How to Weld 2205 Code Plus Two®

UNS S32205, UNS S31803

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 UNS S31803 as established in ASTM and ASME, but also to meet two additional requirements. The first requirement was that nitrogen should be in the 0.14-0.20% 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 New Castle for this purpose have been formalized as the ASTM A923 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 UNS 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, and 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 slow 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, and additional allowance for springback is necessary. New Castle 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 thickness, 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 40–55%, and is virtually free of intermetallic phases. Welding procedures should be designed to produce a similar microstructure in the weld metal and heat-affected zones. The weld thermal cycle, as well as filler metal and protective atmosphere, will control this structure. Near the fusion temperature, the structure of duplex stainless steels is entirely ferrite. The desired 35–65% 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. Excessive time in the 1300–1800°F (705–980°C) range can lead to formation of intermetallic phases having a detrimental effect on properties. 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.

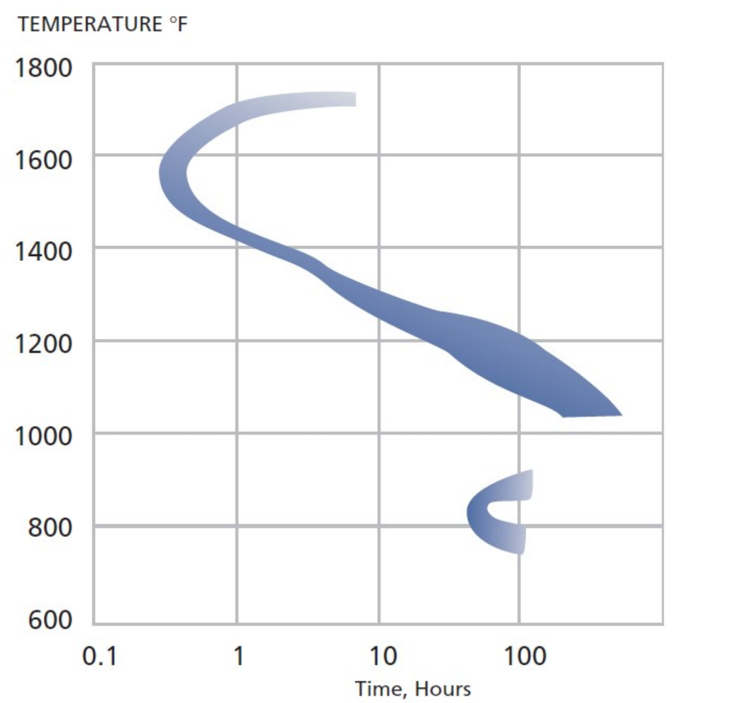
New Castle 2205 Code Plus Two has been produced to assist the welder. One important feature is that 2205 Code Plus Two has 0.14–0.20% nitrogen, compared to the 0.08–0.20% nitrogen permitted by ASTM and ASME. This higher nitrogen helps austenite re-form quickly during cooling so that the weld and heat -affected zone are more easily converted back to the optimal austenitic-ferritic balance. In addition, quality assurance procedures combined with the higher nitrogen content make 2205 Code Plus Two more resistant to the formation of intermetallic phases. 2205 filler metals, typically designated as AWS 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 2205 base metal and AWS 2209 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 precipitate between 800–1500°F (425–815°C), and “885F (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 .

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).

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 A923 Method B, which calls for a single impact test at -40F (-40C). 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 A923 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. New Castle is willing to assist in choosing the proper welding technique for the procedure qualifications based on test temperature.

Pitting Test

The standard pitting test used on 2205 is ASTM A923 Method C. Testing is done in a ferric chloride solution for 24 hours at a specific temperature, 25C for base material and 22C for welds. 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. 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 shielding gas or use an over-alloyed filler metal, such as AWS 2594.

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

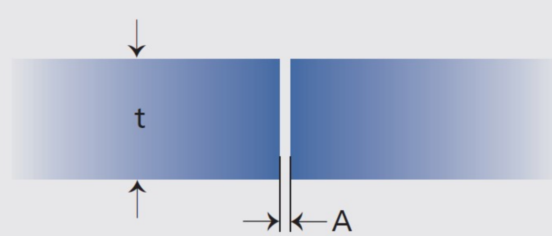
Selection of a joint design should accommodate the following guidelines:

- It should be easy to achieve full penetration with a good margin of safety.
- The welder should keep slag formation and the weld pool under observation.

Square Butt Joint

Joint Design 1

0.08 in (2mm) ≤ t ≤ 0.16 in (4mm)
A = 0.04–0.08 in (1–2mm)



Suitable for single-sided SMAW or double-sided SMAW or GMAW.

- Adequate backing gas shielding should be provided to avoid root defects harmful to corrosion resistance or mechanical properties.
- Excessive weaving and wide molten pools should be avoided to prevent excessively high heat input and high stresses.
- Extremely low heat inputs with rapid quenching should be avoided to prevent predominantly ferritic heat-affected zones.

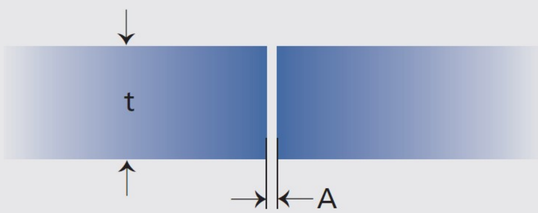
Joint Preparation Cleaning

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 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.

Square Butt Joint

Joint Design 2

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

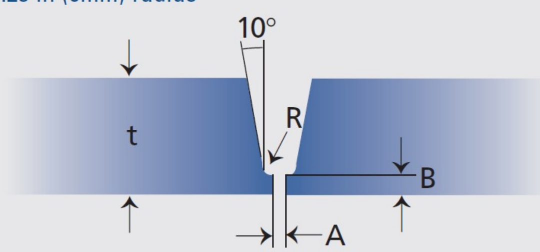


Suitable for GTAW from one side. Backing gas required.

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

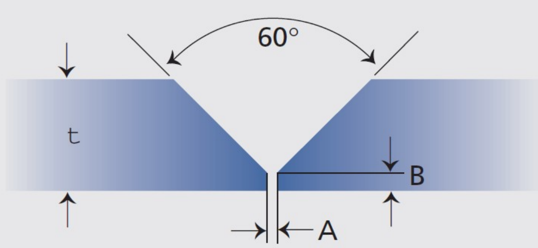


Suitable for very thick base metal with SMAW, FCAW, and GMAW. Double groove joints of this design are also suitable.

Single V Joint

Joint Design 3

0.16 in (4mm) ≤ t ≤ 0.50 in (12mm)
A = 0.08 in (2mm)
B = 0.08 in (2mm)

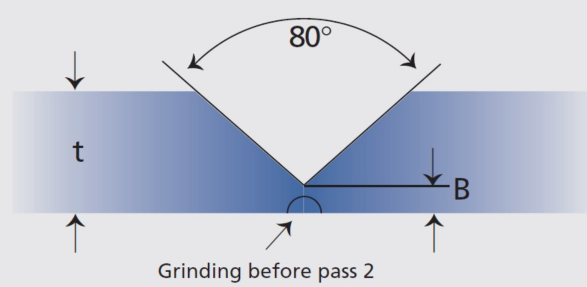


Suitable for heavier sections with SMAW, FCAW, and GMAW. Increase A to 0.12 in (3mm) for vertical up SMAW and FCAW. Double groove joints of this design are also suitable.

Single V Joint

Joint Design 5

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

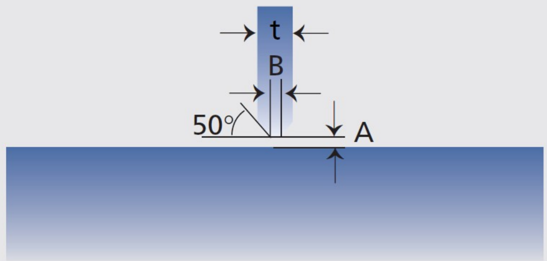


Suitable for SAW. Grinding after first pass facilitates full penetration. Double groove joints of this design are also suitable.

Fillet Joint with Full Penetration

Joint Design 6

0.16 in (4mm) < t < 0.5 in (12mm)
A = 0.1 in (2.5mm)
B = 0.08 in (2mm)

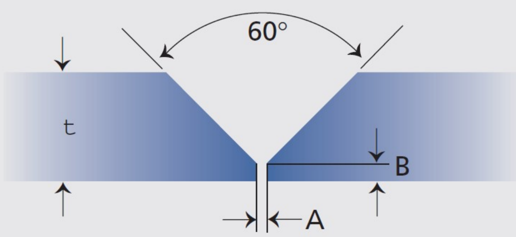


Suitable for SMAW and FCAW. Tack weld with SMAW, FCAW or GMAW.

Single V Joint

Joint Design 7

0.16 in (4mm) ≤ t < 0.5 in (12mm)
A = 0.1 in (2.5mm)
B = 0.08 in (2mm)

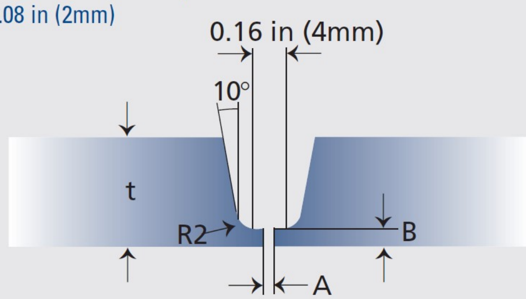


Pipe welding. Suitable with SMAW.

Single U Joint

Joint Design 8

0.12 in (3mm) ≤ t < 0.5 in (12mm)
A = 0.04–0.08 in (1–2mm)
B = 0.08 in (2mm)



Pipe welding. Suitable with GTAW.

Preheating and Post-Weld Heat Treatment

Preheating of 2205 is not normally necessary unless it is to avoid the risk of condensation. 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 (≤12 kJ/inch, 0.5 kJ/mm), pre-heating 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 an extremely high ferrite content. A similar upper temperature limit applies to interpass temperatures.

Post-weld 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 1300–1800°F (700–980°C) is very harmful to toughness and corrosion resistance because of the formation of carbides, 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 procedures by skilled and trained operators.

Fabrication of 2205 components 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 welding trials are required 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 A923, Method C, may also be useful.

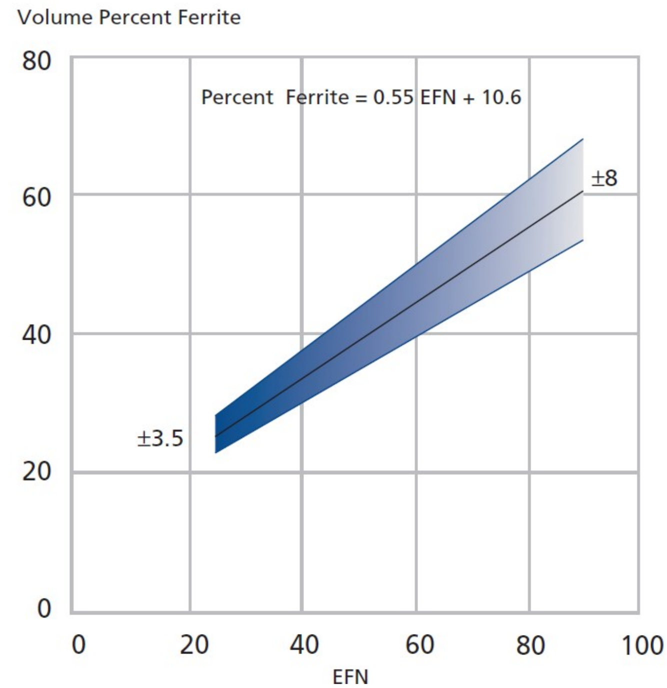
Ferrite Measurement

2205 Code Plus Two is controlled to have an austenitic-ferrite balance with 40–55% 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 per ASTM E562 is a destructive test and time consuming, requiring a well-equipped laboratory. A less precise but non-destructive test method is determination of ferrite number by magnetic measurements of ferrite in duplex stainless welds. Electronic instruments based on magnetic response, e.g., the Fischer Feritscope, is useful for quality control when adequately calibrated.

Figure 2

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



Dissimilar Metal Welds

For dissimilar welds such as 2205 to carbon or low alloy steels, appropriate filler metals such as AWS E/ER309LMo may be used. For joining 2205 to an austenitic stainless steel, AWS E/ER309LMo 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 oxides, 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 alternative acids, as described in ASTM A380 or A967, 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 a subsequent chemical cleaning.

If mechanical cleaning is not to be used, then the removal of oxide or heat tint will require the use of acid 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. All of these chemicals are aggressive and appropriate precautions for personal safety as defined in ASTM A380 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, use of a 2209 wire is more highly alloyed with nickel relative to the 2205 base composition. 2209 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) for the shielding gas, 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 to enhance penetration when welding thicker sections. 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 AWS ER2209 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) AWS ER2209 filler metal with an argon based shielding 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)

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. AWS 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 welding-grade argon with additions of helium and carbon dioxide 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 shown in Table 1:

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 shown in Table 2:

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 argon based as discussed above. 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

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 AWS ER2209 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 AWS ER2209 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.

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

AWS 2209 flux cored wire 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 shown in Table 3:

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 AWS 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.

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.

AWS E2209 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 shown in Table 5:

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.

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, AWS ER2209 wire should be used. However, if 2205 is to be welded to austenitic stainless steels, carbon steel, or low-alloy steels, AWS ER309LMo can be used.

Typical submerged arc welding parameters are shown in Table 6:

Table 6

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

New Castle

Technical Support

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

New Castle 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 New Castle at 1-800-349-0023.

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