) Not heat treatable (cannot be heat treated to increase strength or hardness).
(4) Can be strengthened only by cold work.
(5) Good ductility and toughness at low and high temperatures (nickel provides good cryogenic properties).
(6) Poor resistance to:
- Stress corrosion cracking
- Pitting corrosion
- Crevice corrosion

Chemical compositions of typical austenitic stainless steels are provided in Tables 2-1–2-3.

The most common stainless steels used are the wrought austenitics in Table 2-1. Type 302 is the basic austenitic 18Cr-8Ni alloy. Type 304 has a higher chromium and nickel content to improve corrosion resistance. Although Type 316 has lower chromium, a higher nickel content, plus the addition of molybdenum provides even better resistance to pitting corrosion, crevice corrosion, and stress-corrosion cracking (especially in chloride environments).

The "L" grades (e.g., 304L and 316L) contain a lower carbon content, thus, they are less likely to be sensitized or produce intergranular corrosion. The "H" grades (e.g., 304H and 316H) have a higher carbon content for greater strength at elevated temperatures.

There are many cast austenitic stainless steels with compositions similar to the wrought stainless steels, as shown in Table 2-2. For example, alloy designation CF-8 is the cast equivalent of Type 304 and CF-3M is the cast equivalent of Type 316L. The "C" denotes corrosion resistant, the 8 indicates a maximum of 0.08% carbon, the 3 indicates 0.03% maximum carbon, and the M denotes molybdenum.

The superaustenitic stainless steels in Table 2-3 contain higher levels of chromium, nickel, and molybdenum, with significantly lower carbon and nitrogen contents (such as Type 904L). These provide better corrosion resistance in specific environments, such as improved pitting and stress-corrosion cracking resistance in chlorides.

Ferritic Stainless Steels

Ferritic stainless steels are iron-chromium alloys that contain approximately 11–30 wt.% chromium and low levels of carbon. The name refers to

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Table 2-1—Chemical Compositions of Typical Wrought Austenitic Stainless Steels

Type	UNS Number	Composition, wt.%[a]							
		C	Mn	Si	Cr	Ni[b]	P	S	Other
201	S20100	0.15	5.5–7.5	1.00	16.0–18.0	3.5–5.5	0.06	0.03	0.25 N
202	S20200	0.15	7.5–10.0	1.00	17.0–19.0	4.0–6.0	0.06	0.03	0.25 N
301	S30100	0.15	2.00	1.00	16.0–18.0	6.0–8.0	0.045	0.03	—
302	S30200	0.15	2.00	1.00	17.0–19.0	8.0–10.0	0.045	0.03	—
302B	S30215	0.15	2.00	2.0–3.0	17.0–19.0	8.0–10.0	0.045	0.03	—
303	S30300	0.15	2.00	1.00	17.0–19.0	8.0–10.0	0.20	0.15 min	0–0.6 Mo
303Se	S30323	0.15	2.00	1.00	17.0–19.0	8.0–10.0	0.20	0.06	0.15 Se min
304	S30400	0.08	2.00	1.00	18.0–20.0	8.0–10.5	0.045	0.03	—
304H	S30409	0.04–0.10	2.00	1.00	18.0–20.0	8.0–11.0	0.045	0.03	—
304L	S30403	0.03	2.00	1.00	18.0–20.0	8.0–12.0	0.045	0.03	—
304LN	S30453	0.03	2.00	1.00	18.0–20.0	8.0–12.0	0.045	0.03	0.10–0.16 N
304N	S30451	0.08	2.00	1.00	18.0–20.0	8.0–10.5	0.045	0.03	0.10–0.16 N
305	S30500	0.12	2.00	1.00	17.0–19.0	10.0–13.0	0.045	0.03	—
308	S30800	0.08	2.00	1.00	19.0–21.0	10.0–12.0	0.045	0.03	—
309	S30900	0.20	2.00	1.00	22.0–24.0	12.0–15.0	0.045	0.03	—
309S	S30908	0.08	2.00	1.00	22.0–24.0	12.0–15.0	0.045	0.03	—
310	S31000	0.25	2.00	1.50	24.0–26.0	19.0–22.0	0.045	0.03	—
310S	S31008	0.08	2.00	1.50	24.0–26.0	19.0–22.0	0.045	0.03	—
314	S31400	0.25	2.00	1.5–3.0	23.0–26.0	19.0–22.0	0.045	0.03	—
316	S31600	0.08	2.00	1.00	16.0–18.0	10.0–14.0	0.045	0.03	2.0–3.0 Mo
316H	S31609	0.04–0.10	2.00	1.00	16.0–18.0	10.0–14.0	0.040	0.03	2.0–3.0 Mo
316L	S31603	0.03	2.00	1.00	16.0–18.0	10.0–14.0	0.045	0.03	2.0–3.0 Mo
317	S31700	0.08	2.00	1.00	18.0–20.0	11.0–15.0	0.045	0.03	3.0–4.0 Mo
317L	S31703	0.03	2.00	1.00	18.0–20.0	11.0–15.0	0.045	0.03	3.0–4.0 Mo
321	S32100	0.08	2.00	1.00	17.0–19.0	9.0–12.0	0.045	0.03	5 × %C Ti min
329	S32900	0.08	1.00	0.75	23.0–28.0	2.5–5.0	0.045	0.03	1.0–2.0 Mo
330	N08330	0.08	2.00	0.75–1.5	17.0–20.0	34.0–37.0	0.04	0.03	
347	S34700	0.08	2.00	1.00	17.0–19.0	9.0–13.0	0.045	0.03	Note c
348	S34800	0.08	2.00	1.00	17.0–19.0	9.0–13.0	0.045	0.03	0.20 Co[c,d]
384	S38400	0.08	2.00	1.00	15.0–17.0	17.0–19.0	0.045	0.03	

Notes:

a. Single values are maximum percentages unless indicated otherwise.

b. Higher percentages are required for certain tube manufacturing processes.

c. 10 × %C (Nb +Ta) min.

d. 0.10% T...

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Table 2-2—Chemical Compositions of Typical Cast Austenitic Stainless Steels

Alloy Designation	UNS Number	Similar Wrought Type[b]	Composition, wt.%[a]					
			C	Si	Cr	Ni	Mo	Other
CE-30	J93423	312	0.30	2.0	26–30	8–11	—	—
CF-3	J92700	304L	0.03	2.0	17–21	8–12	—	—
CF-3M	J92800	316L	0.03	1.5	17–21	9–13	2.0–3.0	—
CF-8	J92600	304	0.08	2.0	18–21	8–11	—	—
CF-8C	J92710	347	0.08	2.0	18–21	9–12	—	Note c
CF-8M	J92900	316	0.08	1.5	18–21	9–12	2.0–3.0	—
CF-12M	—	316	0.12	1.5	18–21	9–12	2.0–3.0	—
CF-16F	J92701	303	0.16	2.0	18–21	9–12	1.5	0.20–0.35 Se
CF-20	J92602	302	0.20	2.0	18–21	8–11	—	—
CG-8M	—	317	0.08	1.5	18–21	9–13	3.0–4.0	—
CH-20	J93402	309	0.20	2.0	22–26	12–15	—	—
CK-20	J94202	310	0.20	2.0	23–27	19–22	—	—
CN-7M	J95150	—	0.07	1.5	18–22	27.5–30.5	2.0–3.0	3–4 Cu
HE	J93403	—	0.2–0.5	2.0	26–30	8–11	0.5	—
HF	J92603	304	0.2–0.4	2.0	19–23	9–12	0.5	—
HH	J93503	309	0.2	—	—	—	0.5	—
HI	J94003	—	0.2–0.5	2.0	26–30	14–18	0.5	—
HK	J94224	310	0.2–0.6	2.0	24–28	18–22	0.5	—
HL	J94604	—	0.2–0.6	2.0	28–32	18–22	0.5	—
HN	J94213	—	0.2–0.5	2.0	19–23	23–27	0.5	—
HP	—	—	0.35–0.75	2.0	24–28	33–37	0.5	—
HT	J94605	330	0.35–0.75	2.5	15–19	33–37	0.5	—
HU	—	—	0.35–0.75	2.5	17–21	37–41	0.5	—

Notes:
a. Single values are maximum percentages. 1.50% Mn max for CX-XX types. 2.0% Mn max for HX types. 0.04% P max (exception: CF-16F has 0.17% P max). 0.04% S max.
b. Compositions are similar but not exactly the same as the cast types.
c. 8 × %C Nb, 1.0% Nb max, or 9 × %C (Nb + Ta), 1.1% (Nb + Ta) max.

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Table 2-3—Chemical Compositions of Typical Superaustenitic Stainless Steels

Alloy[a]	UNS Number	Nominal Composition, wt.%[b]										
		C	Cr	Ni	Mo	Cu	Mn	N	Si	P	S	Other Elements
20 Cb3™	N08020	0.07	19–21	32–38	2–3	3–4	2.0	—	1.0	0.045	0.035	8 × %C ≤ Nb ≤ 1.0
20 Mo6™	N08026	0.03	22–26	33–37	5–6.7	2–4	1.0	—	0.5	0.030	0.030	—
SANICRO™ 28	N08028	0.03	26–28	29.5–32.5	3–4	0.6–1.4	2.5	—	1.0	0.030	0.030	—
AL-6XN®	N08367	0.03	20–22	23.5–25.5	6–7	0.75	2.0	0.18–0.25	1.0	0.040	0.030	—
JS™ 700	N08700	0.04	19–23	24–26	4.3–5.0	0.5	2.0	—	1.0	0.040	0.030	8 × %C ≤ Nb ≤ 0.5
904L	N08904	0.02	19–23	23–28	4–5	1–2	2.0	—	1.0	0.045	0.035	—
1925hMo, 25-6MO™	N08925	0.02	19–21	24–26	6–7	0.8–1.5	1.0	0.18–0.20	0.5	0.045	0.030	—
254SMO™	S31254	0.02	19.5–20.5	17.5–18.5	6.0–6.5	0.5–1.0	1.0	0.18–0.22	0.8	0.030	0.010	—
317LM	S31725	0.03	18–20	13–17	4–5	—	2.0	—	0.75	0.045	0.030	—
17-14-4 LN	S31726	0.03	17–20	13.5–17.5	4–5	—	2.0	0.10–0.20	0.75	0.030	0.030	—

Notes:

a. AL-6XN is a registered trademark of Allegheny Ludlum Corporation. 20 Cb3 and 20 Mo6 are trademarks of Carpenter Technology Corporation; SANICRO is a registered trademark of AB Sandvik Steel; 25-6MO is a trademark of INCO; JS is a trademark of Jessop Steel; and 254SMO is a trademark of Avesta Jernwerke AB.

b. Single values are maximum percentages; balance is Fe.

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the body-centered cubic (BCC) structure present at room temperature, called *ferrite*. Some properties of these stainless steels include:

(1) Ferromagnetic.
(2) Intermediate general corrosion resistance.
(3) Better stress-corrosion cracking resistance than austenitics.
(4) Good pitting and crevice corrosion resistance.
(5) Not heat treatable (by quenching and tempering).
(6) Lower strength and toughness than austenitics.
(7) Good ductility.

The chemical compositions of typical ferritic stainless steels are provided in Tables 2-4 and 2-5.

The ferritic stainless steels shown in Table 2-4 include both wrought and cast alloys. These alloys essentially contain no nickel, but have chromium contents from the lowest allowable levels in stainless steels (Type 409) up to very high levels (29-4-2). Some of these alloys contain moderate levels of carbon (Type 430) and can form martensite, although most form only ferrite.

The superferritic stainless steels shown in Table 2-5 have even higher levels of chromium, with some molybdenum and significantly lower carbon. These alloys provide much improved corrosion resistance, especially in chloride environments.

Martensitic Stainless Steels

Martensitic stainless steels are iron-chromium alloys with 11–17 wt.% chromium and enough carbon (0.1–1.2 wt.%) to produce some martensite on cooling. This *martensite* is a body-centered tetragonal (BCT) structure that forms when these stainless steels are quenched (rapidly cooled), often when cooled in air. Some properties of these stainless steels include:

(1) Ferromagnetic.
(2) Lowest corrosion resistance.
(3) Heat treatable (can be strengthened by quenching).
(4) High strength.
(5) Lowest ductility and toughness.
(6) Good high temperature oxidation resistance.

When these steels are quenched from high temperatures, martensite is produced, which gives the steels high strength and hardness. Since the steels also become very brittle and subject to cold (or hydrogen) cracking, they are often tempered after quenching. This process improves ductility (reduces the brittleness), although strength and hardness are somewhat reduced.

The chemical compositions of typical martensitic stainless steels are provided in Table 2-6.

Duplex Stainless Steels

Duplex stainless steels are iron-chromium-nickel alloys that contain 23–30 wt.% chromium and 2–7 wt.% nickel, plus other elements. Since these stainless steels have two phases present at room temperature, *ferrite* and *austenite*, they are referred to as *duplex*. Some properties of these stainless steels include:

(1) Partially magnetic.
(2) Good general corrosion resistance.
(3) Better stress-corrosion cracking resistance than austenitics.

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Table 2-4—Chemical Compositions of Typical Ferritic Stainless Steels

Type	UNS Number	Composition, wt.%[a]							
		C	Mn	Si	Cr	Ni	P	S	Others
Wrought Alloys									
405	S40500	0.08	1.00	1.00	11.5–14.5	—	0.04	0.03	0.10–0.30 Al
409	S40900	0.08[b]	1.00	1.00	10.5–11.75	—	0.045	0.045	Ti, 6 × %C min
429	S42900	0.12	1.00	1.00	14.0–16.0	—	0.04	0.03	—
430	S43000	0.12	1.00	1.00	16.0–18.0	—	0.04	0.03	—
430Ti	S43036	0.10	1.00	1.00	16.0–19.5	0.75	0.04	0.03	Ti, 5 × %C min, 0.75 max
434	S43400	0.12	1.00	1.00	16.0–18.0	—	0.04	0.03	0.75–1.25 Mo
436	S43600	0.12	1.00	1.00	16.0–18.0	—	0.04	0.03	0.75–1.25 Mo; (Nb+Ta), 5 × %C min
439	S43035	0.07	1.00	1.00	17.0–19.0	0.50	0.04	0.03	0.15 Al max; 0.04 N max; Ti, 0.20 + 4(%C + %N) min, 1.10 max
442	S44200	0.20	1.00	1.00	18.0–23.0	—	0.04	0.03	Ti, 0.20 + 4(%C + %N)
444	S44400	0.025	1.00	1.00	17.5–19.5	1.00	0.04	0.03	1.75–2.5 Mo; 0.035 N max; (Nb+Ta), 0.2 + 4 (%C + %N) min
446	S44600	0.20	1.50	1.00	23.0–27.0	—	0.04	0.03	0.25 N
26-1	S44626	0.006	0.75	0.75	25.0–27.0	0.50	0.04	0.020	0.75–1.50 Mo; 0.20–1.0 Ti; 0.04 N; 0.2 Cu
29-4	S44700	0.010	0.20	0.30	28.0–30.0	0.15	0.025	0.020	3.5–4.2 Mo; 0.020 Ni; 0.15 Cu
29-4-2	S44800	0.010	0.20	0.30	28.0–30.0	2.0–2.5	0.025	0.020	3.5–4.2 Mo; 0.020 Ni, 0.15 Cu
Casting Alloys									
CB-30	J91803	0.30	1.50	1.00	18.0–21.0	2.0	0.04	0.04	—
CC-50	J92616	0.50	1.50	1.00	26.0–30.0	4.0	0.04	0.04	—

Notes:
a. Single values are a maximum.
b. Most producers can now make a low-carbon with 0.02% carbon.

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Table 2-5—Chemical Compositions of Typical Superferritic Stainless Steels

Alloy[a]	UNS Number	Nominal Composition, wt.%[b]						
		C	Cr	Mo	Ni	N	Mn	Other Elements
E-BRITE®	S44726	0.010	25–27	0.75–1.5	0.30	0.015	0.4	0.05–0.20 Nb
MONIT™	S44635	0.025	24.5–26	3.5–4.5	3.5–4.5	0.035	1.0	$[0.20 + 4(C + N)] \leq (Nb + Ti) \leq 0.80$
SEA-CURE®	S44660	0.025	25–27	2.5–3.5	1.5–3.5	0.035	1.0	$[0.20 + 4(C + N)] \leq (Nb + Ti) \leq 0.80$
AL 29-4®	S44700	0.010	28–30	3.5–4.2	0.15	0.020	0.3	
AL 29-4C®	S44735	0.030	28–30	3.6–4.2	1.0	0.045	1.0	$6(C + N) \leq (Nb + Ti) \leq 1.0$
AL 29-4-2®	S44800	0.010	28–30	3.5–4.2	2.0–2.5	0.020	0.3	
SHOMAC® 30-2	—	0.003[c]	30[c]	2.0[c]	0.2[c]	0.007[c]	0.05[c]	

Notes:
a. E-BRITE, AL 29-4, AL 29-4-2, and AL 29-4C are registered trademarks of Allegheny Ludlum Corporation; SEA-CURE is a registered trademark of Crucible Materials Corporation; SHOMAC is a registered trademark of Showa Denko KK. Monit is a trademark of Nyby Uddeholm AB.
b. Single values are maximum percentages; balance is Fe.
c. Typical value.

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Table 2-6—Chemical Compositions of Typical Martensitic Stainless Steels

Type	UNS Number	Composition, wt.%[a]							
		C	Mn	Si	Cr	Ni	P	S	Other
Wrought Alloys									
403	S40300	0.15	1.00	0.50	11.5–13.0	—	0.04	0.03	—
410	S41000	0.15	1.00	1.00	11.5–13.0	—	0.04	0.03	—
414	S41400	0.15	1.00	1.00	11.5–13.5	1.25–2.50	0.04	0.03	—
416	S41600	0.15	1.25	1.00	12.0–14.0	—	0.04	0.15 min	—
420	S42000	0.15 min	1.00	1.00	12.0–14.0	—	0.04	0.03	—
422	S42200	0.20–0.25	1.00	0.75	11.0–13.0	0.5–1.0	0.025	0.025	0.75–1.25 Mo; 0.75–1.25 W; 0.15–0.3 V
431	S43100	0.20	1.00	1.00	15.0–17.0	1.25–2.50	0.04	0.03	—
440A	S44002	0.60–0.75	1.00	1.00	16.0–18.0	—	0.04	0.03	0.75 Mo
440B	S44003	0.75–0.95	1.00	1.00	16.0–18.0	—	0.04	0.03	0.75 Mo
440C	S44004	0.95–1.20	1.00	1.00	16.0–18.0	—	0.04	0.03	0.75 Mo
Casting Alloys									
CA-6NM	J91540	0.06	1.00	1.00	11.5–14.0	3.5–4.5	0.04	0.03	0.40–1.0 Mo
CA-15	J91150	0.15	1.00	1.50	11.5–14.0	1.0	0.04	0.03	0.5 Mo
CA-40	J91153	0.20–0.40	1.00	1.50	11.5–14.0	1.0	0.04	0.03	0.5 Mo

Note:
a. Single values are maximum percentages.

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(4) Better pitting corrosion resistance than austenitics.
(5) Better intergranular corrosion resistance than austenitics.
(6) Higher strength than austenitics.

The chemical compositions of typical duplex stainless steels are provided in Table 2-7.

Precipitation-Hardening Stainless Steels

Precipitation-hardening stainless steels are iron-chromium-nickel alloys that have other elements added to form precipitates. During a postweld heat treatment, these constituents precipitate and dramatically improve hardness, thus the name *precipitation-hardening*. Some properties of these stainless steels include:

(1) Intermediate corrosion resistance.
(2) Very high strength (when heat treated).

Depending on their compositions, these alloys can be one of three types as shown in Table 2-8:

(1) Martensitic.

(2) Semiaustenitic (structure is austenite with some ferrite and/or martensite).

(3) Austenitic.

Precipitation-hardening stainless steels require a two-step heat treatment to obtain the best properties. The first is a solution anneal at an elevated temperature of 1900–2200°F (1038–1204°C) followed by quenching. This produces the various structures listed above. Then the steel is aged to cause precipitates of copper, nickel, titanium or other elements to form, which dramatically increase the strength.

The chemical compositions of typical precipitation-hardening stainless steels are provided in Table 2-8.

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Table 2-7—Chemical Compositions of Typical Duplex Stainless Steels

Alloy	UNS Number	Composition, wt.%[a,b,c]					
		C	Cr	Ni	Mo	N	Other Elements
329	S32900	0.08	23.0–28.0	2.5–5.0	1.0–2.0	—	—
44LN	S31200	0.030	24.0–26.0	5.5–6.5	1.2–2.0	0.14–0.20	—
DP3	S31260	0.030	23.0–28.0	2.5–5.0	2.5–3.5	0.10–0.30	0.20–0.80 Cu; 0.10–0.50 W
2205	S31803	0.030	21.0–23.0	4.5–6.5	2.5–3.5	0.08–0.20	—
2304	S32304	0.030	21.5–24.5	3.0–5.5	0.05–0.6	0.05–0.20	—
255	S32550	0.04	24.0–27.0	4.5–6.5	2.9–3.9	0.10–0.25	1.5–2.0 Cu
2507	S32750	0.030	24.0–26.0	6.0–8.0	3.0–4.0	0.24–0.32	—
Z100[d]	S32760	0.030	24.0–26.0	6.0–8.0	3.0–4.0	0.2–0.3	0.5–1.0 Cu; 0.5–1.0 W
3RE60	S31500	0.030	18.0–19.0	4.25–5.25	2.5–3.0	—	—
U50[d]	S32404	0.04	20.5–22.5	5.5–8.5	2.0–3.0	0.20	1.0–2.0 Cu
7MoPLUS	S32950	0.03	26.0–29.0	3.5–5.2	1.0–2.5	0.15–0.35	—
DP3W	S39274	0.03	24.0–26.0	6.0–8.0	2.5–3.5	0.24–0.32	0.2–0.8 Cu; 1.5–2.5 W

Notes:
a. Single values are maximum percentages.
b. 2.5 Mn max.
c. 0.70–1.0 Si max.
d. Z100—Zeron 100; U50—Uranus 50.

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Table 2-8—Chemical Compositions of Typical Precipitation-Hardening Stainless Steels

Type	Designation[a]	UNS Number	Nominal Composition, wt.%							
			C	Mn	Si	Cr	Ni	Mo	Al	Other Elements
Martensitic										
Moderate strength	17-4 PH	S17400	0.04	0.30	0.60	16.0	4.2	—	—	3.4 Cu; 0.25 Nb
	15-5 PH	S15500	0.04	0.30	0.40	15.0	4.5	—	—	3.4 Cu; 0.25 Nb
	Custom 450	S45000	0.03	0.25	0.25	15.0	6.0	0.8	—	1.5 Cu; 0.3 Nb
High strength	PH 13-8 Mo	S13800	0.04	0.03	0.03	12.7	8.2	2.2	1.1	—
	Custom 455	S45500	0.03	0.25	0.25	11.75	8.5	—	—	2.5 Cu; 1.2 Ti; 0.3 Nb
Semiaustenitic	PH 15-7 Mo	S15700	0.07	0.50	0.30	15.2	7.1	2.2	1.2	—
	PH 14-8 Mo	S14800	0.04	0.02	0.02	15.1	8.2	2.2	1.2	—
	AM-350	S35000	0.10	0.75	0.35	16.5	4.25	2.75	—	—
	AM-355	S35500	0.13	0.85	0.35	15.5	4.25	2.75	—	—
Austenitic	A-286	S66286	0.05	0.50	0.50	14.75	25.0	1.30	0.15	0.30 V; 2.15 Ti; 0.005 B
	17-10 P	—	0.10	0.60	0.50	17.0	11.0	—	—	0.30 P
	HNM	—	0.30	3.50	0.50	18.50	9.50	—	—	0.25 P

Note:
a. Some of these designations are registered trademarks.

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Chapter 3—Stainless Steel Filler Materials

Welding Filler Metals

Stainless steels can be welded with or without filler metals.

Processes Requiring Filler Metal:

- SMAW
- GMAW
- FCAW
- SAW

Processes For Which Filler Metal is Optional:

- GTAW
- PAW
- LBW
- EBW

AWS specifications for stainless steel welding electrodes and filler metals are described in the list of standards that are provided at the end of this Advisor. The welding processes covered for filler metals are as follows:

(1) AWS A5.4	SMAW electrodes
(2) AWS A5.9	GMAW electrodes
	GTAW welding rod
	SAW electrodes
(3) AWS A5.22	FCAW electrodes
	Cored wire for GTAW
(4) AWS A5.30	Consumable inserts

Tables 3-1 through 3-6 list the chemical compositions of stainless steel filler metals described in these specifications. The compositions of bare wire or strip are based on chemical analysis of the bare filler metal. The compositions of coated or cored electrodes and rods are based on as-deposited, undiluted weld metal. The UNS numbers have a prefix of "W" to denote welding filler metal.

AWS A5.4

Stainless steel electrodes for shielded metal arc welding (SMAW) are listed in Table 3-1. Electrodes are available for all five major groups of stainless steels; however, there are only a few martensitic and ferritic stainless steel electrodes.

There are electrodes available that closely match the base metal compositions; however, the actual chemical composition of any filler metal is typically higher than the base metal, because some elements are often lost in the transfer across the arc.

The classifications indicated with "-XX" suffixes designate the various types of welding currents and positions of welding, as summarized in Table 3-2. The "XXX(X)" classification denotes the stainless steel composition, such as 308L. The "1" suffix indicates that the electrodes can be used in all welding positions, while the "2" indicates flat and horizontal positions only.

The last digit designates whether the electrode can be used with direct current electrode positive (dcep–reverse polarity) only or with both dcep and alternating current (ac).

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Table 3-1—Chemical Composition Requirements for Stainless Steel Shielded Metal Arc Welding Electrodes[a]

AWS Classification[c]	UNS Number[d]	Composition, wt.%[b]										
		C	Cr	Ni	Mo	Nb + Ta	Mn	Si	P	S	N	Cu
E209-XX[e]	W32210	0.06	20.5–24.0	9.5–12.0	1.5–3.0	—	4.0–7.0	0.90	0.04	0.03	0.10–0.30	0.75
E219-XX	W32310	0.06	19.0–21.5	5.5–7.0	0.75	—	8.0–10.0	1.00	0.04	0.03	0.10–0.30	0.75
E240-XX	W32410	0.06	17.0–19.0	4.0–6.0	0.75	—	10.5–13.5	1.00	0.04	0.03	0.10–0.30	0.75
E307-XX	W30710	0.04–0.14	18.0–21.5	9.0–10.7	0.5–1.5	—	3.30–4.75	0.90	0.04	0.03	—	0.75
E308-XX	W30810	0.08	18.0–21.0	9.0–11.0	0.75	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E308H-XX	W30810	0.04–0.08	18.0–21.0	9.0–11.0	0.75	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E308L-XX	W30813	0.04	18.0–21.0	9.0–11.0	0.75	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E308Mo-XX	W30820	0.08	18.0–21.0	9.0–12.0	2.0–3.0	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E308LMo-XX	W30823	0.04	18.0–21.0	9.0–12.0	2.0–3.0	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E309-XX	W30910	0.15	22.0–25.0	12.0–14.0	0.75	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E309H-XX	—	0.04–0.15	22.0–25.0	12.0–14.0	0.75	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E309L-XX	W30913	0.04	22.0–25.0	12.0–14.0	0.75	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E309Cb-XX	W30917	0.12	22.0–25.0	12.0–14.0	0.75	0.70–1.00	0.5–2.5	0.90	0.04	0.03	—	0.75
E309Mo-XX	W30920	0.12	22.0–25.0	12.0–14.0	2.0–3.0	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E309LMo-XX	W30923	0.04	22.0–25.0	12.0–14.0	2.0–3.0	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E310-XX	W31010	0.08–0.20	25.0–28.0	20.0–22.5	0.75	—	1.0–2.5	0.75	0.03	0.03	—	0.75
E310H-XX	W31015	0.35–0.45	25.0–28.0	20.0–22.5	0.75	—	1.0–2.5	0.75	0.03	0.03	—	0.75
E310Cb-XX	W31017	0.12	25.0–28.0	20.0–22.0	0.75	0.70–1.00	1.0–2.5	0.75	0.03	0.03	—	0.75
E310Mo-XX	W31020	0.12	25.0–28.0	20.0–22.0	2.0–3.0	—	1.0–2.5	0.75	0.03	0.03	—	0.75
E312-XX	W31310	0.15	28.0–32.0	8.0–10.5	0.75	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E316-XX	W31610	0.08	17.0–20.0	11.0–14.0	2.0–3.0	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E316H-XX	W31610	0.04–0.08	17.0–20.0	11.0–14.0	2.0–3.0	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E316L-XX	W31613	0.04	17.0–20.0	11.0–14.0	2.0–3.0	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E317-XX	W31710	0.08	18.0–21.0	12.0–14.0	3.0–4.0	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E317L-XX	W31713	0.04	18.0–21.0	12.0–14.0	3.0–4.0	—	0.5–2.5	0.90	0.04	0.03	—	0.75
E318-XX	W31910	0.08	17.0–20.0	11.0–14.0	2.0–3.0	6 × %C min, 1.00 max	0.5–2.5	0.90	0.04	0.03	—	0.75
E320-XX	W88021	0.07	19.0–21.0	32.0–36.0	2.0–3.0	8 × %C min, 1.00 max	0.5–2.5	0.60	0.04	0.03	—	3.0–4.0

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Table 3-1—Chemical Composition Requirements for Stainless Steel Shielded Metal Arc Welding Electrodes[a] (Continued)

AWS Classification[c]	UNS Number[d]	Composition, wt.%[b]										
		C	Cr	Ni	Mo	Nb + Ta	Mn	Si	P	S	N	Cu
E320LR-XX	W88022	0.03	19.0–21.0	32.0–36.0	2.0–3.0	8 × %C min 0.40 max	1.50–2.50	0.30	0.020	0.015	—	3.0–4.0
E330-XX	W88331	0.18–0.25	14.0–17.0	33.0–37.0	0.75	—	1.0–2.5	0.90	0.04	0.03	—	0.75
E330H-XX	W88335	0.35–0.45	14.0–17.0	33.0–37.0	0.75	—	1.0–2.5	0.90	0.04	0.03	—	0.75
E347-XX	W34710	0.08	18.0–21.0	9.0–11.0	0.75	8 × %C min, 1.00 max	0.5–2.5	0.90	0.04	0.03	—	0.75
E349-XX[e,f,g]	W34910	0.13	18.0–21.0	8.0–10.0	0.35–0.65	0.75–1.2	0.5–2.5	0.90	0.04	0.03	—	0.75
E383-XX	W88028	0.03	26.5–29.0	30.0–33.0	3.2–4.2	—	0.5–2.5	0.90	0.02	0.02	—	0.6–1.5
E385-XX	W88904	0.03	19.5–21.5	24.0–26.0	4.2–5.2	—	1.0–2.5	0.75	0.03	0.02	—	1.2–2.0
E410-XX	W41010	0.12	11.0–13.5	0.75	0.7	—	1.0	0.90	0.04	0.03	—	0.75
E410NiMo-XX	W41016	0.06	11.0–12.5	4.0–5.0	0.40–0.70	—	1.0	0.90	0.04	0.03	—	0.75
E430-XX	W43010	0.10	15.0–18.0	0.6	0.75	—	1.0	0.90	0.04	0.03	—	0.75
E502-XX[h]	W50210	0.10	4.0–6.0	0.4	0.45–0.65	—	1.0	0.90	0.04	0.03	—	0.75
E505-XX[h]	W50410	0.10	8.0–10.5	0.4	0.85–1.20	—	1.0	0.90	0.04	0.03	—	0.75
E630-XX	W37410	0.05	16.0–16.75	4.5–5.0	0.75	0.15–0.30	0.25–0.75	0.75	0.04	0.03	—	3.25–4.00
E16-8-2-XX	W36810	0.10	14.5–16.5	7.5–9.5	1.0–2.0	—	0.5–2.5	0.60	0.03	0.03	—	0.75
E7Cr-XX[h]	W50310	0.10	6.0–8.0	0.4	0.45–0.65	—	1.0	0.90	0.04	0.03	—	0.75
E2209-XX	W39209	0.04	21.5–23.5	8.5–10.5	2.5–3.5	—	0.5–2.0	0.90	0.04	0.03	0.08–0.20	0.75
E2553-XX	W39553	0.06	24.0–27.0	6.5–8.5	2.9–3.9	—	0.5–1.5	1.0	0.04	0.03	0.10–0.25	1.5–2.5
E2593-XX	W39593	0.04	24.0–27.0	8.5–11.0	2.9–3.9	—	0.5–1.5	1.0	0.04	0.03	0.08–0.25	1.5–3.0

Notes:

a. Analysis shall be made for the elements for which specific values are shown in this table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements, except iron, is not present in excess of 0.50%.

b. Single values shown are maximum percentages.

c. Classification suffix may be -15, -16, -17, -25, or -26. See Section A8 of the Appendix of AWS A5.4, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding,* for an explanation.

d. ASTM/SAE Unified Numbering System for Metals and Alloys.

e. 0.10–0.30% V.

f. 0.15% Ti max.

g. 1.25–1.75% W.

h. In the next revision of A5.4, classifications E502, E505, and E7Cr will be eliminated, but they will be added to the next revision of A5.5 and listed as follows: E502 as E901X-B6, E505 as E901X-B8, and E7Cr as E901X-B7.

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Table 3-2—Types of Welding Current and Positions of Welding

AWS Classification	Welding Current[b]	Welding Position[a,c]
EXXX(X)-15	dcep	All[d]
EXXX(X)-25	dcep	H, F
EXXX(X)-16	dcep or ac	All[d]
EXXX(X)-17	dcep or ac	All[d]
EXXX(X)-26	dcep or ac	H, F

Notes:
a. See A5.4, Section A8, Classification as to Usability, for explanation of positions.
b. dcep = Direct current electrode positive (reverse polarity).
ac = Alternating current.
c. The abbreviations H and F indicate welding positions as follows:
F = Flat.
H = Horizontal.
d. Electrodes 3/16 in. (4.8 mm) and larger are not recommended for welding all positions.

As with all SMAW electrodes, it is important to keep these dry and stored properly, according to the code requirements or manufacturer's instructions.

Since some of the alloying in the weld comes from the coating, the solid core wire should never be used as a bare wire for welding.

AWS A5.9

Table 3-3 lists the chemical compositions of numerous types of stainless steel filler metals described in AWS A5.9. These filler metals are used for various welding processes. As listed in Note (c) in Table 3-3, the designations are:

ER—Solid wires used as electrodes (for GMAW and SAW) and rods (for GTAW and PAW)

EC—Composite metal cored or stranded wire (for GTAW or PAW)
EQ—Bare strip electrodes (for SAW)

There are electrodes and rods available for many of the stainless steels, and most stainless steel base metals are welded with filler metals of the same type. However, the actual compositions of the filler metals typically contain greater amounts of most elements, because there is some loss across the arc. Note that there is no Type 304 filler metal; Type 308 is the filler metal used for Type 304 base metal.

AWS A5.22

Table 3-4 lists the chemical compositions of stainless steel flux cored wires as described in AWS A5.22. The designation system includes:

E—Cored electrode for flux cored arc welding (FCAW)
R—Flux cored rod for GTAW (or PAW)
T—Tubular wire

The designations indicate the chemical compositions of the as-deposited, undiluted weld metal, positions of welding, external shielding medium, and type of current. There are flux cored filler metals for many stainless steel alloys.

The "E" designation filler metals shown in Table 3-4 are used for FCAW processes—both gas-shielded and self-shielded; while the "R" designates filler metals for GTAW. These filler metals are typically used for root pass welding of stainless steel pipe, without the use of back shielding gas. The rods contain 5 wt.% or more of non-metallic content. Cored rods with less than this amount are not contained in AWS A5.22, but are classified as metal cored rods in AWS A5.9.

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Table 3-3—Chemical Composition Requirements for Bare Stainless Steel Welding Electrodes and Rods[a]

AWS Classification[c,d]	UNS Number[e]	Composition, wt.%[b]										Other Element	Amount of Other Element
		C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu		
ER209	S20980	0.05	20.5–24.0	9.5–12.0	1.5–3.0	4.0–7.0	0.90	0.03	0.03	0.10–0.30	0.75	V	0.10–0.30
ER218	S21880	0.10	16.0–18.0	8.0–9.0	0.75	7.0–9.0	3.5–4.5	0.03	0.03	0.08–0.18	0.75	—	—
ER219	S21980	0.05	19.0–21.5	5.5–7.0	0.75	8.0–10.0	1.00	0.03	0.03	0.10–0.30	0.75	—	—
ER240	S24080	0.05	17.0–19.0	4.0–6.0	0.75	10.5–13.5	1.00	0.03	0.03	0.10–0.30	0.75	—	—
ER307	S30780	0.04–0.14	19.5–22.0	8.0–10.7	0.5–1.5	3.3–4.75	0.30–0.65	0.03	0.03	—	0.75	—	—
ER308	S30880	0.08	19.5–22.0	9.0–11.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER308H	S30880	0.04–0.08	19.5–22.0	9.0–11.0	0.50	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER308L	S30883	0.03	19.5–22.0	9.0–11.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER308Mo	S30882	0.08	18.0–21.0	9.0–12.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER308LMo	S30886	0.04	18.0–21.0	9.0–12.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER308Si	S30881	0.08	19.5–22.0	9.0–11.0	0.75	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—
ER308LSi	S30888	0.03	19.5–22.0	9.0–11.0	0.75	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—
ER309	S30980	0.12	23.0–25.0	12.0–14.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER309L	S30983	0.03	23.0–25.0	12.0–14.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER309Mo	S30982	0.12	23.0–25.0	12.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER309LMo	S30986	0.03	23.0–25.0	12.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER309Si	S30981	0.12	23.0–25.0	12.0–14.0	0.75	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—
ER309LSi	S30988	0.03	23.0–25.0	12.0–14.0	0.75	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—
ER310	S31080	0.08–0.15	25.0–28.0	20.0–22.5	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER312	S31380	0.15	28.0–32.0	8.0–10.5	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER316	S31680	0.08	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER316H	S31680	0.04–0.08	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER316L	S31683	0.03	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER316Si	S31681	0.08	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—

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Table 3-3—Chemical Composition Requirements for Bare Stainless Steel Welding Electrodes and Rods[a] (Continued)

AWS Classification[c,d]	UNS Number[e]	Composition, wt.%[b]										Other Element	Amount of Other Element
		C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu		
ER316LSi	S31688	0.03	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—
ER317	S31780	0.08	18.5–20.5	13.0–15.0	3.0–4.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER317L	S31783	0.03	18.5–20.5	13.0–15.0	3.0–4.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER318	S31980	0.08	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	Nb[g]	8 × %C min, 1.0 max
ER320	NO8021	0.07	19.0–21.0	32.0–36.0	2.0–3.0	2.5	0.60	0.03	0.03	—	3.0–4.0	Nb[g]	8 × %C min, 1.0 max
ER320LR	NO8022	0.025	19.0–21.0	32.0–36.0	2.0–3.0	1.5–2.0	0.15	0.015	0.02	—	3.0–4.0	Nb[g]	8 × %C min, 0.40 max
ER321	S32180	0.08	18.5–20.5	9.0–10.5	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	Ti	9 × %C min, 1.0 max
ER330	NO8331	0.18–0.25	15.0–17.0	34.0–37.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
ER347	S34780	0.08	19.0–21.5	9.0–11.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	Nb[g]	10 × %C min, 1.0 max
ER347Si	S34788	0.08	19.0–21.5	9.0–11.0	0.75	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	Nb[g]	10 × %C min, 1.0 max
ER383	NO8028	0.025	26.5–28.5	30.0–33.0	3.2–4.2	1.0–2.5	0.50	0.02	0.03	—	0.70–1.5	—	—
ER385	NO8904	0.025	19.5–21.5	24.0–26.0	4.2–5.2	1.0–2.5	0.50	0.02	0.03	—	1.2–2.0	—	—
ER409	S40900	0.08	10.5–13.5	0.6	0.50	0.8	0.8	0.03	0.03	—	0.75	Ti	10 × %C min, 1.5 max
ER409Cb	S40940	0.08	10.5–13.5	0.6	0.50	0.8	1.0	0.04	0.03	—	0.75	Nb[g]	10 × %C min, 0.75 max
ER410	S41080	0.12	11.5–13.5	0.6	0.75	0.6	0.5	0.03	0.03	—	0.75	—	—
ER410NiMo	S41086	0.06	11.0–12.5	4.0–5.0	0.4–0.7	0.6	0.5	0.03	0.03	—	0.75	—	—
ER420	S42080	0.25–0.40	12.0–14.0	0.6	0.75	0.6	0.5	0.03	0.03	—	0.75	—	—

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Table 3-3—Chemical Composition Requirements for Bare Stainless Steel Welding Electrodes and Rods[a] (Continued)

AWS Classification[c,d]	UNS Number[e]	Composition, wt.%[b]										Other Element	Amount of Other Element
		C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu		
ER430	S43080	0.10	15.5–17.0	0.6	0.75	0.6	0.5	0.03	0.03	—	0.75	—	—
ER446LMo	S44687	0.015	25.0–27.5	Note f	0.75–1.50	0.4	0.4	0.02	0.02	0.015	Note f	—	—
ER502	S50280	0.10	4.6–6.0	0.6	0.45–0.65	0.6	0.5	0.03	0.03	—	0.75	—	—
ER505	S50480	0.10	8.0–10.5	0.5	0.8–1.2	0.6	0.5	0.03	0.03	—	0.75	—	—
ER630	S17480	0.05	16.0–16.75	4.5–5.0	0.75	0.25–0.75	0.75	0.03	0.03	—	3.25–4.00	Nb[g]	0.15–0.30
ER19-10H	S30480	0.04–0.08	18.5–20.0	9.0–11.0	0.25	1.0–2.0	0.30–0.65	0.03	0.03	—	0.75	Nb[g] Ti	0.05 0.05
ER16-8-2	S16880	0.10	14.5–16.5	7.5–9.5	1.0–2.0	1.0–2.0	0.30–0.65	0.03	0.03	—	0.75	—	—
ER2209	S39209	0.03	21.5–23.5	7.5–9.5	2.5–3.5	0.50–2.0	0.90	0.03	0.03	0.08–0.20	0.75	—	—
ER2553	S39553	0.04	24.0–27.0	4.5–6.5	2.9–3.9	1.5	1.0	0.04	0.03	0.10–0.25	1.5–2.5	—	—
ER3556	R30556	0.05–0.15	21.0–23.0	19.0–22.5	2.5–4.0	0.50–2.00	0.20–0.80	0.04	0.015	0.10–0.30	—	Co W Nb Ta Al Zr La B	16.0–21.0 2.0–3.5 0.30 0.30–1.25 0.10–0.50 0.001–0.10 0.005–0.10 0.02

Notes:

a. Analysis shall be made for the elements for which specific values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total, excluding iron, does not exceed 0.50%.

b. Single values shown are maximum percentages.

c. In the designator for composite, stranded, and strip electrodes, the "R" shall be deleted. A designator "C" shall be used for composite and stranded electrodes, and a designator "Q" shall be used for strip electrodes. For example, ERXXX designates a solid wire and EQXXX designates a strip electrode of the same general analysis and the same UNS number. However, ECXXX designates a composite metal cored or stranded electrode and may not have the same UNS number. Consult ASTM/SAE Uniform Numbering System for the proper UNS number.

d. For special applications, electrodes and rods may be purchased with less than the specified silicon content.

e. ASTM/SAE Unified Numbering System for Metals and Alloys.

f. 0.5% (Ni + Cu) max.

g. Nb may be reported as Nb + Ta.

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