

How to Weld Type 2205 Code Plus Two® Duplex Stainless Steel

Material Description

2205 is a duplex (austenitic-ferritic) stainless steel that combines many of the best properties of austenitic and ferritic stainless steels. High chromium and molybdenum contents provide excellent resistance to pitting and crevice corrosion. The duplex structure is highly resistant to chloride stress corrosion cracking. 2205 has outstanding strength and toughness and possesses good weldability.

The trademark Code Plus Two® indicates the commitment, not only to meet the requirements for S31803 as established in ASTM and ASME, but also to meet two additional requirements. The first requirement was that nitrogen should be in the 0.14 to 0.20% range to gain its benefits in higher strength, higher corrosion resistance, greater metallurgical stability, and superior properties after welding. The second requirement was that all mill products should pass a test for the absence of detrimental intermetallic phases. The tests developed by Outokumpu Stainless for this purpose have been formalized as the ASTM A 923 standard test method.

Specifications

UNS S32205, S31803 (wrought products)

UNS S39209 (bare welding wire)

UNS J92205 (cast products)

	ASTM	ASME
Plate, Sheet, Strip	A 240, A 480	SA-240, SA-480
Bar, Billet	A 276, A 479	SA-479
Pipe, Tubing	A 789, A 790, A 928	SA-789, SA-790
Forgings, Fittings	A 182, A 815	SA-182, SA-815
Castings	A 890	
Testing	A 923	

ASME Code Case 2186 (Embossed Assemblies)

ASME/ANSI B16.34 for A 182, A 240, A 479, A 789, A 790

ASME/ANSI B16.5, ASME/ANSI B31.1 Code Case 153

ASME/SFA 5.4, SFA 5.9, and SFA 5.22 P No. 10H, Group 1

AWS/A5.4 E 2209-XX, A5.9 ER 2209, A5.22 E 2209T0-X

NACE MR0175

These special requirements now define a new quality of 2205, designated S32205. S32205 is dual certifiable as S31803, but represents what users have come to expect of 2205 steel. Both S31803 and S32205 are included in all applicable ASTM product specifications.

The increased strength of S32205, relative to that of S31803, resulting from its higher nitrogen is now being recognized by ASTM and ASME. The ASTM has designated S32205 as 2205.

Forming, Heat Treatment, and Machining

Hot Forming

2205 is hot formed in the range 2250–1750°F (1230–955°C). In this range, the material has low mechanical strength and good hot ductility. If slowly cooled or held at temperatures between 600 and 1750°F (315–955°C), the combination of strain and temperature can lead to rapid room temperature embrittlement by the formation of sigma phase and other detrimental intermetallic compounds. Full annealing with rapid cooling, ideally water quenching, is recommended after hot forming.

Cold Forming

Because of its higher strength, 2205 requires higher forces for cold forming than those typical for austenitic stainless steels. Additional allowance for springback is necessary. Outokumpu Stainless 2205 may be formed on equipment typically used for forming austenitic stainless steels, once allowance has been made for its higher strength. Designs with 2205 frequently have used its higher strength to permit reductions of gauge, significantly easing many forming applications. Full annealing and quenching is recommended after severe cold forming.

Heat Treatment

2205 is annealed at 1900°F (1040°C) minimum with subsequent rapid cooling, ideally water

quenching. This treatment applies for both full solution annealing and stress-relief annealing.

Machining

2205 may be machined with high-speed steel tooling at the same speeds and feeds as Type 316L austenitic stainless steel. With carbide tooling, positive rake angle, and C-5 and C-6 grades for roughing and finishing, respectively, should be used. Cutting speeds should be reduced by about 20% from those typical for Type 316L. The high strength of 2205 requires powerful machines and exceptionally strong and rigid tool mounting.

Welding—General Guidelines

The goal in welding any duplex stainless steel is to obtain fusion and heat-affected zones having the excellent corrosion resistance of the base metal and sufficiently high impact toughness for the application. 2205 Code Plus Two® base metal has an annealed structure with ferrite content in the range of 30–55%, and is virtually free of intermetallic phases. Welding procedures should be designed to produce this same structure in the weld metal and heat-affected zones. The weld thermal cycle, as well as filler metal and protection atmosphere, will control this structure. Near the fusion temperature, the structure of duplex stainless steels is entirely ferrite. The desired 30–55% ferrite can be achieved only if the cooling rate is slow enough to allow austenite to re-form as the weld cools. If the cooling rate is too slow, however, embrittling intermetallic phases may form in spite of the presence of the optimum ferrite content. Extremely low heat input followed by rapid cooling will produce a predominantly ferritic heat-affected zone with reduced toughness and corrosion resistance. This might occur with a GTAW wash pass or resistance spot welding. On the other hand, excessive time in the 1300–1800°F (705–980°C) range can lead to formation of intermetallic phases having a similar detrimental effect on properties.

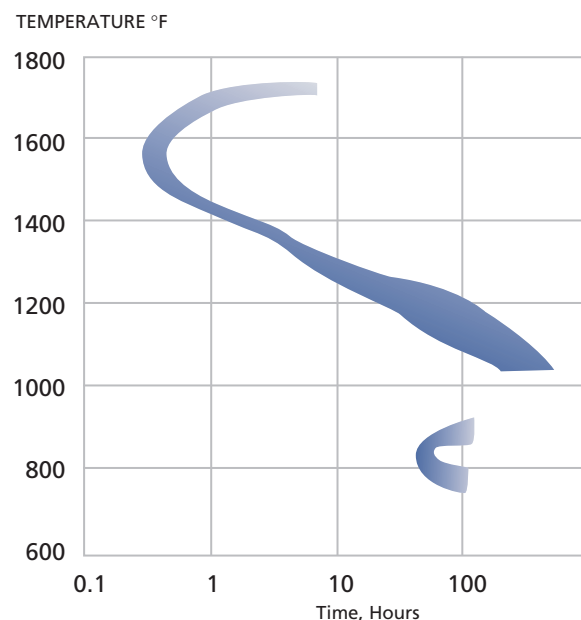
Outokumpu Stainless 2205 Code Plus Two has been produced to assist the welder. One important feature is that 2205 Code Plus Two has 0.14–0.20% nitrogen, compared to the 0.08–0.20% nitrogen permitted by ASTM and ASME. This higher

nitrogen helps austenite re-form quickly during cooling so that the weld and heat-affected zone are more easily converted back to the optimal austenitic-ferritic balance. In addition, special quality assurance procedures combined with the higher nitrogen content make 2205 Code Plus Two more resistant to formation of intermetallic phases. Avesta Welding Products 2205 filler metals, typically designated as 2209, are more highly alloyed with nickel relative to the base metal to assure a fusion zone with austenite-ferrite balance, toughness, and corrosion resistance similar to those of the base metal. With Outokumpu Stainless 2205 base metal and filler, the welder has a workable range of operating conditions. By following the guidelines provided in properly qualified procedures, the welder can produce economical constructions with consistent, high-quality welds.

Control of Intermetallic Phases

2205 duplex stainless steel can experience several precipitation reactions. The intermetallic compound, sigma phase, can precipitate between 1300–1800°F (705–980°C). Carbides can

Figure 1
Time—Temperature Precipitation Diagram for 2205 Plate with 0.14 N



The curve corresponds to an ambient temperature impact toughness of 20 ft.-lb. (27J).

precipitate between 800–1500°F (425–815°C), and “885 (425°C) embrittlement” can occur in the temperature range of 650–950°F (340–510°C). If 2205 is held for sufficiently long times in any of these temperature ranges, precipitation reactions will occur. The formation of precipitates can embrittle 2205, reducing its ambient temperature ductility and toughness, and can reduce its corrosion resistance. The rate of the precipitation reactions is dependent on the chemical composition of 2205 and other metallurgical factors. Figure 1 shows a Time-Temperature-Precipitation curve for a 2.25 inch (57 mm) thick 2205 plate with 0.14% nitrogen. The curve corresponds to an ambient temperature impact toughness of 20 ft.-lb. (27J). Time-temperature combinations to the right of the curve have less than 20 ft.-lb. of toughness.

Low Temperature Impact Tests

Low temperature impact testing may be required by the ASME code (e.g., Section VIII Div. 1 UHA-51), by a customer specification, or a requirement to meet ASTM A 923 Method B, which calls for a single impact test at -40°F (-40°C). Many factors may adversely affect the low temperature impact properties of welds, e.g., elevated ferrite content, presence of deleterious phases, and elevated oxygen content. The latter is a factor in welding processes that use a flux, and is affected by the type of flux. Welds may not meet the minimum requirements of A 923 Method B, because these acceptance criteria were established for solution annealed plate, but that does not necessarily mean detrimental intermetallic phases are present. As a general guideline, it is possible to arrange the welding processes in order of increasing impact toughness as follows: SMAW-rutile coating; FCAW; SMAW-basic coating; SAW, GMAW, GTAW. Outokumpu Stainless is willing to assist in choosing the proper welding consumable for the procedure qualifications based on test temperature.

Pitting Test

The standard pitting test used on 2205 is ASTM A 923 Method C. Prior to the creation of A 923, the pitting test was often referred to as “ASTM G 48 Practice B modified.” Testing is done in a ferric

chloride solution at a specific temperature, 25°C for base material and 22°C for annealed welds for 24 hours. Other temperatures may be set by customer specifications, sometimes with minor variations to the test method. The performance of welds in this solution may have no correlation to corrosion performance in other media and is not intended as a fitness for service test in any specific service environment. As with impact toughness, the welding process can influence corrosion performance. The welding processes in order of increasing corrosion resistance in this solution are: GTAW; GMAW; FCAW and SAW; SMAW-basic coating; SMAW-rutile coating. The low ranking of the GTAW process is explained by a loss of nitrogen from the weld pool. To counteract this effect, it is possible to either add nitrogen to the torch gas or use an overalloyed filler metal, e.g., Avesta Welding Products P100 (25Cr-9.5Ni-3.6Mo-0.22N).

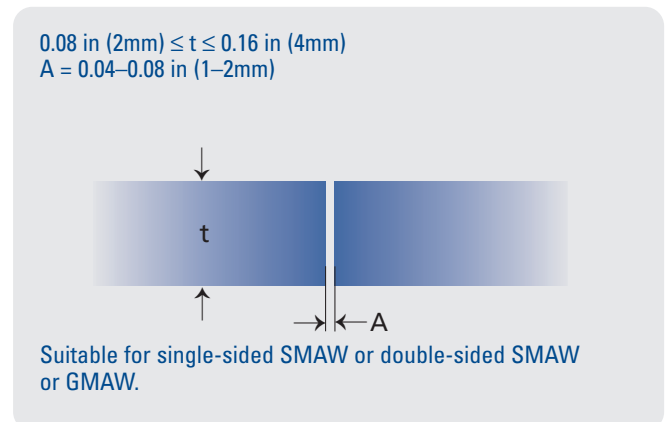
Joint Design

Some joint designs that can be used for 2205 are shown in Joint Designs 1–8. The goal of the designs is full penetration with minimal risk of burn-through. Many other designs are possible. For example, when the material thickness exceeds 0.5 inch (12 mm) and it is possible to weld from both sides, the joint designs in Joint Designs 3–5 can be made symmetrical.

The root bead may be deposited using either GTAW (TIG) or SMAW (coated electrodes). If GTAW is used, an inert backing gas should be applied when tacking. The root side of a root bead deposited by SMAW should be cleaned after

Square Butt Joint

Joint Design 1



welding. A suitable electrode diameter is $\frac{5}{64}$ – $\frac{3}{32}$ inch (2–2.4 mm), depending on base metal thickness, welding position, and accessibility for root-side grinding.

Selection of a joint design should accommodate the following guidelines:

1. It should be easy to achieve full penetration with a good margin of safety.
2. The welder should keep slag formation and the weld pool under observation.
3. Adequate backing gas shielding should be provided to avoid root defects harmful to corrosion resistance or mechanical properties.
4. Excessive weaving and wide molten pools should be avoided to prevent excessively high heat input and high stresses.

5. Extremely low heat inputs with rapid quenching should be avoided to prevent predominantly ferritic heat-affected zones.

Joint Preparation Cleaning

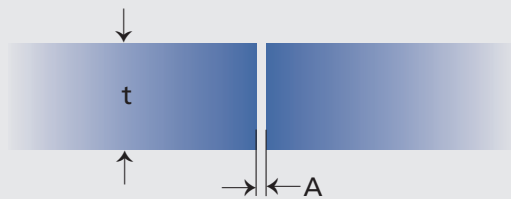
Cleaning of joints and adjacent surfaces before welding is good practice for all stainless steels. Dirt, oils, and paint can cause weld defects. Common solvents such as acetone or mineral spirits can be used as cleaning agents. Moisture in the joint can cause porosity or weld metal cracking.

It is important that joint preparation follow the desired joint design accurately. Large variations in preparation can cause substantial variations in the land thickness or the gap distance, thereby affecting the consistency of the weld. Edge preparation

Square Butt Joint

Joint Design 2

$t \leq 0.1$ in (2.5mm)
 $A = 0.04$ – 0.08 in (1–2mm)

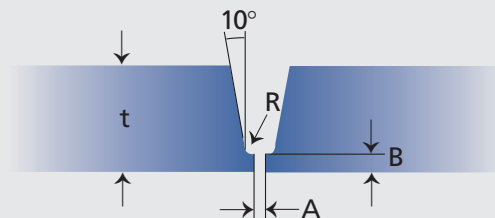


Suitable for GTAW from one side. Backing gas required.

Single U Joint

Joint Design 4

0.5 in (12mm) $< t < 2.5$ in (60mm)
 $A = 0.06$ in (1.5mm)
 $B = 0.08$ in (2mm)
 $R = 0.25$ in (6mm) radius

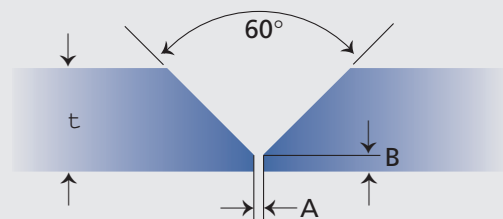


Suitable for very thick base metal with SMAW, FCAW, and GMAW. Double groove joints of this design are also suitable.

Single V Joint

Joint Design 3

0.16 in (4mm) $\leq t \leq 0.50$ in (12mm)
 $A = 0.08$ in (2mm)
 $B = 0.08$ in (2mm)

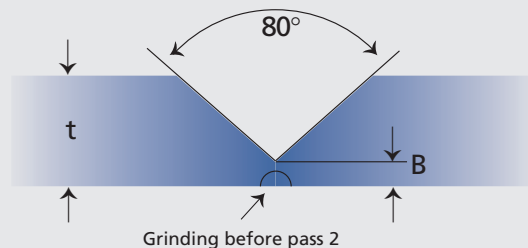


Suitable for heavier sections with SMAW, FCAW, and GMAW. Increase A to 0.12 in (3mm) for vertical up SMAW and FCAW. Double groove joints of this design are also suitable.

Single V Joint

Joint Design 5

0.36 in (9mm) $< t < 0.5$ in (12mm)
 $B = 0.1$ – 0.2 in (3–5mm)

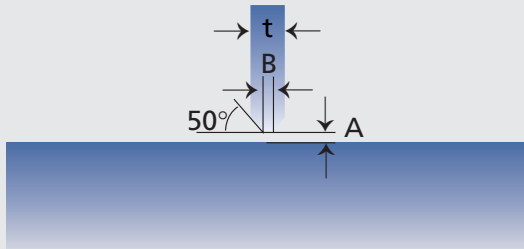


Suitable for SAW. Grinding after first pass facilitates full penetration. Double groove joints of this design are also suitable.

Fillet Joint with Full Penetration

Joint Design 6

$0.16 \text{ in (4mm)} < t < 0.5 \text{ in (12mm)}$
 $A = 0.1 \text{ in (2.5mm)}$
 $B = 0.08 \text{ in (2mm)}$

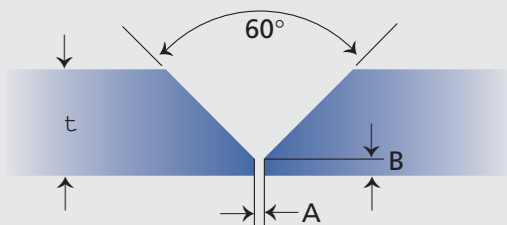


Suitable for SMAW and FCAW. Tack weld with SMAW, FCAW or GMAW.

Single V Joint

Joint Design 7

$0.16 \text{ in (4mm)} \leq t < 0.5 \text{ in (12mm)}$
 $A = 0.1 \text{ in (2.5mm)}$
 $B = 0.08 \text{ in (2mm)}$

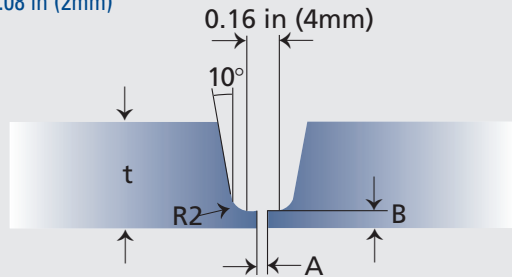


Pipe welding. Suitable with SMAW.

Single U Joint

Joint Design 8

$0.12 \text{ in (3mm)} \leq t < 0.5 \text{ in (12mm)}$
 $A = 0.04\text{--}0.08 \text{ in (1\text{--}2\text{mm})}$
 $B = 0.08 \text{ in (2mm)}$



Pipe welding. Suitable with GTAW.

may be done by a metal cutting operation, or by grinding if carefully done. Any grinding burr must be removed so it does not interfere with complete fusion.

Preheating and Post-Weld Heat Treatment

Preheating of 2205 is not normally necessary. It may be helpful in cold ambient conditions to avoid the risk of condensation and possible resultant porosity. In such cases the 2205 may be heated carefully and uniformly to less than 200°F (95°C), and only after the weld joint has been thoroughly cleaned.

If the 2205 is greater than about 0.625 inch (16 mm) thickness, and welding is to be done with very low heat input ($\leq 12 \text{ kJ/inch}$, 0.5 kJ/mm), preheating to the range of 200–300°F (95–150°C) can be useful. The purpose of this preheating is to avoid excessively rapid cooling and a resulting extremely high ferrite content. A similar upper temperature limit applies to interpass temperatures.

Postweld heat treatment is not normally necessary. If it becomes necessary for any reason, it should be done at 1900°F (1040°C) minimum, followed by rapid cooling. Exposure in the range 1200–1830°F (650–1000°C) is very harmful to toughness and corrosion resistance because of formation of carbides, or sigma or other intermetallic phases.

Interpass Temperature

The maximum interpass temperature for 2205 is 300°F (150°C).

Distortion

Controlling distortion of 2205 is not significantly different from controlling distortion of austenitic stainless steels. Good practice includes proper fixturing, cross supports, braces, staggered bead placement, and weld sequence, etc. The edges of the plate or sheet should be squared, aligned, and tacked prior to welding. The coefficient of thermal expansion of 2205 is intermediate to those for carbon steel and for austenitic stainless steels such as Type 304L.

Workmanship, Inspection, and Quality Assurance

2205 should be welded in accordance with predetermined fabrication and inspection plans by skilled and trained operators.

Fabrication of components in 2205 is not difficult but it does require some modification of the practices commonly used for Type 316L. 2205 has high strength, which may require changes of technique in cold forming. Welding can be done with little risk of hot cracking, but the welder should be aware that a high cooling rate, weld spatter, strike scars, damp electrodes, and high interpass temperatures can lead to embrittlement and reduced corrosion resistance.

To obtain welded joints with corrosion resistance and mechanical properties equivalent to those of the base metal, the welders and inspectors should be informed in advance of the special aspects of forming and welding 2205. Preparing written welding procedures and having welders perform trial welds are sensible precautions prior to beginning production.

Because 2205 is often selected for critical components in highly corrosive environments, welded joints must be inspected carefully. Incomplete fusion, incomplete penetration, a poorly cleaned root side, spatter, and strike scars must be remedied. Suitable nondestructive testing methods are X-ray inspection, liquid penetrant inspection, hydrostatic testing, leak detection, and ferrite measurement. Destructive testing methods include bend tests, impact tests, and metallographic examination. A corrosion test such as that in ASTM A 923, Method C, may also be useful.

Ferrite Measurement

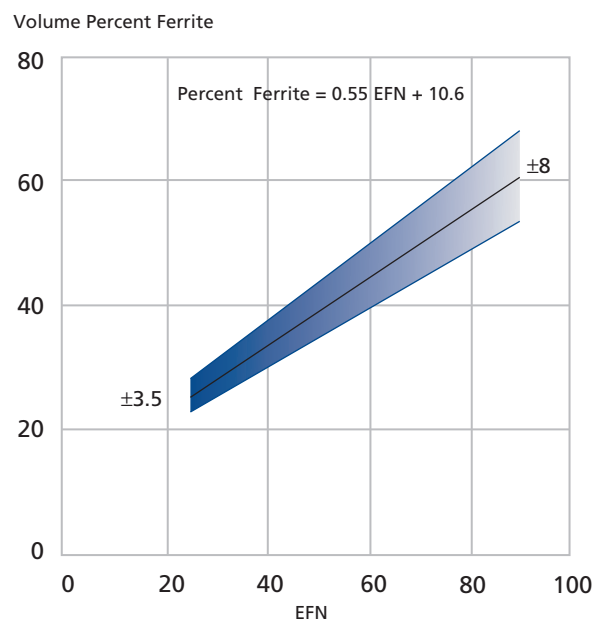
2205 Code Plus Two is controlled to have an austenitic-ferrite balance with 30–55% ferrite, typically about 45% ferrite. Substantial deviations of the austenite-ferrite ratio from this range can adversely affect the mechanical properties and corrosion resistance of the welded joint. Excessively low ferrite content (<25%) can result in reduced strength and a risk of stress corrosion cracking. Excessively high ferrite content (>75%) can lead to reduced corrosion resistance and impact toughness.

Metallographic measurement of ferrite is a destructive test and very time consuming, requiring a well-equipped laboratory. A less precise but non-destructive test method is determination of ferrite number by a Magnegage equipped with a counterweight. The Magnegage determines the

magnetic capacity of a metal by measuring the force exerted in lifting a small permanent magnet from the test surface. This force is converted to a Ferrite Number (FN). Because the original instrument went only to 28FN, a counterweight is used to extend the range to higher ferrite numbers expressed as Extended Ferrite Number (EFN). Outokumpu Stainless has used this method on a large number of unannealed weld metals and determined the relationship of EFN to the volume

Figure 2

Relationship Between Volume Percent Ferrite and EFN in Unannealed Duplex Weld Metals



fraction of ferrite measured metallographically. This relationship is shown in Figure 2 and may be expressed as:

$$\text{Volume Percent Ferrite} = 0.55 \text{ EFN} + 10.6$$

Magnetic measurements of ferrite in duplex stainless welds are best made using metallographically measured reference samples of similar weld geometry. Electronic instruments based on magnetic response, e.g., the Fischer Feritscope, also may be useful for quality control when adequately calibrated.

Dissimilar Metal Welds

For dissimilar welds such as 2205 to carbon or low alloy steels, appropriate filler metals may be Avesta Welding Products P5 wire (~AWS ER309 LMo,

nominal composition 21.5Cr-15Ni-2.7Mo-0.025C max) and Avesta Welding Products P5 electrodes and flux cored wire (AWS E309LMo, nominal composition 22.5Cr-13Ni-2.7Mo-0.04C max). For joining 2205 to an austenitic stainless steel, Avesta Welding Products P5 or another low carbon austenitic stainless filler metal with molybdenum content greater than that of the lesser of the dissimilar metals may be used. Consideration should be given to whether the filler metal will provide adequate strength in these dissimilar welds.

Removal of Dirt, Slag, and Heat Tint

To obtain the best corrosion resistance, it is essential to remove oxide, tarnish, heat tint, and other surface contamination by mechanical or chemical methods, ideally both. Because there is a very thin, chromium-depleted layer below the heat tint, wire brushing the heat tint alone is not sufficient to restore maximum corrosion resistance.

Mechanical methods include fine grinding and polishing, and abrasive blasting with 75–100 micron soda-lime glass beads. Subsequent chemical cleaning is not required if it is certain that the mechanical cleaning methods will not transfer iron to the surface. However, a chemical cleaning with nitric acid or similar media, as described in ASTM A 380 or A 967, subsequent to mechanical cleaning is good practice because it guards against contamination from the cleaning medium. Mechanical cleaning with steel brushes or an abrasive blasting medium capable of transferring iron (for example, a steel blasting medium or any blasting medium previously used on steel) must be avoided unless there is to be a subsequent complete chemical cleaning.

If mechanical cleaning is not to be used, then the removal of oxide or heat tint will require the use of pickling, a more aggressive form of chemical treatment than the removal of free iron, commonly called “passivation.” 2205 is more difficult to pickle than the 300-series austenitic stainless steels and requires an aggressive pickling solution. Pickling is readily accomplished using Avesta Welding Products RedOne 140 paste or 240 spray gel or a solution of 20% nitric acid and 5% hydrofluoric acid in water. Avesta Welding Products regular pickling paste may be used also but requires longer pickling times (e.g., two 2-hour applications vs. a

single 3-hour application with RedOne 140 paste or 240 spray gel). All of these chemicals are aggressive and appropriate precautions for personal safety, and the safety of others that you work with, as defined in ASTM A 380 must be followed. Proper environmental procedures are required for the disposal of wash liquors from pickling operations.

When SMAW or FCAW is used as a root pass, it is especially important to remove all weld splatter, slag, and heat tint from the root side. This is best accomplished by mechanical means followed by pickling.

Gas Tungsten Arc Welding (GTAW, TIG)

Equipment

Gas tungsten arc welding, also called TIG, may be performed manually or by machine. A constant-current power supply should be used, preferably with a high-frequency circuit for starting the arc and a stepless control current delay unit incorporated in the power supply unit. GTAW should be done using direct current straight polarity (DCSP), electrode negative. Use of direct current reverse polarity (DCRP) will result in rapid electrode deterioration.

Choice of Filler Metal and Electrode

The nonconsumable electrode shall meet the requirements of AWS specification 5.12 Classification EWTh-2 (2% thoriated tungsten electrode). Good arc control is achieved by grinding the electrode to a point. Vertex angles of 30–60 degrees with a small flat at the point are generally used. For automatic GTAW, the vertex angle will affect penetration. A few simple tests prior to actual fabrication should be made to determine the best electrode configuration.

For optimal corrosion performance, GTAW welds should be made with filler metal. For GTAW welding with filler, Avesta Welding Products provides a 2209 wire that is more highly alloyed with nickel relative to the 2205 base composition. It has 7.0 to 9.0% nickel as compared to the 5.5% nickel typically in the base metal. Extensive studies demonstrated that higher nickel was the most reliable and effective method of maintaining the desired austenite-ferrite balance in the weld metal

with mechanical properties and corrosion resistance equivalent to those of the base metal.

Weld Pool Protection

The weld pool in GTAW should be protected from atmospheric oxidation by inert gas flowing through the weld torch. Turbulence of the inert gas, with the resulting entrainment of air, can be minimized by a gas diffuser screen (gas lens) on the torch.

Operating procedures should be adjusted to assure adequate inert gas shielding. Gas flow should precede arc initiation by several seconds and should be held over the pool for at least five seconds after the arc is extinguished. If the flow is too low, the weld pool will not be adequately protected. If the flow is too high, gas turbulence may aspirate air into the weld region. Argon backing gas is required on the back side of the joint for all root passes, regardless of joint design. The argon should be welding grade 100% argon with a purity of at least 99.95% argon.

Approximate flow rates are 0.4–0.6 cfm (12–18 liters/minute) {0.2–0.3 cfm (6–8 liters/minute) if using a normal gas nozzle} for the electrode, and 0.1–0.7 cfm (3–20 liters/minute) for the backing purge, depending on the root volume. The enclosed volume should be purged a minimum of seven times before welding. Argon should be fed at the bottom and out at the top because of its weight relative to air.

Addition of up to 3% dry nitrogen may be considered in the torch gas for enhanced corrosion performance; however, increased electrode wear may result. Addition of helium may be useful in some circumstances. Additions of oxygen and carbon dioxide to the argon welding gas are detrimental to the corrosion resistance of the weld.

There should be regular inspections of O-rings for water-cooled torches and of gas hoses to assure that only pure, dry shielding gas is delivered to the weld area.

Welding Techniques

The joint should be prepared in one of the suggested geometries with attention to surface preparation, edge preparation, alignment, and root spacing. A non-copper backing bar may be installed to

ensure full argon backing gas coverage while making tack welds and the root pass.

Ignition of the arc should always take place within the joint itself. Any strike scars outside of the joint should be removed by fine grinding.

Tacking welds of appropriate length and spacing should be made with full argon shielding. The root pass should be made using Outokumpu Stainless 2209 filler metal and the appropriate shielding gas flow. There should be no tack weld at the starting point of the actual root pass weld. To avoid cracking of the root pass weld related to tack welds, the welder should interrupt the root pass before a tack weld. Either grind away the tack completely with a slitting wheel grinder, or make the tack shorter by grinding the start and finish of the tack prior to restarting the root pass. The width of the root gap should be maintained against shrinkage.

The start and finish of the root pass weld should be ground off prior to the start of any filler passes. The filler passes should be allowed to cool to less than 300°F (150°C) between passes. The joint may be filled using 1/16-, 3/32-, or 1/8-inch diameter (1.6-, 2.4-, or 3.2-mm) Outokumpu Stainless 2209 filler metal with 100% argon filler gas. GTA welding gives the best results when done in the flat position but vertical welds can be made successfully. The torch should be as near to perpendicular to the workpiece as possible. Excessive deviation from the perpendicular may cause air to be drawn into the shielding gas. Filler wire should be kept clean at all times and stored in a covered container.

Gas tungsten arc welding parameters depend on the material thickness, joint design, welding process, and other variables. Typical heat inputs for GTAW range from 15 to 65kJ/inch (0.5–2.5kJ/mm). Heat input is calculated by the expression:

$$\text{Heat input} = \frac{V \times A \times 60}{S \times 1000}$$

where V = voltage (volts)
A = current (amps)
S = travel speed (in/min)

Removal of Dirt, Slag, and Heat Tint

All welds should be cleaned in accordance with the procedures outlined on page 7.

Gas Metal Arc Welding (GMAW, MIG)

Equipment

Gas metal arc welding, also called MIG, is performed using a constant voltage power supply with variable slope and variable inductance control or with pulsed arc current capability. Three arc transfer modes are available.

Short-Circuiting Transfer

This mode requires separate slope and secondary inductance controls. It is useful for material up to 0.125 inch (3 mm) thick. Short-circuiting transfer occurs with low heat input and is particularly useful for joining thin sections that could be distorted by excessive heat. It is also useful for out-of-position welding.

Pulsed Arc Transfer

This mode requires two power sources, one for each of the two ranges. Switching sources produces the pulsed output. The current has its peak in the spray transfer range and its minimum in the globular range. This method provides the benefits of spray arc but limits heat input, making the method useful in all positions.

Spray Transfer

This mode provides a stable arc and high deposition rates but occurs with high heat input. It is generally limited to flat position welding. The best results are generally achieved with synergic pulsed arc. GMAW should be done with direct current reverse polarity (DCRP), electrode positive.

Choice of Filler Metal and Welding Parameters

GMAW uses a consumable electrode in the form of a continuous solid wire fed through the GMA torch by an automatic wire feed system. Avesta Welding Products 2209 filler metal is more highly alloyed with nickel relative to the base metal to help achieve the desired ferrite-austenite balance in the weld metal.

Shielding gas is typically 80% welding-grade argon with additions of helium, nitrogen,

and oxygen to enhance weldability and corrosion performance.

Typical welding parameters for spray arc transfer at a shielding gas flow rate of 0.5–0.6 cfm (14–16 liters/minute) are:

Table 1

Weld Wire (in)	Diameter (mm)	Current (amps)	Voltage (volts)
0.035	1.0	170-200	26
0.045	1.2	210-280	29
0.063	1.6	270-330	30

Typical welding parameters for short-circuiting arc transfer at a shielding gas flow rate of 0.4–0.5 cfm (12–14 liters/minute) are:

Table 2

Weld Wire (in)	Diameter (mm)	Current (amps)	Voltage (volts)
0.035	1.0	90-120	19-21
0.045	1.2	110-140	20-22

Weld Pool Protection

The weld pool in GMA welding should be protected from atmospheric oxidation by inert gas flowing through the torch. The shielding gas is typically 100% welding grade argon. Other gas mixtures may be suitable also. Appropriate flow rates are 0.4–0.6 cfm (12–16 liters/minute) for 0.035–0.063 inch (1.0–1.6 mm) diameter wire. There should be regular inspections of O-rings in water-cooled torches and of gas hoses. Welding in the presence of air drafts, regardless of welding positions, should be avoided.

Welding Techniques

Joints should be prepared in one of the suggested geometries with attention to surface preparation, edge preparation, alignment, and root spacing. A backing bar may be installed to assure gas coverage while making tack welds and the root pass. Copper backing bars should be avoided to eliminate the possibility of copper contamination and to avoid excessive cooling rates.

Ignition of the arc should always take place within the joint itself. Strike scars and spatter have

a microstructure with a very high ferrite content, a structure susceptible to cracking and possibly lower in corrosion resistance. Such defects should be removed by fine grinding.

The root pass should be made using Avesta Welding Products 2209 filler metal with the appropriate shielding gas. There should be no tack welds at the starting point of the actual root pass weld. To avoid cracking of the root pass weld related to tack welds, the welder should interrupt the root pass before a tack weld. Either grind away the tack completely with a slitting wheel grinder, or make the tack shorter by grinding the start and finish of the tack prior to restarting the root pass. The width of the root gap should be maintained against shrinkage.

The start and finish of the root pass weld should be ground prior to the start of any fill passes. The fill passes should be made with straight stringer beads. The metal should be allowed to cool to less than 300°F (150°C) between passes. The joint may be filled using 0.035-, 0.045-, or 0.063-inch (1.0-, 1.2-, or 1.6-mm) diameter Avesta Welding Products 2209 filler metal. GMA welding gives the best results when done in the flat position but vertical welds can be made successfully. The torch should be as near to perpendicular to the workpiece as possible. Excessive deviation from the perpendicular may cause air to be drawn into the shielding gas. The filler metal and guide tube should be kept clean at all times. Filler wire should be stored in a covered container.

Removal of Dirt, Slag, and Heat Tint

All welds should be cleaned in accordance with the procedures outlined on page 7.

Flux Cored Wire Welding (FCW)

Equipment

Flux cored wire welding is closely related to GMAW. The flux-filled wire is automatically fed through the center of the gun using the same equipment as when GMA welding. The shielding gas is supplied through the gun. The flux inside the wire will protect the weld from the atmosphere because it forms a slag which covers the weld. The FCW process can

be made automatic or semiautomatic. The method is economical because of the high weld deposition rate, suitability for out-of-position work, and suitability for a wide range of thicknesses.

Choice of Filler Metal and Welding Parameters

Avesta Welding Products 2209 flux cored wire carries the AWS designation A5.22 E 2209T0-1. The filler metal is more highly alloyed with nickel relative to the base metal to help achieve the desired ferrite-austenite balance in the weld metal.

The shielding gas typically used is either 75% argon plus 25% carbon dioxide or 100% carbon dioxide. The argon-carbon dioxide mixture offers the best weldability in the horizontal position and carbon dioxide the best in vertical welding.

Typical welding parameters for horizontal FCW using 75% argon plus 25% carbon dioxide shielding gas at 0.7–0.9 cfm (20–25 liters/minute) are:

Table 3

Weld Wire (in)	Diameter (mm)	Current (amps)	Voltage (volts)
0.045	1.2	150-250	22-38

Typical welding parameters for vertical FCW using 100% carbon dioxide shielding gas at 0.7–0.9 cfm (20–25 liters/minute) are:

Table 4

Weld Wire (in)	Diameter (mm)	Current (amps)	Voltage (volts)
0.045	1.2	60-110	20-24

Welding Techniques

Joints should be prepared in one of the suggested geometries with attention to surface preparation, edge preparation, alignment, and root spacing. Copper backing bars should be avoided to eliminate the possibility of copper contamination and to avoid excessive cooling rates.

Ignition of the arc should always take place within the joint itself. Strike scars and spatter have a microstructure with a very high ferrite content, a structure susceptible to cracking and possibly lower in corrosion resistance. Such defects should be

removed by fine grinding.

Tack welds of appropriate length and spacing should be made with full argon shielding. The root pass should be made using Avesta Welding Products 2209 filler metal with appropriate shielding gas flow. There should be no tack weld at the starting point of the actual root pass weld. To avoid cracking of the root pass weld related to tack welds, the welder should interrupt the root pass before a tack weld. Either grind away the tack completely with a slitting wheel grinder, or make the tack shorter by grinding the start and finish of the tack prior to restarting the root pass. The width of the root gap should be maintained against shrinkage. The start and finish of the root pass weld should be ground prior to the start of any fill passes. The fill passes should be made with straight stringer beads. The metal should be allowed to cool to less than 300°F (150°C) between passes. The filler metal and guide tube should be kept clean at all times. Flux cored wire should be stored in a covered container.

Removal of Dirt, Slag, and Heat Tint

All welds should be cleaned in accordance with the procedures outlined on page 7.

Shielded Metal Arc Welding (SMAW)

Equipment

Shielded metal arc welding, also called stick or covered electrode welding, is performed using a constant current power supply. SMA welding is done using direct current reverse polarity (DCRP), electrode positive.

Electrode Selection and Use

SMA welding uses a consumable electrode having a stainless steel core wire with a flux coating. This coating provides arc stability, shields the molten metal during arc transfer, and protects the weld during solidification.

Avesta Welding Products offers four electrodes for welding 2205 duplex stainless steel. 2205 Basic provides the highest impact toughness. 2205-PW-17 is an all-position electrode. 2205-17 AC/DC is an all purpose electrode for long, flat welds. 2205-VDX is for vertical down welding. All Avesta Welding

Products covered electrodes conform to AWS E 2209 requirements.

Electrodes are furnished in factory-sealed containers suitable for storage until ready for use. Once the container is opened, electrodes should be stored in an electrode oven heated to at least 200°F (95°C) to keep the coating dry because any moisture absorbed into the flux coating can cause weld porosity or weld metal cracking. The operating current required for good welding characteristics increases with increasing electrode diameter. Typical SMA welding parameters are:

Table 5

Electrode (in)	Diameter (mm)	Current (amps)	Voltage (volts)
5/64	2.0	35-60	22-28
3/32	2.5	60-80	22-28
1/8	3.25	80-120	22-28
5/32	4.0	100-160	22-28

Weld Pool Protection

In SMAW, the weld pool is protected by gases and slag from the electrode coating. To maximize this protection, the welder should maintain as short an arc as possible. “Long arc,” an increased gap between electrode and workpiece, can produce weld porosity, excessive oxidation, excessive heat input, and reduced mechanical properties.

Welding Techniques

The root pass should be made with 5/64-inch or 3/32-inch (2.0- or 2.5-mm) diameter electrodes. Larger electrodes may be used for subsequent filler passes. Ignition of the arc should always occur within the joint itself. Any strike scars or spatter should be removed by fine grinding.

SMAW should not be used to weld 2205 of less than 0.08 inch (2 mm) thickness. For optimal speed and economy, the workpiece should be in the flat position. The electrode should be held at 20 degrees (drag angle) from the perpendicular with the electrode grip inclined toward the direction of travel. The metal should be deposited in a straight stringer bead with the width of weave not exceeding two times the electrode diameter. The current should be set only high enough to

obtain a smooth arc and good fusion of the weld to the parent metal.

Removal of Dirt, Slag, and Heat Tint

All welds should be cleaned in accordance with the procedures outlined on page 7.

When SMA welding is used for the root pass, the root side should subsequently be ground smooth. All weld spatter, slag, and heat tint should be removed.

Submerged Arc Welding (SAW)

2205 Code Plus Two can be welded by submerged arc welding with minimal risk of hot cracking. Joint preparation differs somewhat from that for austenitic stainless steels. Because the 2205 weld metal does not penetrate as deeply as do the austenitic filler metals, the land or the welding parameters must be adjusted to obtain full penetration.

Choice of Filler Metal and Welding Parameters

Highly basic fluxes seem to give the best impact toughness for the duplex stainless steels. Avesta Welding Products Flux 805 provides excellent toughness with 2205 Code Plus Two.

Avesta Welding Products Flux 801 can give good impact toughness for material less than about 0.75-inch (20-mm) thick.

For SAW, Avesta Welding Products 2209 wire should be used. However, if 2205 is to be welded to austenitic stainless steels, carbon steel, or low-alloy steels, Avesta Welding Products P5 (nominal composition, 21.5Cr-15Ni-2.7 Mo-0.025C max) filler can be used.

Typical submerged arc welding parameters are:

Table 6

Weld Wire (in)	Diameter (mm)	Current (amps)	Voltage (volts)
$\frac{3}{32}$	2.6	250-450	28-32
$\frac{1}{8}$	3.25	300-500	29-34
$\frac{5}{32}$	4.0	400-600	30-35
$\frac{13}{64}$	5.0	500-700	30-35

Removal of Dirt, Slag, and Heat Tint

All welds should be cleaned in accordance with the procedures outlined on page 7.

Outokumpu Stainless Welding Consumables

Avesta Welding Products, Inc. provides coated electrodes; wires for GTAW, GMAW, FCW, and SAW, welding fluxes, and pickling pastes, all of which have been formulated to produce excellent results when welding Outokumpu Stainless 2205 Code Plus Two. For these products, call Avesta Welding Products at 1-800-441-7343.

Technical Support

Outokumpu Stainless, assists users and fabricators in the selection, qualification, installation, operation, and maintenance of 2205 Code Plus Two duplex stainless steel. Technical personnel, supported by the research laboratory of Outokumpu Stainless, can draw on years of field experience with Outokumpu Stainless 2205 Code Plus Two to help you make the technically and economically correct materials decision.

Outokumpu Stainless is prepared to discuss individual applications and to provide data and experience as a basis for your selection and fabrication of 2205 Code Plus Two.

Outokumpu Stainless works closely with its distributors to ensure timely availability of 2205 Code Plus Two in the forms, sizes, and quantities required by the user. For assistance with technical questions and to obtain top quality 2205 Code Plus Two, call Outokumpu Stainless at 1-800-833-8703.

2205 Code Plus Two is a registered trademark of Outokumpu Stainless, Inc.

Outokumpu Stainless is a core business within Outokumpu, a dynamic metals and technology group operating worldwide and marketing its metals, metal products, technology and services to customers in a wide range of industries.



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