

# **Guide for Welding Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing**



**American Welding Society**



**AWS D10.18M/D10.18:2008**  
**An American National Standard**

**Approved by the**  
**American National Standards Institute**  
**January 23, 2008**

# **Guide for Welding Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing**

**1st Edition**

Prepared by the  
American Welding Society (AWS) D10 Committee on Piping and Tubing

Under the Direction of the  
AWS Technical Activities Committee

Approved by the  
AWS Board of Directors

## **Abstract**

This standard presents a detailed discussion of the metallurgical and welding characteristics and weldability of duplex stainless steel used in piping and tubing. A number of tables and graphs are presented in order to illustrate the text.



**American Welding Society**

**550 N.W. LeJeune Road, Miami, FL 33126**

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## Foreword

This foreword is not part of AWS D10.18M/D10.18:2008, *Guide for Welding Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing*, but is included for informational purposes only.

This guide is intended to provide information which may be used to avoid, or at least minimize, difficulties in welding duplex stainless steel piping and tubing. The term *pipe* used in the text also includes tube.

This first edition of D10.18M/D10.18 is the first document of its kind offering a guide for welding ferritic/austenitic duplex stainless steel piping and tubing. The duplex stainless steels are finding increased use in industry and the information contained in this guide will be most useful.

Tables listing specific chemical composition ranges for base metal and weld metal that fall under the jurisdiction of other codes or documents have been omitted. Where helpful, however, comparison data is presented.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D10 Committee on Piping and Tubing, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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# Guide for Welding Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing

## 1. Scope

The ferritic/austenitic duplex stainless steels (DSSs) discussed in this document have proven to be weldable using proper welding procedures. The processes GTAW, GMAW (includes all transfer modes), SMAW, FCAW, and SAW have all been used with success on these alloys. Automatic and mechanized welding such as orbital welding with the GTAW, GMAW, and FCAW processes have also been used with success on duplex alloys. Manual welders that have experience with austenitic stainless steels should be able to apply many of the techniques they have learned from these alloys to the welding of duplex stainless steels, while of course keeping in mind the exceptions to be noted within this document.

This standard makes use of both the International System of Units (SI) and U.S. Customary Units. The latter are shown within brackets [ ] or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system must be used independently.

To identify nominal pipe sizes in both SI and U.S. Customary Units, the following designations are used:

- (1) DN (Diameter Nominal) is the SI designation, and
- (2) NPS (Nominal Pipe Size) is the U.S. Customary designation.

Safety and health issues and concerns are beyond the scope of this standard, and therefore are not fully addressed herein. Safety and health information is available from other sources, including, but not limited to, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

## 2. Normative References

The following standards contain provisions which, through reference in this text, constitute mandatory pro-

visions of this AWS guide. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

AWS A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*.<sup>1</sup>

## 3. Terms and Definitions

Terms used in this document should be interpreted in accordance with AWS A3.0, *Standard Welding Terms and Definitions*, except for those not defined by that standard or where these terms require further definition to clarify their usage in this standard.

**orbital welding.** Automatic or mechanized welding of tube or pipe in which a welding arc rotates (orbits) around a stationary weld joint.

## 4. Material Compositions and Specifications

**4.1 Material Compositions.** The duplex stainless steels (DSSs) have a microstructure of approximately equal parts of ferrite and austenite, consequently in the welding and fabrication, the duplex alloys exhibit some characteristics of both ferritic and austenitic stainless steels. As a result, the welding procedures for the duplex alloys require different parameters than ferritic or austenitic stainless steels.

Attractive features of DSSs include a yield strength about double that of the austenitic grades, while maintaining ductility and toughness approaching that of the austenitics. DSSs are especially resistant to chloride

<sup>1</sup> AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

stress corrosion cracking, pitting, crevice corrosion and erosion corrosion. The useful service temperature range is more restricted than the austenitics and varies with the particular duplex alloy. In general, the duplex range is –40°C [–40°F] to 280°C [535°F].

**4.2 Specifications.** The wrought DSSs are often classified into three families based on composition. The compositions of the wrought alloy families are shown in Tables 1, 2, and 3. Cast alloys are shown in Table 4. Type 2205 is the most widely used of the DSSs and is estimated to represent 80% of DSSs used. Most literature references to welding DSSs refer to 2205, however details of welding procedures for the three groups are discussed in later subclauses.

Common duplex stainless steel specifications for pipe and tubing, fittings, and castings are as follows:

(1) ASTM A 351, *Castings, Austenitic-Ferritic (Duplex), for Pressure-Containing Parts; Standard Specification for*;

(2) ASTM A 380, *Cleaning, and Descaling Stainless Steel Parts, Equipment and Systems; Standard Recommended Practice for*;

(3) ASTM A 789, *Seamless Welded Ferritic/Austenitic Stainless Steel Tubing for General Service; Standard Specification for*;

(4) ASTM A 790, *Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe; Standard Specification for*;

(5) ASTM A 815, *Wrought Ferritic, Ferritic/Austenitic, and Martensitic Stainless Steel Piping Fittings; Standard Specification for*;

(6) ASTM A 890, *Castings, Iron-Chromium-Nickel-Molybdenum Corrosion-Resistant, Duplex (Austenitic/Ferritic) for General Applications; Standard Specification for*;

(7) ASTM A 923, *Detecting Detrimental Intermetallic Phase in Wrought Duplex Austenitic/Ferritic Stainless Steels; Standard Test Methods for*;

**Table 1**  
**Chemical Composition by Weight Percent<sup>a</sup> of Wrought Lean Duplex Stainless Steels**

| Common Name | UNS Number | C    | N         | Cr        | Ni       | Mo        | P     | S     | Si   | Mn      | Other           |
|-------------|------------|------|-----------|-----------|----------|-----------|-------|-------|------|---------|-----------------|
| LDX 2101    | S32101     | 0.04 | 0.20–0.25 | 21.0–22.0 | 1.35–1.7 | 0.10–0.80 | 0.040 | 0.030 | 1.00 | 4.0–6.0 | Cu<br>0.10–0.80 |
| 2304        | S32304     | 0.03 | 0.05–0.20 | 21.5–24.5 | 3.0–5.5  | 0.05–0.60 | 0.040 | 0.040 | 1.00 | 2.50    | Cu<br>0.05–0.60 |
| 2003        | S32003     | 0.03 | 0.14–0.20 | 19.5–22.5 | 3.0–4.0  | 1.5–2.0   | 0.030 | 0.020 | 1.00 | 2.00    | —               |

<sup>a</sup> Single values are maximums.

**Table 2**  
**Chemical Composition by Weight Percent<sup>a</sup> of Standard Duplex Stainless Steels**

| Common Name       | UNS Number | C    | N         | Cr        | Ni        | Mo        | P     | S     | Si   | Mn   | Other         |
|-------------------|------------|------|-----------|-----------|-----------|-----------|-------|-------|------|------|---------------|
| 2205 <sup>b</sup> | S32205     | 0.03 | 0.14–0.20 | 22.0–23.0 | 4.5–6.5   | 3.00–3.50 | 0.030 | 0.020 | 1.00 | 2.00 | —             |
| 255               | S32550     | 0.04 | 0.10–0.25 | 24.0–27.0 | 4.5–6.5   | 2.9–3.9   | 0.040 | 0.030 | 1.00 | 1.5  | Cu<br>1.5–2.5 |
| Cr-Ni-Mo-N        | S32950     | 0.03 | 0.15–0.35 | 26.0–29.0 | 3.50–5.20 | 1.00–2.5  | 0.035 | 0.01  | 0.60 | 2.00 | —             |

<sup>a</sup> Single values are maximums.

<sup>b</sup> There is an older UNS version of alloy 2205, UNS S31803. This older version has been replaced by S32205, but some references may still be made to S31803. S32205 has higher chromium, molybdenum and nitrogen content. Higher levels of nitrogen reduce the tendency to form excess ferrite leading to poor heat-affected zone (HAZ) mechanical properties (toughness). Higher levels of all three elements improve corrosion resistance.

**Table 3**  
**Chemical Composition by Weight Percent<sup>a</sup> of Super Duplex Stainless Steels**

| Common Name            | UNS Number | C    | N         | Cr        | Ni      | Mo      | P     | S     | Si  | Mn   | Other                                                   |
|------------------------|------------|------|-----------|-----------|---------|---------|-------|-------|-----|------|---------------------------------------------------------|
| 2507                   | S32750     | 0.03 | 0.24–0.32 | 24.0–26.0 | 6.0–8.0 | 3.0–5.0 | 0.035 | 0.020 | 0.8 | 1.20 | —                                                       |
| Zeron <sup>®</sup> 100 | S32760     | 0.03 | 0.2–0.3   | 24.0–26.0 | 6.0–8.0 | 3.0–4.0 | 0.03  | 0.01  | 1.0 | 1.0  | Cu<br>0.5–1.0 <sup>b</sup><br>W<br>0.5–1.0 <sup>b</sup> |

<sup>a</sup> Single values are maximums.

<sup>b</sup> Other: %Cr + 3.3 × %Mo + 16 × %N ≥ 40.

**Table 4**  
**Chemical Composition by Weight Percent<sup>a</sup> of Cast Duplex Stainless Steels**

| ACI Designation | Wrought Equivalent     | UNS Number | C    | N         | Cr        | Ni        | Mo        | P     | S     | Si   | Mn  | Other                     |
|-----------------|------------------------|------------|------|-----------|-----------|-----------|-----------|-------|-------|------|-----|---------------------------|
| CD4MCu          | —                      | J93370     | 0.04 | —         | 24.5–26.5 | 4.75–6.00 | 1.75–2.25 | 0.04  | 0.04  | 1.0  | 1.0 | Cu<br>2.75–3.25           |
| CD4MCuN         | S32550                 | J93372     | 0.04 | 0.10–0.25 | 24.5–26.5 | 4.7–6.0   | 1.7–2.3   | 0.04  | 0.04  | 1.00 | 1.0 | Cu<br>2.7–3.3             |
| CD3MN           | 2205                   | J92205     | 0.03 | 0.10–0.30 | 21.0–23.5 | 4.5–6.5   | 2.5–3.5   | 0.04  | 0.020 | 1.0  | 1.5 | Cu<br>1.0                 |
| CE3MN           | 2507                   | J93404     | 0.03 | 0.10–0.30 | 24.0–26.0 | 6.0–8.0   | 4.0–5.0   | —     | —     | 1.0  | 1.5 | Note b                    |
| CD3MWCuN        | Zeron <sup>®</sup> 100 | J93380     | 0.03 | 0.20–0.30 | 24.0–26.0 | 6.5–8.5   | 3.0–4.0   | 0.030 | 0.025 | 1.0  | 1.0 | W<br>0.5–1.0 <sup>b</sup> |

<sup>a</sup> Single values are maximums.

<sup>b</sup> Other: %Cr + 3.3 × %Mo + 16 × %N ≥ 40.

(8) ASTM A 928, *Ferritic/Austenitic (Duplex) Stainless Steel Pipe Electric Fusion Welded with Addition of Filler Metal; Standard Specification for*; and

(9) ASTM A 995, *Castings, Austenitic-Ferritic (Duplex) Stainless Steel, for Pressure-Containing Parts; Standard Specification for*.

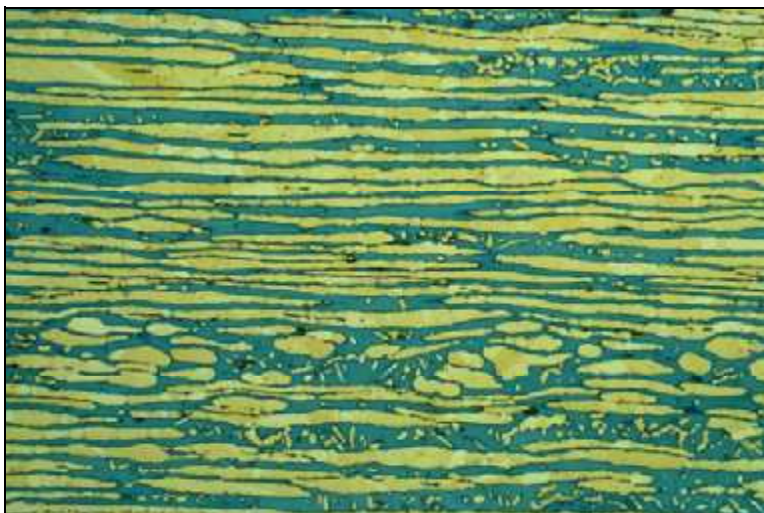
## 5. Basic Metallurgy

**5.1 Solidification and Ferrite/Austenite Phases.** All DSSs solidify as ferrite whether solidification is in an ingot, casting, or a weld. Islands of austenite form in the ferrite matrix down to a temperature of about 1000°C [1832°F]. When wrought products are hot worked, the austenite phase typically assumes an elongated morphol-

ogy such as shown on Figure 1, a cross section of an alloy 2205 plate. The austenite phase is the lighter constituent in the darker ferrite matrix.

The preferred amount of ferrite is 40% to 60%, although the range may be expanded somewhat depending upon the application. When there is a high level of ferrite, toughness and ductility are reduced while at high levels of austenite, resistance to stress corrosion cracking is reduced and mechanical properties may be somewhat reduced. It is generally accepted that as long as there is at least 25% of the lesser phase, the expected properties of the duplex alloy will be realized.

In mill or wrought product forms, the amount of ferrite and austenite depends upon the composition and the thermal history. Elements that mainly influence phase



Note: Austenite is the lighter phase in the darker ferrite matrix.

Source: Adapted, with permission, from International Molybdenum Association (IMOA), *Practical Guidelines for the Fabrication of Duplex Stainless Steels*, Revised Edition, 2001, Figure 2.

**Figure 1—Alloy 2205 Plate Showing Elongated Microstructure**

balance are chromium, molybdenum, nickel, and nitrogen. Thermal processing employed by the mills include factors such as hot working temperature and cooling rates, both of which can vary depending on the particular product being produced.

Weld ferrite measurements can be made using either destructive or nondestructive examinations. The most common destructive technique is a ferrite point count which requires removing a section and metallographic preparation and photography. Nondestructive measurements can be made using an electronic hand-held measuring device described in 11.10.

The duplex stainless steels have been known since the 1930s, and these early alloys are often referred to as first-generation DSSs. However, these early grades characteristically had poor weldability and significantly reduced corrosion resistance in the as-welded condition. The addition of nitrogen as an alloying element in the second-generation DSSs is primarily responsible for the improvements in weldability and corrosion resistance.

One beneficial role of nitrogen is that of causing austenite to form more quickly and at a higher temperature during the solid state transformation. However, there are incidences such as in rapidly cooled welds where excessively high levels of ferrite may be retained. This will be discussed in more detail later.

**5.2 Precipitating Phases.** As noted above, after the molten metal solidifies as ferrite, some ferrite transforms to austenite down to a temperature of about 1000°C [1832°F]. As the DSS cools below this temperature, other phases such as carbides, nitrides, sigma, and other intermetallic phases can form. Chi phase and other intermetallic phases are often lumped together with sigma phase, and the term “sigma phase” will be taken hereafter to include these other intermetallic phases. Sigma, in significant amounts, can be particularly detrimental in that toughness and corrosion resistance may be reduced. Sigma forms in the temperature range of 700°C to 980°C [1300°F to 1800°F] with the most rapid formation at 870°C [1600°F]. It is formed whenever the alloy is in the 700°C to 980°C [1300°F to 1800°F] temperature range, that is there is an accumulative effect. The total exposure time for sigma formation includes time at the steel mill during in-process heating and exposure time during welding including repair welding unless there is an intervening anneal above 1040°C [1900°F]. The proper level of nitrogen delays sigma formation, but does not prevent it. It has been shown that in the case of alloy 2205 with nitrogen in the upper range of 0.14% to 0.20%, there is about a five minute exposure time at 870°C [1600°F] available before the amount of sigma formed causes a significant loss of toughness and corrosion resistance.

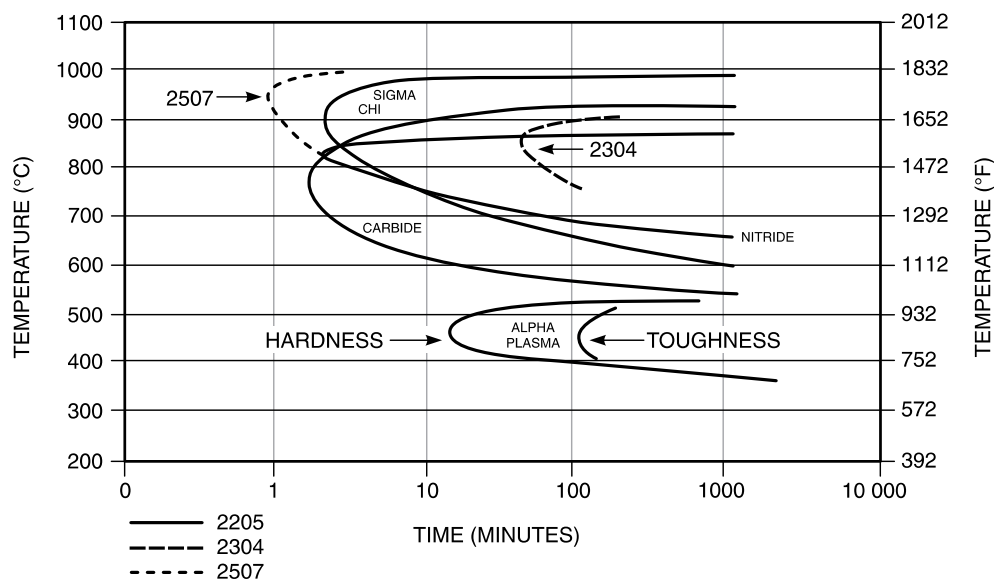
Since time at temperature in processing the wrought products is equally as important as time incurred during welding a very useful document is ASTM A 923. The standard describes three test methods for detecting detrimental intermetallic phases. The methods include illustrations of acceptable microstructures, Charpy impact test acceptance criteria and a ferric chloride corrosion test. ASTM A 923 can be specified as a procurement requirement and is particularly useful for the thicker product forms. It is an aid in assuring that a significant portion of the allowable “five minutes at sigma formation temperature” has not been used at the steel mill, allowing less time at temperature during welding.

With nitrogen present in the duplex stainless steels, there is a potential to form chromium nitrides in the interior of large ferrite grains in the HAZ which can result from too rapid cooling and/or inappropriate alloy balance. Large amounts of chromium nitrides could create chromium depleted areas that if not corrected by annealing could reduce corrosion resistance. However, it is found that the higher levels of nitrogen such as 0.14% to 0.20% in 2205 (UNS S32205) promote austenite which has a much higher solubility of nitrogen with the final result that

chromium nitrides essentially do not present a problem in the second-generation duplex stainless steels. Also, since the second-generation alloys are made to very low carbon levels, carbide formation is seldom a practical concern.

Alpha prime is an embrittling phase that forms in ferritic stainless steels with over 16% chromium, as well as in the ferrite phase of DSS, when exposed in the temperature range of 400°C to 540°C [750°F to 1000°F] with peak embrittling occurring at 475°C [885°F]. The phenomena is commonly referred to as 475°C [885°F] embrittlement and results in a severe loss of room temperature ductility and toughness. The time to embrittle at 475°C [885°F] can vary from a few minutes for a DSS with a low level of nitrogen and large amount of ferrite to several hours for alloys with lower ferrite and higher nitrogen. It is the concern for alpha prime embrittlement that ASME limits DSS to an upper service temperature limit of 315°C [600°F] while other Standards such as some European Codes limit welded alloy 2205 to 250°C [480°F].

The time and temperature to form the phases discussed above, i.e., sigma, carbides, nitrides, and alpha prime is illustrated in Figure 2 for 2205 that was annealed at



Note: Duplex grades 2304 and 2507 are shown for comparison.

Source: Adapted, with permission, from International Molybdenum Association (IMO), *Practical Guidelines for the Fabrication of Duplex Stainless Steels*, Revised Edition, 2001, Figure 4.

**Figure 2—Isothermal Precipitation Diagram for 2205 Duplex Stainless Steel, Annealed at 1050°C [1920°F]**

1050°C [1920°F]. The “nose” of the lines is the start of the particular phase formation and transformation continues for some time and could take some time to reach a deleterious level. Alloys 2304 and 2507 are shown for comparison. Significant points to note are:

(1) While chromium carbides and nitrides start to form in 1–2 minutes, this is actually slower than in the ferritic and highly alloyed austenitic grades and as noted earlier these phases are seldom of a practical concern.

(2) Sigma and chi formation takes place at a somewhat higher temperature, but at about the same time as carbides and nitrides. It will be noted that transformation of the higher alloyed 2507 initiates in less time and the leaner alloy 2304 takes considerably longer time than 2205.

(3) The “nose” of the alpha prime formation is at 47°C (885°F) and an increase in hardness occurs followed by a reduction in toughness.

## 6. Corrosion

The DSSs exhibit good corrosion resistance in a wide range of environments and in general are equal or better than comparable austenitic grades. The high chromium content provides good resistance to oxidizing acids and the levels of molybdenum and nickel provide resistance to weakly reducing acids.

The alloys' excellent resistance to crevice corrosion and pitting corrosion in chloride containing environments accounts for one of the principle uses for the DSSs. For example, 2205 is decidedly superior to Type 316 while the superduplex stainless steels (SDSSs) have comparable resistance to the higher alloy content 6% molybdenum alloys in pitting and crevice corrosion resistance in chloride containing environments. In a microstructure containing as little as 30% ferrite, the duplex alloys have far superior resistance to stress corrosion cracking than the austenitic grades. However, there is a note of caution in that the ferrite phase is susceptible to hydrogen embrittlement and the DSSs are not well suited to applications where hydrogen is charged into the metal.

When the service environment is very corrosive for the DSS alloy, weld corrosion tests may be imposed. Weld corrosion testing and welding procedure controls for corrosion considerations are discussed in Annex B.

## 7. Joint Design and Fit-Up

**7.1 General.** There are several factors that should be considered when designing edge preparations for duplex

stainless steel welded pipe joints. The thermal expansion and thermal conductivity properties of DSSs are closer to those of carbon steel and therefore do not raise the shrinkage and distortion concerns that are common to austenitic stainless steels, however it is still a good practice to minimize the amount of weld metal deposited in the weld groove, often by the use of narrower grooves (reduced bevel angles). However, there has been less field experience in welding DSSs than with austenitic stainless steels. Many different procedures have proven successful, while other methods are still under development.

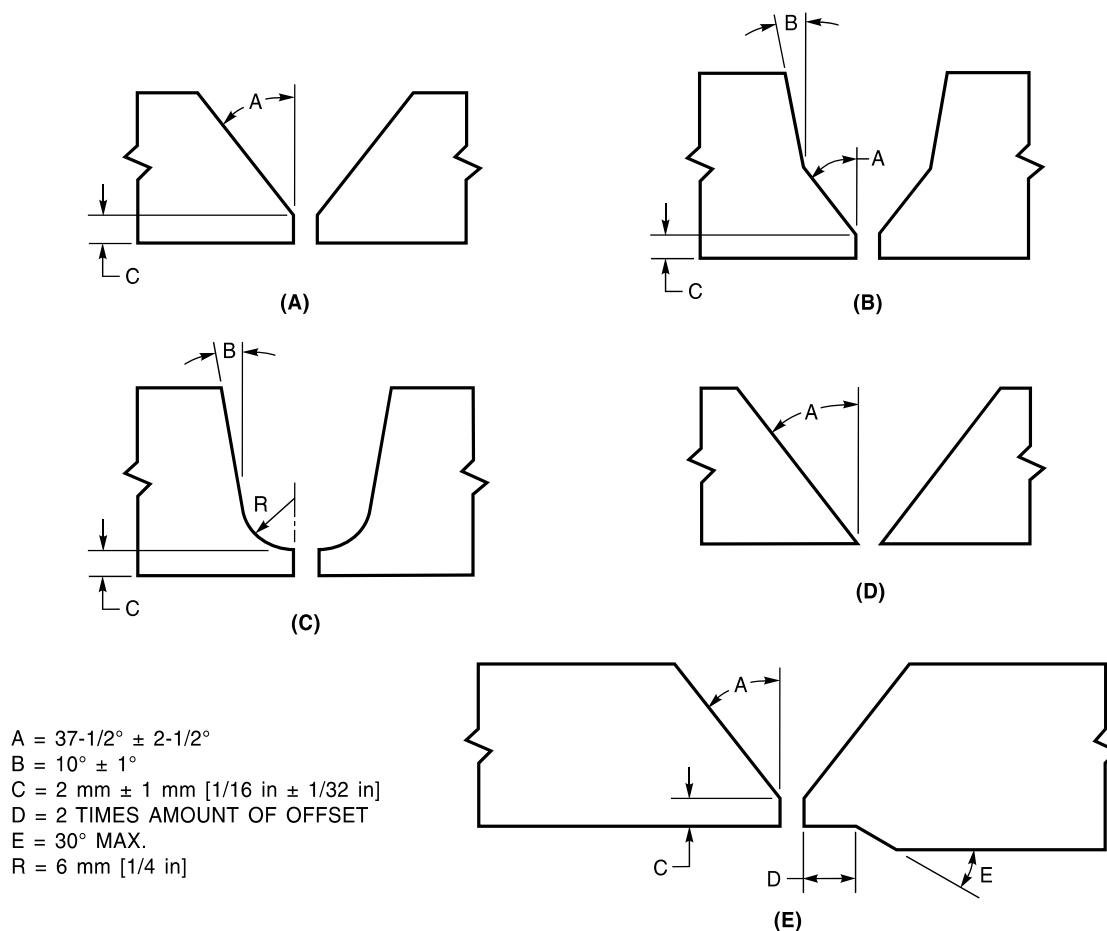
The choices for joint designs are similar to those for austenitic stainless steels, except that closed root joints are generally best avoided unless the weldment is thin wall tubing, the type of weld is J-groove, or the weldment is to be subsequently solution annealed. This is because little or no filler metal can be used for the root pass with a closed root, and without the higher nickel of the filler metal, the root pass tends to retain excessive ferrite under the rapid cooling conditions of welding in thicker material. Appropriate open root designs are shown in Figure 3. For more details on joint designs, see AWS D10.11M/D10.11, *Recommended Practices for Root Pass Welding of Pipe Without Backing*. Use of backing rings is not recommended for most applications since the crevice between the pipe wall and the backing ring increases the possibility of crevice corrosion when the fluid being handled is a corrosive media.

**7.2 Open Root Joints.** Typical open root joint designs are shown in Figure 3. Figure 3(A) is a standard V-groove with 37-1/2° bevels and a root face of dimension “C.” As with austenitics, the bevel angle (Angle A) can be reduced, for example to 30°, if desired to reduce residual stresses and weld metal volume. The limit on angle reduction is that point where lack of side wall fusion is a possibility for the welding process used and weld accessibility.

In manual welding, the root opening requirement is determined by the method used to add filler metal. A root opening equal to or slightly smaller than the filler metal wire diameter is used with the keyhole technique. In this technique, the filler metal is introduced intermittently as necessary to fill the gap. A larger opening is used with the continuous feed technique in which the filler metal is always in the opening and can be melted continuously if desired.

For heavier wall thickness, Figure 3(B) or 3(C) is often used. The U-groove joint design, as in Figure 3(C) is useful when inserts are used since it allows good torch access to the root.

**7.3 Consumable Inserts.** Consumable inserts are an alternate to the hand fed filler metal technique in making



**Figure 3—Typical Joint Designs Used with Open Root Designs**

the pipe root pass weld. Full penetration welds with good root contour are obtainable with trained welders. The choice between the hand fed filler metal technique and consumable inserts often varies from industry to industry and with the welder's work experience. AWS A5.30 lists five different consumable insert shapes of different sizes, but no DSS compositions are listed in that standard.

Limited insert shapes, with compositions similar to those of GTAW filler metal compositions found in AWS A5.9, can be obtained from consumable insert manufacturers. These insert rings are generally enriched in nickel as compared to corresponding base metal compositions to assist in achieving a balanced microstructure and acceptable weld bead profile with small diameter thin wall orbital welding. Inserts have been used in orbital welding small diameter thin wall tubing, and are also an option in manual welding larger diameter heavier wall pipes. In installing the insert, the ring is fitted and tacked on one

side, then the joint is fit-up and tacked on the other side of the joint. Care and caution must be taken when tacking inserts to avoid prestressing the weld joint. Also, care must be taken to avoid oxidized tack welds which in turn could lead to areas of lack of fusion or weld defects.

The success of this technique is dependent upon welder proficiency with the gas tungsten arc process and adequacy of interior gas purge. With experience, the welder is able to recognize when the insert has melted and the molten pool reaches proper height and width to form the proper root reinforcement. Speed of travel is adjusted accordingly. Less skill may be required to weld joints with consumable inserts than to weld joints without backing.

**7.4 Autogenous Orbital GTAW.** Autogenous orbital welding with a groove weld in the square butt configuration is practical for small diameters (25 mm [1 in] or less) with thinner walls (3 mm [1/8 in] or less).

**7.5 Orbital GTAW with Filler Metal Addition.** For both single pass and multipass orbital GTAW the filler metal may be added automatically by cold wire or hot wire addition.

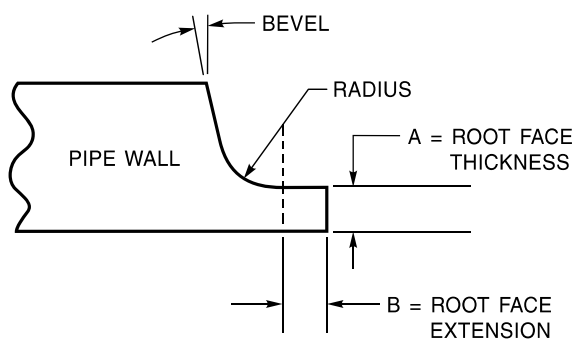
#### 7.5.1 Single Pass Orbital GTAW with Wire Feed.

For thin-wall small diameter tubing or pipe, a closed root butt weld joint with a bevel through part of the wall thickness may be used if the joint can be welded in a single pass. The bevel helps to facilitate penetration and to achieve a flatter weld bead than with a standard groove weld in the square butt configuration with the addition of wire.

**7.5.2 Multipass Orbital GTA Welding with Wire Feed.** For heavier wall thickness up to approximately 12 mm [0.50 in] and multipass welding, a modified “J” joint design shown in Figure 4 has been used. Torch oscillation may be used to distribute the heat input across the weld joint concentrating the heat near the side of the joint so full penetration is achieved without excessive heat input. This joint configuration also reduces heat input which in turn aids in avoiding undesirable phases that can reduce corrosion resistance and toughness. A further advantage of the root face extension is in preventing the weld pool from “climbing” the side walls of the joint. In developing the welding procedure specification (WPS), dimensions of both the root face and root face extension have been found to be critical and may vary with pipe diameter. Root face thicknesses as small as 1.2 mm [0.05 in] have been used which in turn requires tight control over joint alignment.

## 8. Filler Metals

In welding DSSs it is good practice to always add filler metal when ever possible and practical. Autogeneous



**Figure 4—Modified “J” Joint Design**

DSS welds tend to be higher in ferrite than the base metal being welded. Also, fast weld cooling rates increase the amount of ferrite in the weld. To compensate, nickel an austenite former, is increased in the E2209 filler metal, the standard filler metal for welding 2205 and many of the lean DSSs. Filler metal E2209 has a nickel content of 7.5% to 9.5% compared to 4.5% to 6.5% for 2205. With this nickel adjustment, a much better ferrite to austenite balance is obtained. An exception to the need for a nickel enhanced filler metal would be when the weld receives a final full solution anneal.

There are near matching composition proprietary filler metals for many of the lean and super DSSs. Suggested filler metals are shown in Table 5. It is also advisable to consult the alloy producer of proprietary alloys for their filler metal recommendations and filler metal availability.

Nickel alloy filler metals have also been used to weld both the standard and super DSSs. One such nickel alloy filler metal for which data is available is AWS A5.14 ERNiCrMo-14. Welds made with this filler metal have pitting corrosion resistance comparable to those made with super DSS filler metal. Since the nickel alloy welds are fully austenitic, there is no concern regarding obtaining a balance of austenite and ferrite. All-weld metal yield strength of ERNiCrMo-14 welds made by the GTAW process have exceeded the minimum 560 MPa [80 000 psi] yield strength of the super DSS base metal using a rather low heat input of 0.8 kJ/mm [20 kJ/in] or a higher heat input of 1.3 kJ/mm [33 kJ/in]. The all-weld metal tensile strength also exceeded the minimum base metal properties at both levels of heat input. Charpy V-notch weld impact properties were in excess of 60 J [44 ft-lbs] for both  $-50^{\circ}\text{C}$  [ $-58^{\circ}\text{F}$ ] and  $-196^{\circ}\text{C}$  [ $-320^{\circ}\text{F}$ ] indicating good weld metal toughness.

A commonly encountered dissimilar metal weld is between DSS and an austenitic stainless steel such as Type 304 or 316. For joining 304L to DSS, 308L filler metal is adequate, while for joining 316L to DSS, 316L filler metal is adequate. However, 2209 or 309LMo metals, though more expensive and less readily available, are also appropriate. In joining any of the DSSs to carbon or low alloy steel, a suitable filler metal is E309L or E309LMo.

## 9. Welding Processes

**9.1 General.** The welding processes of GTAW, GMAW, SMAW, FCAW, and SAW have all been used with success on these alloys.

Welders that have experience with austenitic stainless steels should be able to apply the skills and techniques

**Table 5**  
**Welding Filler Metals for Duplex Stainless Steels**

| Base Metal<br>Common Name | Base Metal<br>UNS Number | Bare Wire                                  | SMAW Electrodes                          | FCAW Electrodes                            |
|---------------------------|--------------------------|--------------------------------------------|------------------------------------------|--------------------------------------------|
| LDX 2101                  | S32101                   | LDX 2101<br>AWS A5.9 ER2209                | LDX 2101<br>AWS A5.4 E2209               | AWS A5.22 E2209TX-X                        |
| 2304                      | S32304                   | 2304<br>AWS A5.9 ER2209<br>AWS A5.9 ER309L | 2304<br>AWS A5.4 E2209<br>AWS A5.4 E309L | AWS A5.22 E2209TX-X<br>AWS A5.22 E309LTX-X |
| 2003                      | S32003                   | AWS A5.9 ER2209                            | AWS A5.4 E2209                           | AWS A5.22 E2209TX-X                        |
| 2205                      | S32205                   | AWS A5.9 ER2209                            | AWS A5.4 E2209                           | AWS A5.22 E2209TX-X                        |
| 255                       | S32550                   | AWS A5.9 ER2553                            | AWS A5.4 E2553                           | AWS A5.22 E2553TX-X                        |
| 2507                      | S32750                   | AWS A5.9 ER2594                            | AWS A5.4 E2594                           | E2507TX-X <sup>a</sup>                     |
| Zeron 100                 | S32760                   | AWS A5.9 ER2594                            | AWS A5.4 E2595                           | Zeron 100 <sup>a</sup>                     |

<sup>a</sup> Refer to future revisions of AWS A5.22 for AWS designations.

acquired with these alloys to DSSs. The welding characteristics, puddle manipulation, and viscosity of the two families of alloys are similar; however the duplex weld puddle is more viscous than austenitic stainless steel and thus more difficult to weld by hand.

The GTAW process is considered the best choice for the root pass of pipe welds when all welding is from the OD (outside diameter). Automatic or mechanized welding such as orbital GTAW are capable of producing high quality root pass welds with consistent internal weld profiles.

## 9.2 Single Pass Welding Small Diameter Tubing

**9.2.1 Autogenous Orbital GTAW.** In smaller diameter tubes (25 mm [1 in] or less) with thinner walls (3 mm [1/8 in] or less), autogenous orbital welding with the higher controlled heat input and a special shielding gas mixture (see 9.2.2) is able to consistently produce phase-balanced welds. A square butt joint configuration is used for these smaller diameter tube welds.

**9.2.2 Autogenous with Consumable Insert.** There is also the option of using consumable insert rings to provide filler metal addition. Fusion welds on closed square butt joints, or closed square butt joints with inserts are normally completed in a single pass. The shielding gas commonly used is 88% argon, 10% helium, and 2% nitrogen mixture, where helium is added to increase penetration and nitrogen is used to promote the formation of austenite. The addition of nitrogen is of special benefit in

welding SDSSs to obtain a desired ferrite-austenite balance. Purging gas is discussed in 10.6.

With autogenous orbital welds made with or without a consumable insert and with the low sulfur content of most DSSs, there may be a tendency towards the formation of external weld bead concavity at the 12 o'clock location and internal weld concavity at the 6 o'clock location when welding in the 5G position. Pressure balancing with a pressure-measuring device is frequently used to control the weld bead profile of autogenous welds on small diameter DSSs as well as for austenitic stainless steels.

**9.2.3 Autogenous Orbital Square-Butt Welds with Penetrating Flux.** One approach in obtaining a full penetration autogenous orbital weld using a square groove pipe joint is the use of a penetrating (GTAW) flux. The paste-like penetration enhancing flux is carefully applied to the outside of the joint following the manufacturers recommended procedure. The weld will normally be accomplished in one pass. Argon is used for both the internal purge and the welding head shield gas. A special procedure to control the internal purge pressure is needed to prevent excessive weld penetration or OD concavity. After the weld is made, there is a tenacious coating of flux that requires removal with a powered nylon cleaning wheel. The use of stainless steel wire brushes is not recommended.

**9.2.4 Single Pass Weld with Wire.** Small diameter thin wall DSS tubing has been successfully welded with

orbital GTAW with the addition of filler wire. A slight bevel on the closed root square butt end preparation may be used.

**9.3 Root Pass Welding Heavier Walls.** On heavier wall thickness an orbital GTA pipe weld is typically made using a modified “J” preparation shown in Figure 4. The root pass is typically done as a stringer bead without torch oscillation. On DSS the addition of wire filler metal on the root pass is recommended. The root face on the “J” preparation can be extended to assure repeatable penetration of the joint. Care must be taken when welding the second or “hot” pass to avoid excessive remelting of the root pass which may result in underfill on the root surface (suck-back).

**9.4 Fill Welding.** In fill welding, automated or orbital GTAW systems with wire feed results in high quality piping welds. For production fill welding GMAW, FCAW and SAW offer advantages.<sup>2</sup> In SAW, a metallurgically basic flux is a good choice to avoid loss of elements that could affect the preferred weld metal composition. However, the increased heat input and inclusion content normally associated with SAW can influence corrosion and toughness results. Where both corrosion resistance and toughness are important issues, one of the modes of GMAW will typically provide more reproducible and satisfactory results. SMAW may be a choice for field welding applications.

In GMAW there are a number of proprietary welding head shield gases used in welding DSS and SDSS alloys. Most gases are argon with various additions of helium, nitrogen and CO<sub>2</sub>. The selection of shielding gases and welding parameters for FCAW should reflect the filler metal manufacturer’s recommendations.

## 10. Welding Procedures

**10.1 General.** The ferritic/austenitic duplex stainless steels have proven to have good weldability when the proper procedures are followed. The same welding processes used for austenitic stainless steels are used for the duplex alloys. Since many welding characteristics of the two types of stainless steels are quite similar (e.g., puddle manipulation and viscosity), welders easily adapt to welding either family of alloy. However, a major difference between duplex and austenitic stainless steels lies in the fact that the DSS alloys respond differently to the heat of welding, a factor that is a part of the Welding

<sup>2</sup>“Development of mechanized field girth welding of high-alloy corrosion-resistant pipeline materials,” by R. E. Avery and C. M. Schillmoller, NiDI Technical Series, No. 10,061.

Procedure Specification and not related to the welders skill.

**10.2 Cleaning Before Welding.** The weld area to be cleaned before welding includes the joint edges and about 50 mm [2 in] of adjacent surfaces on both the inside and outside of the pipe. Improper cleaning can cause weld defects such as cracks, porosity, and lack of fusion. The joints should be free of surface oxides such as might be left after thermal cutting. Grinding or other mechanical means should be used to remove all paint, scale, oxides, and dirt. There are a number of elements and compounds that if not removed can cause cracking, weld defects, or reduced corrosion resistance resulting from the heat of welding. Sulfur, phosphorous, and low-melting metals may cause cracks in the weld or HAZ. These contaminants could be present in cutting fluids, marking materials, oil, grease, or any shop dirt. Carbon or carbonaceous material left on the surface during welding can result in a high carbon surface layer which in turn lowers corrosion resistance in certain environments. Hand tools, such as wire brushes, used in the fabrication of duplex stainless steels should be made from stainless steel and should be used exclusively on duplex stainless steel material.

Oil and grease compounds can be removed by suitable solvent cleaning followed by a thorough rinse. A suitable solvent is one that does not leave a residue and is not harmful to the welder or to the weldment. ASTM A 380, *Standard Recommended Practice for Cleaning, and Descaling Stainless Steel Parts, Equipment and Systems*, is an excellent guide to use.

**10.3 Preheat.** Preheating is not recommended with duplex stainless steels except to dry the surface or when the temperature is below 5°C [40°F], or when welding heavy sections under restraint where a preheat of 150°C [300°F] may be appropriate.

**10.4 Interpass Temperature.** The maximum interpass temperature control often used for 2205 and the leaner DSS is 150°C [300°F] while the maximum for SDSSs is 65°C [150°F]. However, these temperatures are conservative and higher temperatures of 200°C [400°F] and 150°C [300°F], respectively, are often employed. Basically there is no single interpass temperature that covers all situations. The lower the maximum interpass temperature, the less time the HAZ is in the sigma formation range which may be a consideration for multipass weld joints or when maximum corrosion resistance is of primary concern. On the other hand, lower interpass temperatures introduce the economic constraint of increased welding times. Consequently, there is no single interpass temperature that covers all situations.

**10.5 Heat Input.** Heat input is often a compromise between a heat input high enough to avoid fast cooling with the resultant tendency to form excessive ferrite and heat input low enough to avoid excessive time in the 700°C to 980°C [1300°F to 1800°F] sigma formation range. A heat input range commonly used for DSS is 0.5 kJ/mm to 2.5 kJ/mm [12.5 kJ/in to 62.5 kJ/in]. However, there are codes and user specifications that restrict the maximum heat input to 1.75 kJ/mm [44.4 kJ/in] for alloy 2205 and 1.5 kJ/mm [38 kJ/in] for the SDSS. Also, special heat input guides for the root pass and first fill pass are discussed in Annex B.

**10.6 Purging (Backing) Gas.** Nitrogen is the most suitable backing gas for DSS because it protects the root surface from nitrogen loss, especially in GTAW. It is also less expensive than argon, although argon has been used successfully. Hydrogen addition, as is sometimes used with austenitic steels, is dangerous for DSS because of the possibility of hydrogen embrittlement and should be avoided. See AWS D10.11M/D10.11, *Recommended Practices for Root Pass Welding of Pipe Without Backing*, for guides in pipe purging techniques and purging gas specifications. When using an oxygen analyzer, an oxygen content of less than 0.2% is a good starting point to determine if the surface discoloration is satisfactory.

The gas tungsten arc process is the most reliable process to make a quality root pass weld. A gas purge is essential in providing a full penetration weld that is essentially free of oxidation. An extreme example of root pass oxidation made without purging or with improper purging is a condition described as “sugaring.” The term is used because the weld metal has a crust-like structure and appearance of burned sugar. A “sugared” weld often has weld defects, has poor corrosion resistance in many environments, and should be removed.

More often the weld and HAZ may have various degrees of heat-tint discoloration due to some level of oxygen in the purge. Parts being purged should be clean and dry prior to assembly since excessive moisture can also contribute to tinting of the root side. Depending upon the service, the presence of heat-tint can significantly reduce pitting or crevice corrosion resistance or particles of oxide may be a source of product contamination. For applications where heat-tint discoloration could influence service performance, a weld discoloration level guide such as shown in AWS D18.1, *Specification of Welding Austenitic Stainless Steel Tube and Pipe Systems in Sanitary (Hygienic) Applications*, is more useful than specifying an oxygen level.

Nitrogen may be included in the purge gas and/or the shielding gas to compensate for any loss of nitrogen during welding. A reduction of nitrogen in the weld will

increase the amount of ferrite and in turn affect the ferrite to austenite balance. Nitrogen additions for ferrite balance are often used in automatic welding operations where there is closer control of welding parameters than in manual welding.

**10.7 Postweld Heat Treatment.** Postweld heat treatment is seldom performed or considered necessary for piping assemblies. The as-welded structure is normally satisfactory when proper welding procedures are used. If a heat treatment is employed after welding, it must be a full anneal. The correct annealing temperature depends upon whether or not filler metal with higher nickel content than that of the base metal was used. If no filler metal was used, or if matching nickel filler metal was used, then an appropriate annealing temperature is generally 1040°C [1900°F] minimum. However, if enriched nickel filler metal, such as 2209, is used, then the annealing temperature needs to be higher (1150°C [2100°F]) in order to dissolve all the intermetallic phases that form during heating to the annealing temperature. The higher nickel content makes sigma phase stable to higher temperatures. Water quenching directly from the annealing temperature is necessary to avoid sigma formation on cooling after annealing.<sup>3</sup> As discussed previously, time in the 315°C to 980°C [600°F to 1800°F] range should be kept to a minimum to minimize the development of harmful phases.

Some situations where postweld heat treatment may be appropriate are:

- (1) When cold deformation exceeds 15% such as the U bending of tubes,
- (2) Welding with a nonrecommended process where heat input cannot be kept within the recommended range, and
- (3) After hot bending.

If for some reason a postweld heat treatment is considered necessary, it is advisable to consult the metal producer for heat treatment specifics.

## 11. Weldment Quality Verification

**11.1 Inspection Method.** Because of the need for good inspection, this subclause briefly describes several inspection and test methods that have proven satisfactory for stainless steel pipe welds. In addition to the usual final inspection, a preweld and in-process inspection

<sup>3</sup> Kotecki, D. J.; 1989; “Heat treatment of duplex stainless steel weld metals.” *Welding Journal*, 68(11): 431-s–441-s

program is of prime importance. A complete quality control program may include:

- (1) Visual inspection of finished bevels and all areas within 12 mm [1/2 in] of the planned joint;
- (2) Review of welder training, qualification, and practice pipes;
- (3) Penetrant testing (PT) of root bead to examine questionable areas;
- (4) Check that proper interpass temperature and heat input control are employed;
- (5) Removal of surface irregularities and undercut to prevent stress concentrations; and
- (6) Radiography (RT) of final welds on a 100% or spot basis, as required. If this is not possible due to joint location or lack of adequate equipment, the use of in-process PT inspection should be considered.

**11.2 Visual Inspection.** Visual inspection is of greatest importance and is the most versatile method of inspection available. However, the inspection is only as good as the experience, knowledge, and judgment of the inspector. The AWS publication, *Welding Inspection*, is suggested as a guide for visual inspection.

**11.3 Hydrostatic Testing.** A test with water under static pressure will generally reveal only fully penetrating defects which were overlooked during visual inspection. A water pressure test is usually made at one and one-half times the operating pressure, or just below the yield strength of the weakest elements. With the weld under stress, near-penetrating and micro-thin defects may enlarge sufficiently to seep water. Temperature of the water should be above that of the ambient air to avoid condensation on the pipe which may interfere with the detection of seeping water. Particular care should be taken to avoid entrapment of air when testing. Test pressures for pipe are provided in applicable codes and specifications. Water high in chlorides, such as sea water, should never be employed as the test water. A good rule is to employ only potable water. After the hydrostatic test, the water should be drained and the system dried to preclude the possibility of corrosion such as microbiologically influenced corrosion.

**11.4 Liquid Penetrant Methods.** Several methods of surface examination of welds are available. Essentially, all utilize a suitable penetrating liquid and a developer to expose surface discontinuities by contrasting color. A few methods use a fluorescent penetrant in the solution which is readily visible under ultraviolet light. A smooth, clean surface is preferable; however, defects can be dis-

tinguished from surface roughness by experienced personnel. Since chloride can pit or cause cracking of DSSs and SDSSs, chloride-free cleaners and penetrants should be employed.

**11.5 Radiography.** Radiographic examination is a non-destructive inspection method which is frequently used to determine surface as well as internal weld defects, such as slag and tungsten inclusions, porosity, cracks, incomplete fusion, and incomplete joint penetration. The acceptance criteria for such defects are covered by established radiographic standards. Experience, knowledge, and good judgment are essential in the proper interpretation of radiographs. Rules, procedures, and standards are available from several sources, such as the AWS publications, *Welding Inspection* and *Welding Handbook*, ASTM standards, and ASME *Boiler and Pressure Vessel Code*, Sections I, III, V, and VIII.

**11.6 Ultrasonic Methods.** These methods utilize equipment capable of propagating an electronically-timed ultrasonic beam through the material under inspection. The signals reflected from the surfaces and interior structure of the metal are indicated on a cathode ray tube or digital display for comparison and interpretation. Since sound reflection in DSSs and SDSSs is complex, the use of the equipment requires a special skill and experience. It is usually not practical to ultrasonically inspect welds involving duplex castings because of their large grain structures.

**11.7 Acoustic Emission Testing (AET) Methods.** These methods consist of the detection of acoustical signals produced by plastic deformation or crack initiation or propagation during loading. Transducers, strategically placed on a structure, detect the acoustic signals. Acoustic emission testing has been applied during proof testing, during recurrent inspections, during service, and during fabrication. This technique is considered to be in its early stages of use by industry. More extensive application is anticipated in the future.

**11.8 Mass Spectrometer Testing Method.** This method employs an electronic instrument using helium as a tracer gas and is capable of detecting very minute leaks. Several procedures are available when using the mass spectrometer, including the helium blanket, the helium probe, and the instrument probe techniques. Considerable technical knowledge is required for procedure preparation, but actual operation may be performed by shop personnel after a short training period. This method is generally used only on very critical pipe work.

**11.9 Ferrite Measurement.** Electronic hand-held measurement devices (ferritescopes) are a useful tool for monitoring ferrite content in weld during fabrication. They are not practical for very small diameter tubing due to the measurement distortion produced by the curvature of the tube, but can be used on larger diameter tubing and to check the root of larger diameter piping prior to the welding of additional passes. Magne-Gage<sup>4</sup> testing may

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<sup>4</sup> Magne-Gage is a registered trademark of Magne-Gage Sales & Service Co., Inc.

be used to predict the amount of ferrite when destructive testing is acceptable.

**11.10 Charpy Impact Test.** The Charpy impact test is used to provide a measure of base metal or weld toughness. It is one of the tests used in ASTM A 923, *Standard Test Methods for Detecting Detrimental Intermetallic Phase in Wrought Duplex Austenitic/Ferritic Stainless Steels*. The Charpy impact test is also specified by some users on DSS welds for special applications where weld toughness is a concern. Charpy impact tests are particularly indicated where low temperature environments are expected.

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## Annex A (Informative)

# Guidelines for the Preparation of Technical Inquiries

This annex is not part of AWS D10.18M/D10.18:2008, *Guide for Welding Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing*, but is included for informational purposes only.

*Phase in Wrought Duplex Austenitic/Ferritic Stainless Steels.* The Charpy impact test is also specified by some users on DSS welds for special applications where weld toughness is a concern. Charpy impact tests are particularly indicated where low temperature environments are expected.

### A1. Introduction

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is directed through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

### A2. Procedure

All inquiries shall be directed to:

Managing Director  
Technical Services Division  
American Welding Society  
550 N.W. LeJeune Road  
Miami, FL 33126

All inquiries shall contain the name, address, and affiliation of the inquirer, and they shall provide enough information for the committee to understand the point of

concern in the inquiry. When the point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and in the format specified below.

**A2.1 Scope.** Each inquiry shall address one single provision of the standard unless the point of the inquiry involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the inquiry along with the edition of the standard that contains the provision(s) the inquirer is addressing.

**A2.2 Purpose of the Inquiry.** The purpose of the inquiry shall be stated in this portion of the inquiry. The purpose can be to obtain an interpretation of a standard's requirement or to request the revision of a particular provision in the standard.

**A2.3 Content of the Inquiry.** The inquiry should be concise, yet complete, to enable the committee to understand the point of the inquiry. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annex) that bear on the inquiry shall be cited. If the point of the inquiry is to obtain a revision of the standard, the inquiry shall provide technical justification for that revision.

**A2.4 Proposed Reply.** The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry or provide the wording for a proposed revision, if this is what the inquirer seeks.

### A3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS technical committee. The secretary of

interpretation of the Society, and the secretary transmits the response to the inquirer and to the *Welding Journal* for publication.

#### **A4. Publication of Interpretations**

All official interpretations will appear in the *Welding Journal* and will be posted on the AWS web site.

#### **A5. Telephone Inquiries**

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The AWS Board of Directors' policy requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can

be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

#### **A6. AWS Technical Committees**

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees or to consideration of revisions to existing provisions on the basis of new data or technology. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

## Annex B (Informative)

# Guidelines for Weld Corrosion Testing and Welding Procedure Controls for Corrosion Considerations

This annex is not part of AWS D10.18M/D10.18:2008, *Guide for Welding Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing*, but is included for informational purposes only.

### B1. Introduction

Some DSSs are being used in quite severe corrosive environments where there can be concerns regarding the weld and heat-affected zone (HAZ) corrosion resistance. This annex addresses guidelines that have been found helpful in performing corrosion tests and welding procedure controls for optimum corrosion resistance. It should be recognized that for most normal services, DSS welds made using qualified welding procedures perform entirely satisfactorily, and careful consideration should be given before imposing expensive corrosion testing.

corners rounded.<sup>5</sup> It has also been found that pickling reduces weight loss and test to test variability. A typical pickling treatment is 20% nitric acid + 5% hydrofluoric acid at 60°C [140°F] for 5 minutes.

The test temperature should be realistic for the particular alloy. For alloy 2205 in the as-welded condition, 22.5°C [72°F] is often used as the test temperature. With the superduplex stainless steels, the test temperature is often 35°C [95°F], but with both alloys, the test temperature can be selected to best suit the particular end application.

### B2. Corrosion Testing

ASTM G 48 Method A or G 48A Modified pitting corrosion test is commonly used to evaluate weld and HAZ corrosion resistance. Employment of this test will be discussed.

**B2.1 Specimen Surface Preparation and Test Temperature.** ASTM G 48 provides very specific instructions on specimen preparation, test equipment used, how the test is to be performed, and guides on the evaluation of test results. However, G 48A may be used for a range of stainless steels and related alloys for pitting corrosion and it is often advisable to be more specific for particular alloys such as DSS. It is important that the corrosion specimen surface grinding be closely followed to obtain consistent, reliable results. The cut faces should be ground to a very high finish, e.g., 1200 grit and the

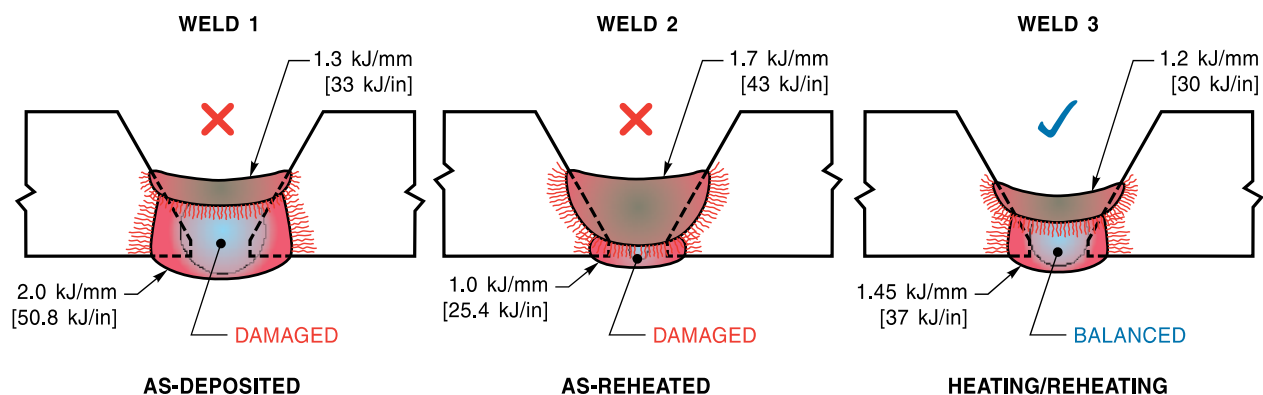
### B3. Suggested Root Pass Welding Procedure

In pipe or tube welding, The Welding Institute has shown a special need for close heat input control of the root and second pass for corrosion resistance considerations. This is illustrated in the following three examples (see Figure B.1).

(1) **Weld 1**—Root with poor corrosion resistance—root made with too high a high heat input, 2 kJ/mm [50.8 kJ/in] and second pass made with low heat input, 1.3 kJ/mm [33 kJ/in].

(2) **Weld 2**—Root with poor corrosion resistance—weld damaged by too high a second pass reheating, low

<sup>5</sup> *Effective Welding of Duplex & Superduplex Stainless Steels*, Graham Holloway, Metrode Products.



**Figure B.1—Heat Input and Corrosion Resistance**

heat input root, 1 kJ/mm [25.4 kJ/in] and high heat input second pass, 1.7 kJ/mm [43 kJ/in].

(3) **Weld 3**—Root with optimum corrosion resistance—balanced root and second pass heat input—medium heat input root, 1.43 kJ/mm [37 kJ/in] and second pass about 75% of root pass heat input, 1.2 kJ/mm [30 kJ/in].

It is acceptable to use the wider range of heat input after the controlled root and second pass.

Another option to maximize root pass weld metal corrosion resistance is to use the SDSS filler metal, AWS A5.9 ER2594 for the root pass in welding alloy 2205. In welding the SDSS, an added option is the use of Ar–2% N<sub>2</sub> for the shielding (torch) gas.

## Annex C (Informative)

### Reference Documents

This annex is not part of AWS D10.18M/D10.18:2008, *Guide for Welding Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing*, but is included for informational purposes only.

American Welding Society (AWS) standards:

AWS A4.2M (ISO 8249 MOD), *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal*

AWS A5.4, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding*

AWS A5.9, *Specification for Bare Stainless Steel Welding Electrodes and Rods.*

AWS A5.11, *Specification for Nickel and Nickel Alloy Electrodes for Shielded Metal Arc Welding*

AWS A5.12, *Specification for Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting*

AWS A5.14, *Specification for Nickel and Nickel Alloy Bare Welding Electrodes and Rods*

AWS A5.22, *Specification for Stainless Steel Electrodes for Flux Cored Arc Welding and Stainless Steel Flux Cored Rods for Gas Tungsten Arc Welding*

AWS A5.30, *Specification for Consumable Inserts*

AWS A5.32/A5.32M, *Specification for Welding Shielding Gases*

AWS A5.34/A5.34M, *Specification for Nickel Alloy Electrodes for Flux Cored Arc Welding*

AWS B2.1, *Specification for Welding Procedure and Performance Qualification*

AWS D10.10, *Recommended Practices for Local Heating of Welds in Piping and Tubing*

AWS D10.11M/D10.11, *Recommended Practices for Root Pass Welding Without Backing*

AWS *Welding Handbook*, Volume 4, Chapter 5, "Stainless and Heat Resistant Steels," Eighth Edition

AWS *Welding Inspection Handbook*

AWS *Safety and Health Fact Sheets*

American National Standards Institute (ANSI) Documents:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

American Society of Mechanical Engineers (ASME) Standards:

ASME Boiler and Pressure Vessel Code, Sections I, III, V, VIII, and B 31.3.

National Institute for Occupational Health and Safety (NIOSH) Documents:

NIOSH Criteria Document 76-129 and 77-164

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### List of AWS Documents on Piping and Tubing

| Designation    | Title                                                                                                 |
|----------------|-------------------------------------------------------------------------------------------------------|
| D10.4          | <i>Recommended Practices for Welding Austenitic Chromium Nickel Stainless Steel Piping and Tubing</i> |
| D10.6/D10.6M   | <i>Recommended Practices for Gas Tungsten Arc Welding Titanium Piping and Tubing</i>                  |
| D10.7M/D10.7   | <i>Recommended Practices for Gas Shielded Arc Welding Aluminum and Aluminum Alloy Pipe</i>            |
| D10.8M/D10.8   | <i>Guide for Welding Chromium Molybdenum Steel Piping and Tubing</i>                                  |
| D10.10/D10.10M | <i>Recommended Practices for Local Heating of Welds in Piping and Tubing</i>                          |
| D10.11M/D10.11 | <i>Recommended Practices for Root Pass Welding</i>                                                    |
| 10.12M/D10.12  | <i>Guide for Welding Mild Steel Pipe</i>                                                              |
| D10.13/D10.13M | <i>Recommended Practices for Brazing of Copper Pipe and Tubing for Medical Gas Systems</i>            |

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