Stainless Steels

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WELD TECH NEWS is a newsletter for welders working primarily in maintenance and repair. Each issue contains useful information on materials (cast irons, steels, aluminum, copper alloys, etc.), welding products and welding techniques. By collecting each issue, the reader will soon have a handy reference manual covering all aspects of welding, brazing and soldering for maintenance and repair.

STAINLESS STEELS
What They Are — How They Work

The name "stainless steel" is applied to a family of corrosion-resistant and heat-resistant iron-based alloys that generally contain at least ten percent chromium. Most stainless steels contain other alloying metals, mainly nickel, but also including manganese, molybdenum and other elements.

Stainless steels are widely used for corrosion resistance and appearance, among other properties. There are many types and variations, and their metallurgy can become quite complex. This article discusses the basic classifications, alloys and properties of stainless steels. The articles below, discuss some of the materials and techniques used in arc welding stainless steels.

The first stainless steels were produced between 1910 and 1915 in Sheffield, England for making cutlery. Since then, the family of stainless steels has grown to include a broad range of materials — with different properties — for different applications.

At first, stainless steels were named according to the percentage of chromium and nickel in the alloy. One of the principal early types contained 18% chromium and 8% nickel, and was called "18-8." A variation of this system is still used for a few specialized, high-strength, "precipitation hardened" steels, such as 17-4PH and 17-7PH.

AISI Classification

As many new alloy variations came into use, the old system became cumbersome and the American Iron and Steel Institute (AISI) developed a three-digit numbering system, in which the first digit indicates the general type of alloy. The AISI system is the most widely used method today. It is described in the following chart.
The 200 and 300 series stainless steels are alike in many ways, except that manganese replaces some of the nickel in the 200 series. They cannot be hardened by heat treatment, but cold working will increase hardness somewhat. In the annealed state, all are non-magnetic, although some may become slightly magnetic by cold working. They have good corrosion resistance and excellent strength at high or very low temperatures. They are the most versatile and weldable of the high alloy steels.

The 400 series stainless steels contain 11.5-18.0 percent chromium, but little or no nickel. The martensitic steels (403, 410, 414, 416, 420, 422, 431, 440) can be hardened by heat treatment. The ferritic steels (405, 409, 429, 430, 434, 436, 442, 446) are not considered heat treatable.

The 500 series steels are not generally considered true stainless steels and are not discussed in this article.

Physical Properties

All stainless steels have certain physical and chemical properties, which should be considered in welding. Compared with ordinary carbon steel, stainless has

- a lower melting point,
- lower heat conductivity,
- higher coefficients of expansion (for the chromium-nickel types), and
- higher electrical resistance.

The melting point of type 304 is about 2600°F (1427°C) and type 410 is 2700°F (1482°C), compared with 2800°F (1538°C) for carbon steel. Thus it takes slightly less heat to melt stainless.

The lower heat conductivity means that welding heat does not flow away from the weld as quickly. The result can be local overheating and distortion. The weld zone will stay hot longer, which may contribute to carbide precipitation is discussed below.
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The 200 and 300 type stainless steels expand up to 50% more than carbon steel when heated. This difference in the coefficient of expansion can increase both distortion and cooling stresses. On the other hand, the martensitic 400 type stainless steels expand when heated about the same amount as carbon steel.

The higher electrical resistivity of stainless, compared to carbon steel, means that less amperage is needed for welding.

Alloying Metals

Let's look for a moment at the different elements in stainless steels and their properties:

Iron is the main element, making these alloys steels. In contrast, the Inconnels, which may have similar appearance and corrosion resistance to stainless steels, are mainly nickel alloys, with only small amounts of iron.

Chromium makes these steels "stainless". At the surface, the chromium forms a tight, self-healing, oxide film, which protects against further corrosion. The chromium also likes to combine with any carbon present to form chromium carbides. These carbides add useful hardness to the 400 series stainless steels. Stainless steel knives, for example, are made of 400 series alloys.

Chromium carbides can sometimes reduce strength and corrosion resistance. These bad effects of chromium carbides, and how to deal with them, are discussed later on.

Nickel works with chromium to increase corrosion resistance, toughness, weldability and strength. Nickel also adds non-magnetic properties to the "austenitic" 200 and 300 series alloys.

Some of the other alloying metal elements include molybdenum (adds acid resistance and high temperature strength); silicon (helps deoxidize and improves strength and casting fluidity); manganese (another deoxidizer and toughener, used to replace some of the nickel in the 200 series alloys); selenium (improves machinability); and aluminum (to control carbide precipitation for certain "precipitation hardening" steels).

Carbon

All stainless steels contain some carbon. A typical 308 alloy would have .08% carbon, or about eight parts of carbon per 10,000 parts of metal. Normally this carbon is in solid solution within the metallic grain structure. However, when most austenitic (200 and 300 series) stainless steels are heated in the range of 800°-1400°F (425-760°C), the carbon precipitates out of solution, mainly at the grain boundaries, and combines there to form chromium carbides.

This carbide precipitation causes two problems. First, it removes free chromium when it combines with the carbon. Unfortunately, each 0.1% of carbon can reduce the chromium available for corrosion resistance by 1.6%, or 16 times as much. Second, the hard, brittle carbides in the grain boundaries reduce toughness and increase the chance of cracking.
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There are three ways to reduce carbide precipitation problems. Less carbon in the weld metal means less chance of forming carbides. Austenitic stainless steels marked "LC" (low carbon), "ELC" (extra low carbon) or simply "L," all have less carbon than normal grades. A 308L, for example, has only half the carbon of a regular 308.

Another method is to add special alloying metals, such as titanium or columbium. These metals combine with the carbon even more easily than chromium, forming titanium and/or columbian carbides, and leaving the free chromium in solution to keep on fighting corrosion. This method is used in special cases where the steel will encounter service temperatures of 800°-1400°F (425°- 760°C) and corrosion conditions are especially severe.

The most widely used method to fight carbide precipitation is heat control. If the metal is not heated to the critical temperature range, the carbides will not precipitate. If the metal is heated to a temperature above the critical range (when the carbon will redissolve) and then cooled rapidly through the critical range, the carbides do not have time to form.

Corrosion

Although stainless steels are inherently resistant to corrosion, the resistance varies from type to type. Welding procedures can also change the way the metal reacts to corrosive environments.

Corrosion resistance is affected by choice of alloy, surface roughness, and carbide precipitation.

In highly corrosive environments, the welder should select a filler metal with the highest corrosion resistance, as described below in the sections on filler metal choice.

Weld areas that have a different surface finish from the adjacent base metal, or contain pits or crevices, are prime areas for corrosion. The welder should remove all spatter and grind off surface roughness. Special attention should be paid to avoid any small pitting, undercuts around welds, craters at bead ends, or incomplete fusion in root passes. When small holes like these are submerged in an industrial acid, for example, galvanic action tends to cause accelerated corrosion in the bottom of the hole and may eventually ruin the piece.

The Welding Shop

STAINLESS STEEL — ARC WELDING TECHNIQUES

Most stainless steels can be successfully arc welded, with the right materials and techniques. Rockmount engineers have developed a specialized group of alloys to cover most stainless steel arc welding problems. These materials, and how to use them, are explained below.
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Heat, Stress and Cracking

In general, stainless steels should be welded with a minimum of heat input to the base metal. This will reduce overstressing the piece and will minimize metallurgical changes that decrease strength and corrosion resistance.

For this reason, oxy-acetylene welding and submerged arc welding should generally be avoided. (Oxy-acetylene brazing, using filler metals with low melting temperatures works well, however). TIG welding also works well, as does manual stick welding. Laying intermittent stringer beads and not weaving will help keep the workpiece cooler.

Since most 200 series and 300 series stainless steels expand more than ordinary steel when heated (and shrink more when cooled), the welder must make extra allowance for movement. Various ways of compensating for distortion are shown in the back of the Rockmount welding manual. However, the best method is to avoid overheating the part and to use highly ductile, low amperage, Rockmount filler metals. In some cases, light peening between passes helps to relieve the cooling stresses in the weld metal itself.

Stress, due to welding distortions or to applied loads, can cause cracking at any point of weakness. The solution is to:

- reduce the stress, through proper design and proper heat control procedures, and
- strengthen the joint, through proper filler metal selection and through proper heat control procedures.

The filler metal must, of course, have adequate strength. It must also have enough ductility, or "give," to allow it to deform slightly under load to reduce points of high stress concentration. The section below on filler metal selection gives the strength and ductility, among other characteristics, of each Rockmount alloy.

If the filler metal is chosen correctly, the weld metal mixture of filler metal alloy and base metal alloy will have the right properties to insure a strong joint. What happens then when a crack develops in the HAZ next to the weld, not in the weld?

The base metal in the HAZ is heated by the welding process. If it is heated too much, or the heat is kept high too long, changes in the grain chemistry may cause embrittlement and weakness (see Carbide Precipitation below). Cooling stresses may then cause cracking, particularly in some high carbon, 400 series alloys. The proper heat control procedures to avoid these problems are discussed in the paragraphs below on the 400 series stainlesses.

Controlling Carbide Precipitation

When many 200 series and 300 series stainless steels are heated in the range of 800°-1400°F (425°-760°C), the carbon in solution migrates to the grain boundaries and combines there with chromium. The steel is
then said to be "sensitized." It becomes less corrosion resistant and more prone to crack along the weakened grain boundaries.

If a sensitized steel is heated above 1950°F (1068°C), the carbon will redissolve, freeing the chromium to do its job of providing corrosion resistance. This structure can be preserved by rapid cooling.

Left — Carbon dissolved within normal grain structure.

Center — At sensitizing temperature, carbon migrates to grain boundaries and reduces free chromium there.

Right — Above 1950°F (1068°C), carbon redissolves.

The degree of carbide precipitation depends on:

- the amount of carbon available;
- the temperature — precipitation occurs faster about 1100°F (593°C) in the middle of the sensitizing range, than at the lower or higher limits; and
- time — the longer the steel is held in the sensitizing temperature range, the more carbide will precipitate.

Carbon content in the weld can be reduced by using Rockmount's especially designed, low-carbon filler metals. Temperature levels can be reduced by skip welding, cooling between passes and avoiding preheat (except for very heavy pieces). If the workpiece is not allowed to overheat, the weld area will cool more quickly, reducing the time that it remains at the critical sensitizing temperature.
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One trick that many welders use is to place a wet rag on the weld area immediately after welding. This rapidly reduces the temperature below the sensitizing temperature before chromium carbides have a chance to form.

What happens if the steel has already become sensitized? The answer is to heat it to 1900°-2150°F (approximately 1040° - 1180°C) to redissolve the carbon and then cool it rapidly through the sensitizing zone to room temperature.

Quenching or rapid cooling must, of course, be done carefully in very heavy or highly restrained pieces, where the cooling stresses could cause problems of their own.

Choice of Filler Metal

The proper filler metal alloy will react with the base metal to produce a weld that is ductile enough to deform slightly without cracking, yet strong enough to withstand the loads. Rockmount products, when used as directed, will meet the most difficult welding conditions.

Many welders do not realize that, when welding stainless steels, the best filler metal usually has a higher alloy content than the base metal. Often the filler metal must be more crack and/or corrosion resistant than the base metal. For example, if a hard, martensitic 400-series stainless is welded with the same 400 series filler metal, cracking can easily develop, unless elaborate and special heat treatments are followed.

On the other hand, the same 400 series base metal can be easily welded with a Rockmount Gemini-A rod (containing extra alloying ingredients and less carbon) with much less difficulty.

Following are the principal classes of stainless steels, with the correct choice of filler metal to insure strong, trouble-free welds.

Austenitic Stainless Steels — (200 and 300 series)

The 31 steels in the 200 series and 300 series are classified as austenitic. They can be hardened by cold working, but not by heat treatment. In the annealed condition, all are non-magnetic. They generally have high ductility, corrosion resistance and ultimate stretch.

Gemini-A should be used for all 200 series stainless as well as types 301, 302, 303, 304, 304L, 305, 308, 308L, and 321. It provides high strength (85,000 p.s.i.) and good corrosion resistance in a special, low-carbon alloy.

Gemini-B can be used in many of the same applications as Gemini-A. However, Gemini-B provides superior corrosion resistance and is especially suited for joining types 316, 316L, and 329. It is a low-carbon alloy containing molybdenum, with a strength of 80,000 p.s.i. Gemini-B can be used to weld highly restrained joints, because its high ductility permits the joint to "give" slightly, rather than
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crack. Gemini-B's high corrosion resistance makes it widely used in food, chemical and refinery applications.

Gemini-E contains more chromium and nickel than any type of stainless. Because of its high-alloy composition, it can be used to weld any type of stainless, including 309, 310 and 314. Because of its broad applicability, Gemini-E can be used where the exact base metal analysis is not known. At normal temperatures, Gemini- E has a tensile strength of 85,000 p.s.i and it maintains a relatively high strength at temperatures up to 2000°F (1090°C). Gemini-E is often used in heat exchangers, furnace parts, baskets, valves and in repair work that requires stainless to be welded to any type of carbon steel.

Brutus-A and Brutus-AAA are both multipurpose filler metals designed to provide exceptionally strong (125,000-127,000 p.s.i.), crack-free welds in joining steels of all types. They are truly "universal welding rods." In addition to their ability to join dissimilar metals, Brutus rods are also specifically used to join stainless types 330, 347 and 348.

Martensitic Stainless Steels — (400 series)

These steels contain chromium, little or no nickel, and higher levels of carbon than the austenitic alloys. They are relatively soft when annealed, but become quite hard when heated above 1850°F (1010°C) and then quenched. Whether the base metal is hardened or annealed before starting, welding will generally produce a hardened martensitic zone next to the weld. Since these steels have low heat conductivity, welding tends to produce steep temperature gradients and stresses that can cause cracking, unless proper procedures are followed.

Types 403, 410, 414 and 416 contain .15% carbon and can be welded with a preheat to 500°F (260°C) and slow cooling after welding. Types 420, 422 and 431 have .15-40% carbon and may require heat treatment after welding. Type 440 (.6-1.2% carbon) will definitely require heat treatment after welding.

The best filler metal for these steels is Gemini-E or Brutus-A. The weld metal will be strong, but relatively ductile, providing a cushion to absorb distortion stresses. Although the weld will not require heat treatment, the HAZ will be embrittled and must be treated as described above.

Ferritic Stainless Steels — (400 series)

Ferritic stainless steels generally contain less carbon than the martensitic types in the 400 series and, in some cases, more chromium. They give little problems of excess hardening in the HAZ, but heavier sections may have a tendency to crack, unless preheated to 300° - 450°F (150° - 230°C) before welding. Do not preheat sections less than 1/4 inch thick (6-7mm) however.

Ferritic stainless types 405, 409,429,430,434,436; 442 or 446 can be welded with Gemini-A or Brutus-A. In some cases, to insure maintaining corrosion resistance and mechanical properties in the base metal, the workpiece should be annealed after welding at 1450°F (790°C), followed by a slow furnace cool to 1100°F (590°C) and then a rapid cool or quench.
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4-6\% Chromium Steels — (500 series)

These air hardening steels are not true stainlesses, but do have considerable resistance to oxidation and sulfur corrosion at temperatures up to 1100\textdegree-1200\textdegree F (590\textdegree-650\textdegree C). They are widely used in oil refineries, furnace tubes, heat exchangers and high temperature steam lines. In general, they should be preheated before welding and annealed afterward. \textit{Gemini-E} or \textit{Brutus-A} filler metals are recommended, preferably using DC straight polarity (electrode negative).

For additional information on welding stainless steel, consult your local Rockmount sales representative.

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