

# NiDI

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## Guidelines for the welded fabrication of nickel-containing stainless steels for corrosion resistant services

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A Nickel Development Institute  
Reference Book, Series N° 11 007

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# Table of Contents

Introduction .....	i
<b>PART I – For the welder</b> .....	1
Physical properties of austenitic steels .....	2
Factors affecting corrosion resistance of stainless steel welds .....	2
Full penetration welds .....	2
Seal welding crevices .....	2
Embedded iron .....	2
Avoid surface oxides from welding .....	3
Other welding related defects .....	3
Welding qualifications .....	3
Welder training .....	4
Preparation for welding .....	4
Cutting and joint preparation .....	5
Weld joint designs .....	5
Cleaning in preparation for welding .....	7
Oxides and other surface layers .....	7
Contamination elements .....	8
Chlorinated solvents .....	9
Health hazards .....	9
Fixturing, fitting and tack welding .....	9
Fixtures and positioners .....	10
Backing materials .....	10
Tack welding .....	10
Fitting pipe joints for GTAW root welds .....	11
Purging during pipe root welding .....	11
Welding Processes .....	12
Shielded metal arc welding .....	12
Electrode types .....	13
Other guides in SMAW .....	13
Electrode handling and storage .....	13
Welding current .....	15
Arc starting and stopping .....	15
Gas tungsten arc welding .....	15
GTAW equipment .....	16
Consumables .....	16
Operator technique guides .....	17
Gas metal arc welding .....	18
Arc transfer modes .....	18
GMAW equipment .....	18
Consumables .....	19
Other welding processes .....	19
Post-fabrication cleaning .....	19
Surface contaminants .....	20
Detection .....	20
Removal .....	20
Embedded iron .....	20
Detecting embedded iron .....	21
Removing embedded iron .....	21
Mechanical damage .....	22
Safety and welding fumes .....	22

<b>PART II – For the materials engineer</b> .....	23
Stainless steel alloys .....	23
Austenitic stainless steels .....	23
Effect of welding on corrosion resistance .....	23
Role of weld metal ferrite .....	27
Measuring weld metal ferrite .....	27
Duplex stainless steels .....	28
Characteristics of duplex stainless steels .....	30
High temperature exposure .....	30
Effect of welding on duplex stainless steels .....	30
Nickel-enriched filler metal .....	31
Heat input control .....	31
Interpass temperature control .....	31
Preheat .....	32
Other stainless steels .....	32
Martensitic stainless steels .....	33
Ferritic stainless steels .....	33
Precipitation hardening stainless steels .....	34
Corrosion resistant stainless steel castings .....	34
Heat treatment of stainless steel .....	35
Alternate 1 .....	35
Alternate 2 .....	35
Material procurement and storage guides .....	36
Surface finishes .....	36
Purchasing guidelines .....	38
<b>PART III – For the design engineer</b> .....	39
Design for corrosion services .....	39
Tank bottoms .....	39
Tank bottom outlets.....	40
Bottom corner welds .....	40
Attachments and structurals .....	40
Heaters and inlets .....	42
Pipe welds .....	42
<b>Appendix A: Specifications for stainless steel for welded fabrication</b> .....	45
Additional requirements .....	46
<b>Bibliography</b> .....	46
<b>Acknowledgement</b> .....	46
<b>Tables</b>	
Table 1 – Influence of physical properties on welding austenitic stainless steels compared to carbon steel .....	1
Table 2 – Stainless steel cutting methods .....	5
Table 3 – Melting temperatures of metals and metal oxides .....	7
Table 4 – Suggested filler metals for welding stainless steels .....	14
Table 5 – Comparison of GMAW arc modes for stainless steels .....	18
Table 6 – Wrought austenitic stainless steels chemical analysis .....	24
Table 7 – Corrosion resistant stainless steel castings chemical analysis .....	25
Table 8 – Duplex stainless steels chemical analysis .....	29
Table 9 – Duplex stainless steel filler metals typical composition .....	32
Table 10 – Suggested filler metals for welding some of the martensitic, ferritic and precipitation hardening stainless steels .....	33
Table 11 – Stainless steel products forms .....	36
Table 12 – Standard mechanical sheet finishes .....	37

## Figures

Figures 1-1 to 1-7 – Typical weld joint designs .....	6 to 7
Figure 2 – Backing bar groove designs .....	10
Figure 3 – The correct tack weld sequence .....	11
Figure 4 – Typical pipe purging fixtures .....	12
Figure 5 – Shielded metal arc welding .....	12
Figure 6 – Gas tungsten arc welding .....	15
Figure 7 – Gas metal arc welding .....	17
Figure 8 – Typical fabrication defects .....	20
Figure 9 – Crevice corrosion .....	20
Figure 10 – A scratch serves as an initiation site for corrosion .....	20
Figure 11 – Effect of carbon control on carbide precipitation in Type 304 .....	26
Figure 12 – Revised constitution diagram for stainless steel weld metal .....	28
Figure 13 – Typical microstructure of cold rolled, quench annealed Alloy 2205 seamless tube .....	28
Figures 14-1 to 14-36 – Designs for improved corrosion service .....	39 to 44

# Introduction

Nickel-containing stainless steels are indispensable in the construction of equipment for the process industries. These steels are used in place of conventional steels for properties such as excellent corrosion resistance, toughness at low temperatures and good elevated-temperature properties. The stainless steels are an excellent choice for chemical, dairy, food, architectural, biotechnology equipment and similar services. The wrought nickel stainless steels widely used for corrosion services range from Type 304 (Unified Numbering System, UNS, S30400) through the newer 6% molybdenum alloys, along with the comparable cast alloys and the duplex stainless steels.

This publication is presented in three sections identified as, FOR THE WELDER (page 1), FOR THE MATERIALS ENGINEER (page 23) and FOR THE DESIGN ENGINEER (page 39).

In the section FOR THE WELDER, it is assumed that the welders or others involved in welded fabrication are familiar with the basic techniques used in carbon steel fabrication, but have had limited experience with nickel-containing stainless steels. The Welder section employs a “how to do it” approach for the non-engineer but may also serve as a reference for the welding and metallurgical engineer.

The section FOR THE MATERIALS ENGINEER describes the various types of stainless steels, how their metallurgical and corrosion characteristics are affected by welding and some of the more specialized aspects of fabrication such as heat treating. Guidelines for material procurement and handling are also covered.

The section FOR THE DESIGN ENGINEER provides a number of design examples of how the corrosion performance of stainless steels can be enhanced through good design.

# Part I

## For the welder

Part I focuses on the fabrication and welding of austenitic stainless steels, Types 304, 316, 321 and 347 (UNS S30400, S31600, S32100 and S34700) and the more highly alloyed 4 and 6%

molybdenum stainless steels. Duplex stainless steels which are half austenite and half ferrite are discussed in the section entitled "For the materials engineer."

**Table I**  
**Influence of physical properties on welding austenitic stainless steels compared to carbon steel**

	<b>Austenitic stainless steel</b>	<b>Carbon steel</b>	<b>Remarks</b>
Melting point (Type 304)	2550-2650°F (1400-1450°C)	2800°F (1540°C)	Type 304 requires less heat to produce fusion, which means faster welding for the same heat or less heat for the same speed.
Magnetic response	Non-magnetic all temperatures (1)	Magnetic to over 1300°F (705°C)	Nickel stainless steels are not subject to arc blow.
Rate of heat conductivity (% at 212°F) (100°C) (% at 1200°F) (650°C)	(Type 304) 28% 66%	100% 100%	Type 304 conducts heat much more slowly than carbon steel thus promoting sharper heat gradients. This accelerates warping, especially in combination with higher expansion rates. Slower diffusion of heat expansion through the base metal means that weld zones remain hot longer, one result of which may be longer dwell in the carbide precipitation range unless excess heat is artificially removed by chill bars, etc.
Electrical resistance (Annealed) (Microhm-cm, approx.) At 68°F (20°C) At 1625°F (885°C)	72.0 126.0	12.5 125	This is of importance in electrical fusion methods. The higher electrical resistance of Type 304 results in the generation of more heat for the same current or the same heat with lower current, as compared with carbon steel. This, together with its low rate of heat conductivity, accounts for the effectiveness of resistance welding methods on Type 304.
Thermal Expansion over range indicated in./in./F x 10 <sup>-6</sup>	9.8 (68-932°F)	6.5 (68-1162°F)	Type 304 expands and contracts at a faster rate than carbon steel, which means that increased expansion and contraction must be allowed for in order to control warping and the development of thermal stresses upon cooling. For example, more tack welds are used for stainless steel than for carbon steel.
in./in./C x 10 <sup>-6</sup>	17.6 (20-500°C)	11.7 (20-628°C)	

(1) Duplex stainless steels are magnetic.

## Physical properties of austenitic stainless steels

The physical properties of ordinary carbon steels and austenitic stainless steels are quite different and these call for some revision of welding procedures. Physical properties, *Table I*, include such items as melting point, thermal expansion, thermal conductivity and others that are not significantly changed by thermal or mechanical processing. As illustrated in *Table I*, the melting point of the austenitic grades is lower, so less heat is required to produce fusion. Their electrical resistance is higher than that of mild steel so less electrical current (lower heat settings) is required for welding. These stainless steels have a lower coefficient of thermal conductivity, which causes heat to concentrate in a small zone adjacent to the weld. The austenitic stainless steels also have coefficients of thermal expansion approximately 50% greater than mild steel, which calls for more attention to the control of warpage and distortion.

## Factors affecting corrosion resistance of stainless steel welds

Before discussing welding guidelines, it is useful to describe the types of welds and stainless steel surfaces which will give the best performance in corrosive environments. These are factors that the welders or others on the shop floor control, rather than alloy selection, which is usually made by the end user or Materials Engineer. The manufacture of corrosion resistant equipment that will give superior service should be viewed as a joint effort of selecting the correct alloy and then employing the proper welding and fabrication practices. Both elements are essential.

## Full penetration welds

It is well recognized that for optimum strength, butt welds should be full-penetration welds. In corrosion service, any crevice resulting from lack of penetration is also a potential site for crevice corrosion. A typical example of an undesirable crevice is incomplete fusion of a pipe root pass weld such as shown in *Figure 14-31* (see page 43). In some environments, corrosion takes place in the crevice which, in turn, can lead to early failure of the weld joint.

## Seal welding crevices

Crevices between two stainless steel surfaces such as tray supports tacked to a tank, as shown in *Figure 14-16* (see page 40), also invite crevice corrosion. Avoiding such crevices is a design responsibility and discussed further in the section For the Design Engineer, as well as calling for corrective action. However, it is helpful for those actually making the equipment to assist in eliminating crevices whenever possible.

## Embedded iron

When new stainless steel equipment develops rust spots, it is nearly always the result of embedded free iron. In some environments, if the iron is not removed, deep attack in the form of pitting corrosion may take place. In less extreme environments, the iron rust may act as a *contaminant* affecting product purity, or present an unsightly rusty appearance to a surface that should be clean and bright.

Free iron is most often embedded in stainless steels during welding or forming operations. Some cardinal fabrication rules to follow in avoiding free iron are:

- DO NOT bring iron or steel surfaces into intimate contact with stainless steel. The contact could come from lifting tools, steel tables or storage racks, to name a few.



□ DO NOT use tools such as abrasive disks or wheels that have been previously used on ordinary iron or steel and could have iron embedded.

□ Use only stainless steel wire brushes that have never been used on carbon steel. Never use brushes with carbon steel wire.

□ DO NOT leave stainless steel sheets or plates on the floor exposed to traffic. Sheet and plate are best stored in the vertical position.

□ Locate stainless steel fabrication away from carbon steel fabrication, if at all possible, to avoid iron contamination from steel grinding, cutting and blasting operations.

The detection of free iron and removal methods are discussed under Post-Fabrication Cleaning in this section.

## Avoid surface oxides from welding

For best corrosion resistance, the stainless steel surface should be free of surface oxides. The oxides may be in the form of heat tint resulting from welding on the reverse side or heat tint on the weld or in the heat affected zone, HAZ. Oxides can also develop on the root inside diameter, ID, surface of pipe welds made with an inadequate inert gas purge.

The oxides may vary from thin, straw coloured, a purple colour to a black heavy oxide. The darker the colour and heavier the oxide, the more likely pitting corrosion will develop, causing serious attack to the underlying metal. It should be understood that the oxides are harmful in corrosive environments. Oxides normally need not be removed when the stainless steel will operate at high temperatures where oxides would normally form. Heat tint seldom leads to corrosion in atmospheric or other mild environments but is frequently removed for cosmetic purposes.

When, after normal precautions are taken and there are still surface oxides, they can be removed by acid pickling, glass-bead blasting or one of the other methods discussed in Post-Fabrication Cleaning.

## Other welding related defects

Three other welding related defects and their removal procedure are listed below.

□ Arc strikes on the parent material damage stainless steel's protective film and create crevice-like imperfections. Weld stop points may create pinpoint defects in the weld metal. Both imperfections should be removed by light grinding with clean fine grit abrasive tools.

□ Weld spatter creates a tiny weld where the molten slug of metal touches and adheres to the surface. The protective film is penetrated and tiny crevices are created where the film is weakened the most. Weld spatter can easily be eliminated by applying a commercial spatter-prevention paste to either side of the joint to be welded. The paste and spatter are washed off during cleanup.

□ Slag on some coated electrode welds is difficult to remove completely. Small slag particles resist cleaning and particularly remain where there is a slight undercut or other irregularity. Slag particles create crevices and must be removed by wire brushing, light grinding or abrasive blasting with iron free materials.

## Welding qualifications

It is standard practice for fabricators of process equipment to develop and maintain welding procedure specifications, WPS, for the various types of welding performed. The individual welders and welding operators are tested and certified by satisfactorily

## For the welder

making acceptable performance qualification weldments. There are a number of Society or Industry codes that govern welding qualifications, but the two most widely used in the US for corrosion resistance equipment are:

- American Society of Mechanical Engineers, ASME, Boiler and Pressure Vessel Code – Section IX, Welding and Brazing Qualification;
- American Welding Society, AWS, Standard for Welding Procedure and Performance Qualification – AWS B2.1.

Internationally, each country typically has its own individual codes or standards. Fortunately, there is a trend toward the acceptance and interchange of specifications in the interest of eliminating unmerited requalification.

Common to these codes is the identification of essential variables that establish when a new procedure qualification test weldment is required. Essential variables differ for each welding process but common examples might be:

- change in base metal being welded (P-Number);
- change in filler metal (F-Number);
- significant change in thickness being welded;
- change in shielding gas used;
- change in welding process used.

ASME Section IX classification of P-Numbers often first determines if a separate WPS is needed. A change in a base metal from one P-Number to another P-Number requires requalification. Also joints made between two base metals of different P-Numbers require a separate WPS, even though qualification tests have been made for each of the two base metals welded to themselves. P-Numbers are shown below:

P-Number	Base metal
8	Austenitic stainless steels in Table VI from Type 304 through 347 and Alloy 254 SMO plus the similar CF cast alloys of Table VII
10H	Duplex stainless steels including Alloys 255 and 2205 and cast CD 4MCu
45	Alloys 904L and 20Cb-3 and 6% molybdenum alloys of Table VI except Alloy 254 SMO.

Not all alloys have been assigned a P-Number. Alloys without a number require individual qualification even though similar in composition to an alloy already qualified. If an alloy is not listed in the P-Number tables, the alloy manufacturer should be contacted to determine if a number has been recently assigned by the code.

## Welder training

In complying with welding qualification specifications such as ASME and AWS, welders must pass a performance test. A welder training program is not only essential prior to taking the performance test but also insures quality production welding. Stainless steels are sufficiently different in welding characteristics from ordinary steels that the welders should be provided training and practice time. Once they are familiar with the stainless steels, many welders develop a preference over regular steels. In addition to the particular base metal and welding process, training should also cover the shapes to be welded such as pipe and thin sheets or unusual welding positions.

## Preparation for welding

Stainless steels should be handled with somewhat greater care than carbon steels in cutting and fitting. The care taken in preparation for welding is time

well spent in improved weld quality and a finished product that will give optimum serviceability.

## Cutting and joint preparation

With the exception of oxyacetylene cutting, stainless steels can be cut by the same methods used for carbon steel. Oxyacetylene cutting stainless steel (without iron rich powder additions) results in the formation of refractory chromium oxides, preventing accurate, smooth cuts. The thickness and shape of the parts being cut or prepared for welding largely dictates which of the methods shown in *Table II* is most appropriate.

## Weld joint designs

The weld joint designs used for stainless steels are similar to those used for ordinary steels. The weld joint design selected must produce welds of suitable strength and service performance while still allowing low welding

costs. Butt welds should be full penetration welds for corrosive services. Fillet welds need not be full penetration as long as both sides and ends are welded to seal off voids that could collect liquid and allow crevice corrosion.

Fillet welding branch connections on pipe headers leaves a large and severe crevice on the ID. This practice invites crevice and microbiologically influenced corrosion and should be prohibited for stainless steel pipe fabrications in all services.

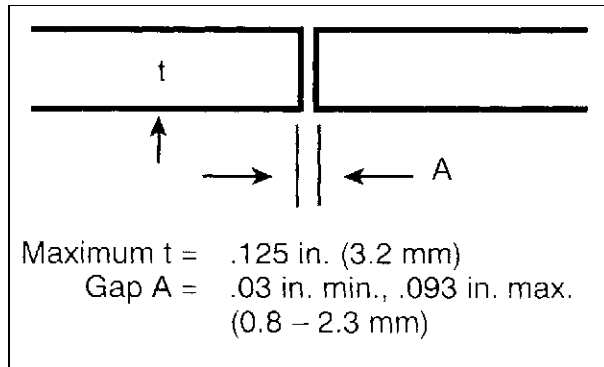
The molten stainless steel weld metal is somewhat less fluid than carbon steel and depth of weld penetration is not as great. To compensate, stainless steel weld joints may have a wider bevel, thinner land and a wider root gap. The welding process also influences optimum joint design. For example, spray arc, gas metal arc welding, GMAW, gives much deeper penetration than short circuiting GMAW, so thicker lands are used with the former process.

**Table II**  
**Stainless steel cutting methods**

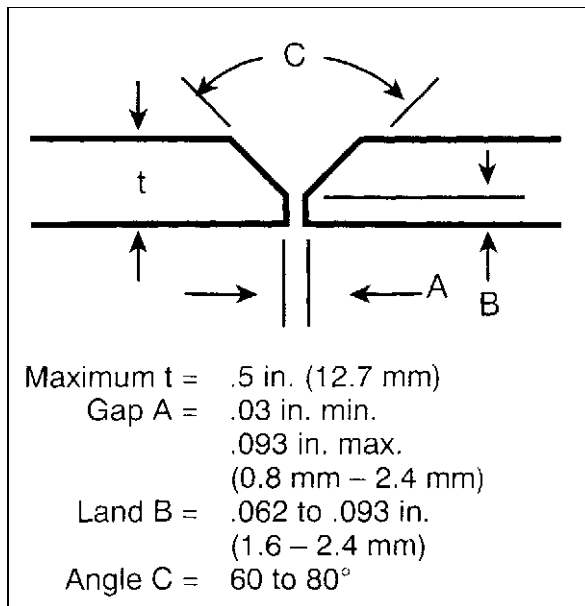
Method	Thickness cut	Comments
Shearing	Sheet/strip, thin plate	Prepare edge exposed to environment to remove tear crevices.
Sawing & abrasive cutting	Wide range of thicknesses	Remove lubricant or cutting liquid before welding or heat treating.
Machining	Wide range shapes	Remove lubricant or cutting liquid before welding or heat treating.
Plasma arc cutting (PAC)	Wide range of thicknesses	Grind cut surfaces to clean metal.
Powder metal cutting with iron-rich powder	Wide range of thicknesses	Cut less accurate than PAC, must remove all dross,
Carbon arc cutting	Used for gouging backside of welds and cutting irregular shapes.	Grind cut surfaces to clean metal.

## For the welder

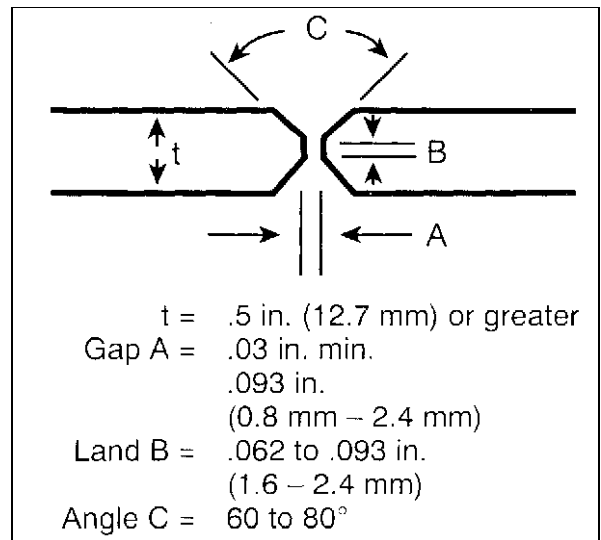
Typical joint designs for sheet and plate welding are shown in *Figures 1-1* through *1-5*. Typical pipe joint designs for gas tungsten arc welding, GTAW, root welds with and without consumable inserts, are shown in *Figures 1-6* and *1-7*. Consumable insert rings are widely used and are recommended for consistent root penetration.



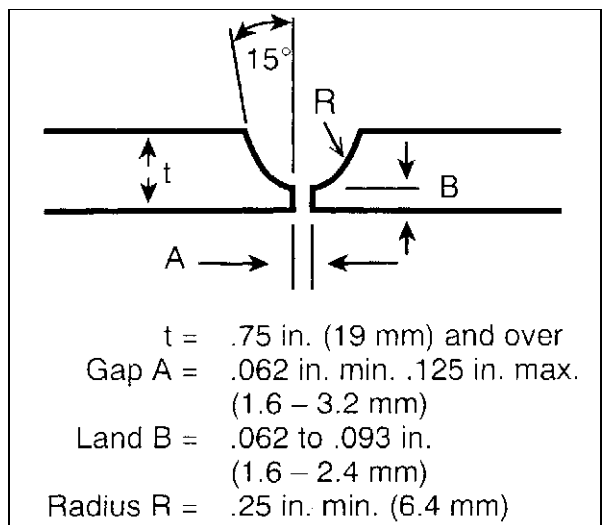
**Figure 1-1** Typical square butt joint for sheet.



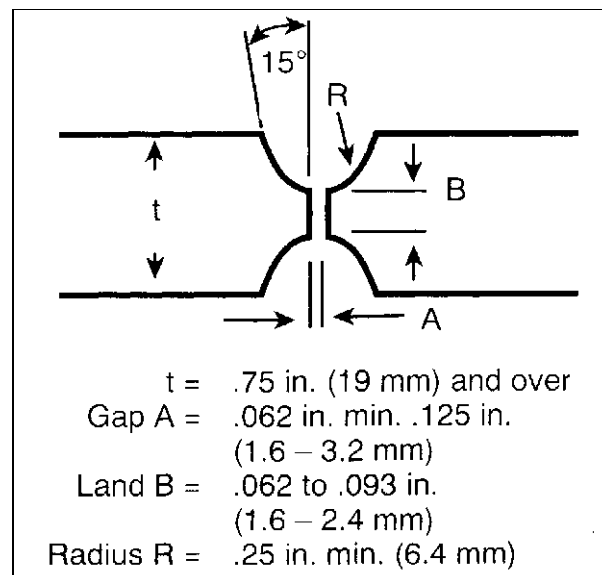
**Figure 1-2** Typical single “V” joint for sheet and plate.



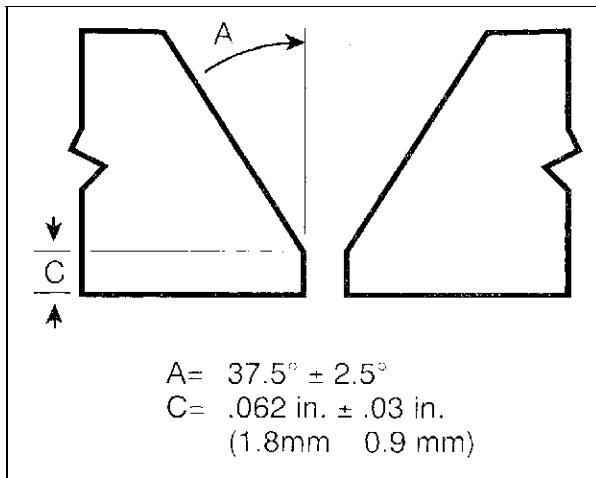
**Figure 1-3** Typical double “V” joint for plate.



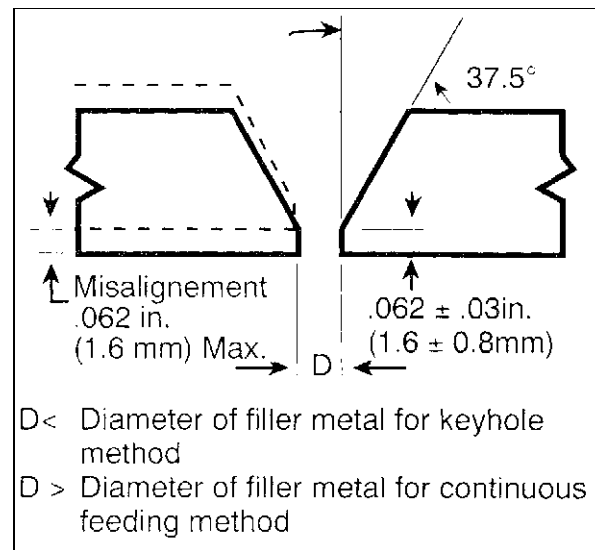
**Figure 1-4** Typical single “U” joint for plate.



**Figure 1-5** Typical double “U” joint for plate.



**Figure 1-6** Typical joint design for pipe with consumable insert.



**Figure 1-7** Typical joint design for pipe welded without consumable insert.

## Cleaning in preparation for welding

The weld area to be cleaned includes the joint edges and two or three inches of adjacent surfaces. Improper cleaning can cause weld defects such as cracks, porosity or lack of fusion. The corrosion resistance of the weld and HAZ can be substantially reduced if foreign material is left on the surface before welding or a heating operation. After cleaning, joints should be covered unless welding will be immediately performed.

### Oxide and other surface layers –

The joints to be welded should be free of the surface oxides frequently left after

thermal cutting. Stainless steel oxides are comprised mainly of those of chromium and nickel. Because these oxides melt at a much higher temperature than the weld metal, they are not fused during welding. Often an oxide film becomes trapped in the solidifying weld resulting in a defect that is difficult to detect by radiography. This is a basic difference from welding steel. With steel, iron oxides melt at about the same temperature as the weld metal. While it is considered poor practice to weld over a heavy steel mill scale, it does not present the problem caused by a stainless steel oxide film. The differences between metal and metal oxide melting temperatures is shown in *Table III*.

**Table III**  
**Melting temperatures of metals and metal oxides**

Metal	Melting temperatures °F (°C)	Metal oxide	Melting temperatures °F (°C)
Iron	2798 (1537)	Fe <sub>2</sub> O <sub>3</sub>	2850 (1565)
		Fe <sub>3</sub> O <sub>4</sub>	2900 (1593)
Nickel	2650 (1454)	NiO	3600 (1982)
304 S/S	2550-2650 (1400-1454)	Cr <sub>2</sub> O <sub>3</sub>	4110 (2266)

## For the welder

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Stainless steel wrought products delivered by the mills are normally free of objectionable oxides and do not need special treatment prior to welding. Any oxide layer would be thin and not likely the cause of welding problems. Very thin metals, such as strip under 0.010 in. (0.25mm) may need special cleaning such as vapour honing since even light oxide layers may be trapped in small, fast solidifying welds.

Stainless steels that have been in service often require special pre-weld cleanup. If the alloy has been exposed to high temperatures, the surface is often heavily oxidized or may have a carburized or sulphurized layer. Such layers must be removed by grinding or machining. Wire brushing polishes and does not remove the tightly adhering oxides. Stainless steel equipment that has been in chemical service may be contaminated by the product media. A good example is caustic. If caustic is left on the surface during welding, the weld and HAZ often develops cracks. Neutralizing caustic residue with an acid solution is part of an effective cleanup prior to welding. It is good practice to give a neutralizing treatment prior to repair welding chemical equipment. That is, neutralize acid contaminated surfaces with a mild basic solution and an alkaline contaminated surface with a mild acidic solution. A hot water rinse should always follow the neutralizing treatment.

**Contamination elements** – There are a number of elements and compounds that must be removed from the surface prior to welding. If not removed, the heat from welding can cause cracking, weld defects or reduced corrosion resistance of the weld or HAZ. The elements to be avoided and common sources of the elements are:

sulphur, carbon	- hydrocarbons such as cutting fluids, grease, oil, waxes and primers
sulphur, phosphorous, carbon	- marking crayons, paints and temperature indicating markers
lead, zinc, copper	- tools such as hammers (lead), hold down or backing bars (copper), zinc rich paint
shop dirt	- any or all of the above

The presence of sulphur, phosphorous and low-melting metals may cause cracks in the weld or HAZ. Carbon or carbonaceous materials left on the surface during welding may be taken in solution, resulting in a high carbon layer which in turn lowers the corrosion resistance in certain environments.

Cleaning to remove the above contaminants should be accomplished by following a few guidelines, along with common sense. Metallic contaminants and materials not having an oil or grease base are often best removed by mechanical means such as abrasive blasting or grinding. It is essential that the blasting material or abrasive disk be free of contaminants such as free iron. A nitric acid treatment, followed by neutralization can also effectively remove some low melting metals without damage to the stainless steel.

Oil or grease (hydrocarbon) base contaminants must be removed by solvent cleaning because they are not removed by water or acid rinses. Large weldments are usually hand cleaned by wiping with solvent saturated cloths. Other acceptable methods include immersion in, swabbing with or spraying with alkaline, emulsion, solvent or

detergent cleaners or a combination of these; by vapour degreasing; by steam, with or without a cleaner; or by high-pressure water jetting. American Society for Testing and Materials, ASTM, A380, Standard Recommended Practice for Cleaning and Descaling Stainless Steel Parts, Equipment and Systems, is an excellent guide for fabricators and users.

A typical procedure to remove oil or grease includes:

- remove excess contaminant by wiping with clean cloth;
- swab the weld area (at least 2 in.(5cm) each side of the weld) with an organic solvent such as aliphatic petroleums, chlorinated hydrocarbons or blends of the two. (See cautionary remarks below.) Use only clean solvents (uncontaminated with acid, alkali, oil or other foreign material) and clean cloths;
- remove all solvent by wiping with clean, dry cloth;
- check to assure complete cleaning. A residue on the drying cloth can indicate incomplete cleaning. Where size allows, either the water-break or atomized test are effective checks.

Selecting the solvent cleaner involves considerations more than just the ability to remove oil and grease. Two precautions are as follows.

**Chlorinated solvents** – Many commercial solvents contain chlorides and are effective in cleaning machined parts and crevice free components. The potential problem with chlorinated solvents is that they may remain and concentrate in crevices and later initiate crevice corrosion and stress corrosion cracking, SCC. There have been unnecessary and costly SCC failures of stainless steel heat exchangers after cleaning with chlorinated solvents. Cleaning of open, bold areas with chlorinated solvents does not present a problem, but rather than risk a

misapplication, some organizations prohibit the use of any chlorinated solvent across the board. Non-chlorinated solvents are preferred for cleaning stainless steels and should always be used for equipment and crevices.

**Health hazards** – The term health hazard has been defined as including carcinogens, toxic agents, irritants, corrosives, sensitizers and any agent that damages the lungs, skin, eyes or mucous membranes. Each organization should assure that the solvents used are not harmful to personnel or equipment. In addition to the toxic effect, consideration must be given to venting of explosive fumes, safe disposal of spent solutions and other related handling practices. Compliance with state and local regulations is obviously a requirement.

Solvents used for pre-weld cleaning include, but are not limited to, the following:

- non-chlorinated: toluene, methyl - ethyl ketone and acetone
- chlorinated solvent: 1.1.1. Trichloroethane

All must be handled in compliance with regulator requirements and manufacturers' instructions.

## Fixturing, fitting and tack welding

Good alignment of the assembly prior to welding can reduce welding time. It is essential that the mating pieces to be joined should be carefully aligned for good quality welding. When one member is considerably thicker than the other, for example a tank head thicker than the shell, the head side should be machined to a taper of 3:1 or more to reduce stress concentrations. Joints with varying root gap require special adjustment by the welding operator and may result in burn through or lack of penetration. When the volume of identical parts is large, use of fixtures is often economically justified.

**Fixtures and positioners** – Fixtures are usually designed for each particular assembly and hold the parts together throughout the welding operation. When fixtures are attached to positioners, there is a further advantage in that welding can be done in the most convenient position. Some advantages of using fixtures are:

- better joint match-up;
- less tacking and welding time;
- distortion from welding is minimized;
- finish assembly is made to closer tolerance.

It is important that fixture surfaces holding the stainless steel parts do not introduce iron contamination. This can be avoided by surfacing the fixture contacting surfaces with stainless steel and using the fixtures only for stainless steel.

**Backing materials** – A backing material should be used in welding sheet or plate, unless both sides of the joint can be welded. Without a backing, the underneath side may have erratic penetration with crevices, voids and excessive oxidation. Such defects reduce weld strength and can initiate accelerated corrosion. Copper, with its high thermal conductivity, is the material

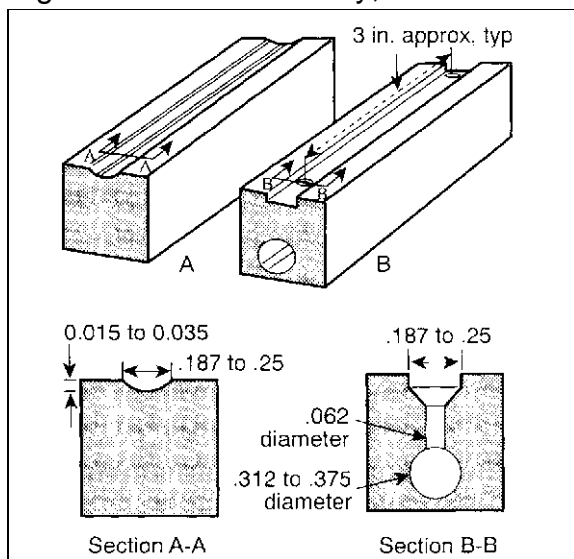
most often used for backing bars. Typical backing bar designs for use with and without a backing gas are shown in *Figure 2*. In the normal course of welding, the copper bar chills the weld to solid metal without melting the copper. The arc should not be misdirected to the extent that copper is melted and incorporated into the stainless steel weld or weld cracking can result. It is good practice to pickle after welding to remove traces of copper from the surface and essential to pickle if solution annealing is to follow welding.

Argon backing gas provides excellent protection to the underneath side of GTAW welds. It helps control penetration and maintain a bright, clean under surface. Nitrogen is also used as a backing gas and has a price advantage over argon. However, nitrogen should not be introduced into the arc atmosphere which, in turn, could alter the weld metal composition balance.

When a copper backing bar or an inert gas backing purge is impractical, there are commercially available tapes, pastes and ceramic backing products. These offer some protection from burn-through but give little protection from oxidation, so final cleaning by abrasive means or acid pickling is needed after welding when these backing materials are used.

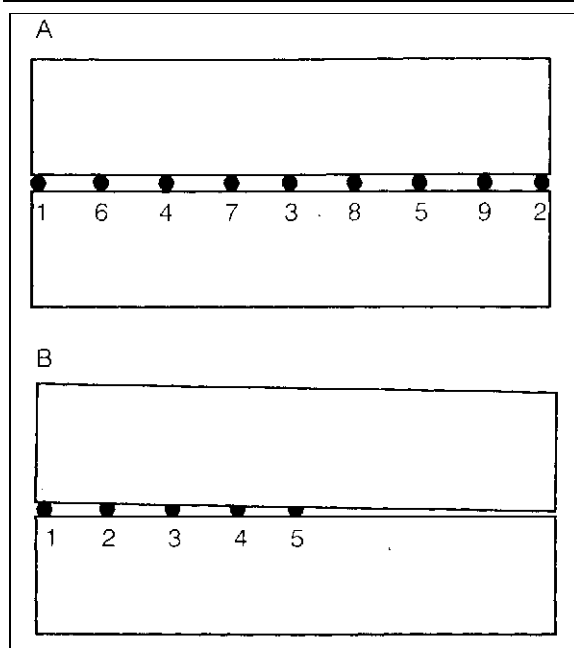
**Tack welding** – Joints not held in fixtures must be tack welded to maintain a uniform gap and alignment along the entire length. The tacks should be placed in a sequence to minimize the effect of shrinkage. In fitting two sheets, tack welds should be placed at each end and then the middle section as shown in *Figure 3 (A)*. *Figure 3 (B)* shows how the sheets close up when tack welding progresses from one end.

Tack welds in stainless steel must be spaced considerably closer than would be needed for ordinary carbon steel since the higher thermal expansion of stainless steel causes greater distortion. A rough guide is to use about half the



**Figure 2** Backing bar groove designs. (A) Standard groove for use without a backing gas. (B) Square-corner groove employed with backing gas.





**Figure 3** The correct tack weld sequence is shown in A above. When tack welding from one end only, as shown in B, the edges close up.

spacing between stainless tacks as used for carbon steel when distortion is a factor.

The length of tack welds may be as short as 0.125 in. (3 mm), or a small spot of weld metal for thin material to over 1 in. (254 mm) long for heavy plate sections. More important, the shape of the tack should not cause a defect in the final weld. Heavy or high tacks or abrupt starts and stops should be contour ground. Bead shape is easier controlled with the GTAW process, making it a good choice for tack welding. Tack welds to be incorporated into the final weld must be wire brushed or ground to clean metal. They should be inspected for crater cracks and any cracks ground out.

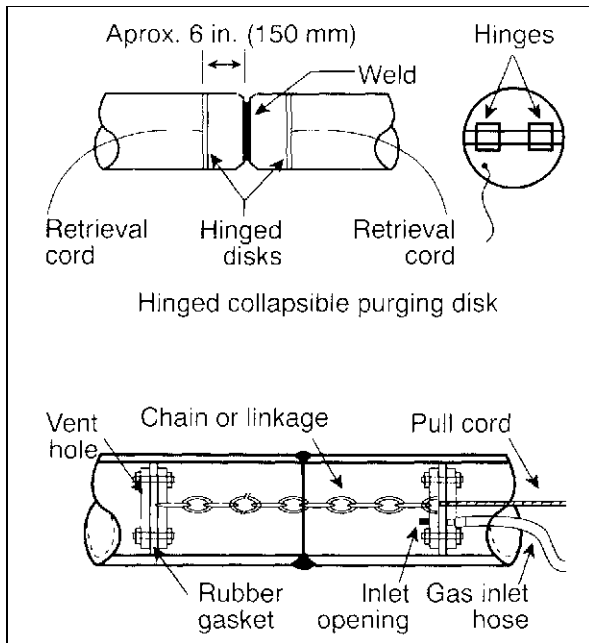
**Fitting pipe joints for GTAW root welds** – Tack welding is important because the tack normally becomes a part of the root weld. Inert gas purging prior to tacking is needed for protection against oxidation. In tacking joints without consumable inserts, or open root welds as they often are called, there is a strong tendency for the shrinkage forces

to pull the joint closed. To maintain the desired gap, it may be necessary to use spacers and to increase the size and number of tack welds. Spacers are usually short lengths of suitable diameter clean stainless steel wire. Any cracked or defective tack welds should be ground out. Both ends of the tacks on open root welds should be tapered to aid in fusing into the root weld.

The need to maintain a proper gap during root pass welding is two-fold. First, a consistent and uniform gap aids the welder in producing the optimum ID root contour. When the joint closes up, there is a tendency for concave roots rather than the desired slightly convex contour. The other reason for a uniform root gap is the need to maintain the optimum root pass chemical composition. For many corrosion services, the filler metal addition is essential to provide a weld with corrosion resistance comparable to the base metal. As the joint closes, it is usually impossible to melt a proper amount of filler metal into the weld root. For example, the 6% molybdenum stainless steels require proper root gap and adequate filler metal addition for high integrity root welds.

**Purging during pipe root welding** – The pipe interior must be purged with an inert gas prior to the GTAW root pass. Failure to use a purge can result in a heavily oxidized ID root surface with substantially lower corrosion resistance. Purging is usually with pure argon, but nitrogen is sometimes used because of lower cost. With duplex stainless steels, nitrogen backing gas compensates for nitrogen lost in the weld metal and restores weld pitting resistance. In Europe, a nitrogen-10% hydrogen mixture is widely used for purging austenitic steel pipe, but would not generally be acceptable for duplex steels.

Purging is a two-step operation, the first being done prior to welding to displace air inside the pipe. To save time and purging gas, baffles on either side of the weld joint are often used to reduce the purge area.



**Figure 4** Typical pipe purging fixtures.

Open root weld joints should be taped and dead air spaces vented prior to purging. The internal oxygen content should be reduced to below 1 % prior to welding. Typical purging fixtures are shown in *Figure 4*.

Before the start of welding, the purge flow rate should be reduced to the point where there is only a slight positive pressure. Tape covering weld joints should be removed just in advance of the area to be welded. After the root pass, the internal purge should be maintained during the next two filler passes in order to minimize heat tint (oxidation) on the inside weld surface. This is especially important when it is impractical to pickle after welding.

For those needing more information on GTAW root pass pipe welding, there are a number of technical articles and specifications available. Two excellent sources are the American Welding Society publications listed in the General References.

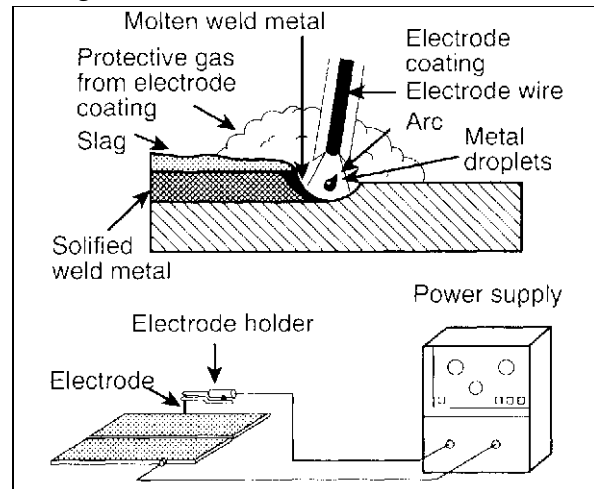
## Welding processes

This section provides information to assist in formulating stainless steel welding procedures for the shielded metal arc welding, SMAW, GTAW and

GTAW processes. The areas covered in earlier sections of this publication such as base metal properties, joint designs and preparation for welding are common to all welding procedures and are not repeated.

## Shielded metal arc welding

SMAW is a versatile process, widely used for welding stainless steel when the shapes or quantity do not justify automatic welding. The electrode is a solid wire covered by an extruded flux coating, although some manufacturers use a cored wire in lieu of the solid core wire. SMAW is frequently referred to as covered electrode or stick welding. The arc zone in the SMAW process is shown in *Figure 5*.



**Figure 5** Shielded metal arc welding.

The welding is performed manually with the welder maintaining control over the arc length and directing the arc into the weld joint. The electrode coating has these functions:

- the outer flux does not burn off as fast as the electrode core which, in turn, helps control the arc action and ability to weld out-of-position;
- the flux is used to provide alloy addition to the weld metal. The core wire is not always the same composition as the deposited weld metal and therefore it is poor practice to remove the flux and use the core wire for filler with another process such as GTAW;

- the gaseous envelope from flux decomposition excludes oxygen and nitrogen from the molten weld metal;
- the molten slag formed on top of the weld protects the weld metal from contamination by the atmosphere and helps to shape the bead.

**Electrode types** – The electrodes are selected first on the basis of weld metal composition and then according to the type of coating. Normally, they are of matching or higher alloy composition to the base metal. In some cases, it is an engineering decision to use a special composition electrode. The electrode coating type is usually left to the individual fabricators. Electrodes for stainless steel base metals are shown in *Table IV*.

The flux formula is usually each manufacturer's jealously guarded proprietary information. The flux coating influences how the electrode operates in various positions, shape and uniformity of weld bead and that hard-to-define operator appeal. There are two basic classifications, namely -15 (lime) and -16 (basic-titania). For example, an electrode may be either type 308-15 or 308-16. Electrode manufacturers often establish their own suffix to designate special electrodes but AWS A 5.4 - 81 recognizes only -15 and -16.

Lime coated electrodes (-15) are also known as lime-fluorspar or basic type. They are used on direct current, electrode positive, DCEP, (reverse polarity) current, but some brands operate on alternating current, AC. Lime coated electrodes give the cleanest weld metal, lowest in nitrogen, oxygen and inclusions. The weld metal tends to be tougher, more ductile, more crack resistant and have the best corrosion resistance. The electrodes have good penetration and all-position weldability, which is desirable for field work.

AC-DC coated electrodes (-16) generally have a mixture of lime and titania and are often used with alternat-

ing current. They are more popular than the lime type because of better operating characteristics. The arc is stable and smooth with a fine metal transfer. The weld bead is uniform with a flat to slightly concave contour. Slag is easily removed without a secondary film remaining on the weld bead.

**Other guides in SMAW** – Factors which contribute to high quality stainless steel welds include proper handling and storage of electrodes, correct welding current along with good arc starting and stopping techniques.

*Electrode handling and storage* – Stainless steel electrodes are normally furnished in packages suitable for long storage. After the package is opened, the electrodes should be stored in heated cabinets at the temperature recommended by the manufacturer. If the electrodes have been overexposed to moisture, they should be reconditioned by a higher temperature bake using the manufacturer's suggested time and temperature. It is preferable to obtain the manufacturer's specific recommendations, since the temperature often varies with the particular coating, but lacking this information, commonly used temperatures are:

- storage of opened electrodes 225°F (110°C);
- recondition bake 500°F (260°C).

Moisture in the coating is a concern because the hydrogen gas generated can cause weld porosity. The pores may be in the weld metal or may reach the surface just as the metal solidifies, forming visible surface pores. The porosity can occur in butt welds when the moisture content of the coating is high, but more often occurs in fillet welds. Excessive moisture in duplex covered electrodes has the added risk of causing hydrogen embrittlement in

**Table IV**  
**Suggested filler metals for welding stainless steels**

<b>Base metal</b>	<b>Covered welding electrode AWS or common name</b>	<b>Bare welding electrodes and rods – AWS or common name</b>	<b>Base metal</b>	<b>Covered welding electrode AWS or common name</b>	<b>Bare welding electrodes and rods – AWS or common name</b>
<b>AISI (UNS)</b>	<b>AWS A 5.4 (UNS)</b>	<b>AWS A 5.9 (UNS)</b>	<b>AISI (UNS)</b>	<b>AWS A 5.4 (UNS)</b>	<b>AWS A 5.9 (UNS)</b>
304 (S30400)	E 308 <sup>(1)</sup> (W30810)	ER 308 <sup>(1)</sup> (S30880)	20 MO-6 <sup>(2)</sup> (N08026)	(3)	(3)
304L (S30403)	E 308L (W30813)	ER 308L (S30883)	20Cb-3 <sup>(2)</sup> (N08020)	E 320LR (W88022)	ER 320LR (N08022)
309 (S30900)	E 309 <sup>(1)</sup> (W30910)	ER 309 <sup>(1)</sup> (S30980)	<b>Castings</b>		
310 (S31000)	E310 (W31010)	ER 310 (S31080)	<b>ACI type (UNS)</b>	<b>AWSA5.4 (UNS)</b>	<b>AWSA5.9 (UNS)</b>
316 (S31600)	E 316 <sup>(1)</sup> (W31610)	ER 316 <sup>(1)</sup> (S31680)	CF-8 (J92600)	E 308 <sup>(1)</sup> (W30810)	ER 308 <sup>(1)</sup> (S30880)
316L (S31603)	E 316L (W31613)	ER 316L (S31683)	CF-3 (J92500)	E 308L (W30813)	ER 308L (S30883)
317 (S31700)	E 317 <sup>(1)</sup> (W31710)	ER 317 <sup>(1)</sup> (S31780)	CF-8M (J92900)	E 316 <sup>(1)</sup> (W31610)	ER 316 <sup>(1)</sup> (S31680)
317L (S31703)	E 317L (W31713)	ER 317L (S31783)	CF-3M (J92800)	E 316L (W31613)	ER 316L (S31683)
317 LM (S31725)	(3)	(3)	CN-7M (J95150)	E 320 LR (W88022)	ER 320 LR (N08022)
321 (S32100)	E 347 (W34710)	ER 321 (S52180)	CK-3MCu (S32154)	(3)	(3)
347 (S34700)	E 347 (W34710)	ER 347 (S34780)	CA-6NM (J91540)	E 410 NiMo (W41016)	ER 410 NiMo (S41086)
Alloy 904L (N08904)	(3)	(3)	<b>Notes:</b>		
Alloy 254 SMO <sup>(2)</sup> (S31254)	(3)	(3)	(1) The "L" or low carbon grade or a stabilized grade is always used for welded fabrication except in a few instances where the slightly higher strength of the regular grades is more important than best corrosion resistance.		
AL-6XN <sup>(2)</sup> (N08367)	(3)	(3)	(2) Trade name.		
1925 hMo <sup>(2)</sup> (N08926)	(3)	(3)	(3) A filler metal with 9% or more molybdenum such as the two listed below is normally used to weld these stainless steels		
25-6 Mo <sup>(2)</sup> (N08926)	(3)	(3)	<b>Covered electrode AWS A5.11 (UNS)</b>	<b>Bare welding electrodes and rods AWS 5.14 (UNS)</b>	
			E NiCrMo-3 (W86112)	ER NiCrMo-3 (N06625)	
			E NiCrMo-4 (W80276)	Er NiCrMo-4 (N10276)	

the ferrite phase which is not a concern with the 300-series austenitic stainless steels. Wet electrodes should not be baked but discarded.

Moisture in the coating is not the only cause of weld metal porosity. Welding on painted, greasy or oily surfaces may lead to pores of the worm-hole type.

*Welding current* – Electrode manufacturers usually print on each package the recommended current ranges for each diameter. Since stainless steels have a higher electrical resistance than ordinary steels, the current ranges may be 25 to 50% of that used for steel electrodes. Excessive current overheats the electrode coating which in turn causes a loss of arc force and difficulty in directing the arc near the end of the electrode.

*Arc starting and stopping* – The same good operator techniques for arc starting and stopping used for low hydrogen carbon steel electrodes such as type E7018, are applicable to stainless steel welding.

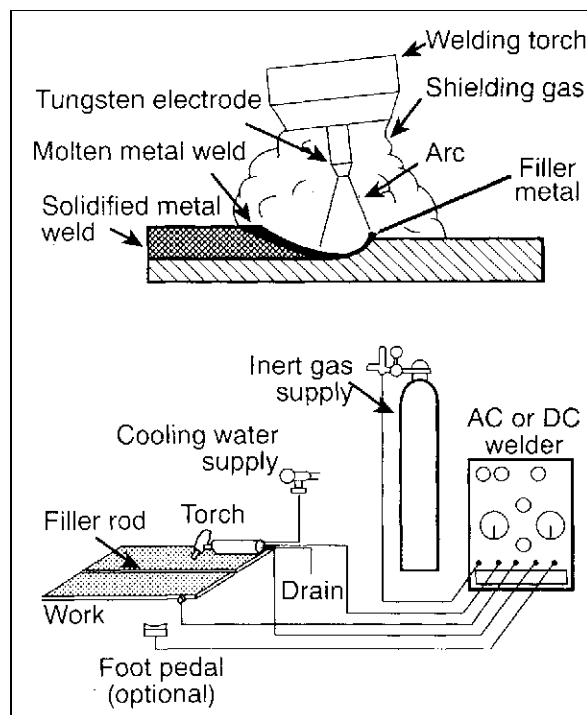
Some guides are:

- Strike the arc at some point in the joint so that the metal is remelted. An arc strike away from the weld may have cracks and unless removed, will result in lower corrosion resistance in that area;
- Do not abruptly extinguish the arc leaving a large weld crater. A depression will form as the metal solidifies, often with a slag-filled pipe or cracks in the center of the crater depression. One acceptable technique is to hold the arc over the weld pool for a few moments and then move quickly back, lifting the arc from the completed weld. Another technique is to extinguish the arc against one of the joint side walls after filling the crater;

- Avoid excessive weaving of the electrode. Acceptable weave limits vary with the particular electrode and some weave or oscillation is often necessary to obtain acceptable bead contour in a lime-type electrode. However, an excessive weave results in a high heat input that can cause hot cracking and increased deformation to the weldment. Weaving is usually limited to 2 to 2.5 times the core wire diameter.

## Gas tungsten arc welding

The GTAW process or TIG, tungsten inert gas, as it is frequently called, is widely used and is well suited for welding stainless steels. An inert gas (usually argon) is used to protect the molten weld metal and the tungsten electrode from the air. Filler metal in the form of bare wire is added as needed, either by manual or automatic feeding into the arc. The process is illustrated in *Figure 6*. GTAW can weld material as thin as a few mils to heavy gauges, but usually faster welding processes are used over 0.25 in. (6.4 mm).



**Figure 6** Gas tungsten arc welding.

## For the welder

Some of the advantages of this process for welding stainless steels include:

- no slag to remove which minimizes post weld cleanup;
- an all position welding process which is particularly useful in pipe welding;
- no weld spatter to clean;
- essentially no alloy loss during welding.

**GTAW equipment** – Direct current, electrode negative, DCEN, (straight polarity) current is standard. One option is the pulsed-current where there is a pulsating high rate of current rise and decay. This current mode is well suited to welding thin material and for joints which have poor fit-up. Pulsed-current is also useful in making the root pass of pipe joints. A high-frequency starting feature is commonly a part of the power source. This allows an arc to be initiated without a scratch start that may result in contamination of the tungsten electrode. Some power sources are provided with a feature that allows the electrode to be positioned on the work but power does not flow until the torch is lifted. An advantage over high frequency starting is that it eliminates possible interference to nearby components such as computers.

In addition to current controls at the power source, it is often useful to have a foot pedal current control. This control allows the welder to increase or decrease current during welding to adjust to conditions such as poor fit-up. A further advantage is at arc stops where slowly reducing the current and in turn the weld pool, effectively eliminates crater cracks.

Torches are either air or water cooled. The air-cooled variety is limited to lower currents than the water-cooled. The 2% thoriated tungsten electrodes are most commonly used because of their excellent emissive qualities, although other tungsten electrode types are acceptable. Opinions differ regarding electrode size for various amperages. Some favour using a different diameter for a number of

specific current ranges while others use a size such as .09 in. (2.4 mm) for a much wider current range. Also the electrode end preparation preferences vary but one commonly used is a 20 to 25° taper with the tip blunted to a 0.010 in. (0.25 mm) diameter.

Nozzle or gas cups come in a wide variety of shapes and sizes and it is often best to match the nozzle to the weld joint or application. Larger cup diameters provide better shielding gas protection to the weld while smaller nozzles help maintain a more stable arc and allow better visibility. An alternate is the gas lens which creates a laminar flow by special screens inside the nozzle. The flow of inert gas is projected a considerable distance beyond the end of the nozzle, giving both better gas protection and good visibility.

With any welding process using inert gas, it is important that all gas lines and connections be checked to ensure freedom from leaks in the system. If a leak is present, for example in a gas line, air will aspirate into the inert gas stream rather than the internal gas exiting as is sometimes believed.

**Consumables** – Pure argon, helium or mixtures of the two are used for shielding gas in welding stainless steels. The oxygen bearing argon mixtures used in GMAW should not be used in GTAW because of rapid deterioration of the tungsten electrode. Nitrogen additions are not recommended for the same reason. In manual welding and joining thicknesses below .06 in. (1.6 mm), argon is the preferred shielding gas. It provides good penetration at lower flow rates than helium and less chance of melt-through. Helium produces a higher heat input and deeper penetrating arc which may be an advantage in some automatic welding applications. Argon-helium mixtures may improve the bead contour and wetability.

The correct filler metals for GTAW stainless steels are shown in *Table IV*.

Straight lengths are commonly used for manual welding and spool or coil wire for automatic welding. Conventional quality control practices to assure clean wire and absence of material mix-up are essential. Bare wire for GTAW should be wiped clean before using and stored in a covered area.

**Operator technique guides** – Arc initiation is made easier by devices such as a high frequency start or a pilot arc. In the absence of these devices, a scratch start is used which risks contaminating the electrode and the metal being welded. Where practical, starting tabs adjacent to the weld joint are useful in eliminating damage to the base metal.

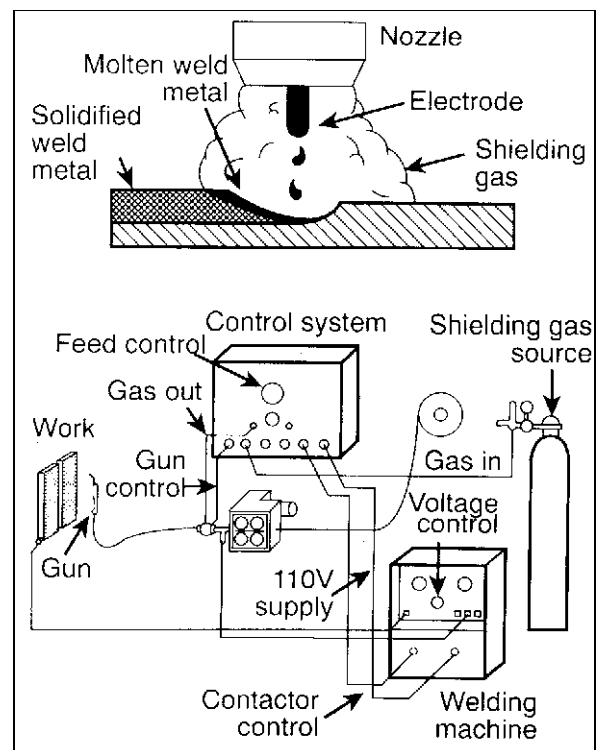
The welder must also be careful when extinguishing the arc. The size of the weld pool must be decreased, otherwise crater cracking is likely as the weld solidifies. In the absence of a foot pedal current control described earlier or a power source current decay system, the arc pool should be decreased in size by increasing the travel speed before lifting the electrode from the joint. Good arc stopping practice is particularly important in the root pass of welds that are welded from only one side, otherwise the cracks may extend completely through the root and are difficult to repair. After the arc is broken, the welder should hold the torch over the crater for several seconds to allow the weld to cool under protection of the argon atmosphere.

Stainless steels are easy to weld with the GTAW process. The alloys are relatively insensitive to marginal shielding compared to reactive metals such as titanium or zirconium. However, it is good practice to provide ample shielding protection to both the weld puddle and backside as well as keeping the filler metal within the inert gas envelope during welding.

If the process has a potential short-coming, it is that the weld may look good but have inadequate filler metal. In some weld joints, this practice can result in a

concave bead that has a tendency for centerline cracking. Adequate filler metal addition produces a slightly convex weld bead and in some alloys enhances the ferrite level, both of which improve cracking resistance.

In welds subject to severe corrosive environments, it is often necessary for the welds to be of higher alloy content than the base materials being joined to give comparable corrosion resistance. Alloy-enriched welds are possible only when ample filler metal additions are made. It is difficult to define just how much is ample and to measure it. A rough guide is that at least 50% of the weld metal should be from filler metal addition. However, it is also important that adequate filler metal mixing takes place before the weld solidifies, otherwise segregated spots of high and low alloy may exist. One cause of this type of segregation is from uneven melting of the filler metal along with fast solidification rates. An example of where this type of weld segregation could adversely affect service performance is a root weld of pipe used in a severe environment.



**Figure 7** Gas metal arc welding

## Gas metal arc welding

In the GMAW process (often referred to as MIG when an inert shielded gas is used or MAG when an active gas is used), an arc is established between a consumable, bare wire electrode and the work piece. The arc and deposited weld metal are protected from the atmosphere by a gas shield, comprised mainly of the inert gases, argon and/or helium. Small amounts of active gases such as carbon dioxide, oxygen and hydrogen are optional for better wetting and arc action. Some advantages of GMAW over GTAW and SMAW include:

- faster welding speeds;
- no slag to remove which minimizes post weld clean-up;
- ease of automation; and,
- good transfer of elements across the arc.

The basic components of the GMAW

process are shown in *Figure 7*.

**Arc transfer modes** – The type of metal transfer in GMAW has a profound influence on the process characteristics to the extent that it is often misleading to make general statements about GMAW without indicating the arc transfer mode. The three modes most used in welding stainless steels are spray, short circuiting and pulsed arc. *Table V* compares some parameter and usability differences in the three.

**GMAW equipment** – The same power sources, wire feed mechanisms and torches used for welding ordinary steels are used for stainless steels. Plastic liners in the wire feed conduit have been found helpful in reducing drag with stainless wire. The GMAW process has more welding parameters to control than GTAW and SMAW such as amperage, voltage, current slope,

**Table V**  
**Comparison of GMAW arc modes for stainless steels**

	<b>Spray arc welding</b>	<b>Short circuiting type transfer</b>	<b>Pulsed arc welding</b>
Typical thickness welded	0.125 in. (3 mm) min. 0.25 in. (6 mm) and thicker normal	0.06 in. (1.6 mm) and up	0.06 in. (1.6 mm) and up
Welding positions	Flat & horizontal	all	all
Relative deposition rate	highest	lowest	intermediate
Typical wire diameter	0.06 in. (1.16 mm)	0.030 or 0.035 in. (0.8 or 0.9 mm)	0.035 or 0.045 in. (0.9 or 1.2 mm)
Typical welding current	250-300 amps	50-225 amps	up to 250 amps peak
Shielding gas(1)	Argon - 1 % O <sub>2</sub> Argon - 2 % O <sub>2</sub>	90 % Helium 7.5 % Argon 2.5% CO <sub>2</sub> or 90 % Argon 7.5 % Helium 2.5%CO <sub>2</sub>	90 % Helium 7.5 % Argon 2.5 % CO <sub>2</sub> or 90 % Argon 7.5 % Helium 2.5%CO <sub>2</sub> or Argon -1 % O <sub>2</sub>

(1) Other gas mixtures are used, however, the shielding gas should contain at least 97.5 % inert gas, i.e., argon, helium or a mixture of the two.



wire feed, pulse rate and the arc transfer mode. Consequently the GMAW power sources are often more complex and expensive. Some of the newer power sources such as the synergic pulsed arc have made operation simpler by providing only one control dial for the operator, with other parameters adjusted automatically. The welding current used more than 95% of the time is DCEP (reversed polarity). This current gives deeper penetration than DCEN (straight polarity) and a stable arc. DCEN is limited to applications requiring shallow penetration such as overlay welding.

**Consumables** – Some of the more common shielding gases used in GMAW are shown in *Table V*. Spray arc shielding gas is usually argon with either 1 % or 2% oxygen. Short circuiting and pulsed arc welding use a greater variety of shielding gases. A popular mixture in North America is 90% helium, 7.5% argon and 2.5% CO<sub>2</sub> but in Europe, helium is quite expensive and 90% argon, 7.5% helium and 2.5% CO<sub>2</sub> is widely used. Whatever the combination, the shielding gas should contain at least 97.5% inert gases (argon, helium or a mixture of the two). Carbon dioxide should not exceed 2.5% or the weld quality and corrosion resistance may be reduced.

The preferred filler metals to be used in GMAW stainless steels are shown in *Table IV*. The most widely used diameters are 0.035 in. 0.045 in. and 0.062 in. (0.9 mm, 1.2 mm and 1.6 mm) but others are available.

## Other welding processes

Stainless steels can be welded by most of the commercial welding processes. These processes may offer advantages not obtainable in SMAW, GTAW and GMAW processes and should not be overlooked for high production or special fabrications. As an example, there have been recent

advances in flux cored arc products which produce quality welds at higher efficiency than SMAW. Cored wires are often easier to produce to special compositions or ferrite ranges than it is to melt large heats for solid wire.

Submerged arc welding, SAW, has been used extensively for welding thickness about 0.25 in. (6.4 mm) and thicker and for overlay welding. Commercial fluxes are available for use with standard filler metals used for GMAW. Plasma arc, electroslag, electron beam, laser and friction welding are used more and more and the resistance welding processes; spot, seam, projection and flash welding are readily adaptable to stainless steels.

Stainless steel may be joined to itself or a number of other metals by brazing. It is not usually used when the joint will be exposed to severe corrosive environments but there are instances in food and other process industries where brazing provides adequate properties.

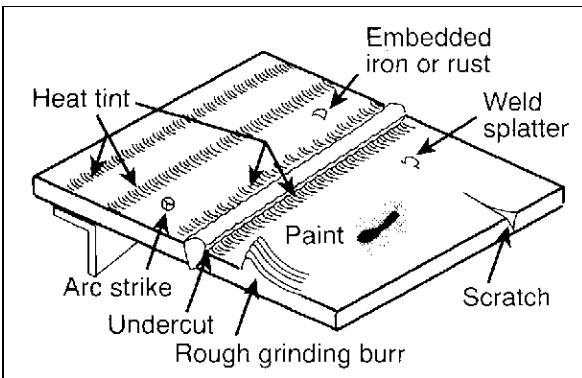
Oxyfuel welding, OFW, is not recommended for stainless steels. The chromium oxide formed on the surface makes oxyacetylene welding difficult. However, more important is the extreme care needed in welding to avoid reducing the corrosion resistance of the weld and weld area.

## Post-fabrication cleaning

All too often, it is assumed the fabrication, be it a tank, pressure vessel, pipe assembly etc., is ready for service after the final weld is made and inspected. Post-fabrication cleaning may be as important as any of the fabrication steps discussed above. The surface condition of stainless steels is critical, both where the product must not be contaminated, e.g., pharmaceutical, food and nuclear plants; and where the stainless must resist an aggressive environment such as in a chemical or other process industry plant. Surface conditions that

## For the welder

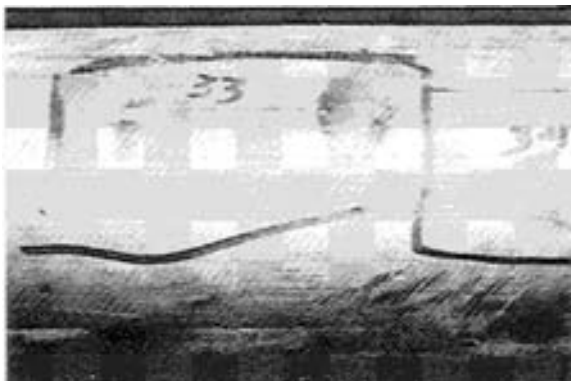
can reduce corrosion resistance may be grouped into four categories; surface contamination, embedded iron, mechanical damage or welding related defects. *Figure 8* illustrates some of the common conditions.



**Figure 8** Typical fabrication defects or surface conditions commonly encountered.

## Surface contaminants

In aggressive environments, organic contaminants on stainless steel surfaces can foster crevice corrosion. Such contaminants include grease, oil, crayon marks, paint, adhesive tape and other sticky deposits. *Figure 9* shows crevice corrosion pits (in the area marked 33) on a stainless steel vessel. The pits formed where crayon markings were not removed from the surface before the vessel was put in service. Surfaces to be pickled or acid treated



**Figure 9** Crevice corrosion occurred where crayon marks were made and not removed on a stainless steel vessel.

must be free of organic contaminants for the acid to be effective in removing free iron, surface oxides or similar conditions. Because little can be done during fabrication to reduce organic contamination, the fabricator must do this during the final cleanup.

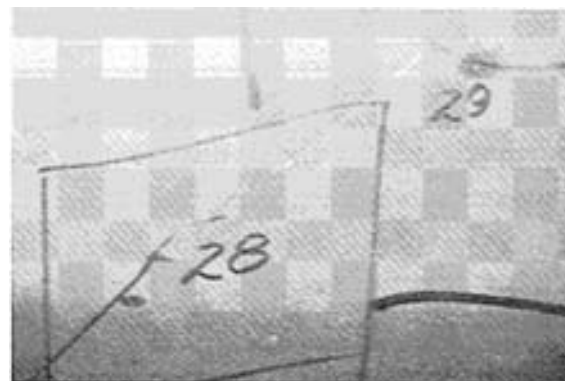
**Detection** – Visual inspection is usually used for organic contamination, while cloth or paper can be used for oil or grease detection.

**Removal** – Degreasing, using a nonchlorinated solvent, is effective. The water-break test is a simple way to judge the effectiveness of degreasing. A thin sheet of water (applied by a hose) directed on a vessel wall will break around oil, grease or similar surface contamination. Degreasing should be redone until the water stops breaking.

A chlorinated solvent is not recommended because residual chlorides may remain in crevices and cause crevice corrosion or chloride stress corrosion cracking later when the unit is placed in service.

## Embedded iron

Sometimes, new stainless-steel tanks or vessels rust shortly after delivery from a fabricator. This may be due to iron embedded in the surface during fabrication. The iron particles corrode in moist air or when wetted, leaving telltale



**Figure 10** A deep scratch made during fabrication served as an initiation site for corrosion in this vessel.

rust streaks. In addition to being unsightly as they corrode, the larger particles of embedded iron may initiate crevice corrosion in the underlying stainless steel. *Figure 10* shows corrosion at several points along a scratch where iron had been embedded. In corrosive service, crevice corrosion initiated by large embedded iron particles may lead to corrosion failure that would not otherwise occur. In the pharmaceutical, food, and other processing industries in which stainless is used primarily to prevent contamination of the product, embedded iron cannot be tolerated.

**Detecting embedded iron –** The simplest test for embedded free iron is to spray the surface with clean water and drain the excess. After 24 hours, the surface is inspected for rust streaks. This is a minimum test that any fabricating shop can conduct. To ensure against rust-streaked units, the water test should be specified in procurement documents.

A more sensitive indication of embedded iron is obtained by use of the ferroxyl test for free iron. The test solution is prepared by mixing the following ingredients:

Ingredient	%	Amount volume or weight
Distilled water	94	1,000 cm <sup>3</sup>
Nitric acid, 60-67%	3	30 cm <sup>3</sup>
Potassium ferrocyanide	3	30 g

The solution is best applied using a one-quart spray applicator, the type that applies bleach to laundry. Iron contamination is indicated by the appearance of a blue colour after a few minutes. The depth of colour roughly indicates the degree of contamination. The solution should be removed after a few minutes with a water spray or a damp cloth.

The ferroxyl test is not only sensitive but it can be performed in the field as easily as in the shop. Personnel can be

trained to administer it in only a few hours. This test is generally required for stainless steel equipment used in, for example, pharmaceutical, food and nuclear plants, as well as for equipment used to process chemicals. An excellent basic guide to these tests is ASTM A380, "Standard Recommended Practice for Cleaning and Descaling Stainless Steel Parts."

#### **Removing embedded iron –**

Pickling, which is carried out after degreasing, is the most effective method for removing embedded iron. In pickling, the surface layer, less than 0.001 in. (0.025 mm), is removed by corrosion, normally in a nitric/hydrofluoric acid bath at 120°F, (50°C). Pickling not only removes embedded iron and other metallic contamination, it leaves the surface bright and clean, and in its most resistant condition. Since pickling is controlled corrosion, low-carbon or stabilized grades of stainless are preferred. The process may initiate intergranular corrosion in the HAZ of regular unstabilized grades. Because pickling is aggressive, it will destroy a polished or high-luster surface.

Using nitric acid alone will remove superficial iron contamination but few, if any, of the larger, deeply embedded particles. Nitric acid treatment is referred to as passivation. This can be misleading, since the pickled surface is also passivated when it contacts air.

Small objects are best pickled by immersion. Piping, field-erected tanks and vessels too large to immerse can be treated by circulating the pickling solution through them. Typically, chemical-cleaning contractors are hired to do this.

When ferroxyl testing shows only spotty patches of iron, these can be removed by local application of nitric/hydrofluoric acid paste. For large tanks, filling to about 6 in. (150 mm)

to pickle the bottom, and locally removing embedded iron on side-walls is often a practical alternative to circulating pickling solution throughout them.

When pickling is not practical, blasting can be used, but not all abrasives yield good results. Glass-bead blasting produces good results but, before blasting, a test should be made to determine that it will remove the surface contamination. Also, periodic tests should be made to see how much reuse of beads can be tolerated before they begin to recontaminate the surface. Walnut shells have also performed well as an abrasive.

Abrasive blasting with steel shot or grit is generally unsatisfactory because of the possibility of embedding iron particles. Also, grit blasting leaves a rough profile that makes the stainless steel susceptible to crevice corrosion, whether or not the surface is free of iron. Sand blasting should also be avoided if possible, because even new sand is seldom free of iron particles or other contaminants.

### **Mechanical damage**

When the surface has been damaged and reconditioning is needed, the repair is usually made by grinding or by welding and grinding. Shallow defects are first removed by grinding, preferably with a clean fine grit abrasive disk, a flapper wheel or a pencil type grinder. The maximum grinding depth to remove defects is often specified by the fabrication specification and may vary from 10% to 25% of the total thickness.

When weld repair is needed, it can be made by SMAW, GMAW or GTAW.

GTAW is usually used because of greater ease in making small repair welds. Filler metal should always be added and wash passes or cosmetic welds never allowed because of the risk of weld cracking and reduced corrosion resistance.

### **Safety and welding fumes**

Safety rules for welding stainless steels are essentially the same as for all metals as they pertain to areas such as electrical equipment, gas equipment, eye and face protection, fire protection, labeling hazardous materials and similar items. A good reference guide on welding safety is American National Standard Institute / Accredited Standards Committee, ANSI/ASC, Z49.1-88, "Safety in Welding and Cutting," published by the American Welding Society.

Proper ventilation to minimize the welders' exposure to fumes is important in welding and cutting all metals, including stainless steels. In addition to good ventilation, the welders and cutters should try to avoid breathing the fume plume directly, by positioning the work so that their head is away from the plume. The composition of welding fumes varies with the welding filler metal and welding process. Arc processes also produce gaseous products such as ozone and oxides of nitrogen. Concern has been expressed in welding with stainless steel and high alloy steel consumables because of the chromium and, to a lesser extent, the nickel usually present in the welding fume. Good ventilation will minimize the potential health risk. The International Institute of Welding has developed a series of "Fume information sheets for welders" which offer internationally accepted suggested guidelines for fume control.

# Part II

## For the materials engineer

This section is for the engineer who needs further information about the wrought and cast stainless steel alloys, how their corrosion resistance is affected by welding and typical heat treating practices. Also included are guides for material procurement and good storage practices.

### Stainless steel alloys

Steel is made corrosion resistant by the addition of 11 % or more chromium. The term stainless describes the non-rusting, bright appearance of these alloys. The earliest types of stainless steel were the straight chromium grades with chromium ranging from over 10% to about 18%, but through the years a number of different types of stainless steel alloys have been developed and categorized into five groups, namely:

- martensitic (AISI\* 400-series)
- ferritic (AISI\* 400-series)
- austenitic (AISI\* 300-series)
- precipitation hardening
- duplex

*\*American Iron and Steel Institute*

The austenitic stainless steels are the most widely used but the use of duplex alloys is increasing, although they still represent a small part of the stainless steels used. This publication describes these two alloy families and their use. The other three groups, martensitic, ferritic and precipitation hardening are also identified as stainless steels but the fabrication and welding is often quite different from the austenitic and duplex grades. When discussing welding and fabrication techniques, the particular stainless steel group must be identified, otherwise serious mistakes could be made. For example, using a procedure

developed for an austenitic stainless steel to weld a martensitic stainless steel could result in low quality welds.

### Austenitic stainless steels

Austenitic stainless steels are non-magnetic or only slightly magnetic in the annealed state and can be hardened only by cold working. They possess excellent cryogenic (low temperature) properties and good strength at high temperatures. Corrosion resistance is outstanding in a wide range of environments. They exhibit good weldability and are easy to fabricate provided suitable procedures are maintained.

The composition of common grades of wrought stainless steels and corrosion-resistant stainless steel castings is shown in *Tables VI and VII*. It includes alloys commercially available worldwide and those most frequently used for corrosion resistant applications. The UNS numbers in *Table VI* have either an S or N prefix. Stainless steels are defined by ASTM as having at least 50% iron which UNS identifies with a S number. Alloys with a N number are classified as nickel alloys, but the distinction is purely artificial. The fabricability of the high alloy S grades and the nickel alloys in *Table VI* is essentially the same.

### Effect of welding on corrosion resistance

Austenitic stainless steels are usually specified for their excellent corrosion resistance. Welding can reduce base metal corrosion resistance in aggressive environments. In welding, heat is generated that produces a temperature gradient in the base metal, i.e. the HAZ.

**Table VI**  
**Wrought austenitic stainless steels chemical analysis, %, of major elements**

(Max. except as noted)

AISI Type or common name (UNS)	C	Cr	Ni	Mo	Other
304 (S30400)	0.08	18.0-20.0	8.0-10.5	-	0.10N
304 L (S30403)	0.03	18.0-20.0	8.0-12.0	-	0.10N
309 (S30900)	0.20	22.0-24.0	12.0-15.0	-	-
310 (S31000)	0.25	24.0-26.0	19.0-22.0	-	-
316 (S31600)	0.08	16.0-18.0	10.0-14.0	2.0-3.0	0.10N
316L (S31603)	0.03	16.0-18.0	10.0-14.0	2.0-3.0	0.10N
317 (S31700)	0.08	18.0-20.0	11.0-15.0	3.0-4.0	0.10N
317L (S31703)	0.03	18.0-20.0	11.0-15.0	3.0-4.0	0.10N
317 LM (S31725)	0.03	18.0-20.0	13.0-17.0	4.0-5.0	0.10N
321 (S32100)	0.08	17.0-19.0	9.0-12.0	-	5 x %C min, 0.70 max. Ti
347 (S34700)	0.08	17.0-19.0	9.0-13.0	-	10 x %C min, 1.10 max. (Nb + Ta)
Alloy 904L (N08904)	0.02	19.0-23.0	23.0-28.0	4.0-5.0	1.0-2.0 Cu
Alloy 254 SMO* (S31254)	0.02	19.5-20.5	17.5-18.5	6.0-6.5	0.18-0.22N 0.50-1.00 Cu
AL-6XN* (N08367)	0.03	20.0-22.0	23.5-25.5	6.0-7.0	0.18-0.25N 0.75 Cu
1925 h Mo* (N08926)	0.02	20.0-21.0	24.5-25.5	6.0-6.8	0.18-0.20N 0.8-1.0 Cu
20 Mo-6* (N08026)	0.03	22.0-26.0	33.0-37.0	5.0-6.7	2.0-4.0 Cu
20Cb-3* (N08020)	0.07	19.0-21.0	32.0-38.0	2.0-3.0	3.0-4.0 Cu 8 x C min, 1.00 %max.
25-6 MO* (N08926)	0.02	19.0-21.0	24.0-26.0	6.0-7.0	0.15-0.25N 0.5-1.5 Cu

\* 254 SMO is a trademark of Avesta AB  
AL-6XN is a trademark of Allegheny Ludlum Steel Corporation  
1925 hMo is a trademark of VDM Nickel Technologie A.G.  
20 Mo-6 and 20 Cb-3 are trademarks of Carpenter Technology Corp.  
25-6 MO is a trademark of Inco Alloys International, Inc.

**Table VII**  
**Corrosion resistant stainless steel castings chemical analysis, %, of major elements**  
 (Max. except as noted)

ACI Type (UNS)	Similar wrought type	C	Cr	Ni	Mo	Others	Most common structure	Anneal at °F (°C)
CF-8 (J92600)	304	0.08	18.0-21.0	8.0-11.0	-	-	Ferrite in austenite	1900-2050 (1035-1120)
CF-3 (J92500)	304L	0.03	17.0-21.0	8.0-11.0	-	-		1900-2050 (1035-1120)
CF-8M (J92900)	316	0.08	18.0-21.0	9.0-12.0	2.0-3.0	-		1900-2050 (1035-1120)
CF-3M (J92800)	316L	0.03	17.0-21.0	9.0-13.0	2.0-3.0	-		1950-2050 (1065-1120)
CN-7M (N08007)	20Cb-3 (1)	0.07	19.0-22.0	27.5-30.5	2.0-3.0	3.0-4.0Cu	Austenite	2050 (1120) Min.
CK-3M Cu (J93254)	Alloy254SMO(2)	0.02	19.5-20.5	17.5-18.5	6.0-6.5	0.18-0.22N 0.50-1.00 Cu	Austenite	2100-2200 (1150-1205)
CA-6NM (J91540)		0.06	11.5-14.0	3.5-4.5	0.4-1.0	-	Martensite	1900-1950 (1035-1065) followed by double temper
CD-7MCuN	FERRALIUM (3) 255	0.04	24.0-27.0	4.5-6.5	2.0-4.0	0.10-0.25N 1.5-2.5 Cu	Duplex-austenite & ferrite	1925 (1050) Min.
CD-3MN ASTM-A-890, Gr4A (J92205)	2205	0.03	21.0-23.5	4.5-6.5	2.5-3.5	0.10-0.30N	Duplex-austenite & ferrite	2050 (1120) Min.
Zeron 100 (4) (J93380)	Zeron 100 (4)	0.03	24.0-26.0	6.0-8.5	3.0-4.0	0.2-0.3N	Duplex-austenite & ferrite	2050 (1120) Min.

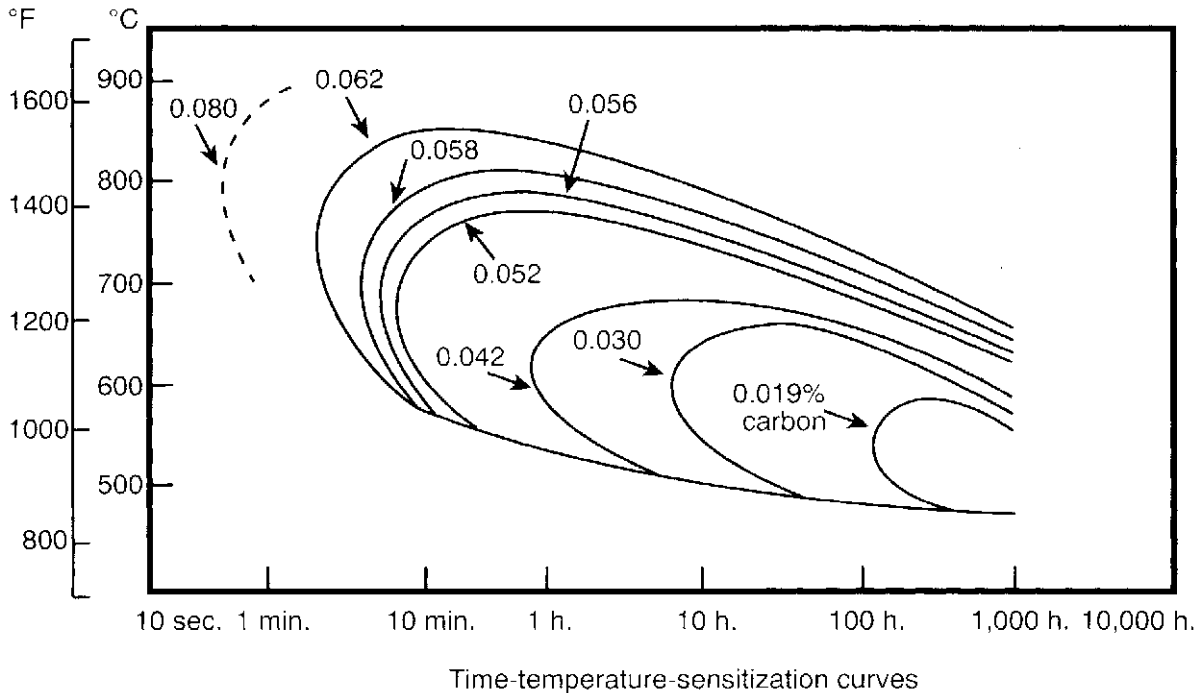
(1) 20Cb-3 is a tradename of Carpenter Technology Corporation  
 (2) 254SMO is a trademark of Avesta AB

(3) FERRALIUM is a trademark of Langley Alloys, Ltd  
 (4) Zeron 100 is a trademark of Weir Material Services, Ltd.

Welding may also induce residual stresses in the weld area which in certain environments can lead to SCC. Heat treatments to reduce residual stresses are discussed in the section Heat Treatment of Austenitic Stainless Steels.

One of the early corrosion problems related to welding was intergranular

attack, IGA, in the weld HAZ. In the temperature range of about 800°F to 1650°F (425°C to 900°C), carbon combines with chromium to form chromium carbides at the grain boundaries. The area adjacent to the carbides is depleted in chromium. When the carbide network is continuous, the low chromium envelope around grains may



**Figure 11** Effect of carbon control on carbide precipitation in Type 304.

be selectively attacked, resulting in intergranular corrosion. In the worst case, the depleted chromium layer is corroded away and complete grains are separated from the base metal and can even fall out. Alloys are said to be sensitized when welding or heat treatment results in chromium depleted areas that will be attacked in these corrosive environments. Sensitized alloys may still provide good service in many of the milder environments in which stainless steels are used. Today, with the trend of mills to furnish lower carbon products, IGA of austenitic stainless steels occurs less often.

The degree of sensitization, i.e., the amount of grain boundary chromium carbides formed, is influenced by the amount of carbon, exposure temperature and time at this temperature. *Figure 11* illustrates the time-temperature-sensitization curves for Type 304 stainless steel. Curves of other austenitic stainlesses would be similar but the actual values would be somewhat different. To explain *Figure 11*, the alloy is sensitized, that is a network of

chromium carbides have formed at the grain boundaries, when the time at temperature for any particular carbon content Type 304 is to the right of the % carbon curve. It can be seen that the temperature where sensitization occurs most rapidly varies from 1300°F (700°C), with an alloy of 0.062% carbon, to 1100°F (600°C), for a 0.03% carbon alloy. From *Figure 11*, an alloy with 0.062% carbon could become sensitized in as little time as 2 to 3 minutes at 1300°F (700°C). On the other hand, 304L with 0.030% carbon could be held at 1100°F (595°C) for 8 hours before being sensitized. For this reason the low carbon "L" grades are most commonly used for corrosion resistant equipment where IGA is a possibility. With the "L" grade, the weld HAZ is not at temperature long enough to become sensitized.

Grain boundary chromium carbides can be prevented from forming when titanium or niobium-tantalum are present in the alloy. (Niobium, Nb, is also known by the name columbium, Cb, in some references). These ele-



ments have a greater affinity for carbon than chromium and form evenly distributed carbides away from the grain boundaries, where there is no adverse affect on the corrosion resistance. Type 321 (UNS S32100) contains titanium and 347 (UNS S34700) contains niobium-tantalum. Both are stabilized versions of type 304. The stabilized grades are usually preferred where there will be long time service in the sensitizing temperature range of 800°F to 1650°F (425°C to 900°C).

A third method of preventing IGA in the weld HAZ in alloys containing over 0.03% carbon is to redissolve the chromium carbides by a solution anneal at 1900°F to 2150°F (1040°C to 1175°C), followed by rapid cooling. The solution anneal is a good method to restore full corrosion resistance when the shape, size and geometry of the weldment allows the heat treatment. Solution annealing must be closely controlled in both heating and cooling to minimize distortion within acceptable limits.

## Role of weld metal ferrite

Microfissures or cracks have been known to occur in austenitic stainless steel welds. They can appear in the weld metal during or immediately after welding, or they may occur in the HAZ of previously deposited weld metal. The microstructure of the weld metal strongly influences susceptibility to microfissuring. A fully austenitic weld is more prone to microfissuring than a weld with some ferrite.

Ferrite levels of 5% to 10% or more in welds or castings can be quite beneficial in reducing hot cracking and microfissuring. For example, a Type 308 (UNS W30840) weld with zero to 2% ferrite might be quite crack sensitive while another 308 weld with 5% to 8% ferrite would have good crack resistance. The amount of ferrite in a 300-series weld is controlled by the composition and the weld cooling rate, the faster the

cooling, the higher the ferrite content.

Unfortunately, ferrite is not obtainable in all nickel stainless steel alloys. For example, it is not possible to adjust the composition to obtain ferrite in Type 310 (UNS S31000). In spite of being fully austenitic and prone to fissures, the alloy has been used over 50 years with excellent service. In the absence of weld metal ferrite, it is more important for the filler metal manufacturer to control minor elements such as silicon, phosphorus and sulphur to as low a level as possible to prevent cracking.

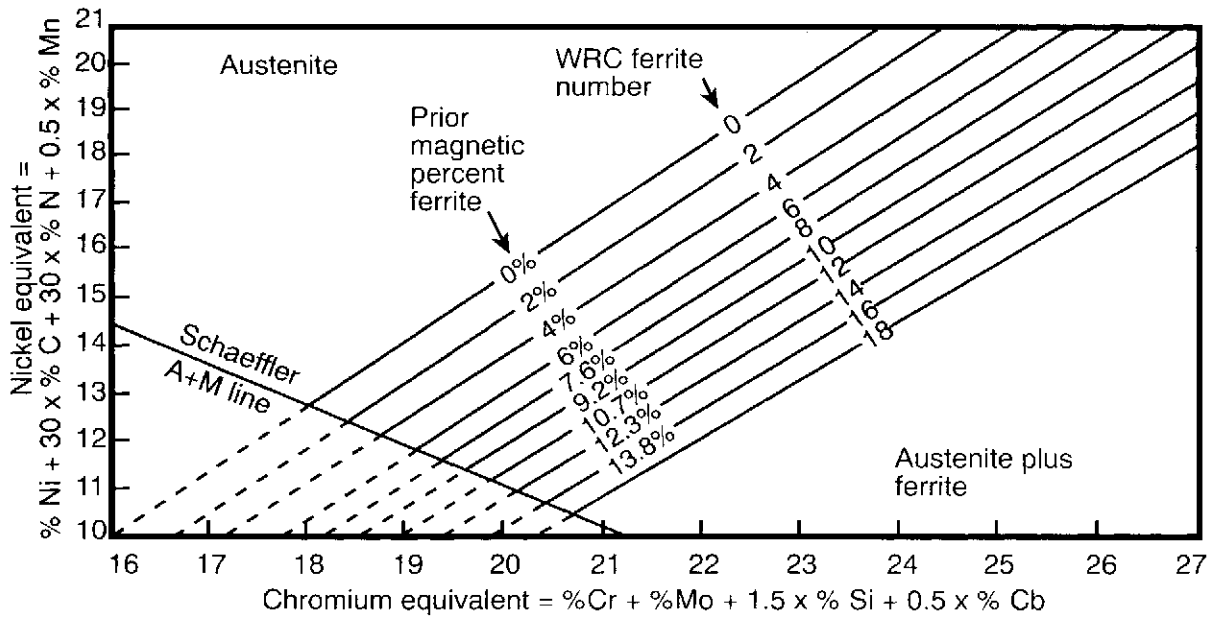
When a filler metal is required with a specific ferrite level, the purchaser or user should specify the level to the supplier. Stainless steel filler metal specifications, ANSI/AWS A5.4 for electrodes and ANSI/AWS A5.9 for bare wire do not specify ferrite levels for any of the alloy classes.

### Measuring weld metal ferrite –

While there is wide agreement on the beneficial affect of ferrite in the weld, it is not always easy to measure the amount accurately in a given weld deposit. One of the three following methods can be used.

1. Magnetic instruments can measure ferrite on a relative scale and this is the method most used by filler metal producers. Calibration of the instruments is very critical and AWS has developed a special calibration procedure. AWS also details how the weld pad is to be made and prepared for testing, since this can influence the measurement. Ferrite determination using sophisticated laboratory magnetic instruments is often not practical for the average user. Portable magnetic instruments are commercially available that, even though they may be less accurate, are easier for the fabricator to use.

2. Using the weld chemical composition, ferrite content can be estimated from a constitution diagram for stainless



**Figure 12** Revised constitution diagram for stainless steel weld metal. (from *Metals Handbook, Volume 6, Ninth Edition*)

steel weld metal, *Figure 12*. Earlier, ferrite diagrams represented ferrite in units of volume-%. The most recent Welding Research Council, WRC, diagram determines ferrite number, FN, by the magnetic response. The FN and volume-% are the same up to 6% but differ at higher levels. Ferrite determination using the diagram is easy and quite accurate, provided a reliable chemical analysis has been made.

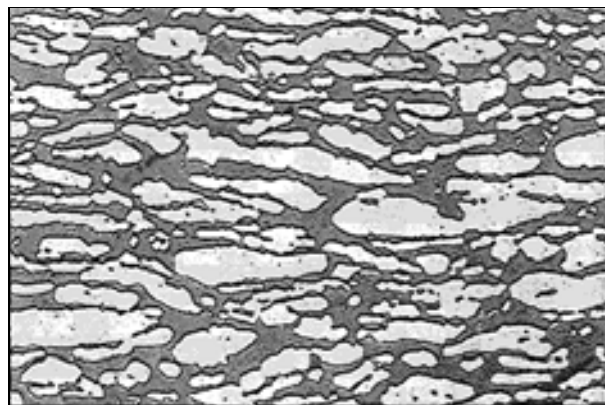
3. The ferrite content can be estimated by metallographic examination. It is most accurate when ferrite is in the range of 4% to 10% and should be performed by an experienced technician. One advantage to this method is that it can be used on small specimens removed from weldments or where the two other methods are not practical.

There are services where ferrite in the weld structure is not a benefit. At cryogenic temperatures, viz., -320°F (-195°C), toughness and impact strength are reduced by ferrite and it is common practice to specify welds with no more than 2 FN and preferably 0 FN. It is also desirable to have low ferrite when the welds are exposed to service

temperatures 900°F to 1700°F (480°C to 925°C) to avoid a loss of room temperature ductility as a result of a high temperature sigma phase. Sigma forms more readily from ferrite than from austenite and is discussed in the duplex stainless steel section.

### Duplex stainless steels

Duplex stainless steels are an alloy family that have two phases – ferrite and austenite – with ferrite typically



**Figure 13** Typical microstructure of cold rolled, quench annealed Alloy 2205 seamless tube. Dark phase – ferrite, light phase – austenite. (from *Sandvik AB*)

between 40% and 60%. The ferrite/austenite ratio is accomplished in wrought alloys by composition adjustment along with controlled hot working and annealing practices at the mill. The alloys could properly be called ferritic-austenitic stainless steels but the term "duplex" is more widely used. A typical duplex stainless steel microstructure is shown in *Figure 13*. The matrix which appears as the darker background is ferrite and the elongated, island-like lighter phase is austenite.

Duplex alloys date to the 1930s and the early alloys are now identified as first-generation. Unfortunately, the early alloys had a problem of significant loss of corrosion resistance in the as-welded condition and it has taken some time for the new second-generation alloys to overcome this reputation. All the alloys shown in *Table VIII* are second-generation alloys and typically contain 0.15% to 0.30% nitrogen. One benefit of nitrogen

is improved pitting and crevice corrosion resistance. With proper welding procedures, as-welded second-generation duplex stainless steels can have nearly the same level of corrosion resistance as mill annealed material. Nitrogen is also beneficial in the manufacture of second-generation alloy plates, where the ductile-brittle transition is depressed well below room temperature, making heavy section weldments practical. However, duplex alloys are generally not used below about -50°F (-45°C) whereas some fully austenitic alloys may be used to -456°F (-270°C).

Alloy 2205 (UNS S31803) is the most widely used duplex alloy and is available from a number of producers. Comparing the duplex composition to a fully austenitic stainless steel such as Type 316, 2205 is higher in chromium, lower in nickel and contains nitrogen. The nitrogen addition is very critical in duplex alloys as will be discussed shortly.

**Table VIII**  
**Duplex stainless steels chemical analysis, %, of major elements**

Common name	(Max. except as noted)				
	C	Cr	Ni	Mo	Others
<b>(UNS)</b> 7-Mo PLUS <sup>(1)</sup> (S32950)	0.03	26.0-29.0	3.5-5.2	1.0-2.5	0.10-0.35N
Alloy 2205 (S31803)	0.03	21.0-23.0	4.5-6.5	2.5-3.5	0.08-0.20N
FERRALIUM 255 <sup>(2)</sup> (S32550)	0.03	24.0-27.0	4.5-6.5	2.0-4.0	0.10-0.25N 1.5-2.5Cu
SAF 2507 <sup>(3)</sup> (S32750)	0.03	24.0-26.0	6.0-8.0	3.0-5.0	0.24-0.32N
Zeron 100 <sup>(4)</sup> (S32760)	0.03	24.0-26.0	6.0-8.0	3.0-4.0	0.5-1.0 Cu 0.5-1.0 W 0.2-0.3 N

(1) 7-Mo PLUS is a trademark of Carpenter Technology Corporation  
(2) FERRALIUM is a trademark of Langley Alloys, Ltd.  
(3) SAF 2507 is a trademark of Sandvik AB  
(4) Zeron 100 is a trademark of Weir Material Services, Ltd.

## Characteristics of duplex stainless steels

The duplex alloys offer two important advantages over austenitic alloys such as 304L and 316L, namely greater resistance to chloride stress corrosion cracking, CSCC, and higher mechanical properties. The yield strength of duplex alloys is typically two to three times higher and the tensile strength 25% higher while still maintaining good ductility at normal operating temperatures.

The susceptibility of austenitic stainless steels to CSCC at temperatures above about 140°F (60°C) is a well known concern. The ferritic stainless steels are highly resistant but are more difficult to fabricate and weld. The duplex alloys have intermediate resistance to CSCC which, in many environments, represents a substantial improvement over the austenitics. The duplex alloys also offer:

- general and pitting corrosion resistance equal to or better than type 316L stainless steel in many environments;
- resistance to intergranular corrosion due to the low carbon content;
- good resistance to erosion and abrasion; and,
- a thermal expansion coefficient close to that of carbon steel which can result in lower stresses in weldments involving duplex stainless and carbon steel.

There are metallurgical differences compared to the austenitic alloys that when known and recognized are easily handled. The differences occur as a result of high temperature exposure.

### High temperature exposure –

Duplex stainless steels are normally used in the temperature range of about -50°F to 500°F (-45°C to 260°C). In

producing or fabricating the alloys, a high temperature solution anneal at 1900°F (1040°C) or higher, depending on the alloy, followed by rapid cooling is employed to give optimum mechanical properties and corrosion resistance. In exposure to the temperature range of 600°F to 1750°F (315°C to 950°C) the duplex alloys act differently than the austenitics but once the differences are recognized, no problems should arise.

An intermetallic phase called sigma can form when duplex alloys are held in the 1200°F to 1750°F (650°C to 950°C) temperature range. Sigma causes room temperature embrittlement and, when present in appreciable amounts, corrosion resistance is lowered. However, attention to minimum time in the sigma forming range during annealing and welding, improved processing control at the steel mill and the beneficial effect of nitrogen can essentially eliminate any sigma problem. In normal second-generation duplex welding procedures, the weld or HAZ is not at temperature long enough for sigma to be a factor. Another high temperature occurrence is a phenomenon called 885°F (475°C) embrittlement. It can occur when a duplex alloy (or any iron-chromium alloy containing 13% to 90% Cr) is held within or slowly cooled through the temperature range of 600°F to 1000°F (315°C to 540°C). With the second-generation duplex alloy and using standard annealing and welding practices, the weld or HAZ is not at temperature long enough for this embrittlement to occur. It is mentioned here as a precaution should there be need to deviate from standard procedures.

## Effect of welding on duplex stainless steels

The weldability of second-generation duplex alloys has been greatly improved through controlled nitrogen additions and the development of nickel-enriched filler metals. Using a few welding procedure controls, sound welds with

corrosion resistance comparable to the base metal are obtained. The importance of controls on heat input, interpass temperature, preheat and nickel-enriched filler metal are as follows:

**Nickel-enriched filler metal** – Duplex stainless steel welds made with matching composition filler metal or autogenously welded (no filler metal) may exhibit 80% or more ferrite in the fusion zone in the as-welded condition. A weld with such a high ferrite level has poor toughness and ductility and often will not pass a bend test. The higher ferrite content of such welds also markedly reduces corrosion resistance in many aggressive environments. An anneal at 1900°F to 2100°F (1040°C to 1150°C) restores the desired ferrite/austenite balance but the treatment is not practical for many fabrications and is expensive. Increasing the nickel content of the filler metal allows more austenite to form so that welds in the as-welded condition have typically 30% to 60% ferrite. Welds made with nickel-enriched filler metals have good as-welded ductility, are able to pass bend tests, and have corrosion resistance comparable to the base metal.

It is desirable that all weld passes be made with substantial filler metal addition to provide a nickel enhanced weld metal composition. A large amount of base metal dilution can result in welds having a high ferrite content with lower ductility and toughness. An example of where this can occur is the root pass of a pipe weld with high base metal dilution. Special care should be taken to add sufficient nickel-enriched filler metal. Joints with a feather edge and tight fit-ups favor high dilution and are best avoided. Joints with an open root spacing and a land are preferred since they require the addition of filler metal.

Nickel-enriched filler metal products for the duplex alloys are available as covered electrodes, bare filler metal and flux cored wire as shown in *Table IX*. Duplex filler metals are not covered by

current AWS stainless steel filler metal specifications but will be included in future editions.

**Heat input control** – There is not complete agreement on the part of producers and welding investigators as to the proper limits on heat input. The argument for high heat input (see formula) is that it allows more time for ferrite to transform to austenite, particularly in the heat affected zone. The concern for high heat input is that it could allow embrittling phases, such as sigma and 885°F (475°C) embrittlement to develop in the ferrite: With the second-generation duplex stainless steels, longer time at temperature is needed for these phases to develop, so there should be no significant embrittlement. A generally accepted heat input range in kilo joules (kJ) is 15 to 65 kJ/in. (0.6 to 2.6 kJ/mm) although levels as high as 152 kJ/in. (6.0 kJ/mm) are claimed to have been successfully used. When a welding process with less than 15 kJ/in. (0.6 kJ/mm) heat input must be used, preheating to 200°F-400°F (95°C - 205°C) is helpful in reducing the cooling rate and increasing austenite in the weld. Where there is a question on heat input for a particular duplex alloy, it is a good practice to contact the material supplier for specific recommendations.

Heat input in kJ/in. is calculated:

$$\text{Voltage} \times \text{Amperage} \times 60$$

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$$\text{Travel speed (inch/minute)} \times 1000$$

**Interpass temperature control** – An early concern was that a high interpass temperature could result in 885°F (475°C) embrittlement and a limit of 300°F (150°C) maximum interpass temperature was suggested. This limit is conservative and in some instances a maximum limit of 450°F (230°C) could be acceptable. However, in the interest of consistency, fabricators often specify

**Table IX**  
**Duplex stainless steel filler metals**  
**typical composition**

Filler metal common name (UNS)	For welding base metal	C	Cr	Ni	Mo	Others
<b>Covered electrodes</b>						
2209-16 <sup>(1)</sup> (W39209) tentative	2205 (S31803)	0.03	23	9.7	3.0	0.10N
22.9.3.L-16 <sup>(2)</sup> 22.9.3.L-15 <sup>(2)</sup> 22.9.3.LR <sup>(2)</sup>	3RE60 (S31500) 2205 (S31803) 2304(S32304)	0.03	22	9.5	3	0.15N
7-Mo PLUS Enriched Ni <sup>(3)</sup>	7-MO PLUS (S32950)	0.03	26.5	9.5	1.5	0.20N
FERRALIUM 255 <sup>(4)</sup> (W39553) tentative	FERRALIUM 255 (S32550)	0.03	25	7.5	3.1	0.20N 2.0 Cu
<b>Bare filler wire</b>						
22.8.3L <sup>(2)</sup>	3 RE60 (S31500) 2205(S31803) 2304(S32304)	0.01	22.5	8	3	0.10N
7-Mo PLUS Enriched Ni <sup>(3)</sup>	7-Mo Plus (S32950)	0.02	26.5	8.5	1.5	0.20N
FERRALIUM 255 <sup>(4)</sup> (S39553) Tentative	FERRALIUM 255 (S32550)	0.03	25	5.8	3.0	0.17N
Zeron 100 filler wire <sup>(5)</sup>	Zeron 100 (S32760)	0.03	25	10*	3.5	0.25N 0.7 Cu 0.7 W
<b>Flux Cored Wire</b>						
In-Flux 2209-0 <sup>(1)</sup> (W31831)	2205 (S31803)	0.02	22.0	8.5	3.3	0.14N
In-Flux 259-0 <sup>(1)</sup>	FERRALIUM 255 (S32550)	0.02	25	10	3.2	0.14N 2.0 Cu

<sup>(1)</sup> 2209-16, In-Flux 2205-0 and In-Flux 259-0 are trademarks of Teledyne McKay

<sup>(2)</sup> 22.9.3L-16, 22.9.3L-15, 22.9.3.LR and 22.8.3L are trademarks of Sandvik AB

<sup>(3)</sup> 7-Mo PLUS is a trademark of Carpenter Technology Corporation

<sup>(4)</sup> FERRALIUM is a trademark of Langley Alloys, Ltd.

<sup>(5)</sup> Zeron 100 is a trademark of Weir Material Services, Ltd.

\* When the joint is fully heat treated after welding, Ni should be 6.0-8.0%

the same value used for austenitic stainless steel, 300°F to 350°F (150°C to 175°C).

**Preheat** – There is no need for preheat on thicknesses 0.25 in. (6 mm) and less on welds made with nickel-enriched filler metals. In heavier sections and high restraint welds, preheat may be used to advantage in minimizing the chance of weld cracking. When a

low heat input welding process, below 15 kJ/in. (0.6 kJ/mm), must be used, a preheat of 200°F-400°F (95°C-205°C) reduces rapid cooling and decreases the amount of ferrite in the weld metal and HAZ.

## Other stainless steels

Other types of stainless steels are martensitic, ferritic and precipitation

three types follows and illustrates some of the basic differences from the austenitic alloys. Some of the more common alloys and their welding filler metals are shown in *Table X*.

**Table X**  
**Suggested filler metals for welding some of the martensitic, ferritic and precipitation hardening stainless steels**

Base metal	Covered welding electrode	Bare welding electrodes and rods
AISI (UNS)	AWS A5.4 (UNS)	AWS A5.9 (UNS)
Type 410 (wrought) (S41000)	E410 (W41010)	ER410 (W41040)
CA-15 (casting) (J91540)	E410 (W41010)	ER410 (W41040)
CA-6NM (casting) (J91540)	E410NiMo (W41016)	ER410NiMo (W41046)
Type 430 (wrought) (S43000)	E430 (W43010)	ER430 (W43040)
17-4PH (S17400)	E630 <sup>(1)</sup> (W37410)	ER630 <sup>(1)</sup> (W37440)

<sup>(1)</sup> When weld does not need to match bare metal strength, E 308 (UNS W30810) or ER 308 (UNS W30840) are often used.

### Martensitic stainless steels

The martensitic alloys can be hardened and strengthened by heat treatment and only slightly hardened by cold working. They are strongly magnetic, resist corrosion in mild environments and have fairly good fabricating qualities. The alloys are often selected because of high mechanical properties and low cost.

Weldability of the martensitic stainlesses varies with alloy content, particularly the amount of carbon. The higher the carbon content, the greater the need for preheat and postweld heat treatment to produce sound welds.

While the wrought martensitic stainless steels have limited use in process industries, the cast grades have been

extensively used for heavy components such as pump bowls, valve bodies and compressor cases. CA-15 (UNS J91150) was the standard alloy but has been largely replaced by CA-6NM (UNS J91540). Compared to CA-15, CA-6NM has improved toughness and weldability, along with better resistance to cavitation.

It is preferable to weld CA-6NM castings in the heat treated condition rather than the as-cast. Welding is usually done at room temperature although a preheat of 250°F to 300°F (120°C to 150°C) may be beneficial for large welds in heavy or highly stressed sections. After welding, the casting is heated to not higher than 1100°F to 1150°F (590°C to 620°C) and air-cooled. When there is a special hardness requirement, CA-6NM may be given a normalizing heat treatment above 1750°F (950°C) and air cooled, followed by a double temper of 1100°F to 1150°F (590°C to 620°C). The casting should be cooled to room temperature between each tempering treatment.

### Ferritic stainless steels

The ferritic alloys are not hardenable by heat treatment and only slightly hardenable by cold working. They are magnetic and have good resistance to corrosion in many environments. Most typical of the ferritic stainless steels is type 430 (UNS S43000), a straight-chromium alloy with 16% to 18% chromium, 0.12% max. carbon, some minor elements and the balance iron.

Weldability of the ferritic stainless steels is generally better than the martensitic. Exposure to high temperatures, such as in the weld heat affected zone, causes a reduction in ductility and toughness along with grain coarsening. Solution annealing to prevent IGA is done at 1450°F (790°C) for ferritic stainless steels instead of 1900°F to 1950°F (1040°C to 1065°C) as for austenitic stainless steels. There is greater need for preheating and postweld annealing as the thickness and joint restraint increases.

## Precipitation hardening stainless steels

Iron-chromium-nickel alloys containing precipitation-hardening elements such as copper, aluminum and titanium have good weldability, comparable to that of the austenitic alloys, but are often used for components which require little or no welding. When welding is required, it is best to weld these alloys in the annealed condition prior to the final age hardening heat treatment. These stainless steels are hardenable by a combination of cold working and a low-temperature heat treatment, 850°F to 1100°F (455°C to 595°C).

## Corrosion resistant stainless steel castings

Stainless steel castings are classified, based on their end use, as corrosion resistant or heat resistant, and are designated accordingly by the first letter C or H. The heat resistant grades are generally higher in alloy content than the corrosion types and in nearly all cases have higher carbon. The following remarks apply to corrosion resistant types and may not be applicable to the heat resistant alloys. The chemical composition of the more common austenitic and duplex cast alloys is shown in *Table VII* (see page 25).

The most widely used, CF-3, CF-3M, CF-8 and CF-8M grades, normally have 5% to 20% ferrite in the austenitic matrix. The amount will vary with composition, thermal history of the casting and at different locations in the casting. Ferrite is beneficial in minimizing casting cracks and improving weldability. Some cast corrosion resistant stainless steel grades such as CN-7M are fully austenitic by nature of their composition. ASTM Specifications do not as yet include the 0.03% carbon grade for CN-7M as they do for the standard grades. Weld repair of castings at the foundry or weld buildup of

areas worn and corroded in later service will sensitize the HAZ to IGA. Users can and should request a 0.03% C maximum as an exception to the specification in order to prevent IGA in this alloy. Normally, these castings are welded without problems, but where welding is extensive, special techniques may be needed to prevent microfissures next to the weld. Techniques available are low interpass temperatures, low heat input and peening of the weld to relieve mechanical stresses.

The austenitic and duplex castings in *Table VII* are usually purchased to one of the following specifications:

ASTM A 743 – Castings, Iron-Chromium, Iron-Chromium-Nickel, Nickel-Base, Corrosion Resistant, For General Application.

ASTM A 744 – Castings, Iron-Chromium, Nickel-Base, Corrosion Resistant, For Severe Service.

Both specifications require that the casting be solution annealed which largely removes alloy segregation and dendritic structures occurring in castings, particularly in heavy sections. The high temperature anneal of 1900°F (1040°C) or higher, depending on the alloy, promotes a more uniform chemical composition and microstructure, as well as dissolving carbides. As a result of the anneal, the casting is in the most corrosion resistant state. For best corrosion resistance, the widely used CF-3M and CF-8M grades must be annealed at 2050°F (1120°C), not 1900°F (1040°C) as allowed by the specification.

Stainless steel castings are often welded, either by fabricators making assembly welds, during service life or by the foundries weld repairing defects. When the casting will be placed in a severe corrosive environment, selecting a low carbon version such as CF-3 or CF-3M can avoid problems resulting



from the formation of chromium carbides in the weld HAZ. The same effect of chromium carbides on IGA discussed in wrought alloys is true for cast alloys. The need for a low carbon version applies not only for the initial fabrication welds but also for later maintenance overlay and weld buildup of cast components. When a low carbon grade is not included in ASTM A743 or A744, an exception to the specification can usually be reached with the foundry.

One difference between A743 and A744 is that A744 requires a full solution anneal after all weld repairs except for minor repairs as defined in the specification. Austenitic A743 castings which are intended for general service do not require the solution anneal to be made after all weld repairs. Knowledge of the intended service conditions is helpful in selecting the correct material specification and casting grade but if this information is not available, a low carbon grade of W744 is usually a good choice.

## Heat treatment of stainless steel

Austenitic stainless steels, both wrought forms and castings, are normally supplied in the solution annealed condition. In solution annealing, the alloy is heated to a high temperature, 1900°F to 2150°F (1040°C to 1175°C) depending on the alloy type, and rapidly cooled, usually by a water quench. At the annealing temperature, chromium carbides are put back into solution as chromium and carbon, restoring the full resistance to IGA of the alloy. The anneal also removes the effect of cold working and places the alloy in a soft, ductile condition, however, the quenching operation may leave considerable residual stresses.

In fabrication, even higher residual stresses may be developed as a result of forming operations and welding.

When weldments are solution annealed and rapidly cooled, new residual stresses are often introduced. These stresses can cause movement after machining, with the result that the part exceeds dimensional tolerance limits. Stress relieving of mild steel weldments is frequently performed but it is best to avoid stress relief treatments of stainless steel weldments unless absolutely necessary. When it is necessary, two alternates are available, namely:

**Alternate 1** – Use a low temperature stress equalizing treatment at 600°F to 800°F (315°C to 425°C) with a hold of 4 hours per inch of thickness, followed by a slow cool. Since the alloys have excellent creep strength, the low temperature treatment removes only peak stresses. The treatment is safe to use with the standard grades such as 304 and 316 as well as the stabilized and low carbon grades since the temperature is below that at which harmful chromium carbides form.

**Alternate 2** – If the 600°F to 800°F (315°C to 425°C) treatment is inadequate in reducing stresses to the level desired, stress relieving in the range of 800°F to 1700°F (425°C to 925°C) may be required. The higher the temperature and the longer the time, the more complete the stress relief. For example, one hour at 1600°F (870°C) removes about 85% of the residual stresses. However, the standard grades such as Types 304 and 316 cannot be heated in this range without sacrificing corrosion resistance as a result of carbide precipitation. A stabilized grade, e.g., 321, 347 or 348 or a low carbon grade, e.g., 304L, 316L etc. should be used when stress relief in this temperature range is required. Refer to *Figure 11*, page 26, in developing stress relief treatments that will avoid carbide precipitation and IGA in Type 304.

**Table XI**  
**Stainless steel products forms**

Item	Description	Thickness	Width	Diameter or size
Sheet	Coils and cut lengths:	under .187 in.	24 in. & over	–
	Mill finishes Nos. 1, 2D & 2B Pol. finishes Nos. 3, 4, 6, 7 & 8	under .187 in.	all widths	–
Strip	Cold finished, coils or cut lengths	under .187 in.	under 24 in.	–
Plates	Flat rolled or forged	.187 in. & over	over 10 in.	–
Bars	Hot finished rounds, squares, octagons and hexagons	– .125 in. & over	– .25 in. to 10 in. incl.	.25 in. & over –
	Hot finished flats	–	–	–
	Cold finished rounds, squares, octagons and hexagons	–	–	over 1.2 in.
	Cold finished flats	–	.375 in. & over	–
Rods	Hot rolled rounds, squares, octagons, and hexagons in coils for cold rolling or cold drawing.	–	–	.25 in. to .75 in.
Wire	Cold finished only: round, square, octagon, hexagon, flat wire	0.010 in. to under .187 in.	.062 in. to under .375 in.	.5 in. & under
Extrusions	Not considered “standard” shapes, but of wide interest. Currently limited in size to approximately 6.5 inches diameter circle, or structurals to 5 inches diameter.			
Tubing	Dimensions by the outside diameter and wall thickness.			
Piping	Nominal pipe size is the inside diameter from .125 inch to and including 12 inches. Nominal pipe size is the outside diameter for 14 inches and larger diameters. The wall thickness is dimensioned by schedules (5S, 10S, 20, 30, 40, 80, 120, 160, XX and variations thereof) for all nominal pipe sizes.			

## Material procurement and storage guides

*Table XI* shows the principal stainless steel wrought product forms – plate, sheet, pipe and tubing – most commonly used in welded fabrication. These are normally purchased in the low carbon modification for each grade, although the alloys stabilized with titanium or niobium-tantalum are also used as discussed in the section on welding for corrosion resistance. Bars and structural shapes are sometimes included in the fabrication. With bars and shapes, the higher carbon grades are normally used because of their somewhat higher strength. When they

are included in weldments, it is useful to review the extent to which the heat affected zone of welds may suffer IGA in the process fluid of interest.

## Surface finishes

*Table XII* shows the standard finishes for sheet and strip. The most widely used finish for sheet is 2B. Polished finishes are also available but are not normally used in welded fabrications for the chemical and other process industries except food and medical equipment.

There is no standard surface finish for plate as there is for sheet and strip. Plate is normally hot rolled, annealed and pickled. Surface defects and

**Table XII**  
**Standard mechanical sheet finishes**

**Unpolished or rolled finishes:**

No. 1	A rough, dull surface which results from hot rolling to the specified thickness followed by annealing and descaling.
No. 2D	A dull finish which results from cold rolling followed by annealing and descaling, and may perhaps get a final light roll pass through unpolished rolls. A 2D finish is used where appearance is of no concern.
No. 2B	A bright, cold-rolled finish resulting in the same manner as No. 2D finish, except that the annealed and descaled sheet receives a final light roll pass through polished rolls. This is the general-purpose cold-rolled finish that can be used as is, or as a preliminary step to polishing.
No. 2BA or BA	Non-standard but widely offered bright annealed finish, highly reflective surface.

**Polished finishes:**

No. 3	An intermediate polished surface obtained by finishing with a 100-grit abrasive. Generally used where a semi-finished polished surface is required. A No. 3 finish usually receives additional polishing during fabrication.
No. 4	A polished surface obtained by finishing with a 120 –150 mesh abrasive, following initial grinding with coarser abrasives. This is a general-purpose bright finish with a visible “grain” which presents mirror reflection.
No. 6	A dull satin finish having lower reflectivity than No. 4 finish. It is produced by Tampico brushing the No. 4 finish in a medium of abrasive and oil. It is used for architectural and ornamental applications where a high luster is undesirable, and to contrast with brighter finishes.
No. 7	A highly reflective finish that is obtained by buffing finely ground surfaces but not to the extent of removing the “grit” lines. It is used chiefly for architectural and ornamental purposes.
No. 8	The most reflective surface, which is obtained by polishing with successively finer abrasives and buffing extensively until all grit lines from preliminary grinding operations are removed. It is used for applications such as mirrors and reflectors.

**Standard mechanical strip finishes:**

No. 1	Approximates a 2D finish for sheet.
No. 2	Approximates a 2B finish for sheet:
BA	Bright annealed, highly reflective finish. Used extensively for automotive trim.
Mill-buffed	No. 2 or BA strip finish followed by buffing to produce a uniform colour and uniform reflectivity. Used for automotive trim, household hardware and for subsequent chromium plating.

*For more information consult: NiDI 9012, “Finishes for stainless steels”.*

roughness in plate can initiate crevice attack in severe environments. For such services, it is necessary to negotiate surface finish required with the producer.

Pipe is not normally furnished to a specific finish. Welded pipe is made from cold finished coils in sizes up to

about 8 in. (200mm), and from sheet in larger sizes. The finish on welded pipe normally approaches the 2B or 2D finish on sheet, except in the area of the weld. The finish on extruded seamless pipe is not quite as smooth but is normally satisfactory from the standpoint of corrosion.

Electropolishing is an electrochemical process which provides a high luster finish and is finding increased use in applications where cleanability is a major concern, such as bioprocessing and paper mill head box equipment. The process may be described as the reverse of electroplating in that there is an electrolyte but the current is reversed and metal is removed rather than plating a new layer. The electropolishing process selectively reduces the peaks and sharp edges that exist on the metal surfaces, which in turn lessens the chance of product build up and eases cleaning. There is evidence that the corrosion resistance is improved over that of mechanically polished surfaces.

Electropolishing may be performed on the completed fabrication rather than sheet, strip or other starting products. The surface roughness, that is the distance between the peaks and valleys, is reduced about 25% through electropolishing. The surface may be ground to a 180 to 250 grit finish before electropolishing but mechanical polishing on electropolished surfaces is avoided.

### Purchasing guidelines

The following guidelines are offered when purchasing stainless steel to be used in the fabrication of corrosion resistant equipment.

1. Select the low carbon grades or the stabilized alternates for welded fabrications that will not be solution annealed after fabrication.
2. Specify a 2B finish for sheet. Specify the finish the application requires for plate in the procurement documents.
3. Specify protective paper for sheet and plate to be applied at the mill when special surface protection during storage and fabrication warrants. The protective paper can be stripped back in the area to be

welded and removed from the rest of the surface just prior to final cleaning and inspection.

4. Pipe is normally ordered to either ASTM A 312, which requires a final heat treatment after welding, or to ASTM A 774, which does not. Pipe to A 312 is standard for most warehouse stock. Only five of the more common grades are covered in A 778. A 778 tends to be used for the larger diameter sizes where the low carbon grades have proven to have adequate corrosion resistance in the as-welded condition. ASTM A 403 and A 774 are the comparable specifications for stainless steel fittings. Large diameter welded stainless steel pipe spiral can be obtained to ASTM A 409.
5. The interior finish in the area of the weld is often of concern. Most welded pipe producers achieve a good finish in the area of the weld but the finish desired should be identified in procurement to avoid misunderstandings.
6. Standard pipe lengths are 20 ft. (6m), but longer lengths up to 60 ft. (18m) are available. For smaller diameter lines, considerable savings can be made by ordering in longer lengths and utilizing bends in lieu of fittings.

Standard specifications for stainless steel product forms for welded fabrication are shown in APPENDIX A. The ASTM specifications do not cover assembly welds such as required to fabricate pipe assemblies, tanks and other process equipment. Specifications for fabrication weld quality are the responsibility of the user and must be included in procurement documents.

# Part III

## For the design engineer

### Design for corrosion services

Much can be done in the detailed design to improve corrosion resistance and obtain better service from less expensive grades.

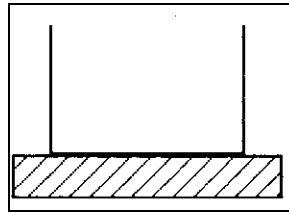
There are two cardinal rules:

1. DESIGN FOR COMPLETE AND FREE DRAINAGE.
2. ELIMINATE OR SEAL WELD CREVICES.

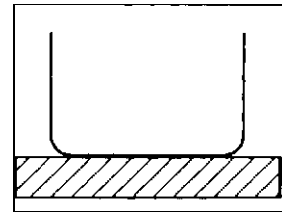
**Tank bottoms** – *Figures 14-1 through 14-6* show six common tank bottom arrangements. The square corner flat bottom arrangement, *Figure 14-1*, invites early failure from the inside at the corner weld where sediment will collect, increasing the probability of crevice attack. Moisture penetrating the flat bottom to pad support invites rapid crevice corrosion from the underside.

The rounded bottom shown in *Figure 14-2* is much more resistant from the inside, but is actually worse from the outside as condensation is funnelled directly into the crevice between the tank bottom and pad support. The grout used to divert such condensation, *Figure 14-3*, does help initially but soon shrinks back and becomes a maintenance demand itself. The drip skirt shown in *Figure 14-4* is much the best arrangement for flat bottom tanks. The concave bottom and the dished head bottom on supports, *Figures 14-5* and *14-6*, are very good and superior to all flat bottom tanks not only in corrosion resistance but also in fatigue. Fatigue stresses from filling and emptying are seldom considered in

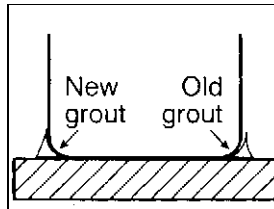
design, but can be significant and have led to failures in flat bottom tanks. The concave and dished head arrangements can withstand much greater fatigue loadings than can flat bottoms.



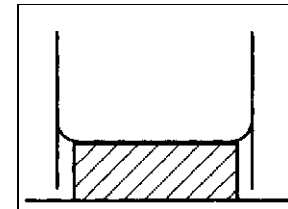
**Figure 14-1** Flat bottom, square corners – worst.



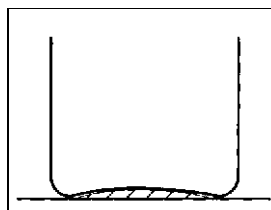
**Figure 14-2** Flat bottom, rounded corners – good corners, poor outside.



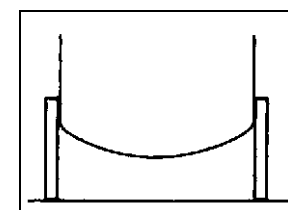
**Figure 14-3** Flat bottom, rounded corners, grouted – poor inside, poor outside.



**Figure 14-4** Flat bottom, rounded corners, drip skirt – good inside, good outside.



**Figure 14-5** Concave bottom, rounded corners – good inside, good outside, fatigue resistant.

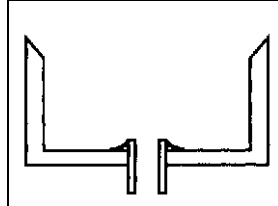


**Figure 14-6** Dished head – best inside, best outside, fatigue resistant.

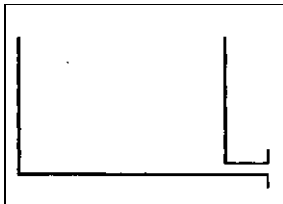
**Tank bottom outlets** – Water left standing in the bottom of stainless steel tanks has been a source of tank bottom failures in both fresh and saline waters. Side outlets and centre outlets, shown in *Figures 14-7 and 14-8*, allow for convenient construction but invite early failure of stainless steel tank bottoms. Not only is a layer of stagnant water held on the tank bottom but sediment cannot be easily flushed out. A flush side outlet and a recessed bottom outlet as in *Figures 14-9 and 14-10* allow the bottom to be completely drained and all debris and sediment to be flushed out, leaving the bottom clean and dry. The sloped arrangements shown in *Figures 14-11 and 14-12* make it easier to flush out and clean.



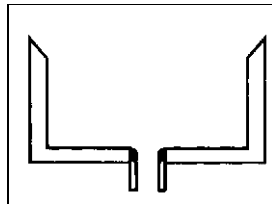
**Figure 14-7** Side outlet, above bottom – poor.



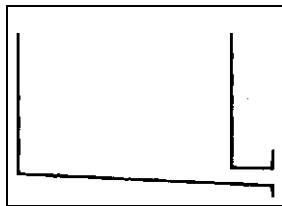
**Figure 14-8** Centre outlet, above bottom – poor.



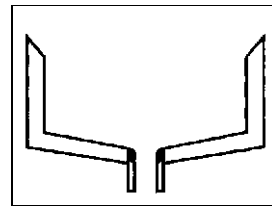
**Figure 14-9** Side outlet, flush – good.



**Figure 14-10** Centre outlet, recessed – good.

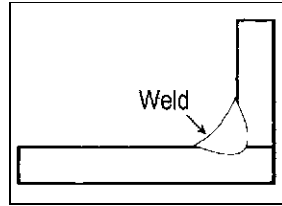


**Figure 14-11** Side outlet, flush, sloped – best.

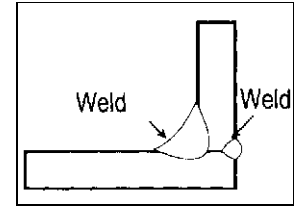


**Figure 14-12** Centre outlet, recessed, sloped – best.

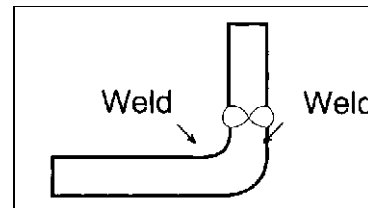
**Bottom corner welds** – When the side wall forms a right angle with the bottom, the fillet weld is seldom as smooth as shown in *Figure 14-13*. It is usually rough and frequently varies in width compensating for variations in fit up. Because of the location, it is very difficult to grind and blend the weld into the adjacent sides. Debris tends to collect and is difficult to remove, leading to *under sediment type crevice attack*. Unless welded from the outside as in *Figure 14-14*, the crevice is vulnerable to crevice attack. Rounding the corner and moving the weld to the side wall overcomes both shortcomings as shown in *Figure 14-15*. This construction has much improved corrosion resistance and also has better fatigue resistance.



**Figure 14-13** Corner weld from inside – poor inside, worst outside.



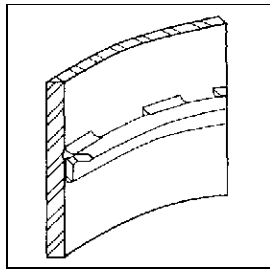
**Figure 14-14** Corner weld from both sides – poor inside, good outside.



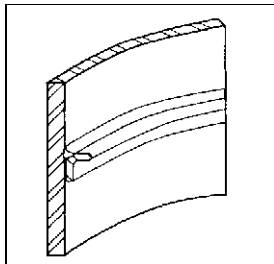
**Figure 14-15** Side wall in lieu of corner weld – best inside, good outside, fatigue resistant.

**Attachments and structurals** – All attachments create potential crevice sites. *Figure 14-16* shows a tray support angle with intermittent welds adequate for strength. There is a severe crevice between the angle and the inside wall of the vessel which will become filled with debris and invite premature failure from

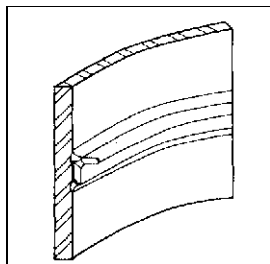
crevice corrosion. *Figure 14-17* shows the same tray support with a continuous seal weld at the top preventing unwanted material from finding its way down the wall and into the crevice. The angle to side wall crevice is still open from the bottom but this is a much less severe crevice which vapors but not material can still enter. *Figure 14-18* shows a full seal weld at the top and bottom of the tray support angle. Here the crevice is fully sealed.



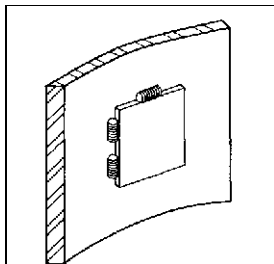
**Figure 14-16** Tray support, staggered strength weld – adequate support, severe crevice.



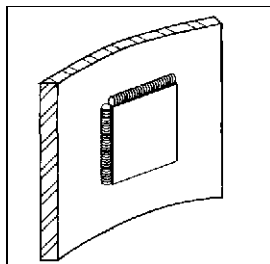
**Figure 14-17** Tray support, full seal, weld top – good crevice resistance.



**Figure 14-18** Tray support, full seal weld top & bottom – best crevice resistance.



**Figure 14-19** Reinforcing pad, staggered welds – adequate strength.

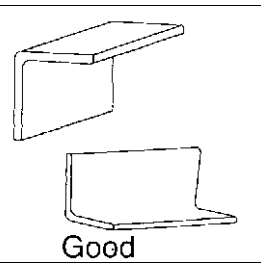


**Figure 14-20** Reinforced pad, seal weld – best crevice resistance.

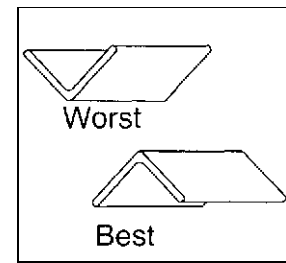
*Figure 14-19* shows a reinforcing pad to which other attachments are frequently welded. The intermittent weld creates a severe pad-to-sidewall crevice inviting premature failure. It takes very little more time to complete the seal weld as shown in *Figure 14-20* which should

always be done. It is good practice to drill a weep hole through the outer wall and must be done if the vessel is to receive a stress relief or solution anneal, otherwise the expansion of the trapped air could damage the vessel wall.

*Figure 14-21* shows structural angles positioned so they can drain, an important factor when shutting down and flushing out. Angles should never be positioned as in the top section of *Figure 14-22*. The best position for complete drainage is shown in the lower view.



**Figure 14-21** Position of angles.

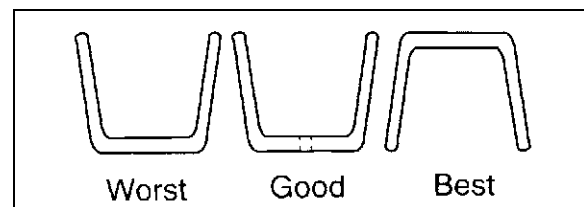


**Figure 14-22** Position of angles.

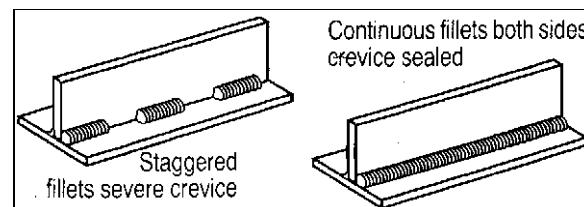
When channels are used, drain holes should be drilled about every 12 in. (300 mm) in the centre, unless they can be positioned as in the right hand view of *Figure 14-23*.

Continuous fillet welds on support beams will seal the severe beam to horizontal plate crevice shown in the upper section of *Figure 14-24*.

Baffles in tanks and heat exchangers create dead spaces where sediment



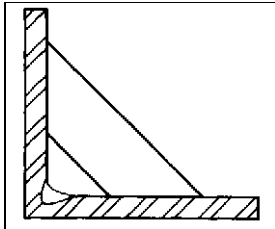
**Figure 14-23** Position of channels.



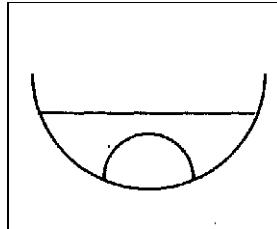
**Figure 14-24** Vertical beams.

can collect and where full cleaning is difficult. *Figure 14-25* shows a cut out at the lower corner of a tank baffle and *Figure 14-26* a cut out in the lower portion of a heat exchanger tube support plate. Both arrangements reduce debris collection and facilitate cleaning.

**Heaters and inlets** – Heaters should be located so they do not cause hot



**Figure 14-25**  
Corner baffle cut out – good.

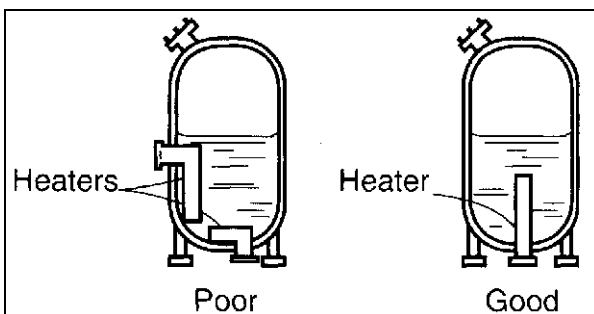


**Figure 14-26**  
Heat exchanger, baffle cut out – good.

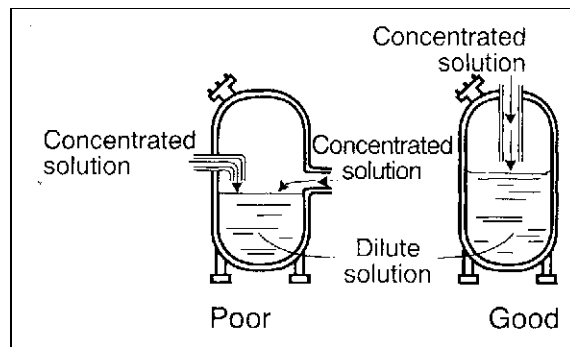
spots on the vessel wall. In *Figure 14-27*, the poor location of heaters creates hot spots which in turn may result in higher corrosion in the area between the heater and vessel wall. The good design avoids hot spots by centrally locating the heater.

When a concentrated solution is added to a vessel, it should not be introduced at the side as shown in the poor design of *Figure 14-28*. Side introduction causes concentration and uneven mixing at the side wall. With the good design, mixing takes place away from the side wall. It is also good design practice to introduce feed below the liquid level to avoid splashing and drying above the liquid line.

**Pipe welds** – It is frequently convenient to socket weld small diameter



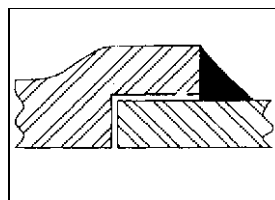
**Figure 14-27**  
Poor and good designs for the location of heaters in a vessel.



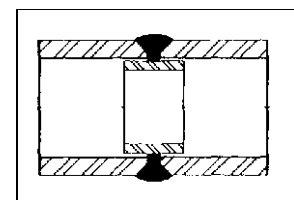
**Figure 14-28**  
Poor and good designs for mixing concentrated and dilute solutions.

stainless steel pipe rather than butt weld, as in *Figure 14-29*. On larger diameter pipe, over 2 in. (50 mm), a backing ring as shown in *Figure 14-30* is often used. Both designs may be satisfactory for those services where the stainless steel alloy has adequate crevice corrosion resistance. Because of the crevice formed, these designs often lead to unnecessary corrosion in aggressive environments and are not recommended. The backing ring has the further disadvantage of protruding into the flow stream, which in turn can cause product build up or unnecessary turbulence.

Very often stainless steel piping is installed as commercial quality, that is



**Figure 14-29**  
Socket weld joint severe crevice.

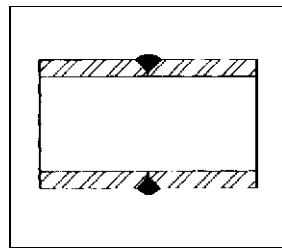


**Figure 14-30**  
Pipe weld made with backing ring – severe crevice.

without imposing code standards such as the ASME or the American Petroleum Institute, API, which require full penetration butt welds. When procurement does not require full penetration smooth ID butt welds, it is all too common to have a beautiful looking weld from the outside but incomplete pen-

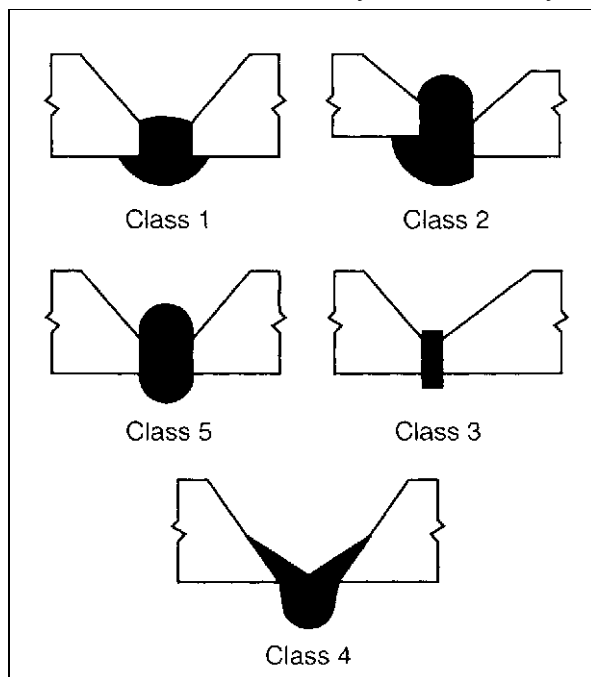


etration on the inside, such as shown in *Figure 14-31*. Many corrosion failures originate in crevices created by incomplete penetration at the root of pipe butt welds. Since ASTM does not cover fabrication, procurement specifications must specify full penetration and smooth ID for the root bead of butt welds when the weld quality is not covered by other specifications.



**Figure 14-31** Pipe weld with incomplete penetration – severe crevice.

The preferred pipe butt welding procedure to insure high quality root welds is the use of GTAW for the root pass with an inert gas backing. In manual root pass welds, the hand fed filler metal technique or the use of consumable inserts is commonly used. *Figure 14-32* shows some standard consumable insert designs. Properly made welds with either technique can provide a crevice free ID surface with minimum bead convexity or concavity.

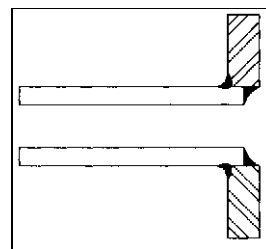


**Figure 14-32** Standard consumable inserts, (from AWS A5.30).

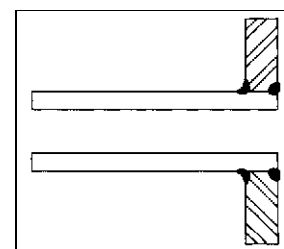
The hand fed filler metal method is more widely used in the chemical process industry but the experience of the particular company or welders, strongly influences the selection. It is important that the root bead have adequate and uniform amounts of filler metal melted into the weld for best corrosion resistance. This addition is readily obtained with consumable inserts or by skilled welders using the hand fed filler metal method.

There are a number of automatic GTAW machines available for root pass and fill welding. The root pass can be made using an insert, with automatic wire feed or in thin wall pipe, single pass welds can be made without filler metal addition. The ID root contour of automatic welds is very consistent and it is an excellent process to use where the economics are favourable. Automatic GTAW is a particular advantage for tubing and pipe 2 in. (50 mm) diameter and less.

Three good pipe-to-flange welding arrangements are shown in *Figures 14-33, 14-34* and *14-35*. The recessed arrangement shown in *14-33* avoids the need for machining or grinding smooth the surface of the weld on the flange face in *Figure 14-34*. Both these arrangements are suitable when the flange is of the same material as the pipe. Neither is suitable when carbon steel or ductile iron flanges are used on stainless steel pipe. In this case a stub end arrangement shown in *Figure 14-35* is preferred. In the case of pressure



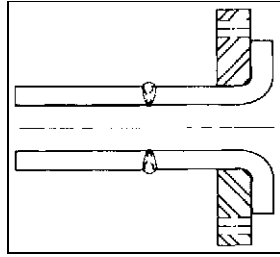
**Figure 14-33** Pipe recessed flange and pipe, same alloy – good.



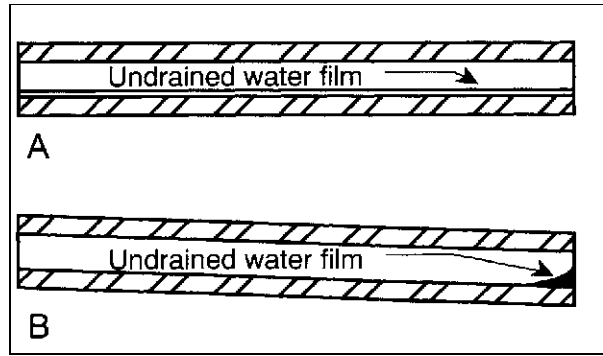
**Figure 14-34** Pipe flush, pipe and flange same alloy – better.

pipings, the flange design must also be in accordance with the applicable design or fabrication specification.

For piping and heat exchanger tubing to drain completely, it is necessary to slope the piping or heat exchanger just enough so that water will drain and not be trapped where the pipe or tubing sags slightly between support points. *Figure 14-36* shows how a water film tends to remain in horizontal runs of pipe or tubing and how water drains when sloped.



**Figure 14-35** Stub end, flange carbon steel or ductile iron – very good.



**Figure 14-36**  
(A) Horizontal (standard) – poor.  
(B) Horizontal sloped – very good.

# Appendix A

## Specifications for stainless steel for welded fabrication

### **ASTM A240 – “Heat resisting chromium and chromium-nickel stainless steel plate, sheet and strip for pressure vessels.”**

A240 is the basic specification for procurement of stainless steel for welded fabrication. A240 requires solution annealing at the mill. This specification includes 40 austenitic, 4 duplex and 16 ferritic grades. Caution: Care must be taken to select the low carbon or stabilized grades for corrosion resistant services, as the higher carbon grades, used primarily in heat resistant applications, are included.

### **ASTM A262 – “Detecting susceptibility to intergranular attack in austenitic stainless steels.”**

A262 is a supplemental specification that covers five tests that can be included in procurement specifications when maximum resistance to intergranular attack is required. When A262 is used, the criteria to be met in the test (practice) must be included as pass/fail criteria are not part of A262.

### **ASTM A264 - “Stainless chromium-nickel steel-clad plate, sheet and strip.”**

A264 is the specification for the clad construction using the austenitic grades covered in A240.

### **ASTM A265 - “Nickel and nickel-base alloy-clad steel plate.”**

A265 is the specification for clad construction using the ten highly alloyed nickel and nickel-base grades covered under separately identified ASTM B section specifications.

### **ASTM A312 – “Seamless and welded austenitic stainless steel pipe.”**

### **ASTM A403 – “Wrought austenitic stainless steel piping fittings.”**

A312 (pipe) and A403 (fittings) are the older specifications for welded austenitic stainless steel pipe for aggressive environments developed for, and widely used by, the chemical industry. Both products require a solution anneal after welding. Most of the common stainless steels are covered. Caution: Care must be taken to select the low carbon or stabilized grades for corrosion resistant services, as the higher carbon grades are also included in A 312. Sizes from 1/8 inch to 30 inch diameter are included.

### **ASTM A778 – “Welded, unannealed austenitic stainless steel tubular products.”**

### **ASTM A774 – “As-welded austenitic stainless steel fittings for general corrosive services at low and moderate temperatures.”**

A778 (pipe) and A774 (fittings) are used where the low carbon and stabilized grades can be used in the as-welded condition. Solution annealing after welding is not required. Only low carbon and stabilized grades are included in these specifications. Sizes from 3 inches to 48 inches are covered.

### **ASTM A409 - “Welded large diameter austenitic steel pipe for corrosive or high temperature service.”**

A409 covers light wall, spiral welded, as well as straight seam welded, pipe 14 inches to 30 inches in diameter. Solution annealing is required unless waived. Fourteen grades are covered. Caution: Care must be taken to select the low carbon or stabilized grades for corrosion resistant services, as the higher carbon grades are also included. There is no specification for fittings.

## Additional requirements:

Few ASTM pipe and fitting specifications require pickling after production.

ASTM specifications do not cover shop fabrication of pipe and fittings. The user must develop his own specifications for butt welding and fabrication to pipe drawings. Important points to include are the following:

1. Full penetration, smooth ID, TIG made root beads.
2. Inert gas backup on the inside of the pipe during welding to minimize oxidation and heat tint.
3. Matching composition or higher Mo content filler metal for Mo-containing grades.
4. Protection of piping with protective end caps to minimize contamination during shipment and storage.

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