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Introduction to Selecting Filler Metals for Stainless Steel

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The capabilities that make stainless steel so attractive — the ability to tailor its mechanical properties and resistance to corrosion and oxidation — also increase the complexity of selecting an appropriate filler metal. For any given base material combination, any one of several types of electrodes may be appropriate depending on cost issues, service conditions, desired mechanical properties and a host of welding-related issues.

This article provides the necessary technical background to give the reader an appreciation for the complexity of the topic and then answers some of the most common questions filler metal suppliers receive. It establishes general guidelines for selecting appropriate stainless steel filler metals — and then explains all the exceptions to those guidelines! The article does not cover welding procedures, as that is a topic for another article.

Four Grades, Many Alloying Elements

There are four principal categories of stainless steels: austenitic, martensitic, ferritic and duplex. The names are derived from the crystalline structure of the steel normally found at room temperature. When low carbon steel is heated above 912 °C, the atoms of the steel are rearranged from the structure called ferrite at room temperatures to the crystal structure called austenite. On cooling, the low carbon steel atoms return to their original structure, ferrite. The high temperature structure, austenite, is non-magnetic, plastic and has lower strength and greater ductility than the room temperature form of ferrite.

When more than 16% chromium is added to the steel, the room temperature crystalline structure, ferrite, is stabilized and the steel remains in the ferritic condition at all temperatures. Hence the name, ferritic stainless steel is applied to this alloy base. When more than 17% chromium and 7% nickel are added to the steel, the high temperature crystalline structure of the steel, austenite, is stabilized so that it persists at all temperatures from the very lowest to almost melting.

Austenitic stainless is commonly referred to as the “chrome-nickel” Type, and the martensitic and ferritic steels are commonly called the “straight chrome” types. Certain alloying elements used in stainless steels and weld metals behave as austenite stabilizers and others as ferrite stabilizers. The most important austenite stabilizers are nickel, carbon, manganese and nitrogen. The ferrite stabilizers are chromium, silicon, molybdenum and niobium. Balancing the alloying elements controls the quantity of ferrite in the weld metal.

Austenitic grades are more readily and satisfactorily welded than those that contain less than 5% nickel. Weld joints produced in austenitic stainless steels are strong, ductile and tough in their as-welded condition. They do not normally require preheat or post-weld heat treatment. Austenitic grades account for approximately 80% of the stainless steel welded, and this introductory article focuses heavily on them.

Fig. 1 – Stainless steel types and their chromium and nickel content.

Type	% Chromium	% Nickel	Types
Austenitic	16 – 30%	8 – 40%	200, 300
Martensitic	11 – 18%	0 – 5%	403, 410, 416, 420
Ferritic	11 – 30%	0 – 4%	405, 409, 430, 422, 446
Duplex	18 – 28%	4 – 8%	2205

How do I choose the correct stainless filler metal?

If the base material in both plates is the same, the original guiding principle used to be, “Start by matching the base material.” That works well in some cases; to join Type 310 or 316, choose the corresponding filler Type.

To join dissimilar materials, follow this guiding principle: choose a filler to match the more highly alloyed material. To join 304 to 316, choose a 316 filler.

Unfortunately, the “match rule” has so many exceptions that a better principle is, “Consult a filler metal selection table.” For example, Type 304 is the most common stainless steel base material … but no one offers a Type 304 electrode.

If I am supposed to match the filler metal to base metal, what do I use to weld Type 304 stainless?

To weld Type 304 stainless, use Type 308 filler, as the additional alloying elements in Type 308 will better stabilize the weld area.

However, 308L is also an acceptable filler. The “L” designation after any Type indicates low carbon content. A Type 3XXL stainless has a carbon content ≤ 0.03%, where standard Type 3XX stainless can have a maximum carbon content of 0.08%.

Because a Type L filler falls within the same classification as the non-L product, fabricators can, and should strongly consider, using a Type L filler because lower carbon content reduces the risk of intergranular corrosion issues. In fact, the authors contend Type L filler would be more widely used if fabricators simply updated their procedures.

Fabricators using the GMAW process may also want to consider using a Type 3XXSi filler, as the addition of silicon improves wet out. In situations where the weld has a high or rough crown, or where the weld puddle does not tie-in well at the toes of a fillet or lap joint, using a Si Type GMAW electrode can smooth the weld bead and promote better fusion.

If carbide precipitation is a concern, consider a Type 347 filler (see below), which contains a small amount of niobium.

How do you weld stainless steel to carbon steel?

This situation occurs in applications where one portion of a structure requires a corrosion-resistant exterior face joined to a carbon steel structural element to lower cost. When joining a base material with no alloying elements to a base material with alloying elements, use an over-alloyed filler so that the dilution within the weld metal balances or is more highly alloyed than the stainless base metal.

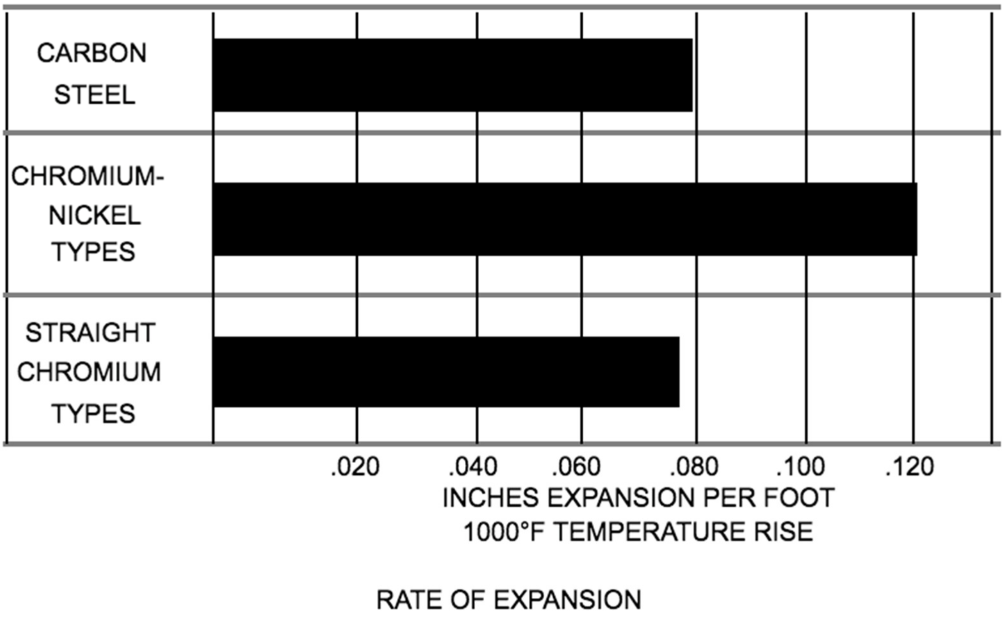
For joining carbon steel to Type 304 or 316, as well as for joining dissimilar stainless steels, consider a Type 309L electrode for most applications. If a higher Cr content is desired, consider Type 312.

Fig. 2 – The high alloy content of Type 309L and 312 make them suitable for joining stainless steel to carbon steel.

	Ni	Si	C	Mn	Cr	FN WR C-92	N	Mo
309L	13.4 %	0.4 %	0.02 %	1.8 %	23.2 %	10%	0.05 %	0.10%
312	8.8 %	0.4 %	0.10 %	1.6 %	30.7 %			

As a cautionary note, austenitic stainless steels exhibit a rate of expansion that is about 50% greater than that of carbon steel. When joined, the different rates of expansion can cause cracking due to internal stresses unless the proper electrode and welding procedure is used.

Fig. 3 – Because of different expansion rates, distortion from warping must be compensated for to a greater extent when welding carbon steel to austenitic stainless.



What are proper weld preparation cleaning procedures?

As with other metals, first remove oil, grease, markings and dirt with a non-chlorinated solvent. After that, the primary rule of stainless weld preparation is, "Avoid contamination from carbon steel to prevent corrosion." Some companies use separate buildings for their "stainless shop" and "carbon shop" to prevent cross-contamination.

Designate grinding wheels and stainless brushes as "stainless only" when preparing edges for welding. Some procedures call for cleaning 2-in. back from the joint. Joint preparation is also more critical, as compensating for inconsistencies with electrode manipulation is harder than with carbon steel.

What is the proper post-weld cleaning procedure, or why does my stainless weld rust?

To start, remember what makes a stainless steel stainless: the reaction of chromium with oxygen to form a protective layer of chromium oxide on the surface of the material. Stainless rusts because of carbide precipitation (see below) and because the welding process heats the weld metal to the point where ferritic oxide can form on the surface of the weld. Left in the as-welded condition, a perfectly sound weld might show "wagon tracks of rust" at the boundaries of the heat-affected zone in less than 24 hours.

So that a new layer of pure chromium oxide can properly reform, stainless steel requires post-weld cleaning by polishing, pickling, grinding or brushing. Again, use grinders and brushes dedicated to the task.

Why is my stainless steel welding wire magnetic?

Fully austenitic stainless steel is non-magnetic. However, welding temperatures create a relatively large grain in the microstructure, which results in the weld being crack-sensitive. To mitigate sensitivity to hot cracking, electrode manufacturers add alloying elements, including ferrite. The ferrite phase causes the austenitic grains to be much finer, so the weld becomes more crack-resistant.

A magnet will not stick to a spool of austenitic stainless filler, but a person holding a magnet might feel a slight pull because of the retained ferrite. Unfortunately, this causes some users to think that their product has been mislabeled or they are using the wrong filler metal (especially if they tore the label off the wire basket).

The correct amount of ferrite in an electrode depends on the service temperature of the application. For example, too much ferrite causes the weld to lose its toughness at low temperatures. Thus, Type 308 filler for an LNG piping application has a ferrite number between 3 and 6, compared to a ferrite number of 8 for standard Type 308 filler. In short, filler metals may seem similar at first, but small differences in composition are important.

Is there an easy way to weld duplex stainless steels?

Typically, duplex stainless steels have a microstructure consisting of approximately 50% ferrite and 50% austenite. In simple terms, the ferrite provides high strength and some resistance to stress corrosion cracking while the austenite provides good toughness. The two phases in combination give the duplex steels their attractive properties. A wide range of duplex stainless steels are available, with the most common being Type 2205; it contains 22% chromium, 5% nickel, 3% molybdenum and 0.15% nitrogen.

When welding duplex stainless steel, problems could arise if the weld metal has too much ferrite (the heat from the arc causes the atoms to arrange themselves in a ferrite matrix). To compensate, filler metals need to promote the austenitic structure with higher alloy content, typically 2 to 4% more nickel than in the base metal. For example, Flux-Cored wire for welding Type 2205 may have 8.85% nickel.

Desired ferrite content can range from 25 to 55% after welding (but can be higher). Note that the cooling rate must be slow enough to allow the austenite to reform, but not so slow as to create intermetallic phases, nor too fast as to create excess ferrite in the heat-affected zone. Follow the manufacturer’s recommended procedures for the weld process and filler metal selected.

Why do I keep adjusting when parameters welding stainless steel?

For fabricators who constantly adjust parameters (voltage, amperage, arc length, inductance, pulse width, etc.) when welding stainless steel, the typical culprit is inconsistent filler metal composition. Given the importance of alloying elements, lot-to-lot variations in chemical composition can have a noticeable affect on weld performance, such as poor wet out or difficult slag release. Variations in electrode diameter, surface cleanliness, cast and helix also affect performance in GMAW and FCAW applications.

How do I control carbide precipitation in austenitic stainless steel?

At temperatures in the range of 426-871°C, carbon content in excess of 0.02% migrates to the grain boundaries of the austenitic structure, where it reacts with chromium to form chromium carbide. If the chromium is tied up with the carbon, it is not available for corrosion resistance. When exposed to a corrosive environment, intergranular corrosion results, allowing the grain boundaries to be eaten away.

To control carbide precipitation, keep the carbon content as low as possible (0.04% maximum) by welding with low carbon electrodes. Carbon can also be tied up by niobium (formerly columbium) and titanium, which have a stronger affinity for carbon than does chromium. Type 347 electrodes are made for this purpose.

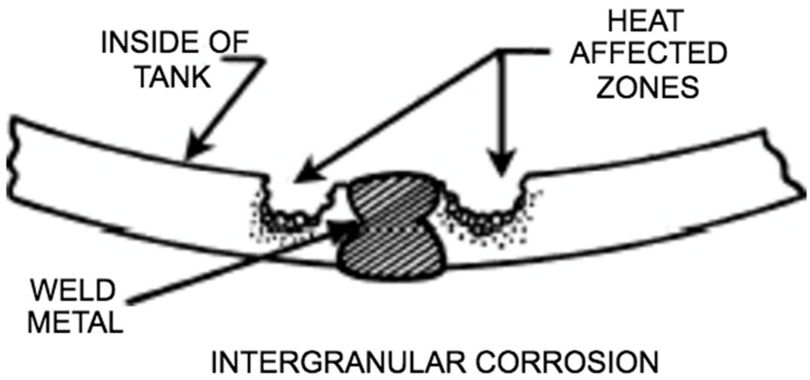


Fig. 3 - Intergranular corrosion takes place in the heat-affected zone on the inside of a tank storing corrosive media. Using low carbon and specially alloyed electrodes can mitigate the risk of carbide precipitation and the resulting corrosion.

How should I prepare for a discussion on filler metal selection?

At a minimum, gather information on the end-use of the welded part, including service environment (especially operating temperatures, exposure to corrosive elements and degree of expected corrosion resistance) and desired service life. Information on required mechanical properties at operating conditions helps greatly, including strength, toughness, ductility and fatigue.

Most of the leading electrode manufacturers provide guidebooks for filler metal selection, and the authors cannot over-emphasize this point: consult a filler metal applications guide or contact their technical experts. They are there to help with selecting the correct stainless steel electrode.

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