Stainless Steels
Welding Guide
STAINLESS STEELS
PROPERTIES –
HOW TO WELD THEM
WHERE TO USE THEM

A description of the physical and mechanical properties of a
variety of commercial stainless steels. Recommendations on the
applications of each type and how to arc weld each including
filler materials.

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Safety in Welding
WELDING OF STAINLESS STEELS

1.0 INTRODUCTION

Stainless steels are defined as iron base alloys which contain at least 10.5% chromium. The thin but dense chromium oxide film which forms on the surface of a stainless steel provides corrosion resistance and prevents further oxidation. There are five types of stainless steels depending on the other alloying additions present, and they range from fully austenitic to fully ferritic.

2.0 TYPES OF STAINLESS STEELS

Austenitic stainless steels include the 200 and 300 series of which type 304 is the most common. The primary alloying additions are chromium and nickel. Ferritic stainless steels are non-hardenable Fe-Cr alloys. Types 405, 409, 430, 422 and 446 are representative of this group. Martensitic stainless steels are similar in composition to the ferritic group but contain higher carbon and lower chromium to permit hardening by heat treatment. Types 403, 410, 416 and 420 are representative of this group. Duplex stainless steels are supplied with a microstructure of approximately equal amounts of ferrite and austenite. They contain roughly 24% chromium and 5% nickel. Their numbering system is not included in the 200, 300 or 400 groups. Precipitation hardening stainless steels contain alloying additions such as aluminum which allow them to be hardened by a solution and aging heat treatment. They are further classified into sub groups as martensitic, semiaustenitic and austenitic precipitation hardening stainless steels. They are identified as the 600-series of stainless steels (e.g., 630, 631, 660).

The alloying elements which appear in stainless steels are classed as ferrite promoters and austenite promoters and are listed below.

2.1 FERRITE PROMOTERS

Chromium – provides basic corrosion resistance.
Molybdenum – provides high temperature strength and increases corrosion resistance.
Niobium (Columbium), Titanium – strong carbide formers.

2.2 AUSTENITE PROMOTERS

Nickel – provides high temperature strength and ductility.
Carbon – carbide former, strengthener.
Nitrogen – increases strength, reduces toughness.

2.3 NEUTRAL EFFECT

- Regarding Austenite & Ferrite
  Manganese – sulfide former
  Silicon – wetting agent
- Sulfur and Selenium – improve machinability, cause hot cracking in welds.

3.0 WELDABILITY OF STAINLESS STEELS

Most stainless steels are considered to have good weldability and may be welded by several welding processes including the arc welding processes, resistance welding, electron and laser beam welding, friction welding and brazing. For any of these processes, joint surfaces and any filler metal must be clean.

The coefficient of thermal expansion for the austenitic types is 50% greater than that of carbon steel and this must be considered to minimize distortion. The low thermal and electrical conductivity of austenitic stainless steel is generally helpful in welding. Less welding heat is required to make a weld because the heat is not conducted away from a joint as rapidly as in carbon steel. In resistance welding, lower current can be used because resistivity is higher. Stainless steels which require special welding procedures are discussed in later sections.

3.1 FERRITIC STAINLESS STEELS

The ferritic stainless steels contain 10.5 to 30% Cr, up to 0.20% C and sometimes ferrite promoters Al, Nb (Cb), Ti and Mo. They are ferritic at all temperatures, do not transform to austenite and therefore, are not hardenable by heat treatment. This group includes the more common types 405, 409, 430, 442 and 446. Table I lists the nominal composition
TABLE I — Nominal Compositions of Ferritic Stainless Steels

<table>
<thead>
<tr>
<th>Type</th>
<th>UNS Number</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>P</th>
<th>S</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>405</td>
<td>S40500</td>
<td>0.08</td>
<td>1.00</td>
<td>1.00</td>
<td>11.5-14.5</td>
<td>0.04</td>
<td>0.03</td>
<td></td>
<td>0.10-0.30 Al</td>
</tr>
<tr>
<td>409</td>
<td>S40900</td>
<td>0.08</td>
<td>1.00</td>
<td>1.00</td>
<td>10.5-11.75</td>
<td>0.045</td>
<td>0.045</td>
<td>6 x %C min. Ti</td>
<td></td>
</tr>
<tr>
<td>429</td>
<td>S42900</td>
<td>0.12</td>
<td>1.00</td>
<td>1.00</td>
<td>14.0-16.0</td>
<td>0.04</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>430</td>
<td>S43000</td>
<td>0.12</td>
<td>1.00</td>
<td>1.00</td>
<td>16.0-18.0</td>
<td>0.04</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>430F**</td>
<td>S43020</td>
<td>0.12</td>
<td>1.25</td>
<td>1.00</td>
<td>16.0-18.0</td>
<td>0.06</td>
<td>0.15 min.</td>
<td>0.06 Mo</td>
<td></td>
</tr>
<tr>
<td>430FSe**</td>
<td>S43023</td>
<td>0.12</td>
<td>1.25</td>
<td>1.00</td>
<td>16.0-18.0</td>
<td>0.06</td>
<td>0.06</td>
<td>0.15 min. Se</td>
<td></td>
</tr>
<tr>
<td>430Ti</td>
<td>S43036</td>
<td>0.10</td>
<td>1.00</td>
<td>1.00</td>
<td>16.0-19.5</td>
<td>0.75</td>
<td>0.04</td>
<td>0.03</td>
<td>5 x %C - Ti min.</td>
</tr>
<tr>
<td>434</td>
<td>S43400</td>
<td>0.12</td>
<td>1.00</td>
<td>1.00</td>
<td>16.0-18.0</td>
<td>0.04</td>
<td>0.03</td>
<td></td>
<td>0.75-1.25 Mo</td>
</tr>
<tr>
<td>436</td>
<td>S43600</td>
<td>0.12</td>
<td>1.00</td>
<td>1.00</td>
<td>16.0-18.0</td>
<td>0.04</td>
<td>0.03</td>
<td></td>
<td>0.75-1.25 Mo; 5 x %C min. Nb(Cr) + Ta</td>
</tr>
<tr>
<td>442</td>
<td>S44200</td>
<td>0.20</td>
<td>1.00</td>
<td>1.00</td>
<td>18.0-23.0</td>
<td>0.04</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>444</td>
<td>S44400</td>
<td>0.025</td>
<td>1.00</td>
<td>1.00</td>
<td>17.5-19.5</td>
<td>1.00</td>
<td>0.04</td>
<td>0.03</td>
<td>1.75-2.5 Mo; 0.035 N; (Ti + Nb(Cr))</td>
</tr>
<tr>
<td>18-2FM**</td>
<td>S18200</td>
<td>0.08</td>
<td>2.50</td>
<td>1.00</td>
<td>17.5-19.5</td>
<td>0.04</td>
<td>0.15 min.</td>
<td>0.25 N</td>
<td></td>
</tr>
<tr>
<td>18SR</td>
<td></td>
<td>0.04</td>
<td>0.3</td>
<td>1.00</td>
<td>18.0</td>
<td></td>
<td></td>
<td></td>
<td>2.0 Al; 0.4 Ti</td>
</tr>
<tr>
<td>26-1T (E-Brite)</td>
<td>S44625</td>
<td>0.01</td>
<td>0.40</td>
<td>0.40</td>
<td>25.0-27.5</td>
<td>0.50</td>
<td>0.02</td>
<td>0.02</td>
<td>0.75-1.5 Mo; 0.015N; (Ni+Cu)</td>
</tr>
<tr>
<td>26-1Ti</td>
<td>S44626</td>
<td>0.06</td>
<td>0.75</td>
<td>0.75</td>
<td>25.0-27.0</td>
<td>0.5</td>
<td>0.04</td>
<td>0.02</td>
<td>0.75-1.5 Mo; 0.04 N; (Ti + Nb(Cr))</td>
</tr>
<tr>
<td>29-4</td>
<td>S44700</td>
<td>0.01</td>
<td>0.30</td>
<td>0.20</td>
<td>28.0-30.0</td>
<td>0.15</td>
<td>0.025</td>
<td>0.02</td>
<td>3.5-4.2 Mo</td>
</tr>
<tr>
<td>29-4-2</td>
<td>S44800</td>
<td>0.01</td>
<td>0.30</td>
<td>0.20</td>
<td>28.0-30.0</td>
<td>2.0-2.5</td>
<td>0.025</td>
<td>0.02</td>
<td>3.5-4.2 Mo</td>
</tr>
<tr>
<td>Monit</td>
<td>S44635</td>
<td>0.25</td>
<td>1.00</td>
<td>0.75</td>
<td>24.5-26.0</td>
<td>3.5-4.5</td>
<td>0.04</td>
<td>0.03</td>
<td>3.5-4.5 Mo; 0.3-0.6 (Ti + Nb(Cr))</td>
</tr>
<tr>
<td>Sea-cure/</td>
<td>S44660</td>
<td>0.025</td>
<td>1.00</td>
<td>0.75</td>
<td>25.0-27.0</td>
<td>1.5-3.5</td>
<td>0.04</td>
<td>0.03</td>
<td>2.5-3.5 Mo; (Ti + Nb(Cr))</td>
</tr>
</tbody>
</table>

*Single values are maximum values. **These grades are generally considered to be un weldable.

of a number of standard and several non-standard ferritic stainless steels. They are characterized by weld and HAZ grain growth which can result in low toughness of welds.

To weld the ferritic stainless steels, filler metals should be used which match or exceed the Cr level of the base alloy. Type 409 is available as metal cored wire and Type 430 is available in all forms. Austenitic Types 309 and 312 may be used for dissimilar joints. To minimize grain growth, weld heat input should be minimized. Preheat should be limited to 300-450°F and used only for the higher carbon ferritic stainless steels (e.g., 430, 434, 442 and 446). Many of the highly alloyed ferritic stainless steels are only available in sheet and tube forms and are usually welded by GTA without filler metal.

3.2 MARTENSITIC STAINLESS STEELS

The martensitic stainless steels contain 11 to 18% Cr, up to 1.20% C and small amounts of Mn and Ni and, sometimes, Mo. These steels will transform to austenite on heating and, therefore, can be hardened by formation of martensite on cooling. This group includes Types 403, 410, 414, 416, 420, 422, 431 and 440. Both standard and non-standard martensitic stainless steels are listed in Table II. They have a tendency toward weld cracking on cooling when hard brittle martensite is formed.

Chromium and carbon content of the filler metal should generally match these elements in the base metal. Type 410 filler is available as covered electrode, solid wire and cored wire and can be used to weld types 402, 410, 414 and 420 steels. Type 410NiMo filler metal can also be used. When it is necessary to match the carbon in Type 420 steel, Type 420 filler, which is available as solid wire and cored wire, should be used. Types 308, 309 and 310 austenitic filler metals can be used to weld the martensitic steels to themselves or to other steels where good as-deposited toughness is required.

Preheating and interpass temperature in the 400 to 600°F (204 to 316°C) range is recommended for most
martensitic stainless steels. Steels with over 0.20% C often require a post weld heat treatment to soften and toughen the weld.

### 3.3 AUSTENITIC STAINLESS STEEL

The austenitic stainless steels contain 16-26% Cr, 8-24% Ni + Mn, up to 0.40% C and small amounts of a few other elements such as Mo, Ti, Nb (Cb) and Ta. The balance between the Cr and Ni + Mn is normally adjusted to provide a microstructure of 90-100% austenite. These alloys are characterized by good strength and high toughness over a wide temperature range and oxidation resistance to over 1000°F (538°C). This group includes Types 302, 304, 310, 316, 321 and 347. Nominal composition of these and other austenitic stainless steels are listed in Table III. Filler metals for these alloys should generally match the base metal but for most alloys, provide a microstructure with some ferrite to avoid hot cracking as will be discussed further. To achieve this, Type 308 is used for Type 302 and 304 and Type 347 for Type 321. The others should be welded with matching filler. Type 347 can also be welded with Type 308H filler. These filler materials are available as coated electrodes, solid bare wire and cored wire. Type 321 is available on a limited basis as solid and cored wire.

Two problems are associated with welds in the austenitic stainless steels: 1) sensitization of the weld heat affected zone, and 2) hot cracking of weld metal.

#### 3.3.1 SENSITIZATION:

Sensitization leads to intergranular corrosion in the heat affected zone as shown in Figure 1. Sensitization is caused by chromium carbide formation and precipitation at grain boundaries in the heat affected zone when heated in the 800 to 1600°F (427 to 871°C) temperature range. Since most carbon is found near grain boundaries, chromium carbide formation removes some chromium from solution near the grain boundaries, thereby reducing the corrosion resistance of these local areas. This problem can be remedied by using low carbon base material and filler material to reduce the amount of carbon available to combine with chromium. Welds should be made without preheat and with minimum heat input to shorten the time in the sensitization temperature range.

The degree of carbide precipitation increases with:

1. Higher carbon content (for example, because 301 and 302 grades have a maximum carbon content of 0.15% they are more susceptible to carbon precipitation than grade 304 which has a maximum carbon content of only 0.08%).

2. Time at the critical mid-range temperatures – a few seconds at 1200°F (649°C) can do more damage than several minutes at 850°F (454°C) or 1450°F (788°C).

Welding naturally produces a temperature gradient in the steel. It ranges from melting temperature at the weld to room temperature some
distance from the weld. A narrow zone on each side of the weld remains in the sensitizing temperature range for sufficient time for precipitation to occur. If used in severely corrosive conditions, lines of damaging corrosion appear alongside each weld.

**Control of Carbide Precipitation**

The amount of carbide precipitation is reduced by promoting rapid cooling. Fortunately, the copper chill bars, skip welding and other techniques needed to control distortion in sheet metal (see pg 34) help reduce carbide precipitation. Annealing the weldment at 1900°F (1038°C) or higher, followed by water quench, eliminates carbide precipitation, but this is an expensive and often impractical procedure. Therefore, when weldments operate in severe corrosive applications or within the sensitizing temperature range, either ELC or stabilized grades are needed.

Another remedy is to use stabilized stainless steel base metal and filler materials which contain elements that will react with carbon, leaving all the chromium in solution to provide corrosion resistance. Type 321 contains titanium and Type 347 contains niobium (columbium) and tantalum, all of which are stronger carbide formers than chromium.

**ELC – Extra Low Carbon – Grades** (304L, 308L)

The 0.04% maximum carbon content of ELC grades helps eliminate damaging carbide precipitation caused by welding. These grades are most often used for weldments which operate in severe corrosive conditions at temperatures under 800°F (427°C).

ELC steels are generally welded with the ELC electrode, AWS E308L-XX. Although the stabilized electrodes AWS E347-XX produce welds of equal resistance to carbide precipitation and similar mechanical properties, the ELC electrode welds tend to be less crack sensitive on heavy sections and have better low temperature notch toughness. The low carbon content in ELC grades leaves more chromium to provide resistance to intergranular corrosion.

**Stabilized Grades** (321, 347, 348)

Stabilized grades contain small amounts of titanium (321), niobium (columbium) (347), or a combination of niobium and tantalum (347, 348). These elements have a stronger affinity for carbon than does chromium, so they combine with the carbon leaving the chromium to provide corrosion resistance.

These grades are most often used in severe corrosive conditions when service temperatures reach the sensitizing range. They are welded with the niobium stabilized electrodes, AWS E347-XX.

Type 321 electrodes are not generally made because titanium is lost in the arc. AWS E347-XX is usually quite satisfactory for joining type 321 base metal.

**Molybdenum Grades** (316, 316L, 317, 317L, D319)

Molybdenum in stainless steel increases the localized corrosion resistance to many chemicals. These steels are particularly effective in combating pitting corrosion. Their most frequent use is in industrial
# TABLE III — Nominal Compositions of Austenitic Stainless Steels

<table>
<thead>
<tr>
<th>Type</th>
<th>UNS Number</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>P</th>
<th>S</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitronic 32</td>
<td>S24100</td>
<td>0.10</td>
<td>12.0</td>
<td>0.50</td>
<td>18.0</td>
<td>1.6</td>
<td>0.04</td>
<td>0.03</td>
<td>0.35 N</td>
</tr>
<tr>
<td>Nitronic 33</td>
<td>S24000</td>
<td>0.06</td>
<td>13.0</td>
<td>0.5</td>
<td>18.0</td>
<td>3.0</td>
<td>0.04</td>
<td>0.03</td>
<td>0.30 N</td>
</tr>
<tr>
<td>Nitronic 40</td>
<td>S21900</td>
<td>0.08</td>
<td>8.0-10.0</td>
<td>1.00</td>
<td>18.0-20.0</td>
<td>5.0-7.0</td>
<td>0.06</td>
<td>0.03</td>
<td>0.15-0.40 N</td>
</tr>
<tr>
<td>Nitronic 50</td>
<td>S20910</td>
<td>0.06</td>
<td>4.0-6.0</td>
<td>1.00</td>
<td>20.5-23.5</td>
<td>11.5-13.5</td>
<td>0.04</td>
<td>0.03</td>
<td>1.5-3.0 Mo; 0.2-0.4 N; 0.1-0.3 Nb; 0.1-0.3 V</td>
</tr>
<tr>
<td>Nitronic 60</td>
<td>S21800</td>
<td>0.10</td>
<td>7.0-9.0</td>
<td>3.5-4.5</td>
<td>16.0-18.0</td>
<td>8.0-9.0</td>
<td>0.04</td>
<td>0.03</td>
<td>1.5-3.0 Mo; 0.2-0.4 N; 0.30 N</td>
</tr>
</tbody>
</table>

*Single values are maximum values. (From *ASM Metals Handbook*, Ninth Edition, Volume 3) **These grades are generally considered to be unweldable.
cracks will appear as the weld cools and shrinkage stresses develop.

Hot cracking can be prevented by adjusting the composition of the base material and filler material to obtain a microstructure with a small amount of ferrite in the austenite matrix. The ferrite provides ferrite-austenite grain boundaries which are able to control the sulfur and phosphorous compounds so they do not permit hot cracking. This problem could be avoided by reducing the S and P to very low amounts, but this would increase significantly the cost of making the steel.

Normally a ferrite level of 4 FN minimum is recommended to avoid hot cracking. Ferrite is best determined by measurement with a magnetic instrument calibrated to AWS A4.2 or ISO 8249. It can also be estimated from the composition of the base material and filler material with the use of several constitution diagrams. The oldest of these is the 1948 Schaeffler Diagram. The Cr equivalent (% Cr + % Mo + 1.5 x % Si + 0.5 x % Cb) is plotted on processing equipment. 316 and 316L are welded with AWS E316L-XX electrodes.

316L and 317L are ELC grades that must be welded with ELC type electrodes to maintain resistance to carbide precipitation. 317 and 317L are generally welded with E317 or E317L electrodes respectively. They can be welded with AWS E316-XX electrode, but the welds are slightly lower in molybdenum content than the base metal with a corresponding lower corrosion resistance.

When hot oxidizing acids are encountered in service, E316, E316L, E317 or E317L welds may have poor corrosion resistance in the as-welded condition. In such cases, E309 or E309Cb electrodes may be better. As an alternative, the following heat treatment will restore corrosion resistance to the weld:

1. For 316 or 317 – full anneal at 1950-2050°F (1066-1121°C).
2. For 316L and 317L – stress relieve at 1600°F (871°C).

**High Temperature Grades**

(302B, 304H, 309, 309S, 310, 310S)

These high alloy grades maintain strength at high temperatures and have good scaling resistance. They are primarily used in industrial equipment at high service temperatures – sometimes over 2000°F (1093°C).

AWS E310-XX electrodes are needed to match the high temperature properties and scaling resistance of grades 310 and 310S.

302B and 309 grades are generally welded with E309-XX electrodes. 304H is generally welded with E308H-XX electrodes. E310-XX electrodes can be used on light plate.

E310-XX welds on heavy plate tend to be more crack sensitive than E309-XX weld metals.

**Free Machining Grades**

(303, 303Se)

Production welding of these grades is not recommended because the sulfur or selenium and phosphorous cause severe porosity and hot short cracking.

If welding is necessary, special E312-XX or E309-XX electrodes are recommended because their high ferrite reduces cracking tendencies. Use techniques that reduce admixture of base metal into the weld metal and produce convex bead shapes.

### 3.3.2 HOT CRACKING:

Hot cracking is caused by low melting materials such as metallic compounds of sulfur and phosphorous which tend to penetrate grain boundaries. When these compounds are present in the weld or heat affected zone, they will penetrate grain boundaries and cracks will appear as the weld cools and shrinkage stresses develop.

**FIGURE 2 — New 1992 WRC diagram including solidification mode boundaries.**


\[
N_{eq} = Ni + 35C + 20N + 0.25Cu \\
Cr_{eq} = Cr + Mo + 0.7Cb
\]
the horizontal axis and the nickel equivalent (% Ni + 30 x % C + 0.5 x % Mn) on the vertical axis. Despite long use, the Schaeffler Diagram is now outdated because it does not consider nitrogen effects and because it has not proven possible to establish agreement among several measurers as to the ferrite percent in a given weld metal.

An improvement on the Schaeffler Diagram is the 1973 WRC-DeLong Diagram, which can be used to estimate ferrite level. The main differences are that the DeLong Diagram includes nitrogen (%N) in the Ni equivalent (% Ni + 30 x % C x 30 x % N + 0.5 x % Mn) and shows Ferrite Numbers in addition to “percent ferrite.” Ferrite Numbers at low levels may approximate “percent ferrite.” The most recent diagram, the WRC-1992 Diagram, Figure 2, is considered to be the most accurate predicting diagram at present. The WRC-1992 Diagram has replaced the WRC-DeLong Diagram in the ASME Code with publication of the 1994-95 Winter Addendum. Its Ni equivalent (% Ni + 35 x % C + 20 x % N + 0.25 Cu) and Cr equivalent (% Cr + % Mo + 0.7 x % Cb) differ from those of Schaeffler and WRC-DeLong.

Ferrite Number may be estimated by drawing a horizontal line across the diagram from the nickel equivalent number and a vertical line from the chromium equivalent number. The Ferrite Number is indicated by the diagonal line which passes through the intersection of the horizontal and vertical lines.

Predictions by the WRC-1992 and WRC-DeLong Diagrams for common grades like 308 are similar, but the WRC-1992 diagram generally is more accurate for higher alloy and less common grades like high manganese austenitic or duplex ferritic-austenitic stainless steels.

Ferrite Number can be measured directly on weld deposits from the magnetic properties of the ferrite. Several instruments are available commercially, including the Magne Gage, the Severn Gage, the Inspector Gage and the Ferritescope which can be calibrated to AWS A4.2 or ISO 8249 and provide readings in Ferrite Number.

The amount of ferrite normally should not be greater than necessary to prevent hot cracking with some margin of safety. The presence of ferrite can reduce corrosion resistance in certain media and excess ferrite can impair ductility and toughness.

3.4 PRECIPITATION HARDENING STAINLESS STEELS

There are three categories of precipitation hardening stainless steels – martensitic, semi-austenitic and austenitic.

The martensitic stainless steels can be hardened by quenching from the austenitizing temperature [around 1900°F (1038°C)] then aging between 900 to 1150°F (482 to 621°C). Since these steels contain less than 0.07% carbon, the martens-
site is not very hard and the main hardening is obtained from the aging (precipitation) reaction. Examples of this group are 17-4PH, 15-5PH and PH13-8M0. Nominal compositions of precipitation hardening stainless steels are listed in Table IV.

The semiaustenitic stainless steels will not transform to martensite when cooled from the austenizing temperature because the martensite transformation temperature is below room temperature. These steels must be given a conditioning treatment which consists of heating in the range of 1350 to 1750°F (732 to 954°C) to precipitate carbon and/or alloy elements as carbides or intermetallic compounds. This removes alloy elements from solution, thereby destabilizing the austenite, which raises the martensite transformation temperature so that a martensite structure will be obtained on cooling to room temperature. Aging the steel between 850 and 1100°F (454 to 593°C) will stress relieve and temper the martensite to increase toughness, ductility, hardness and corrosion resistance. Examples of this group are 17-7PH, PH 15-7 Mo and AM 350.

The austenitic precipitation hardening stainless steels remain austenitic after quenching from the solutioning temperature even after substantial amounts of cold work. They are hardened only by the aging reaction. This would include solution treating between 1800 and 2050°F (982 to 1121°C), oil or water quenching and aging at 1300 to 1350°F (704 to 732°C) for up to 24 hours. Examples of these steels include A286 and 17-10P.

If maximum strength is required in martensitic and semiaustenitic precipitation hardening stainless steels, matching or nearly matching filler metal should be used and the component, before welding, should be in the annealed or solution annealed condition. Often, Type 630 filler metal, which is nearly identical with 17-4PH base metal, is used for martensitic and semiaustenitic PH stainleses. After welding, a complete solution heat treatment plus an aging treatment is preferred. If the post weld solution treatment is not feasible, the components should be solution treated before welding then aged after welding. Thick sections of highly restrained parts are sometimes welded in the overaged condition. These would require a full heat treatment after welding to attain maximum strength.

The austenitic precipitation hardening stainless steels are the most difficult to weld because of hot cracking. Welding should preferably be done with the parts in the solution treated condition, under minimum restraint and with minimum heat input. Nickel base alloy filler metals of the NiCrFe type or conventional austenitic stainless steel type are often preferred.

### 3.5 DUPLEX STAINLESS STEELS

**Duplex Ferritic – Austenitic Stainless Steels**

Duplex stainless steels solidify as 100% ferrite, but about half of the ferrite transforms to austenite during cooling through temperatures above approx. 1900°F (1040°C). This behavior is accomplished by increasing Cr and decreasing Ni as compared to austenitic grades. Nitrogen is deliberately added to speed up the rate of austenite formation during cooling. Duplex stainless steels are ferromagnetic. They combine higher strength than austenitic stainless steels with fabrication properties similar to austenitics, and with resistance to chloride stress corrosion cracking of ferritic stainless steels. The most common grade is 2205 (UNS S32205), consisting of 22%Cr, 5%Ni, 3%Mo and 0.15%N.

**TABLE V — Physical Properties of Groups of Stainless Steels**

<table>
<thead>
<tr>
<th>Property</th>
<th>Austenitic Types</th>
<th>Ferritic Types</th>
<th>Martensitic Types</th>
<th>Precipitation Hardening Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic Modulus; 10⁶ psi GPa</td>
<td>28.3</td>
<td>29.0</td>
<td>29.0</td>
<td>29.0</td>
</tr>
<tr>
<td>Density; lb./in.² g/cm³</td>
<td>0.29</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
</tr>
<tr>
<td>Coeff. of Therm. Expansion: µin./in. °F µm/m °C</td>
<td>9.2</td>
<td>5.8</td>
<td>5.7</td>
<td>6.0</td>
</tr>
<tr>
<td>Thermal Conduct.; Btu/hrft. °F w/mk</td>
<td>9.1</td>
<td>14.5</td>
<td>14.0</td>
<td>12.9</td>
</tr>
<tr>
<td>Specific Heat; Btu/lb. °F J/k °K</td>
<td>0.12</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Electrical Resistivity, Ω cm</td>
<td>74</td>
<td>61</td>
<td>61</td>
<td>80</td>
</tr>
<tr>
<td>Magnetic Permeability</td>
<td>1.02</td>
<td>600-1,100</td>
<td>700-1000</td>
<td>95</td>
</tr>
<tr>
<td>Melting Range °F °C</td>
<td>2,500-2,650</td>
<td>2,600-2,790</td>
<td>2,600-2,790</td>
<td>2,560-2,625</td>
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<tr>
<td></td>
<td>1,375-1,450</td>
<td>1,425-1,530</td>
<td>1,425-1,530</td>
<td>1,400-1,440</td>
</tr>
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</table>
Average physical properties for each of the main groups of stainless steel are listed in Table V. This includes elastic modulus, density, coefficient of thermal expansion, thermal conductivity, specific heat, electrical resistivity, magnetic permeability and melting range. These values should be close enough for most engineering purposes. If more precise data is required for a particular type of stainless steel, it can be found in the 


### 5.0 MECHANICAL PROPERTIES

Nominal mechanical properties of austenitic and ferritic stainless steels in the annealed condition are listed in Table VI and Table VII respectively. The austenitic stainless steels generally have higher tensile strengths and elongation than the ferritic stainless steels but lower yield strengths. Reduction in area is about the same for both groups. Nominal mechanical properties of martensitic stainless steels in both the annealed and tempered condition are listed in Table VIII. The tempered condition involves heating to austenitize, cooling to form martensite and reheating to the indicated temperature to increase toughness. Table IX lists the mechanical properties of the precipitation hardening stainless steels as solution annealed and after aging treatments at the temperature indicated. Properties of three duplex stainless steels are included.

---

**Table VI — Properties of Austenitic Stainless Steels**

<table>
<thead>
<tr>
<th>Type</th>
<th>Condition</th>
<th>Tensile Strength</th>
<th>0.2% Yield Strength</th>
<th>Elong.</th>
<th>R.A.</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ksi</td>
<td>MPa</td>
<td>Ksi</td>
<td>MPa</td>
<td>%</td>
</tr>
<tr>
<td>201</td>
<td>Anneal</td>
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<td>793</td>
<td>55</td>
<td>379</td>
<td>55</td>
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<tr>
<td>201</td>
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<td>1275</td>
<td>140</td>
<td>965</td>
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<tr>
<td>202</td>
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<td>724</td>
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<td>301</td>
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<td>110</td>
<td>758</td>
<td>40</td>
<td>276</td>
<td>60</td>
</tr>
<tr>
<td>301</td>
<td>Full Hard</td>
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<td>140</td>
<td>965</td>
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<td>586</td>
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<tr>
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<td>304N</td>
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<td>586</td>
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<td>305</td>
<td>Anneal</td>
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<td>37</td>
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<tr>
<td>308</td>
<td>Anneal</td>
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<td>586</td>
<td>35</td>
<td>241</td>
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</tr>
<tr>
<td>308L</td>
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<td>55</td>
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<td>586</td>
<td>35</td>
<td>241</td>
<td>55</td>
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<tr>
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<td>35</td>
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<td>80</td>
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<tr>
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<td>550</td>
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<td>241</td>
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<td>586</td>
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<td>290</td>
<td>45</td>
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<td>332</td>
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<td>552</td>
<td>35</td>
<td>241</td>
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### TABLE VII — Nominal Mechanical Properties of Ferritic Stainless Steels

<table>
<thead>
<tr>
<th>Type</th>
<th>Condition</th>
<th>Tensile Strength</th>
<th>0.2% Yield Strength</th>
<th>Elong.</th>
<th>R.A.</th>
<th>Hardness</th>
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<tr>
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<td>MPa</td>
<td>Ksi</td>
<td>MPa</td>
<td>%</td>
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<td>405</td>
<td>Anneal</td>
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<td>480</td>
<td>40</td>
<td>275</td>
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<tr>
<td>409</td>
<td>Anneal</td>
<td>65</td>
<td>450</td>
<td>35</td>
<td>240</td>
<td>25</td>
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<tr>
<td>429</td>
<td>Anneal</td>
<td>71</td>
<td>490</td>
<td>45</td>
<td>310</td>
<td>30</td>
</tr>
<tr>
<td>430</td>
<td>Anneal</td>
<td>75</td>
<td>515</td>
<td>45</td>
<td>310</td>
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</tr>
<tr>
<td>430Ti</td>
<td>Anneal</td>
<td>75</td>
<td>515</td>
<td>45</td>
<td>310</td>
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<td>53</td>
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<td>50</td>
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<td>26-1EBrite</td>
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<tr>
<td>26-1Ti</td>
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<td>45</td>
<td>310</td>
<td>20</td>
</tr>
<tr>
<td>29-4</td>
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<td>550</td>
<td>60</td>
<td>415</td>
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<td>29-4-2</td>
<td>Anneal</td>
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<td>550</td>
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<td>Sea-cure/SC-1</td>
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</table>

M = Maximum


### TABLE VIII — Nominal Mechanical Properties of Martensitic Stainless Steels

<table>
<thead>
<tr>
<th>Type</th>
<th>Condition</th>
<th>Tensile Strength</th>
<th>0.2% Yield Strength</th>
<th>Elong.</th>
<th>R.A.</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Ksi</td>
<td>MPa</td>
<td>%</td>
</tr>
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<td>517</td>
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<td>276</td>
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<td>403</td>
<td>*Temp. 800°F</td>
<td>195</td>
<td>1344</td>
<td>150</td>
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<td>17</td>
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<td>Anneal</td>
<td>75</td>
<td>517</td>
<td>40</td>
<td>276</td>
<td>30</td>
</tr>
<tr>
<td>410</td>
<td>*Temp. 800°F</td>
<td>195</td>
<td>1344</td>
<td>150</td>
<td>1034</td>
<td>17</td>
</tr>
<tr>
<td>410S</td>
<td>Anneal</td>
<td>60</td>
<td>414</td>
<td>30</td>
<td>207</td>
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</tr>
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<td>655</td>
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<td>414</td>
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<td>689</td>
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<td>414</td>
<td>*Temp. 800°F</td>
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<td>150</td>
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<td>414</td>
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<td>115</td>
<td>793</td>
<td>80</td>
<td>552</td>
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<tr>
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<td>Anneal</td>
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<td>655</td>
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<td>345</td>
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<td>420</td>
<td>*Temp. 600°F</td>
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<td>1586</td>
<td>195</td>
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<tr>
<td>422</td>
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</table>

*Tempered after austenitizing and cooling to room temperature.
M = Maximum (600°F = 315°C)
Int. = Intermediate temper hot finished (800°F = 427°C)

The selection of a particular type stainless steel will depend on what is required by the application. In most cases the primary consideration is corrosion resistance, tarnish resistance or oxidation resistance at elevated temperature. In addition to these requirements, the selected stainless steel must have some minimum mechanical properties such as strength, toughness, ductility and fatigue strength. Several types and grades of stainless steel may provide the corrosion resistance and mechanical properties required. In this case the final selection should be made on the basis of the lowest cost available alloy which will fulfill the service requirements. Generally, selection of the type of stainless steel is made by the designer of the equipment or component based on his knowledge, experience and data on corrosion behavior of various alloys in the environment of interest. The responsibility of the welding engineer normally does not include selection of the base alloy, only selection of the filler material, welding process and welding procedure. If it becomes necessary for the welding engineer to select a base alloy, information should be gathered on the service environment, expected life of the part and extent of corrosion which is acceptable. To assist in this selection, Table X lists corrosion resistance of several standard types of stainless steel to a number of corrosive media. This indicates that austenitic types and higher chromium types generally are more corrosion resistant than the martensitic and lower chromium ferritic types. A great deal of test data has been generated on the corrosion behavior of many metals and alloys in many kinds of corrosive media. This information on stainless steels is available from several sources which are listed as references.

Other factors which must be considered in selecting a stainless steel are resistance to pitting, crevice corrosion and intergranular attack. Intergranular attack is caused by carbide precipitation in weld heat affected zones and methods of preventing this problem were discussed previously. If the application involves service at elevated temperature, then elevated temperature mechanical properties such as creep strength, stress rupture strength and oxidation resistance must be considered.

With the corrosion and oxidation test data derived from the handbooks and other references, a stainless steel or other alloy may be selected for a particular application. Once the

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**TABLE IX — Nominal Mechanical Properties of Precipitation Hardening and Duplex Stainless Steels**

### TABLE X — Corrosion Resistance of Stainless Steel in Various Environments

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**Notes:**
- **Code:**
  1. No rust, staining or pitting,
  2. Light rust or stains, no pitting,
  3. Light rust or stains, light pitting,
  4. Rust covered or stained,
  5. Rust covered and pitted,
  6. Rust and severe pitting,
  7. Corrosion and pitting in chemical media varies widely with media, concentration, temperature and agitation. Consult literature and handbooks for data on specific application.
stainless steel is selected, it is the welding engineer’s responsibility to design the joints, select the weld filler metal, welding process and welding procedure.

7.0 DESIGN FOR STAINLESS STEELS

Since the coefficient of thermal expansion for austenitic stainless steels is relatively high, the control of distortion must be considered in designing weldments of these alloys. The volume of weld metal in joints must be limited to the smallest size which will provide the necessary properties. In thick plate, a “U” groove, Figure 3(c), which gives a smaller volume than a “V” groove, should be used. If it is possible to weld from both sides of a joint, a double “U” or “V” groove joint preparation should be used. This not only reduces the volume of weld metal required but also helps to balance the shrinkage stresses.

Accurate joint fitup and careful joint preparation which are necessary for high quality welds also help minimize distortion.

Joint location and weld sequence should be considered to minimize distortion.

Strong tooling and fixturing should be employed to hold parts in place and resist tendencies for components to move during welding. When any of the gas shielded processes are used, the tooling should also provide an inert gas backup to the root of the weld to prevent oxidation when the root pass is being made. This is particularly important when GTAW welding pipe with insert rings to allow the weld metal to wet and flow together at the root of the joint.

In welding pipe, insert rings, Figure 4, of the same composition as the filler metal should be used for the root pass and be welded by the GTAW process. If copper chills are to be used near a weld area, they should be nickel plated to prevent copper pickup. If copper is in contact with the high temperature region of the heat affected zone, it can melt and penetrate the grain boundaries of austenitic stainless steel causing cracking.

8.0 SELECTION OF FILLER METALS

Filler metals for welding stainless steels are produced as coated electrodes (AWS A5.4), solid and metal core wire (AWS A5.9) and flux core wire (AWS A5.22). The various electrodes, solid wires, metal cored wires and flux cored wires are contained in AWS “Filler Metal Comparison Charts”, latest edition.

According to these charts, matching filler metal should be available for almost every type of austenitic stainless steel available, although many types may be produced in small quantities by only a few companies and may not be readily available. For example, E219-16 and E240-16 electrodes are produced by
only two U.S. companies and no foreign companies. By contrast, the more popular electrodes, E308-16, E308L-16, E309-16, E310-16, E316-16, E316L-16 and E347-16 are produced by about 40 U.S. companies and 20 to 30 foreign companies. Most electrodes are available with a lime coating (15) (for use with DC only), a titania coating (16) (for use with AC or DC) or a silica-titania coating (17) (for use with AC or DC mainly in the downhand or horizontal positions) and in the standard or low carbon variety.

Most alloys which are available as coated electrodes are also available as either solid wire, metal cored wire or flux cored wire. A few are available only as coated electrodes. These are 310H, 310Cb, 310Mo and 330H. As was mentioned previously, filler metal for austenitic stainless steels should match or exceed the alloy content of the base metal. If a filler material of the correct match is not available, a filler with higher alloy content normally should be used.

There are several austenitic stainless types for which no exact matching fillers are made. Examples are 201, 202, 205, 216, 301, 302, 304 and 305. The filler materials recommended for these base alloys are somewhat higher in Cr and Ni content. For example, 308 is used for 301, 302, 304 and 305 and may be used for 201, 202, 205 and 216 if 209, 219 or 240 are not available. The 6% molybdenum stainless steels 254SMo and AL6-XN are generally welded with higher molybdenum nickel-base alloys. The recommended filler materials in the form of coated electrodes, solid and metal core wire and flux core wire are listed in Tables XI, XII and XIII for austenitic, ferritic and martensitic stainless steels respectively. Note that a modification of a basic type should be welded with a filler material of that same modification, for example, Type 316L should be welded with E316L-XX, ER316L, ER316LS, or E316LT-X.

Except for E630 electrodes and ER630 bare wires which match 17-4PH, matching filler materials for the precipitation hardening stainlesses are not listed in the AWS Filler Metals Comparison Charts, or in any of the AWS filler metal specifications. Matching filler metals are produced and available in the form of coated electrodes and solid wire for some of the precipitation hardening stainless steels and these are listed in Table XIV. Where no matching filler is available, standard austenitic or nickel base filler materials are recommended as indicated in Table XIV.

If maximum strength properties and corrosion resistance are required for the application, a filler metal of matching or similar composition to the base metal should be used. For martensitic or semi-austenitic base alloys, the weldment should then be given the full solution and aging heat treatment if feasible. If not, the components should be solution treated before welding, then given a postweld aging treatment after welding. It is recommended that the austenitic precipitation hardening stainless steels not be heat treated after welding because of cracking problems. In fact, these alloys are difficult to weld for this reason and some are considered unweldable. Nickel base and conventional austenitic filler metals can be used for these alloys, especially if high strength weld metal is not required.
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<th>Base Stainless Steel</th>
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<td>ER209, ER219, ER308, ER308Si</td>
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</table>

From AWS Filler Metal Specifications: A5.4, A5.9, A5.22, A5.14, A5.11
because the lower strength filler can stretch on cooling and minimize the stress on the crack sensitive heat affected zone of the base metal. Nickel base and conventional austenitic stainless steels can also be used to weld the other precipitation hardening stainless steels where full base material strength is not required.

Coated electrodes can be used for welding martensitic and semi-austenitic stainless steels such as 17-4PH, AM350 and AM355 because these alloys do not contain titanium or aluminum which would be lost in the shielded metal arc. Welds can be made in all positions with this process. Electrodes must be dry and stored and handled in the same manner as used for other stainless steel and low hydrogen electrodes as described previously.

Type AMS 5827B (17-4PH) electrodes can be used to weld 17-7PH steel, and reasonable heat treat-ment response can be obtained if the weld deposit is highly diluted with base metal.

Welding conditions suitable for conventional stainless steels are generally applicable for joining the PH types. A short arc length should be used to minimize oxidation, loss of chromium, and nitrogen pickup.

**Lining**

Mild steel process and storage equipment is sometimes lined with stainless steel for corrosion resistance. At least three different methods are used:

<table>
<thead>
<tr>
<th>TABLE XII — Filler Metals for Welding Ferritic Stainless Steels</th>
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<tbody>
<tr>
<td><strong>Wrought</strong></td>
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From AWS Filler Metal Specifications: A5.4, A5.9, A5.22

<table>
<thead>
<tr>
<th>TABLE XIII — Filler Metals for Welding Martensitic and Duplex Stainless Steels</th>
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</tbody>
</table>

From AWS Filler Metal Specifications: A5.4, A5.9, A5.22

a = Welding not recommended.
1. Large formed stainless steel sheets are plug welded at frequent intervals to join them closely to the shell.

2. Overlapping welds deposited on the steel surface.

3. Small strips are overlapped or placed side-by-side and welded to the shell. Sometimes this technique is referred to as “wallpapering”.

TABLE XIV — Filler Metals for Welding Precipitation-Hardening Stainless Steels

<table>
<thead>
<tr>
<th>Designation</th>
<th>UNS No.</th>
<th>Covered Electrodes</th>
<th>Bare Welding Wire</th>
<th>Dissimilar PH Stainless Steels</th>
</tr>
</thead>
</table>
| Martensitic Types
| 17-4PH and 15-5 PH | S17400 | AMS 5827B, E630 (17-4 PH) or E308 | AMS 5826 (17-4 PH) or ER308         | E or ER309, E or ER309 Cb          |
| Stainless W  | S17600   | E308 or ENiMo-3a                    | AMS 5805C (A-286) or ENiMo-3b      | E or ERNiMo-3, E or ER309          |
| Semiaustenitic Types
| 177PH       | S17700   | AMS 5827B (17-4 PH), E308, or E309 | AMS 5824A (177 PH)                  | E or ER310, ENiCrFe-2, or ENiCr-3  |
| PH 15-7Mo   | S15700   | E308 or E309                        | AMS 5812C (PH 15-7Mo)              | E or ER309, E or ER310             |
| AM350       | S35000   | AMS 5775A (AM350)                   | AMS 5774B (AM350)                  | E or ER308, E or ER309             |
| AM355       | S35500   | AMS 5781A (AM355)                   | AMS 5780A (AM355)                  | E or ER308, E or ER309             |
| Austenitic Types
| A-286       | K66286   | E309 or E310                        | ERNiCrFe-6 or ENiMo-3              | E or ER309, E or ER310             |

1. See AWS A5.11-97, Specification for Nickel and Nickel Alloy Welding Electrodes for Shielded Metal Arc Welding
2. See AWS A5.14-97, Specification for Nickel and Nickel Alloy Bare Welding Electrodes and Rod.

Welding Clad Steel

Clad steel consists of stainless steel sheet permanently bonded to mild steel plate. To join clad steel plates, first weld the mild steel with mild steel electrodes. Do not tie into the stainless cladding with the mild steel electrodes. After gouging the back-side of the first mild steel bead, weld from the stainless side using stainless steel electrodes.

Joining Manganese Steel

E308-X or E309-XX electrodes are used to weld manganese steel to carbon steel or to manganese steel. The stainless welds provide excellent joint strength and ductility but are difficult to flame cut. Therefore, when a manganese steel piece must be replaced periodically, such as dipper teeth, Wearshield Mangjet® electrode can be recommended. Wearshield 15CrMn electrode has better crack resistance, but the deposit is difficult to flame cut.

Thick Hardfacing Deposits

E308-X or E309-XX deposits increase the toughness of thick hardfacing deposits. For best results, use one layer of stainless between each two layers of hardfacing.

9.0 SELECTION OF A WELDING PROCESS

Joint Cleanliness

For high-quality welds, stainless steel joints must be clean. The choice of power brushing, degreasing, pickling, grinding or simply wiping depends upon the application and amount of dirt. Here are some specific hints:

1. Remove all moisture by blowing with dry air or heating with a torch. Beware of moisture in air lines, damp rags and humidity deposited overnight.

2. Eliminate organic contaminants like oil, paints, anti-spatter compounds, grease, pencil marks, cutting compounds, adhesive from protective paper, soap used for leak testing, etc.
3. Stainless steels cannot be flame cut with a torch. Acceptable results are achieved with an arc plasma cutter.

4. Be particularly careful to avoid zinc contamination. Do not use brushes or tools previously used on galvanized steel.

5. Use only stainless steel wire brushes, and use these brushes only on stainless steel.

The decision on the form of filler metal to be used will depend upon several factors. These include the available forms of the filler material needed, the available welding equipment, the dimensions of the weldment and number of pieces to be welded.

9.1 SHIELDED METAL ARC WELDING

Coated electrodes are available in most stainless compositions in a range of sizes and these can be used to weld joints in thicknesses from 0.05 inch to several inches. Slag from each pass must be completely removed before depositing the next pass to avoid porosity and slag entrapment. Welding equipment for stick electrode welding is the lowest cost but deposition rates are lowest of all the consumable electrode processes.

If it has been decided to perform the welding with stick electrodes, a further decision must be made regarding the electrode coating. When lime (-15), titania (-16), and silica-titania (-17) type coatings are available for a particular type electrode, the decision will be based mainly on the position of welding. Lime-coated electrodes operate on DC only. They are recommended for:

1. Vertical and overhead welding and all position applications such as pipe. The light slag wets rapidly for good wash-in and no undercutting.

2. Root passes on heavy plate. The full throat section of the slightly convex beads help prevent cracking.

3. Fully austenitic stainless steels such as types 330, 320.

Titania-coated electrodes operate on AC or DC, but always use DC when available. They are recommended for:

1. Vertical up welding when DC is available.

2. Vertical up welding when a wide weave can be used.

3. Overhead welding.

Coated electrodes should be treated and stored as low hydrogen electrodes. They should not be exposed to damp air, and once a sealed container is opened, the electrodes should be used or stored in a holding oven at between 200 and 300°F (93 and 149°C). If the electrodes are exposed to moist air, they can be dried by baking as recommended by the manufacturer. The baking temperature usually is between 500 and 600°F (260 and 316°C), but can be as high as 800°F (427°C). The electrode manufacturer should be consulted for specific recommendations.

The sizes and forms of coated electrodes and also solid and cored wire, which are normally available for welding stainless steels, are listed in Table XV.

9.2 SUBMERGED ARC WELDING

Submerged arc welding (SAW) can be employed to join thick sections, usually greater than 0.5 inch, of most of the austenitic stainless steels. For austenitic stainlesses in which ferrite is not possible in the weld metal (types 310 or 330, for example), submerged arc welding is usually best avoided due to hot cracking.

| TABLE XV — Standard Sizes for Stainless Electrodes |
|---------------------------------|----------------|----------------|
| Form                            | Diameter, in. | Diameter, mm. |
| Electrode in coils, with or     | 0.045, 1/16, 5/64, 3/32, 7/64 | 1.2, 1.6, 2.0, 2.4, 2.8 |
| without support                 | 1/8, 5/32, 3/16, 1/4          | 3.2, 4.0, 4.8, 6.4 |
| Electrode wound on standard     | 0.030, 0.035, 0.045, 1/16     | 0.8, 0.9, 1.2, 1.6 |
| 12-in. O.D. spools              | 5/64, 3/32, 7/64               | 2.0, 2.4, 2.8 |
| Electrodes wound on lightweight | 0.020, 0.025, 0.030            | 0.5, 0.6, 0.8 |
| 1 1/2 and 2 1/2 lb., 4-in. O.D. | 0.035, 0.045                  | 0.9, 1.2 |
| spools                         |                               |                 |
problems. Welding is generally done using direct current, electrode positive. Alternating current is sometimes used for moderate penetration and good arc stability.

Since deposit composition depends upon the filler wire composition, any alloy additions to the flux and chromium oxidation and loss to the slag, flux selection and welding conditions must be rigorously controlled. Voltage, current and travel speed variations will influence the amount of flux melted and the resulting weld deposit composition and ferrite content.

Conventional austenitic stainless steel electrodes such as ER308, ER309 and ER316 can be used with conventional stainless steel fluxes for welding most of the austenitic stainless steels except applications where Ferrite Number must be less than 4.

If base metal strength must be attained in martensitic or precipitation hardening stainless steels, special procedures and fluxes must be used with the correct filler metal to provide a weld deposit which will respond to postweld heat treatment. If special fluxes are not used, the weld metal probably will not respond to heat treatment. This is particularly true for aluminum-bearing electrodes where aluminum is lost through metal-slag reactions. The stainless flux manufacturers should be consulted for recommendation on fluxes and welding procedures.

### 9.3 GAS METAL ARC WELDING

If the production application involves long joints in relatively thick material or a large number of parts, the GMAW process with solid or metal cored wire may be the best choice. Solid or metal cored wire will provide the fastest deposition rates with the

<table>
<thead>
<tr>
<th>WELDING TECHNIQUES FOR SHIELDED METAL ARC WELDING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use a short arc</strong> without touching the puddle. This minimizes alloy loss in the arc and reduces porosity and spatter. Red Baron and Blue Max electrodes can be dragged.</td>
</tr>
<tr>
<td><strong>Weld with a low current</strong> consistent with good fusion to minimize heat input for distortion control. The low current also reduces penetration when minimum admixture is needed for corrosion resistance and cracking or porosity resistance.</td>
</tr>
<tr>
<td><strong>Stringer beads</strong> minimize heat input to control distortion. If weave beads must be used, limit the weave to $2^{1/2}$ times the electrode diameter.</td>
</tr>
<tr>
<td><strong>Flat beads</strong> with good wash-in are needed for easy slag removal, particularly in deep groove welds.</td>
</tr>
<tr>
<td><strong>Fill craters</strong> by holding a short arc and moving back over the finished bead before breaking the arc. This avoids crater cracks.</td>
</tr>
<tr>
<td><strong>Clean each bead</strong> thoroughly before welding over it. Because the slag from lime coated Stainweld XXX-15 electrodes crumbles, particular care is needed to remove all particles.</td>
</tr>
<tr>
<td><strong>For vertical and overhead positions</strong>, weld with $5/32&quot;$ (4.0mm) or smaller electrodes. The easiest to use vertical-up are Stainweld XXX-15 electrodes. Blue Max electrodes require the widest weave for vertical-up. Vertical-down welding is best accomplished with Red Baron -V electrodes.</td>
</tr>
<tr>
<td>For vertical-down welding with Red Baron-V electrodes, use a dragging technique and current towards the high end of the recommended range. For vertical-up, Stainweld XXX-15 can be run without weave. All others require a weave – a triangle weave or inverted Vee weave works well.</td>
</tr>
<tr>
<td>In the overhead position, Red Baron and Blue Max electrodes work best by a dragging technique. Stainweld electrodes work best with a short arc and slight circular motion during steady forward motion.</td>
</tr>
<tr>
<td><strong>Penetration</strong> should be only enough to seal openings in root passes and bond to the base plates. Deep penetration can cause cracking and loss of corrosion resistance and provides no advantages.</td>
</tr>
</tbody>
</table>
GMAW process but wire feeding equipment, power supplies and the requirement for inert gas shielding add to the cost of using these fillers. However, there is little need to remove slag between passes. Solid and metal cored wire can be used in short-circuiting, globular and spray modes of arc operation which gives a wide range of deposition rates and heat input levels. Solid and metal cored wire can therefore be used for welding a wide range of thicknesses.

Gas metal arc welding with spray transfer is used to join sections thicker than about 0.25 inch because deposition rates are higher than with other transfer modes. Welding procedures are similar for conventional austenitic and PH stainless steels.

The shielding gas is generally argon with 1 to 2 percent oxygen added for arc stability. Mixtures of argon and helium are employed if a hotter arc is desired. A small oxygen addition can be added to provide a stable arc, but some aluminum or titanium can be lost from certain PH filler metals during transfer across the arc as a result of oxidation. Response of the weld metal to heat treatment might be less because of this action.

For flat position welding, spray transfer is usually preferred. For other welding positions, short-circuiting transfer is often used with helium-rich gas such as 90% He 7.5% A -2.5% CO₂ or pulsed spray transfer can be employed using argon or an argon-helium mixture with a small addition of oxygen or carbon dioxide.

### 9.4 Flux-Cored Arc Welding

Flux cored wire uses basically the same wire feed equipment and power supply as solid and metal core wire. Wires can be designed for use with gas shielding (AWS Classes EXXXTX-1 or EXXXTX-4) or without gas shielding (AWS Classes EXXXTO-3). The “-1” indicates CO₂ shielding gas, while the “-4” indicates 75% Argon - 25% CO₂ shielding gas. Although carbon dioxide gas shielding is not recommended for gas metal arc welding, it is commonly used with flux cored arc welding because the slag protects the metal from carbon pickup. Use of EXXXTO-3 with gas will result in high ferrite. Use of EXXXTX-1 or EXXXTX-4 without gas will result in little or no ferrite and possibly porosity. Solid wire, metal core and flux core wire have an advantage over coated electrodes by their continuous nature in that it is not necessary to stop welding to change electrodes.

### 9.5 Gas Tungsten Arc Welding

Manual and automatic gas tungsten arc welding (GTAW) processes are frequently used for joining conventional and PH stainless steels, particularly in thicknesses up to about 0.25 inch.

Normally direct current, electrode negative is used with a power supply having drooping volt-amperage characteristic. However, alternating current is sometimes used to weld those steels containing aluminum to take advantage of the arc cleaning action.

### 10.0 Procedures for Welding Stainless Steels

Once a joint design has been established and a welding process and filler material have been selected, a welding procedure may be developed. For any process, it is important that joint edges and filler material be clean and free of any oxide, organic material or other contamination. Thermal cut edges must be cleaned to remove oxide film. Rough machined surfaces on joint edge preparation should be avoided to
10.1 WELDING WITH THE SHIELDED METAL ARC PROCESS

All stainless steel shielded metal arc electrode coverings must be protected from moisture pickup. Normally, electrodes packaged in hermetically sealed containers can be stored for several years without deteriorating. However, after the container is opened, the coating begins to absorb moisture and, depending on the ambient air condition, may need to be reconditioned after only four hours of exposure, otherwise porosity may result, especially at arc starts.

Usually, redrying at 500 to 600°F (260 to 316°C) for 1 hour restores the electrode to its original condition, and storing in a holding oven at 300°F (149°C) is satisfactory. Due to differences in materials and processing, the supplier should be consulted if large amounts of electrodes are involved.

DC electrodes (EXXX-15) operate on DC only, have good penetration, produce fillets with a slightly convex profile, and are recommended for:

- Vertical and overhead welding and all position applications such as pipe. The slag has a fast freeze characteristic.
- Root passes on heavy plate. The larger throat section of the convex bead helps prevent cracking.
- Austenitic stainless welds that cannot contain any ferrite.

AC-DC electrodes (EXXX-16 and EXXX-17) are always used on DC when this type of power is available. The fillet profile is flat (EXXX-16) to slightly concave (EXXX-17), the weld surface is smoother and the penetration is less than with EXXX-15 (DC only) electrodes. The larger amount of slag requires more care to avoid slag inclusions. These electrodes are recommended for horizontal fillets and for all flat position welding. EXXX-16 electrodes are also used in all positions by skilled welders. EXXX-17 electrodes can also be used in all positions, but a wider weave is generally necessary in the vertical-up position than is necessary for EXXX-16 electrodes.

Cleaning: For high quality welds, joints must be clean and dry. The choice of power brushing, degreasing, pickling, grinding or merely wiping depends upon the kind and amount of dirt. Some specific recommendations are:

1. Remove moisture by heating or by blowing with dry air (beware of moisture in the air line). Moisture can collect on a weldment overnight in high humidity conditions.
2. Eliminate organic contaminants such as paints, antispatter compounds, grease pencil marks, cutting compounds, adhesive from protective paper and soap used for leak testing.
3. Flame beveling and machining may leave contaminants or oxide films that must be removed.
4. Avoid zinc contamination from brushes or tools that have been used on galvanized steel. Zinc contamination causes cracking. Use only stainless steel wire brushes that have been used only on stainless steel.
5. Avoid copper contamination from rubbing stainless over copper hold-down fixtures, etc. Copper contamination causes cracking.

Welding Techniques: Welding with stainless steel electrodes requires techniques similar to those used for mild steel low hydrogen electrodes. Use a short arc, but keep the coating from touching the puddle. Certain electrodes are designed to be dragged on the base metal in downhand and horizontal welding. Flat beads with good wash-in promote easy slag removal in deep grooves. Fill each crater before breaking the arc to avoid crater cracks. Clean the slag thoroughly from the finish of the bead before starting another electrode, and clean the complete weld before started the next pass. On deep groove butt joints, the root pass should penetrate only enough to fuse to both plates and seal the opening. More penetration may cause cracks.

For vertical and overhead positions never use an electrode larger than 5/32”. The DC electrodes (EXXX-15) are preferred, but the AC-DC electrodes (EXXX-16) can be used for welding vertical up (using DC). On thick plate, use the triangular weave or inverted Vee technique, welding vertical up. On thin plate, use small beads, vertical down.

The EXXX-17 AC-DC electrodes are more difficult to use vertical up than the EXXX-16 electrodes. A wider weave is generally necessary.

Welding techniques can help control distortion. Weld with low current consistent with sufficient penetration to reduce the heat input to the work (Table XVI). Use stringer beads at a higher speed rather than wide beads at a slower speed. If weave beads must be made, limit the weave to 2-1/2 times the electrode diameter.

Other means to control distortion are:

- Use rigid fixtures to hold parts in alignment.
- Use chill bars near the weld and backing bars under the weld. Rapid cooling of austenitic stainless steels is beneficial rather than harmful. If copper is used as the chill bar material, care must be exercised to prevent copper grain boundary penetration where the
heat affected zone temperature exceeds the melting temperature of copper. This can be prevented by applying a thin nickel plate to the copper.

- Plan the sequence of welding, using the same techniques as with mild steel such as skip welding and back step welding.

Joining Stainless and Other Steels: In some applications, stainless steel weld metal is applied to mild steel: for example, lining mild steel vessels or containers with stainless steel. For such applications, stainless electrodes with higher alloy content are used so the admixture of the mild steel into the stainless weld deposit does not form an unsatisfactory alloy.

When stainless steel is joined to mild steel, the mild steel is often “buttered” with stainless steel. This technique consists of depositing a layer of stainless on the surface of the mild steel, then completing the joint with a stainless electrode, as illustrated in Figure 5. The electrode commonly used for buttering is E309. This technique is also used for joining hard-to-weld or high carbon steels that cannot be preheated.

E308 electrode is used for joining austenitic manganese steel to carbon steel or to manganese steel. However, for the components that must be replaced periodically, such as dipper teeth, a manganese steel electrode is recommended because the stainless weld is more difficult to torch cut.

Power Sources: The open circuit voltage of light duty AC transformer welders may not be high enough for larger diameters of EXXX-16 electrodes; otherwise, the same power sources used with steel electrodes are satisfactory for stainless electrodes. Parameters and procedures for welding stainless steel in thicknesses from 18 gauge to 1/2 inch are given in Figures 6, 7, 8, 9 and 10. These show joint designs and backup bars for butt, tee, lap and 90 degree edge joints.

10.2 WELDING WITH THE SUBMERGED ARC PROCESS

The submerged arc process is applicable to the welding of stainless steels where the higher heat input and slower solidification are tolerable. With submerged arc welding, depending upon the flux chosen, the silicon content may be much higher than with other processes, a factor that may promote hot shortness or fissuring when ferrite is less than 4FN.

The submerged arc process is not recommended where a weld deposit is needed that is fully austenitic or is controlled to a low ferrite content (below 4FN). However, high quality welds may be produced for applications in which more than 4FN in weld deposits is allowable. Figure 11 shows the type of butt joint designs that can be used for submerged arc welding.

Good quality single pass welds up to 5/16 inch thick can be made using the square groove butt joint, Figure 11 (a), without root opening and with suitable backing. Two pass welds up to 5/8 inch thick are also made without root opening. It is essential on two pass welds, however, that the edges be closely butted since weld backing is not used. The advantage of this joint design is that it requires a minimum of edge preparation, yet produces welds of good quality having adequate penetration.

Single V-groove welds with a root face, Figure 11 (b), are used with nonfusible backing for single pass butt welds of 5/16 inch thickness or greater. For most industrial applications, the maximum thickness is of the order of 1-1/4 to 1-1/2 inch. Root face dimensions are 1/8 to 3/16 inch. This joint is also used for two pass welds without backing where plate thickness exceeds 5/8 inch. The first pass is made in the V of the joint, Figure 11 (b). The work is then turned over and the first pass becomes the backing pass. In this position, the finishing pass is made on the flat side of the joint penetrating into the root of the first pass. The root face is approximately 3/8 inch for two pass welds.

The double V-groove butt, Figure 11 (d), is the basic joint design for submerged arc welding. A large root face is generally used with this design. Figure 12 shows a typical double V-groove weld in 3/4 inch 304 plate and describes the welding sequence.

A single U-groove butt joint design, Figure 11 (f), is also commonly used. A small manually produced backing weld is often made from the reverse side of the joint. It is usually desirable to fill the U-groove with 2 passes per layer as soon as possible after the root pass. Slag removal from a submerged arc weld pass tying in to both sides of the groove can be very difficult.

For stainless steel welding, DC power is mostly used on thin sections. Either AC or DC may be used on heavier pieces but DC is preferred. Currents used are about 80% of those used for carbon steel. Single pass techniques usually result in dilution levels of 40% to 60%. This may be decreased by using multipass welds.
Submerged arc welding creates a large volume of molten metal that remains fluid for appreciable time. It is essential that this molten metal be supported and contained until it has solidified. The two most common means of weld backing are nonfusible backing and fusible backing.

Copper backing is the most frequently used nonfusible backing in the welding of stainless steel. When copper is used as a chill bar, care must be taken to prevent copper grain boundary penetration. Recommended groove dimensions are shown in Figure 13. Ceramic backing tapes are also sometimes used.

With a fusible metallic backing, the weld penetrates into and fuses with the stainless backing, which either temporarily or permanently becomes an integral part of the assembly.

Most submerged arc welding is done in the flat position. This results in the best bead contour and ease of operation. Occasionally, welding is done on circumferential seams. Figure 14 illustrates the effect of various inclinations.

Submerged arc fluxes are available as proprietary materials for welding stainless steel. Composition of materials fall into two categories – fused type and bonded type. The fused type is glasslike and is produced by melting the ingredients at high temperatures followed by crushing to granulate the flux. The bonded or agglomerated type is produced by mixing the ingredients with a suitable binder and baking the mixture. Lincoln manufactures only bonded fluxes.

Alloying elements can be added to the weld deposit through some bonded fluxes. These include chromium, nickel, molybdenum and niobium (columbium). If alloying additions to the flux are not made, they are added directly to the workpiece.

![Figure 6 — Suggested procedures for SMAW of butt joints in austenitic stainless steel from 18 (1.3 mm) gauge to 1/2 inch (12.7 mm) thickness in the flat position.](image-url)
Welding Position: Vertical and Overhead
Weld Quality Level: Code
Steel Weldability: Good

<table>
<thead>
<tr>
<th>Plate Thickness (in.)</th>
<th>0.078 (14 ga)*</th>
<th>0.140 (10 ga)</th>
<th>3/16</th>
<th>1/4</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm.</td>
<td>2.0</td>
<td>3.6</td>
<td>4.8</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Pass
1
1
1
2

<table>
<thead>
<tr>
<th>Electrode Class</th>
<th>E3XX-15</th>
<th>E3XX-15</th>
<th>E3XX-15</th>
<th>E3XX-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size in.</td>
<td>3/32</td>
<td>1/8</td>
<td>5/32</td>
<td>5/32</td>
</tr>
<tr>
<td>mm.</td>
<td>2.4</td>
<td>3.2</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Current (amp) DC(+)</td>
<td>50</td>
<td>75</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Arc Speed (in./min.)</td>
<td>14 - 16</td>
<td>6.7 - 7.3</td>
<td>5.2 - 5.8</td>
<td>5.2 - 5.8</td>
</tr>
<tr>
<td>mm/sec.</td>
<td>5.9 - 6.8</td>
<td>2.8 - 3.1</td>
<td>2.2 - 2.5</td>
<td>2.2 - 2.5</td>
</tr>
<tr>
<td>Electrode Req’d (lb/ft)</td>
<td>0.030</td>
<td>0.091</td>
<td>0.160</td>
<td>0.370</td>
</tr>
<tr>
<td>kg/m.</td>
<td>0.045</td>
<td>0.136</td>
<td>0.238</td>
<td>0.551</td>
</tr>
<tr>
<td>Total Time (hr./ft. of weld)</td>
<td>0.0133</td>
<td>0.0286</td>
<td>0.0364</td>
<td>0.0808</td>
</tr>
<tr>
<td>hrs./m of weld</td>
<td>0.0436</td>
<td>0.0938</td>
<td>0.1194</td>
<td>0.2651</td>
</tr>
<tr>
<td>Gap (in.)</td>
<td>0</td>
<td>0</td>
<td>1/16</td>
<td>1/16</td>
</tr>
<tr>
<td>mm.</td>
<td>0</td>
<td>0</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Root face (in.)</td>
<td>0</td>
<td>0</td>
<td>1/16</td>
<td>1/16</td>
</tr>
<tr>
<td>mm.</td>
<td>0</td>
<td>0</td>
<td>1.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

*Vertical down, all others vertical up.

FIGURE 7 — Suggested procedures for SMAW of butt joints in austenitic stainless steel 14 gauge (2.0mm) to 1/4 inch (6.4mm) thickness in the vertical and overhead positions.

Welding Position: Flat or Horizontal*
Weld Quality Level: Code
Steel Weldability: Good

<table>
<thead>
<tr>
<th>Weld Size (in.)</th>
<th>3/32</th>
<th>1/8</th>
<th>3/16</th>
<th>1/4</th>
<th>5/16</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm.</td>
<td>2.4</td>
<td>3.2</td>
<td>4.8</td>
<td>6.4</td>
<td>7.9</td>
</tr>
<tr>
<td>Plate Thickness (in.)</td>
<td>0.078 (14 ga)</td>
<td>0.140 (10 ga)</td>
<td>3/16</td>
<td>1/4</td>
<td>3/8</td>
</tr>
<tr>
<td>mm.</td>
<td>2.0</td>
<td>3.6</td>
<td>4.8</td>
<td>6.4</td>
<td>9.5</td>
</tr>
<tr>
<td>Pass</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Electrode Class</td>
<td>E3XX-16, E3XX-17</td>
<td>E3XX-16, E3XX-17</td>
<td>E3XX-16, E3XX-17</td>
<td>E3XX-16, E3XX-17</td>
<td></td>
</tr>
<tr>
<td>Size in.</td>
<td>3/32</td>
<td>2.4</td>
<td>1/8</td>
<td>4.8</td>
<td>7.9</td>
</tr>
<tr>
<td>mm.</td>
<td>3/32</td>
<td>2.4</td>
<td>3.2</td>
<td>4.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Current (amp) DC(+)</td>
<td>60</td>
<td>85</td>
<td>120</td>
<td>160</td>
<td>170</td>
</tr>
<tr>
<td>Arc Speed (in./min.)</td>
<td>12.5 - 13.5</td>
<td>12.5 - 3.5</td>
<td>6.6 - 9.4</td>
<td>6.2 - 6.8</td>
<td>6.7 - 7.3</td>
</tr>
<tr>
<td>mm/sec.</td>
<td>5.3 - 5.7</td>
<td>5.3 - 5.7</td>
<td>3.6 - 4.0</td>
<td>2.6 - 2.9</td>
<td>2.8 - 3.1</td>
</tr>
<tr>
<td>Electrode Req’d (lb/ft)</td>
<td>0.036</td>
<td>0.056</td>
<td>0.120</td>
<td>0.220</td>
<td>0.430</td>
</tr>
<tr>
<td>kg/m.</td>
<td>0.054</td>
<td>0.083</td>
<td>0.178</td>
<td>0.328</td>
<td>0.640</td>
</tr>
<tr>
<td>Total Time (hr./ft. of weld)</td>
<td>0.0154</td>
<td>0.0154</td>
<td>0.0222</td>
<td>0.0308</td>
<td>0.094</td>
</tr>
<tr>
<td>hrs./m of weld</td>
<td>0.051</td>
<td>0.051</td>
<td>0.073</td>
<td>0.101</td>
<td>0.195</td>
</tr>
</tbody>
</table>

* For vertical and overhead use same procedures as for vertical and overhead butt welds.
Note: AC can be used with a 10% increase in current. E3XX-15 electrode can be used with a 10% decrease in current.

FIGURE 8 — Suggested procedures for SMAW of fillet joints in austenitic stainless steel from 14 gauge (2.0mm) to 3/8 inch (9.5mm) thickness in the flat or horizontal positions.
### Welding Position: Horizontal
### Weld Quality Level: Code
### Steel Weldability: Good

<table>
<thead>
<tr>
<th>Plate Thickness (in.)</th>
<th>Plate Thickness (mm)</th>
<th>Pass</th>
<th>Electrode Class</th>
<th>Current (amp DC+)</th>
<th>Arc Speed (in./min.)</th>
<th>Arc Speed (mm/sec.)</th>
<th>Electrode Req'd (lb/ft)</th>
<th>Electrode Req'd (kg/m)</th>
<th>Total Time (hr/ft of weld)</th>
<th>Total Time (hrs/m of weld)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.078 (14 ga)</td>
<td>2.0</td>
<td>1</td>
<td>E3XX-16, E3XX-17</td>
<td>60</td>
<td>12.5 - 13.5</td>
<td>5.3 - 5.7</td>
<td>0.036</td>
<td>0.054</td>
<td>0.0154</td>
<td>0.051</td>
</tr>
<tr>
<td>0.140 (10 ga)</td>
<td>3.6</td>
<td>1</td>
<td>E3XX-16, E3XX-17</td>
<td>90</td>
<td>12.5 - 13.5</td>
<td>5.3 - 5.7</td>
<td>0.056</td>
<td>0.083</td>
<td>0.0222</td>
<td>0.073</td>
</tr>
<tr>
<td>3/16</td>
<td>4.8</td>
<td>1</td>
<td>E3XX-16, E3XX-17</td>
<td>125</td>
<td>8.6 - 9.4</td>
<td>3.6 - 4.0</td>
<td>0.130</td>
<td>0.194</td>
<td>0.0308</td>
<td>0.101</td>
</tr>
<tr>
<td>1/4</td>
<td>6.4</td>
<td>1</td>
<td>E3XX-16, E3XX-17</td>
<td>170</td>
<td>6.2 - 6.8</td>
<td>2.6 - 2.9</td>
<td>0.240</td>
<td>0.357</td>
<td>0.0594</td>
<td>0.195</td>
</tr>
<tr>
<td>3/8</td>
<td>9.5</td>
<td>2</td>
<td>E3XX-16, E3XX-17</td>
<td>175</td>
<td>6.7 - 7.3</td>
<td>2.8 - 3.1</td>
<td>0.460</td>
<td>0.685</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The notes to fillet weld procedure also apply here.

**Figure 9** — Suggested procedures for SMAW of lap joints in austenitic stainless steel from 14 gauge (2.0mm) to 3/8 inch (9.5mm) thickness in the horizontal position.

### Welding Position: Flat
### Weld Quality Level: Code
### Steel Weldability: Good

<table>
<thead>
<tr>
<th>Plate Thickness (in.)</th>
<th>Plate Thickness (mm)</th>
<th>Pass</th>
<th>Electrode Class</th>
<th>Current (amp DC+)</th>
<th>Arc Speed (in./min.)</th>
<th>Arc Speed (mm/sec.)</th>
<th>Electrode Req'd (lb/ft)</th>
<th>Electrode Req'd (kg/m)</th>
<th>Total Time (hr/ft of weld)</th>
<th>Total Time (hrs/m of weld)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.078 (14 ga)</td>
<td>2.0</td>
<td>1</td>
<td>E3XX-16, E3XX-17</td>
<td>60</td>
<td>14 - 16</td>
<td>5.9 - 6.8</td>
<td>0.028</td>
<td>0.042</td>
<td>0.0133</td>
<td>0.0436</td>
</tr>
<tr>
<td>0.140 (10 ga)</td>
<td>3.6</td>
<td>1</td>
<td>E3XX-16, E3XX-17</td>
<td>85</td>
<td>12.5 - 13.5</td>
<td>5.3 - 5.7</td>
<td>0.056</td>
<td>0.083</td>
<td>0.0154</td>
<td>0.0505</td>
</tr>
<tr>
<td>3/16</td>
<td>4.8</td>
<td>1</td>
<td>E3XX-16, E3XX-17</td>
<td>125</td>
<td>10.5 - 11.5</td>
<td>4.4 - 4.9</td>
<td>0.094</td>
<td>0.140</td>
<td>0.0182</td>
<td>0.0597</td>
</tr>
<tr>
<td>1/4</td>
<td>6.4</td>
<td>1</td>
<td>E3XX-16, E3XX-17</td>
<td>160</td>
<td>6.2 - 6.8</td>
<td>2.6 - 2.9</td>
<td>0.22</td>
<td>0.33</td>
<td>0.0308</td>
<td>0.101</td>
</tr>
<tr>
<td>3/8</td>
<td>9.5</td>
<td>2</td>
<td>E3XX-16, E3XX-17</td>
<td>175</td>
<td>6.2 - 6.8</td>
<td>2.6 - 2.9</td>
<td>0.45</td>
<td>0.67</td>
<td>0.0641</td>
<td>0.210</td>
</tr>
</tbody>
</table>

AC can be used with a 10% increase in current. E3XX-15 electrode can be used with a 10% decrease in current.

**Figure 10** — Suggested procedures for SMAW of corner joints in austenitic stainless steel from 14 gauge (2.0mm) to 3/8 inch (9.5mm) thickness in the flat position.
FIGURE 11 — Butt joint designs for submerged-arc welding.

FIGURE 12 — A typical double-V weld in Type 304 plate. Pass 1 was made at 700 amp, 33 volts, 16 ipm (6.8mm/sec); pass 2 at 950 amp, 35 volts, 12 ipm (5.1mm/sec). The power was DCRP; electrode 3/16-in. (4.8mm). Type 308; neutral flux.

FIGURE 13 — Recommended groove dimensions for copper backing bars in the submerged arc welding of stainless steels.
the flux is called “neutral.” The term neutral is only relative in that the alloy content of the weld is still altered by the flux. Lincoln flux ST-100 is an alloy flux for use with solid stainless steel electrodes. It contains chromium which helps compensate for chromium in the electrode that is oxidized in the arc and therefore not recovered in the weld deposit. Lincoln fluxes 801, 802, 880, 880M, 882, and Blue Max 2000 are neutral fluxes designed for welding with solid stainless steel electrodes. With Nb(Cb) — bearing stainless filler metal (such as ER347), slag removal is often best with Blue Max 2000 or 802 fluxes. Lincoln flux 860 is a neutral flux that can be used with 308L electrode for applications requiring a lower ferrite number. It should be noted that this combination will produce a tighter slag with surface slag sticking. Lincoln MIL-800H flux can be used with ER308L filler metal to produce a 308H (0.04-0.08% C) deposit.

The composition ranges listed in AWS A5.9 are broad. Since composition profoundly affects weld quality and serviceability, the complete range of variations cannot always be tolerated in the deposit. To maintain control, the welding technique, alloy content of the flux or other appropriate changes should be made to compensate for variations in filler metal composition.

The several methods of starting the weld that are commonly in use include:

**Scratch Start** — In a scratch start, the wire is fed toward the work and the carriage travel is also started. When the wire touches the work, it will not fuse to the workpiece because of the relative motion of the carriage. This type of starting is also called a “flying start.”

**Retract Starting** — The wire is “inched” toward the work and covered with flux. When the weld is started, the wire retracts momentarily and then reverses to feed forward. This method is not recommended for light gauge stainless steel.

Once the arc is initiated, it is important to monitor the various parameters. Welding current is the most influential variable. Next in importance is welding voltage. Welding speed changes conform to a pattern; if the speed is increased, there is less weld reinforcement; if decreased, there is more weld reinforcement. In addition, weld speed can affect depth of penetration.

**Cladding with Submerged Arc** — SAW is normally a high dilution process, which is undesirable for cladding. A procedure that works well, however, is to change from the normal DC electrode positive polarity to DC electrode negative polarity, and to limit the wire feed speed to the low end of the normal range — e.g., 60 ipm wire feed for 1/8” electrode, or 80 ipm for 3/32” electrode.

### 10.3 WELDING WITH THE GAS METAL ARC PROCESS

Stainless steels may be welded by the gas metal arc process, using either spray arc, shortcircuiting or pulsed arc transfer.

Copper backup strips are necessary for welding stainless steel sections up to 1/16 inch thick. Backup is also needed when welding 1/4 inch and thicker plate from one side only.

No air must be permitted to reach the underside of the weld while the weld puddle is solidifying.

Oxygen picked up by the molten metal may reduce the corrosion resistance and ductility of the stainless steel as it cools. To prevent this, the underside of the weld should be shielded by an inert gas such as argon. The shielding gas source can be built into the fixture.

Electrode diameters as large as 3/32 inch, but usually less than 1/16 inch, are used with relatively high currents to create the spray arc transfer. A current of approximately 300-350
For welding plate 1/4 inch and thicker, the gun should be moved back and forth in the direction of the joint and at the same time moved slightly from side to side. On thinner metal, however, only back and forth motion along the joint is used. The more economical short-circuiting transfer process for thinner material should be employed in the overhead and horizontal position for at least the root and first passes. Although some operators use a short digging spray arc to control the puddle, the weld may be abnormally porous.

Power supply units with slope, voltage and inductance controls are recommended for the welding of stainless steel with short-circuiting transfer. Inductance, in particular, plays an important part in obtaining proper puddle fluidity.

The shielding gas often recommended for short-circuiting welding of stainless steel contains 90% helium, 7.5% argon and 2.5% carbon dioxide. The gas gives the most desirable bead contour while keeping the CO2 level low enough so that it does not influence the corrosion resistance of the metal. High inductance in the power supply output is beneficial when using this gas mixture.

Single pass welds may also be made using argon-oxygen and argon-CO2 gas mixes. However, arc voltage for steady short-circuiting transfer may be as much as 6 volts lower than for the helium based gas. The colder arc may lead to lack of fusion defects. The CO2 in the shielding gas will affect the corrosion resistance of multipass welds made with shortcircuiting transfer due to carbon pickup.

Wire extension or stickout should be kept as short as possible. Backhand welding is usually easier on fillet welds and will result in a neater weld. Forehand welding should be used for butt welds. Outside corner welds may be made with a straight motion.

A slight backward and forward motion along the axis of the joint

---

**FIGURE 15 — Suggested procedures for GMAW of butt joints in 200 and 300 series stainless steels using the spray arc transfer mode.**
<table>
<thead>
<tr>
<th>Plate Thickness (in.)</th>
<th>0.063</th>
<th>0.078</th>
<th>0.093</th>
<th>0.125</th>
<th>0.063</th>
<th>0.078*</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm.</td>
<td>1.6</td>
<td>2.0</td>
<td>2.4</td>
<td>3.2</td>
<td>1.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Electrode Size in.</td>
<td>0.030</td>
<td>0.030</td>
<td>0.030</td>
<td>0.030</td>
<td>0.030</td>
<td>0.030</td>
</tr>
<tr>
<td>mm.</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Current DC(+)</td>
<td>85</td>
<td>90</td>
<td>105</td>
<td>125</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td>Voltage*</td>
<td>21 - 22</td>
<td>21 - 22</td>
<td>21 - 22</td>
<td>21 - 22</td>
<td>21 - 22</td>
<td>21 - 22</td>
</tr>
<tr>
<td>Wire Feed Speed (ipm)</td>
<td>184</td>
<td>192</td>
<td>232</td>
<td>280</td>
<td>184</td>
<td>192</td>
</tr>
<tr>
<td>mm/sec.</td>
<td>78</td>
<td>81</td>
<td>98</td>
<td>119</td>
<td>78</td>
<td>81</td>
</tr>
<tr>
<td>Welding Speed (ipm)</td>
<td>17 -19</td>
<td>13 - 15</td>
<td>14 - 16</td>
<td>14 - 16</td>
<td>19 - 21</td>
<td>11.5 - 12.5</td>
</tr>
<tr>
<td>mm/sec.</td>
<td>7.2 - 8.0</td>
<td>5.5 - 6.3</td>
<td>5.9 - 6.8</td>
<td>5.9 - 6.8</td>
<td>8.0 - 8.9</td>
<td>4.9 - 5.3</td>
</tr>
<tr>
<td>Electrode Required (lb/ft)</td>
<td>0.025</td>
<td>0.034</td>
<td>0.039</td>
<td>0.046</td>
<td>0.023</td>
<td>0.039</td>
</tr>
<tr>
<td>kg/m</td>
<td>0.037</td>
<td>0.051</td>
<td>0.058</td>
<td>0.069</td>
<td>0.034</td>
<td>0.058</td>
</tr>
<tr>
<td>Total Time (hr/ft of weld)</td>
<td>0.0111</td>
<td>0.0143</td>
<td>0.0133</td>
<td>0.0133</td>
<td>0.0100</td>
<td>0.0167</td>
</tr>
<tr>
<td>hr/m of weld</td>
<td>0.0364</td>
<td>0.0469</td>
<td>0.0436</td>
<td>0.0436</td>
<td>0.0328</td>
<td>0.0548</td>
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</table>

**FIGURE 16** — Suggested procedures for GMAW of butt joints and lap joints in 200 and 300 series stainless steels using the short circuiting transfer mode.

**FIGURE 17** — Schematic of the hot-wire system for the automatic TIG welding of stainless steels.
<table>
<thead>
<tr>
<th>Plate Thickness (in.)</th>
<th>1/16</th>
<th>3/32</th>
<th>1/8</th>
<th>3/16</th>
<th>1/4</th>
<th>1/2</th>
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<td>3.2</td>
<td>4.8</td>
<td>6.4</td>
<td>12.7</td>
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<tr>
<td>Current DC(–)</td>
<td>80 - 100</td>
<td>100 - 120</td>
<td>120 - 140</td>
<td>200 - 250</td>
<td>200 - 350</td>
<td>225 - 375</td>
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<tr>
<td>Electrode Diameter (in.)</td>
<td>1/16</td>
<td>1/16</td>
<td>1/16</td>
<td>3/32</td>
<td>1/8</td>
<td>1/8</td>
</tr>
<tr>
<td>mm.</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>2.4</td>
<td>3.2</td>
<td>3.2</td>
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<td>Gas Flow, Argon (cfh)</td>
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<td>10</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>L/min.</td>
<td>4.7</td>
<td>4.7</td>
<td>4.7</td>
<td>7.1</td>
<td>9.4</td>
<td>11.8</td>
</tr>
<tr>
<td>Filler-Rod Diameter (in.)</td>
<td>1/16</td>
<td>1/16</td>
<td>3/32</td>
<td>1/8</td>
<td>1/8</td>
<td>1/8</td>
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<tr>
<td>mm.</td>
<td>1.6</td>
<td>1.6</td>
<td>2.4</td>
<td>3.2</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Arc Speed (ipm)</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>mm/sec</td>
<td>5.1</td>
<td>5.1</td>
<td>5.1</td>
<td>4.2</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Total Time (hr/ft of weld)</td>
<td>0.0167</td>
<td>0.0167</td>
<td>0.0167</td>
<td>0.0200</td>
<td>0.0250</td>
<td>0.0250</td>
</tr>
<tr>
<td>hr/m. of weld</td>
<td>0.0548</td>
<td>0.0548</td>
<td>0.0548</td>
<td>0.0656</td>
<td>0.0820</td>
<td>0.0820</td>
</tr>
</tbody>
</table>

For vertical-up and overhead, decrease current 10 to 20%.

FIGURE 18 — Suggested procedures for GTAW of butt, corner, tee and lap joints in stainless steels.
should be used. Figure 16 summarizes the welding procedures normally used for the shortcircuiting transfer welding of stainless steel.

Shortcircuiting transfer welds on stainless steel made with a shielding gas of 90% He, 71/2% A, 21/2% CO₂ show good corrosion resistance and coalescence. Butt, lap and single fillet welds in material ranging from .060 inch to .125 inch in 304, 310, 316, 321, 347, 410 and similar stainless steels can be made successfully.

The pulsed arc process, as normally used, is a spray transfer process wherein one small drop of molten metal is transferred across the arc for each high current pulse of weld current. The high current pulse must be of sufficient magnitude and duration to cause at least one small drop of molten metal to form and be propelled by the pinch effect from the end of the wire to the weld puddle. During the low current portion of the weld cycle, the arc is maintained and the wire is heated, but the heat developed is not adequate to transfer any metal. For this reason, the time duration at the low current value must be limited otherwise metal would be transferred in the globular mode.

Wire diameters of 0.045 and 0.035 inch are most commonly used with this process. Gases for pulsed arc welding, such as argon plus 1% oxygen are popular, the same as used for spray arc welding. These and other wire sizes can be welded in the spray transfer mode at a lower average current with pulsed current than with continuous weld current. The advantage of this is that thin material can be welded in the spray transfer mode which produces a smooth weld with less spatter than the shortcircuiting transfer mode. Another advantage is that for a given average current, spray transfer can be obtained with a larger diameter wire than could be obtained with continuous currents. Larger diameter wires are less costly than smaller sizes, and the lower ratio of surface volume reduces the amount of deposit contamination.

The electrode diameters for gas metal arc welding are generally between 0.030 and 3/32 inch. For each electrode diameter, there is a certain minimum welding current that must be exceeded to achieve spray transfer. For example, when welding stainless steel in an argon-oxygen atmosphere with 0.045 inch diameter stainless steel electrode, spray transfer will be obtained at a welding current of about 220 amp DCRP. It must be kept in mind that, along with the minimum current, a minimum arc voltage must also be obtained. This is generally between 22 and 30 volts.

Electrodes come on spools varying in weight between 2 and 60 lb. Also available are electrodes for welding the straight chromium stainless steels and austenitic electrodes that contain more than the usual amount of silicon. The latter have particularly good wetting characteristics when used with the shortcircuiting transfer process.

Some stainless steel weld metals during welding have a tendency toward hot shortness or tearing when they contain little or no ferrite – Type 347, for example. When welding these, more welding passes than indicated in the procedures may be needed. Stringer bead techniques are also recommended rather than weaving or oscillating from side to side. Hot cracking may be eliminated by stringer bead techniques since there is a reduction in contraction stresses, hence cooling is more rapid through the hot short temperature range. A procedure that tends to produce a more convex bead than normal can be very helpful, and care should be taken to fill craters.

Weld metal hot cracking may be reduced by shortcircuiting transfer welding, because of the lower dilution from the base metal. Excessive dilution may produce a completely austenitic weld metal having strong cracking characteristics.

When welding magnetic stainless steels (ferritic and martensitic types) to the relatively nonmagnetic types (austenitic types), it is desirable to:

1. Use a single bevel joint to obtain minimum joint reinforcement.
2. Use low heat input shortcircuiting transfer to minimize the arc deflection encountered when welding magnetic to nonmagnetic steels.
3. For uniform fusion, be sure the wire is kept centered over the nonbeveled edge of the joint.

Parameters and procedures for welding 200 and 300 series stainless

<table>
<thead>
<tr>
<th>Arc Current Amps</th>
<th>Arc Voltage Volts</th>
<th>Travel Speed mm/Sec</th>
<th>Wire Speed Feed mm/Sec</th>
<th>Deposition Rate Kg/Hr</th>
<th>Lbs/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>10 - 12</td>
<td>1.7 - 4.2</td>
<td>4 - 10</td>
<td>46 - 157</td>
<td>110 - 370</td>
</tr>
<tr>
<td>400</td>
<td>11 - 13</td>
<td>2.5 - 5.9</td>
<td>6 - 14</td>
<td>78 - 188</td>
<td>185 - 445</td>
</tr>
<tr>
<td>500</td>
<td>12 - 15</td>
<td>3.4 - 8.5</td>
<td>8 - 20</td>
<td>125 - 282</td>
<td>295 - 665</td>
</tr>
</tbody>
</table>
stainless steels by the GMAW spray arc mode are given in Figure 15. Figure 16 gives parameters and procedures for welding the 200 and 300 series stainless steels by the GMAW shortcircuiting mode.

10.4 WELDING WITH THE GAS TUNGSTEN ARC PROCESS

All stainless steel alloys that are considered weldable can be welded readily with the gas tungsten arc process (GTAW).

The preferred electrodes are thoriated, ceriated, or lanthanated tungsten as specified in AWS A5.12. The advantage of these electrodes is that they have a more stable arc and can be used with higher currents than pure tungsten electrodes.

The shielding gas is usually argon, but helium or mixtures of argon and helium are used on heavy sections. The advantages of argon are that flow rates can be lower, the arc is more stable and the arc voltage is somewhat less than with helium. The lower voltage makes it possible to weld thin sheet without burn through.

Filler materials for use with the gas tungsten arc process are in the form of solid wire available in coils for automatic welding or straight lengths for manual welding. These are specified in AWS A5.9 which also applies to filler material for Gas Metal Arc and Submerged Arc welding. Consumable inserts, specified in AWS A5.30, are useful for root passes with gas tungsten arc.

The DC power source for gas tungsten arc welding must be a constant current type, and it is recommended that a high frequency voltage be superimposed on the welding circuit. The high frequency need be on only to start the arc. As the electrode is brought close to the work, the high frequency jumps the gap from the tungsten to the work and ignites the welding arc. Since the tungsten electrode does not actually touch the work, the possibility of contaminating the stainless steel with tungsten is greatly reduced. Straight polarity (DC-) should be used – which produces a deep, penetrating weld.

A “scratch” start may be used in lieu of a high frequency start, although there is some possibility of tungsten pickup. The arc should not be struck on a carbon block because of the likelihood of carbon contamination.

Stainless steels are readily welded with automatic GTAW. Arc voltage is proportional to arc length – thus a reliable signal can be generated to operate automatic arc voltage control equipment. Filler metal may be used, or light gauge material may be joined by simple fusion of the joint edges. When “cold” filler metal is used, it is always added to the front of the puddle.

The so called “hot wire” method of welding gives greatly increased deposition rates and welding speeds. The wire – which trails the torch, as illustrated in Figure 17 – is resistance heated by a separate AC power supply. It is fed through a contact tube and extends beyond the tube. The extension is resistance heated so that it approaches or reaches the melting point before it contacts the weld puddle. Thus, the tungsten electrode furnishes the heat to melt the base metal and the AC power supply furnishes a large portion of the energy needed to resistance melt the filler wire. The hot wire method is, in effect, an adaptation of the long stickout principle used in submerged arc and self-shielded flux cored arc welding. The wire used for hot wire TIG welding is usually 0.045 inch diameter. Since the wire is melted, or very nearly melted by its own power source, the deposition rate can be controlled almost independently of the arc.

Using the GTA hot wire method, deposition rates up to 18 lb/hr can be achieved when welding at 400 to 500 amp DCEN (Table XVII). Still greater deposition rates can be obtained using an automatic oscillated welding technique. Voltage control is essential to achieve control of the large puddle when welding at high deposition rates. For this reason, TIG hot wire welding requires the use of voltage control equipment.

By using closely spaced multiple tungsten electrodes, the welding speed can also be increased substantially when GTA welding stainless steel tubing or sheet. Multiple electrodes practically eliminate the problem of undercutting at high speeds.

Procedures and parameters for GTA welding of stainless steel in thicknesses from 1/16 inch to 1/2 inch (1.6 to 12.7 mm) are given in Figure 18. These include butt, corner, tee and lap type joints.

Distortion Control in Austenitic, Precipitation Hardening, and Duplex Ferritic–Austenitic Stainless Steels

Austenitic Stainless steels have a 50% greater coefficient of expansion and 30% lower heat conductivity than mild steel. Duplex stainless steels are only slightly better. Allowance must be made for the greater expansion and contraction when designing austenitic stainless steel structures. More care is required to control the greater distortion tendencies. Here are some specific distortion control hints:

Rigid jigs and fixtures hold parts to be welded in proper alignment. Distortion is minimized by allowing the weld to cool in the fixture.

Copper chill bars placed close to the weld zone help remove heat and prevent distortion caused by expansion. Back-up chill bars under the joint are always recommended when butt welding 14 gauge (2.0mm) and thinner material. A groove in the bar helps form the bead shape. **NOTE:** Keep the arc away from the copper. Copper
contamination of the weld causes cracking.

Without fixtures, tack weld the joint every couple of inches and peen the tacks to remove shrinkage stresses. Finish the joint with a welding sequence designed to minimize distortion.

A planned sequence of welding always helps control distortion. The techniques used in mild steel welding can be used. Skip welding and back-step welding are recommended for light gauge steels.

Low current and stringer beads reduce distortion by limiting the amount of heat at the weld. Also, do not deposit excessive weld metal. It seldom adds to the strength of the weld and does increase heat input and promotes distortion.

If a structure of heavy steel is not rigidly held during welding, many small beads will cause more total distortion than a few large beads.

Distortion Control in Ferritic and Martensitic Stainless Steels

Since they have heat expansion properties similar to mild steel, plate structures of ferritic and martensitic stainless steels are designed and welded with about the same distortion controls and allowances as mild steel. However, because they have lower thermal conductivity than mild steel, the heat remains concentrated in the area of the weld. This causes distortion problems in thin-gauge steel. This distortion can be controlled with suitable jigs and fixtures, proper joint design and a correct welding sequence.
SOURCES OF ADDITIONAL INFORMATION

Additional information on the welding of stainless steels can be obtained from the sources listed below:

The Welding Handbook
7th Edition, Volume 4, Chapter 2 – American Welding Society

ANSI/AWS D10.4
Recommended Practices for Welding Austenitic Stainless Steel Piping and Tubing – American Welding Society

AWS – A4.2
Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal – American Welding Society

AWS – A5.4
Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding – American Welding Society

AWS – A5.9
Specification for Bare Stainless Steel Welding Electrodes and Rods – American Welding Society

AWS – A5.22
Specification for Consumable Inserts – American Welding Society

ASM Metals Handbook

ASM Metals Handbook

AWS – FMC
Filler Metal Comparison Charts – American Welding Society

Literature from filler metal manufacturers:

ASM Metals Handbook

The Making, Shaping and Treating of Steel
10th Edition, United States Steel Corporation

ANSI – Z49.1
Safety in Welding, Cutting and Allied Processes – American Welding Society

Welding Metallurgy of Stainless Steels
by Erich Folkhard, Springer - Verlag, New York

WARNING – HEALTH & SAFETY NOTICE

Protect yourself and others. Read and understand the label provided with filler material for welding.

FUMES AND GASES can be dangerous to your health. ARC RAYS can injure eyes and burn skin. ELECTRIC SHOCK can kill.

- Read and understand the manufacturer’s instructions and your employer’s safety practices.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases away from your breathing zone and the general area.
- Wear correct eye, ear and body protection.
- Do not touch live electrical parts or permit electrically live parts or electrodes to contact skin or your clothing or gloves if they are wet.
- Insulate yourself from work and ground.

IMPORTANT:

Special ventilation and/or exhaust are required when welding high chromium alloys such as stainless steels.

Fumes from the normal use of stainless steel filler materials contain significant quantities of chromium compounds. The PEL (OSHA Permissible Exposure Limit for chromium VI (0.005 mg/m³) will be exceeded before reaching the 5.0 mg/m³ maximum exposure guideline for total welding fume.

BEFORE USING, READ AND UNDERSTAND THE MATERIAL SAFETY DATA SHEET (MSDS)* FOR THE FILLER MATERIAL TO BE USED.

- See American National Standard Z49.1, Safety in Welding, Cutting and Allied Processes, published by the American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126;

* Available from The Lincoln Electric Company (for Lincoln products) 22801 St. Clair Avenue Cleveland, Ohio 44117
Lincoln Electric has an extensive standard* line of consumables for welding stainless steels, including:

### Coated Electrodes for Shielded Metal Arc Welding

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<th>AWS A5.4 Classification</th>
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<td>E310-16</td>
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<td>Red Baron 316/316L MR</td>
<td>E316L-16</td>
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### Electrodes Optimized for Vertical Down Welding

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### Coated Electrodes for Shielded Metal Arc Welding

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<td>E347-17</td>
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<td>E308H-16</td>
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### Solid Wires for Submerged Arc Welding

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### Solid Wires for Gas Metal Arc Welding and Gas Tungsten Arc Welding

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### Metal Cored Wire for Gas Metal Arc Welding

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<td>OUTERSHIELD MC 409W</td>
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### Fluxes for Submerged Arc Welding

(No AWS classification is applicable.)

- Lincolnweld MIL 800
- Lincolnweld 801
- Lincolnweld 802
- Lincolnweld 860
- Lincolnweld 880
- Lincolnweld 880M
- Lincolnweld ST-100
- Blue Max 2000

### Flux Cored Wires for CO₂ or 75Ar-25CO₂ Welding

- BLUE MAX FC308L
- BLUE MAX FC309L
- BLUE MAX FC316L

### Fluxes for Strip Cladding

(No AWS Classification is applicable.)

- Blue Max 3000 (for submerged arc)
- Blue Max 4000 (for electroslag)

### Cut Lengths for Manual Gas Tungsten Arc Welding

<table>
<thead>
<tr>
<th>AWS A5.9 Classification</th>
<th>Lincoln</th>
<th>ER308/308L</th>
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<td>ER309/309L</td>
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<td>ER316/316L</td>
<td>ER316, ER316L</td>
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* Many other compositions are available on special order. Contact your Lincoln Electric Representative.
Customer Assistance Policy

The business of The Lincoln Electric Company is manufacturing and selling high quality welding equipment, consumables, and cutting equipment. Our challenge is to meet the needs of our customers and to exceed their expectations. On occasion, purchasers may ask Lincoln Electric for advice or information about their use of our products. We respond to our customers based on the best information in our possession at that time. Lincoln Electric is not in a position to warrant or guarantee such advice, and assumes no liability, with respect to such information or advice. We expressly disclaim any warranty of any kind, including any warranty of fitness for any customer’s particular purpose, with respect to such information or advice. As a matter of practical consideration, we also cannot assume any responsibility for updating or correcting any such information or advice once it has been given, nor does the provision of information or advice create, expand or alter any warranty with respect to the sale of our products.

Lincoln Electric is a responsive manufacturer, but the selection and use of specific products sold by Lincoln Electric is solely within the control of, and remains the sole responsibility of the customer. Many variables beyond the control of Lincoln Electric affect the results obtained in applying these type of fabrication methods and service requirements.

IMPORTANT: SPECIAL VENTILATION AND/OR EXHAUST REQUIRED

Fumes from the normal use of these products contain significant quantities of Chromium compounds which may be harmful.

BEFORE USE, READ AND UNDERSTAND THE MATERIAL SAFETY DATA SHEET (MSDS) FOR THIS PRODUCT AND SPECIFIC INFORMATION PRINTED ON THE PRODUCT CONTAINER.