MODERN SAW

Mild Steel and Low Alloy
Submerged Arc Welding Guide

LINCOLN ELECTRIC

Lincoln Electric is the world's leading manufacturer of welding equipment and consumables. Our focus is on helping companies make their welding operations more effective, more efficient, and more profitable.

We are dedicated to two equally important goals: exceptional quality and exceptional service. Our field support team — with hundreds of field sales engineers and thousands of knowledgeable and responsive Lincoln Electric distributors in countries all over the world — is the largest in the industry.

Innovative thinking. A service-first attitude. Fresh approaches to design, manufacturing and packaging. Worldwide strength.

THAT'S LINCOLN ELECTRIC.

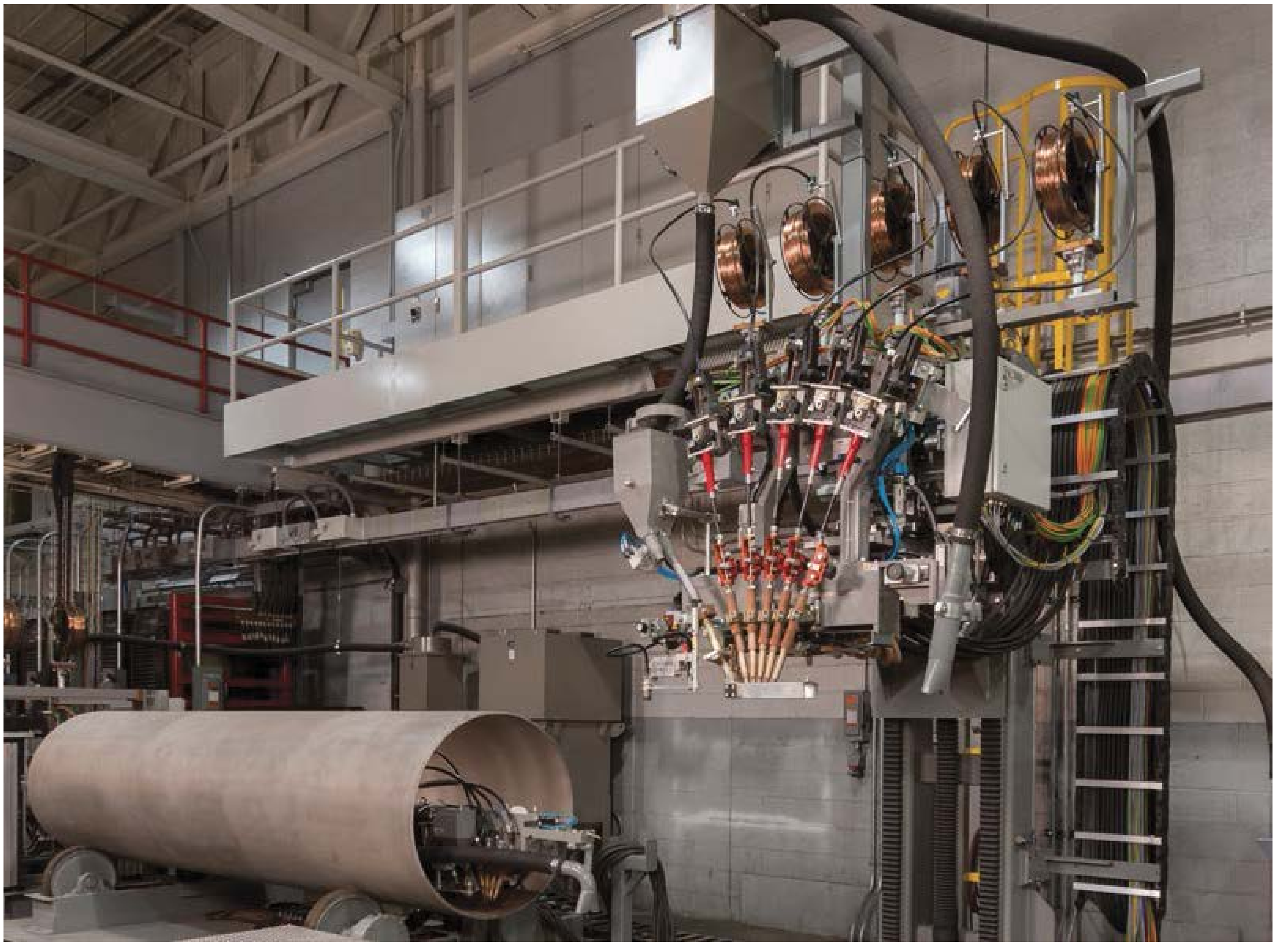
LET US PUT OUR EXPERIENCE TO WORK FOR YOU

Lincoln Electric's Power Wave® AC/DC 1000® SD Subarc Welder Technology Is One of a Kind on the Market.

As a leading supplier of welding equipment and consumables, Lincoln Electric is the leader in submerged arc welding technology. The Power Wave® AC/DC 1000® SD subarc welder is the only one of its kind on the market and, for professional welders, it is considered the standard in the subarc discipline. Lincoln Electric's advanced submerged arc systems couple the industry's most advanced power source with mobile, hard automation or robotic equipment to achieve new levels of welding performance and operational efficiency. Whether your application is bridge decking, pressure vessels, panel line, seamer, pipe mill integrator solutions or submerged arc robotic welding, the software-driven Power Wave® AC/DC 1000® SD subarc welder and your choice of integrated feeding equipment can help your operations improve weld quality, reduce operational costs and increase productivity.

LINCOLN ELECTRIC'S POWER WAVE® AC/DC 1000® SD SUBARC WELDER TECHNOLOGY

The Power Wave® AC/DC 1000® SD subarc welder, when combined with Lincoln Electric SAW consumables, can help increase productivity, quality, and flexibility by delivering Waveform Control Technology® features to submerged arc welding. Choose constant current (CC) or constant voltage (CV) operation and set variable frequency and amplitude. Software-driven AC, DC positive or DC negative output allows the user to control the deposition rate and penetration. The benefit, over conventional power sources, can be increased weld speeds, more consistent & higher quality welds, and improved efficiencies in a single or multi-arc environment. For more information see Section 6.



Five Arc Welding Cell

WHAT MAKES THE POWER WAVE® AC/DC 1000® SD SUBARC WELDER STAND OUT FROM THE REST?

Top Features

» With 380 – 575 VAC and 50/60Hz voltage input, it has the ability to connect anywhere in the world.

» It is easy to parallel machines or run multiple arcs.

» The 3-phase voltage input eliminates the imbalance with transformer-based AC welding machines.

» IP23 environmentally rated, it can be stored outdoors.

» Software-based controls allow upgrades as new features become available.

Lincoln Electric provides the products, expertise, and support to help you meet your goals of consistent, high quality subarc welds. Lincoln Electric's Power Wave® AC/DC 1000® SD subarc welder, combined with help from our technical services team, helps make precise subarc welding easier to achieve.

Contents

SECTIONS:

Contents

Subarc Set Up for Use


DANGER
HOT
LINCOLN ELECTRIC

INTRODUCTION TO SUBMERGED ARC WELDING

Going back to the Middle Ages, the first form of welding was forge welding. During the 1800s, oxyacetylene welding was developed. In 1890, C.L. Coffin of Detroit was awarded the first U.S. patent for metal arc welding, which ushered in the dawn of modern electric arc welding.

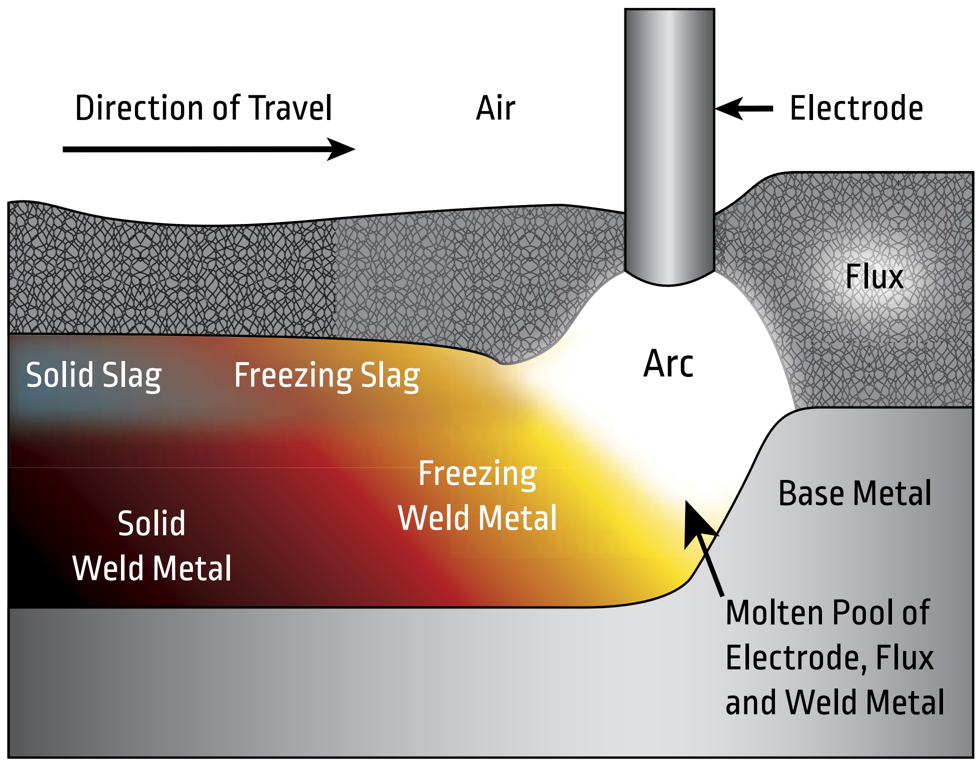


Figure 1-1: Cross Section of a Typical Submerged Arc Weld

Submerged arc welding (SAW) is a welding process that predates gas metal arc welding (GMAW) and flux cored arc welding (FCAW) by a number of years. First patented in 1925, submerged arc welding is generally indicated on welding documents as “SAW,” and is commonly referred to as "subarc." Welding consumables for submerged arc welding are classified to industry standards, such as AWS/SFA-5.17 for plain carbon steels and AWS/SFA-5.23 for low-alloy steels.

Submerged arc welding consists of continuously feeding a solid or cored electrode through a bed of granular material called flux. This flux covers and protects the arc that is established between the electrode and the work piece (see Figure 1-1 on page 11). A certain amount of flux is melted and may function to add or remove alloy from the weld, as well as provide fluxing agents to assure clean, dense weld deposits.

The term *submerged arc* accurately describes one of the major advantages of the process — the absence of a visible arc that is present with other forms of electric arc welding. With no need for dark welding glasses or a welding helmet to protect the operator from arc radiation and weld spatter, operator comfort and safety are optimized. The relatively small amount of smoke and fume generation is another advantage to the subarc process. Because the arc is submerged, the lack of visibility can also be a limitation as the welder is limited in his or her ability make changes to the weld "on the fly," relying more on correct setup and fixturing.

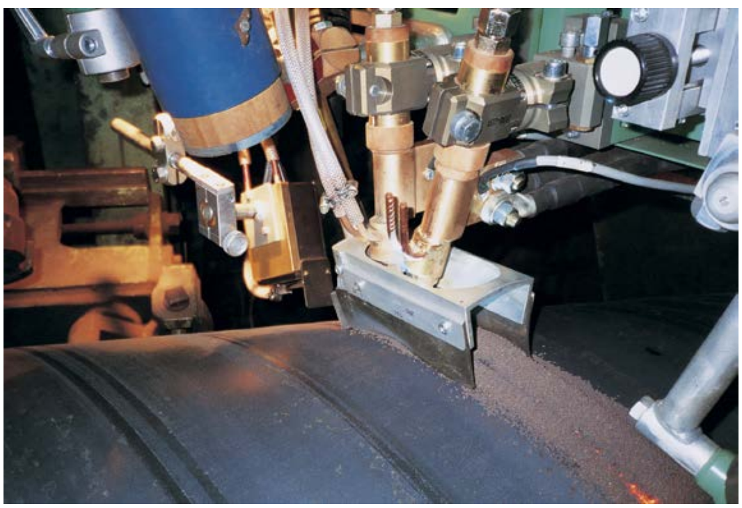


Figure 1-2: Automated Submerged Arc Weld in Progress

With single electrodes, deposition rates of weld metal range from 5 – 45 lbs/hr (3 – 20 Kg/hr) and with multiple-electrode techniques, deposition rates can reach 85 lbs/hr (39 Kg/hr) or more. The majority of SAW welding is done with some type of hard automation, making the purchase and set up of the proper equipment for the application a critical decision (see Figure 1-2). Some end users weld with SAW by hand (semi-automatically) and others use robotics to completely automate the welding process.

1.1 ADVANTAGES OF SUBARC WELDING

- Minimal fumes and arc visibility (radiation)
- Well suited to welding thick sections
- Delivers highest deposition rates and deepest penetration of any arc welding process
- Produces high-quality welds
- Excellent repeatability from weld to weld

1.2 DISADVANTAGES OF SUBARC WELDING

- Relatively high initial startup cost
- Limited portability
- Granular welding flux must be used
- Complex equipment setup
- Lack of visibility limits ability to make corrections during welding
- Limited to flat and horizontal welding only

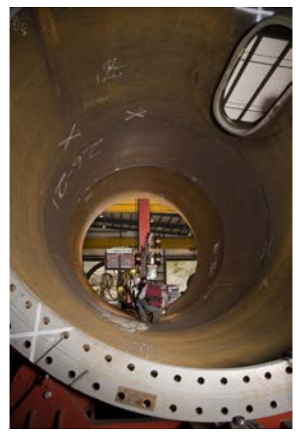
1.3 APPLICATIONS

The subarc process produces weld metal that is suitable for low- and medium-carbon steels, high-strength alloys, stainless steels and some nickel steels. The subarc process may be applied in the construction, fabrication or repair of:

- Pipe, pressure vessels, and cylindrical or conical items
- Ship construction
- Hardfacing overlays including strip cladding
- Structural steel for structures and bridges
- Earth moving, mining, and construction equipment
- Farm equipment
- Heavy machinery components
- Transportation equipment
- Offshore rigging

A

B



C

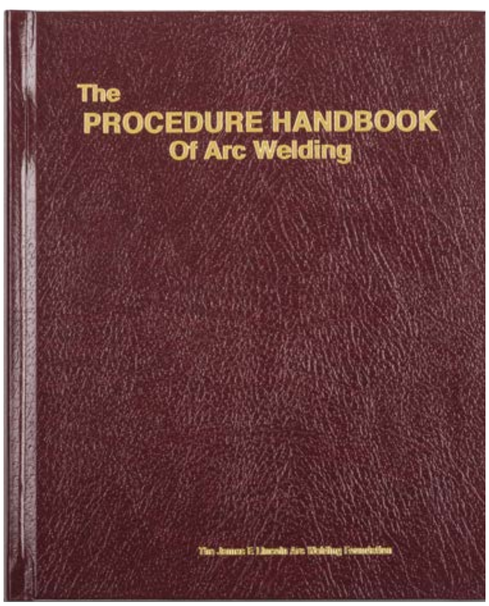
Figure 1-3: Industry SAW Uses; A, Structural Steel Fabrication; B, Wind Tower Construction; C, Bridge Construction

This guide will detail the recommended selection of equipment for the various methods of subarc welding. In addition, consumable selections, and other significant recommendations are outlined. Some of the most common welding procedures are highlighted utilizing each of the modes.

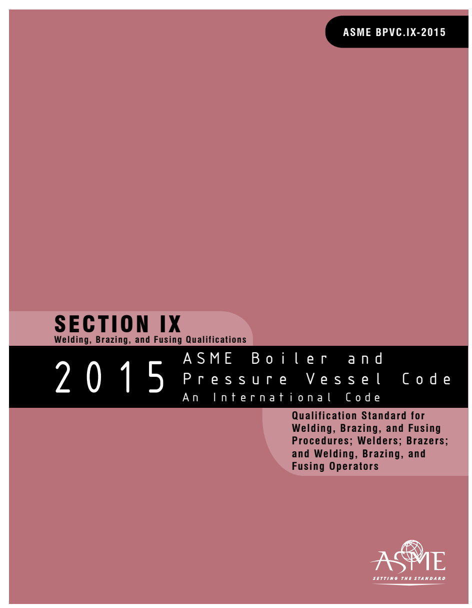
The subarc welding content in this guide references the specific requirements that numerous code bodies require for finished welds, and in some cases, how the weld may be made. Deposition rates, with amps versus wire-feed speed data, are provided to assist in determining suitable arc travel speed for the desired weld size.

This guide highlights common AWS/ASME codes that will prove helpful. Other code bodies have similar rules for qualifying and controlling submerged arc welding.

A



B



C

Figure 1-4: Welding Code Reference Books; A, The Procedure Handbook of Arc Welding; B, ASME Section IX Boiler and Pressure Vessel Code; C, AWS D1.1 Structural Welding Code – Steel.

Notes

The first step to a successful subarc welding project is to select the proper flux and electrode combination to suit the type of weld(s) to be made and produce results that will comply with any specific code or chemistry requirements.

SAW CONSUMABLES, PROCESS AND MODE SELECTION

Section II focuses on making the proper flux and wire (electrode) combination decisions. This section provides insights for choosing the appropriate process and the type of output (mode) best suited for the required application.

2.1 FLUX FUNCTION AND SELECTION

Figure 2-1: Flux in Bags, Bucket, and Bulk Package

SAW flux serves many purposes. Flux provides protection from atmospheric contaminants, as well as providing protection for the operator (by having little to no visible arc and minimal smoke and fume). Flux adds cleaning agents and can add or remove alloy from the weld pool while potentially reducing the carbon content in the weld deposit. While stabilizing the arc, flux provides the appropriate slag viscosity and freezing range for the intended application. It is designed for convenient slag removal from the weld deposit.

Changes to arc voltage will change flux consumption. Higher arc voltages and the resulting longer arc length will increase the amount of flux melted or consumed. When flux contains an alloy, increasing the arc voltage increases the amount of alloy recovered in the weld deposit.

AWS categorizes fluxes into three types (reference AWS A5.17 and A5.23):

- Active flux
- Neutral flux
- Alloy flux

Active Fluxes

Active fluxes are fluxes containing controlled amounts of manganese, silicon, or both. These deoxidizers are added to the flux to improve resistance to porosity caused by contaminants on, or in, the base metal. Active fluxes are primarily used to make single pass welds, even on oxidized base metal.

Changes in the arc voltage affect the alloy in the weld deposit and ultimately the welding deposit's mechanical properties. Alloy in the weld deposit can enhance weld metal strength, but may lower the weld metal ductility.

Key points for active flux submerged arc welding:

- Provides improved resistance to pockmarking or porosity cause by mill scale.
- Identified as Lincoln Electric's 700 Series fluxes, 760™, 761®, 780®, etc.
- Makes single pass welds with the fewest defects.
- Offers limited multiple pass welding applications.

Neutral Fluxes

Neutral fluxes are fluxes that will not produce any significant change in the all-weld metal composition as a result of a large change in the arc voltage, and thus the arc length. Neutral fluxes are used in multiple pass welding to limit alloy buildup. Neutral fluxes are also used for general welding on clean steel and are used for many stainless, nickel and hardfacing applications with high alloy electrodes.

Considerations Concerning Neutral Fluxes:

1. Since neutral fluxes contain little or no alloy, they have little resistance to cracking or porosity caused by contaminants, especially on single pass, high base metal dilution welds.
2. Even when a neutral flux is used to maintain the weld metal composition through a range of welding voltages, weld properties such as strength and impact toughness can change. Changes occur due to the alterations in cooling rate, penetration, heat input, and the number of passes, so welding procedures or instructions should address the essential variables listed in AWS D1.1 or ASME Sec. IX as a minimum.

Key Points for Neutral Flux Submerged Arc Welding:

» With a change in arc voltage, there is little change in the amount of Mn or Si levels in the weld metal.

» All Lincolnweld® 800 and 900 series fluxes are neutral, as well as many fluxes such as WTX®, SPX80® and MIL800-H®.

» Neutral fluxes are suitable for unlimited thicknesses.

» There are few deoxidizing characteristics of neutral flux.

» Weld metal composition is maintained through a range of welding voltages.

Alloy Fluxes

Alloy fluxes may be used to make alloyed weld deposits with a plain carbon steel electrode. The alloys for the weld deposit are added as ingredients in the flux. Alloy fluxes can also be used with alloyed steel electrodes such as in the case of chromium compensating for stainless steel joining or cladding.

Since the alloy level in the weld deposit is dependent upon the arc voltage and the arc length, it is very important the voltage is carefully controlled to ensure intended alloy levels are reached in the deposit.

Key Points for Alloy Flux Submerged Arc Welding:

» Alloyed weld deposits

» Hardfacing, cladding, and joining applications

» Tailored weld deposit composition

» Composition dependent on welding procedures

See Table 2-1: Lincoln Electric Active, Neutral and Alloy Fluxes on page 20.

Table 2-1: Lincoln Electric Active, Neutral and Alloy Fluxes*	
Categorized by Active or Neutral Type Flux	
Active Fluxes	
Lincolnweld® 760™	Lincolnweld® 761®
Lincolnweld® 780®	Lincolnweld® 781™
Lincolnweld® 761-Pipe	
Neutral Fluxes	
Lincolnweld® 822™	Lincolnweld® 882®
Lincolnweld® 842-H®	Lincolnweld® 888®
Lincolnweld® 860®	Lincolnweld® 8500®
Lincolnweld® 865®	Lincolnweld® MIL800-H®
Lincolnweld® 880™	Lincolnweld® 812-SRC®
Lincolnweld® 880M™	Lincolnweld® 801®
Lincolnweld® LA490™	Lincolnweld® 802™
Lincolnweld® 960™	Lincolnweld® 995N®
Lincolnweld® 980®	Lincolnweld® SPX80®
Lincolnweld® P223®	Lincolnweld® SPX80N®
Lincolnweld® P2000™	Lincolnweld® WTX®
Lincolnweld® P2007™	
Alloy Fluxes	
Lincolnweld® A-XXX-10™	Lincolnweld® MIL800-HPNI™
Lincolnweld® ST-100™	

*This is a partial listing; please refer to the complete listing at LincolnElectric.com. (bulletin C1.10).

2.2 ELECTRODE FUNCTION AND SELECTION

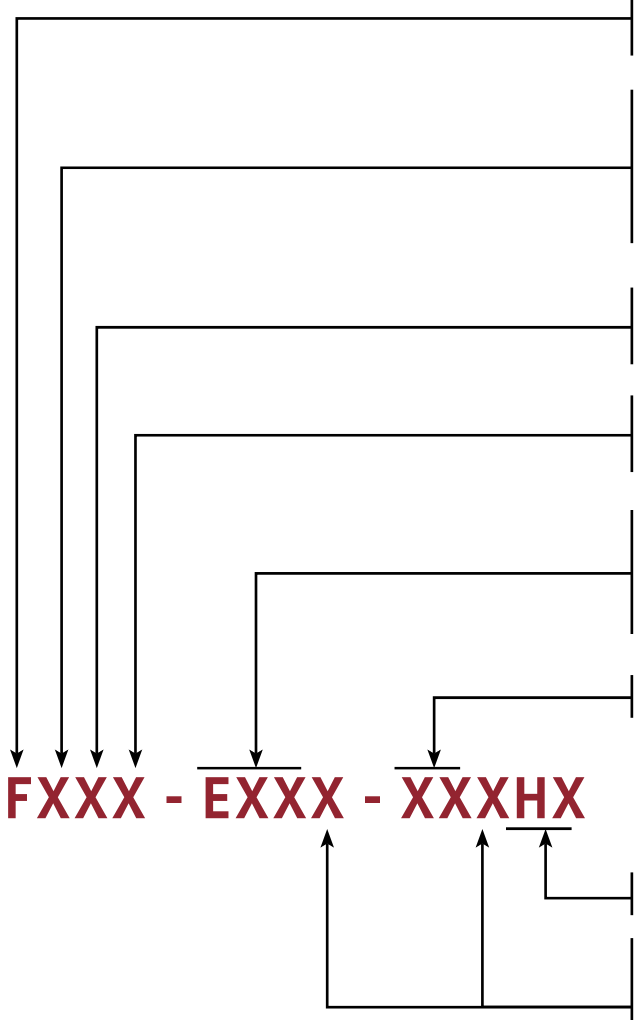
The wire, or electrode, is a key element in the submerged arc welding process. This solid or cored wire consumable carries the current to the work providing heat for melting base material and adding to the weld puddle. The electrode may contain certain alloys to assist with the mechanical and chemical requirements of the weld. Copper or other coatings may be applied to the electrode to facilitate current transfer from the contact tip to the electrode.

Figure 2-2: Stem Pack Bulk Packaging; 60# (27.2Kg) Packaging

Table 2-2: Lincoln Electric Mild Steel and Low Alloy Electrodes*	
Mild Steel Solid Electrodes	
Lincolnweld® L-60™	Lincolnweld® L-56®
Lincolnweld® L-61®	Lincolnweld® L-S3™
Lincolnweld® Emergence 61®	Lincolnweld® LA-71™
Lincolnweld® L-50®	
Low-Alloy Solid Electrodes	
Lincolnweld® AK-10®	Lincolnweld® LA-85™
Lincolnweld® L-70™	Lincolnweld® LA-90™
Lincolnweld® LA-75™	Lincolnweld® LA-92™
Lincolnweld® LA-81™	Lincolnweld® LA-93™
Lincolnweld® LA-82™	Lincolnweld® LA-100™
Lincolnweld® LA-84™	Lincolnweld® Emergence 81®
Lincolnweld® Emergence 70®	Lincolnweld® Emergence 83®
Lincolnweld® Emergence 73®	Lincolnweld® Emergence 90®
Lincolnweld® Emergence 74®	9CRMOV-N™
Low-Alloy Cored Electrodes	
Lincolnweld® LAC-B2™	Lincolnweld® LAC-690™
Lincolnweld® LAC-Ni2™	
Mild Steel Cored Electrodes	
Lincolnweld® LC-72™	

*This is a partial listing; please refer to the complete listing at LincolnElectric.com. (bulletin C1.10).

SAW – AWS Classification



MANDATORY CLASSIFICATION DESIGNATORS[a]

The letter "F" indicates a submerged arc flux. The letter "S" will appear after the "F" as part of the classification designation when the flux being classified is a crushed slag or a blend of crushed slag with unused (virgin) flux.

Indicates the minimum tensile strength (in increments of IO 000 psi) of weld metal deposited with the flux and some classification of electrode under the welding conditions specified in Figure 4 and Table 6. Two digits are used for weld metal of 100000 psi tensile strength and higher. For example, when this designator is 8, the tensi le requirement is 80000 to 100000 psi. When this designator is 11, the tensile requirement is 110000 to 130000 psi (see Table !) .

Designates the condition of heat treatment under which the tests were conducted : "A" is for as-welded and "P" for postweld heat treated. The time and temperature for PWHT are specified in 9.4 and Table 9.

Indicates the tempera ture in °F at or above which the impact strength of the weld metal referred to above meets or exceeds 20 ft·lbf. Two digits are used for test temperatures of - 100°F or lower (see Table 2).

Classification of the electrode used in producing the weld metal referred to above. The letter "E" in the first position indicates electrode. The letter "C" will appear after the "E" as part of the electrode classification when the electrode is a composite electrode. Refer to Table 4 for solid electrode classifications and Table 3 for composite electrode classifications.

Indicates the chemical composition of the weld metal obtained with the flux and the electrode . Two or more letters and/or digits are used (see Table 3).

OPTIONAL SUPPLEMENTAL DESIGNATORS[b]

Optional supplemental diffusible hydrogen designator (see Table 10).

Optional supplemental designator for special limits on residuals. An "N" , when it appears after the electrode designation or after the weld metal composi tion designation , indicates conformance to special requirements for nuclear applications (see Table 4, Note c, and Table 3, Note c). An "R" indicates conformance to special requirements for step cooling applications (see Table 4, Note h, and Table 3, Note i).

a The combination of these designators constitutes the flux-electrode classification.

b These designators are optiona l and do not constitute a part of the flux- electrode classification.

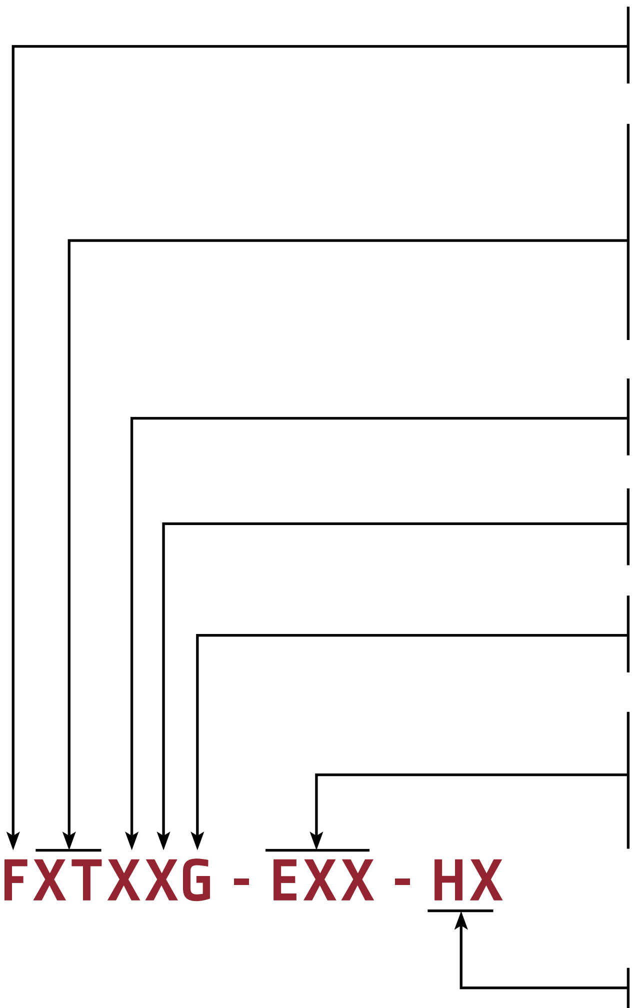
EXAMPLE

F9P0 -EB3-B3 is a comp lete designation for a flux-electrode combination. It refers to a flux that will produce weld metal which, in the postweld heat-treated condition, will have a tensile strength of 90 000 to 110 000 psi and Charpy V-notch impact strength of at least 20 ft· lbf at 0°F when produced with an EB3 electrode under the conditions called for in this specification. The composition of the weld metal will meet the requirements for a B3 designation as specified in Table 3.

Source: Figure lM of AWS A5.23/A5.23M:2007.

Figure 2-3: SAW–AWS Classifications Explained - A5.23 Multiple Pass Classification System for U.S. Customary Units

SAW – AWS Classification



MANDATORY CLASSIFICATION DESIGNATORS[a]

The letter "F" indicates a submerged arc welding flux. The letter "S" will appear after the "F" as part of the classification designation when the flux being classified is a crushed slag or blend of crushed slag with unused (virgin) flux.

Indicates the minimum tensile strength (in increments of 10 000 psi) of weld metal deposited with the flux and some specific classification of electrode under the welding conditions specified in Figure 5 and Table 7. One or two digits may be used depending on the strength leve l, as indicated in Table l. The "T" at the end of the designator identifies the classification as a two-run classification. For example, when this designator is "7T," the two-run classification tensile requirement is 70 000 psi minimum. When this designator is " JOT," the tensile requirement is I 00 000 psi minimum.

Designates the condition of heat treatment in which the tests were conducted: "A" for as-welded and "P" for postweld heat treated. The PWHT procedure is specified in 9.5.

Indicates the temperature in °F at or above which the impact strength of the weld metal referred to above meets or exceeds 20 ft· lbf. Two digits are used for test temperatures of - 100 °For lower (see Table 2).

The letter "G," when it appears in this position, indicates that the base steel used for classification is not one of the base stee ls prescribed in Table 8 but is a different steel as agreed between purchaser and supplier .

Classification of the electrode used in producing the weld metal referred to above. The letter "E" in the first position indicates electrode. The letter "C" will appear after the "E" as part of the electrode classification when the electrode is a composite electrode. Refer to Table 4 for solid electrode classifications and Table 3 for composite electrode classifications.

OPTIONAL SUPPLEMENTAL DESIGNATORS[b]

Optional supplemental diffusible hydrogen designator (see Table 10).

a The combination of these designators constitutes the flux- electrode classification..

b These designators are optional and do not constitute a part of the flux- electrode classification.

EXAMPLE

F7TA4-EM12K is a complete designation for a flux-e lectrode two-run classification. It refers to a flux that , when used with an EM12K electrode to weld the base plate prescribed in Table 8 in accordance with the two-run welding conditions called for in this specification , will produce weld metal in the as-welded condition having a minimum tensile strength of 70 000 psi and Charpy Y-Notch impact strength of at least 20 ft· lbf at -40 °F.

FI0TP2G-EA3 is a complete designation for a flux- electrode two-run classification. It refers to a flux that , when used with an EA3 electrode in accordance with the two-run welding conditions called for in this specification , will produce weld metal in the postweld heat-treated condition having a minimum tensile strength of I 00 000 psi and Charpy Y-notch impact strength of at least 20 ft· lbf at - 20°F. The "G" in the classification indicates that the base steel used is not as prescribed in Table 8 but is some other steel as agreed between purchaser and supplier

Source: Figure 2 of AWS A5.23 /A5.23M:2007.

Figure 2-4: SAW–AWS Classifications Explained - A5.23 Two-Run Classification System for U.S. Customary Units

2.3 GUIDELINES FOR SELECTING SUBMERGED ARC FLUX/WIRE COMBINATIONS BASED ON CLASSIFICATION*

*Classifications are for comparison only and are not meant to imply actual performance in an application.

Lincolnweld® submerged arc electrode and flux combinations come with certificates of conformance. If a certificate of conformance does not appear on the Lincoln Electric website, please contact your local technical sales representative.

To access the certificates:

1. Go to the Lincoln Electric home page at: www.lincolnelectric.com.
2. Click on the Support tab and select Certificate Center from the drop-down menu.
3. Flux and wire product combination certificates of conformance are available in the certificate center of the Lincoln Electric website.

Find flux/wire combinations that meet your required mechanical properties:

Tensile Strength

1. Search by Name/Cert. #/Classification in the second box under the Certificates of Conformance.
2. Enter F#P or F#A for multipass and F#TP or F#TA for two-run.
   - The (#) is 10x the minimal tensile strength in ksi.
   - The (P) represents the stress relieved condition.
   - The (A) represents the as-welded condition.
     a) For example: Entering F7P would mean you are looking for a flux/wire combination with 70 ksi tensile strength in the Stressed Relieved Condition.

Impact Requirements

1. In the list of matches for a required tensile strength, view which flux/wire combinations meet your Impact Property Requirements.
2. To meet Impact Requirements at a certain value, note that the digit following the (A) or (P) in the classifications shows the temperature the weld metal achieves a minimum of 20ft•lbf (27 J).
   a) For example, a classification beginning with F7P2 would mean the flux/wire combination meets 70 ksi (482 MPa) tensile strength in the Stress Relieved Condition with Impact Requirements of 20ft•lbs (27 J) @ -20˚F (-29˚c).

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE OF CONFORMANCE

LINCOLN ELECTRIC
THE WELDING EXPERTS®

Product: **Lincolnweld® 960® Flux / Lincolnweld® LA-75 Electrode**
Classification: **F8A2-ENi1K-Ni1-H8**
Specification: **AWS A5.23:2011, ASME SFA-5.23**
Date **May 13, 2016**

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied according to the Quality System Program of the Lincoln Electric Company, Cleveland, Ohio, U.S.A., which meets the requirements of ISO9001, NCA3800, AWS A5.01, and other specification and Military requirements, as applicable. The Quality System Program has been approved by ASME, ABS, and VdTUV.

Operating Settings	F8A2-ENi1K-Ni1-H8 Requirements	RESULTS
Electrode Size	5/32 in	5/32 inch
Polarity		DC+
Voltage, V	27 - 30	28
Wire Feed Speed, cm/min (in/min)		114 (45)
Current, A	475 - 575	525
Contact Tip to Work Distance, mm (in)	(1 - 1.5)	32 (1 1/4)
Travel Speed, cm/min (in/min)	(15 - 17)	41 (16)
Pass/Layers		15/7
Preheat Temperature, °C (°F)	(275 - 325)	150 (300)
Interpass Temperature, °C (°F)	(275 - 325)	150 (300)
Postweld Heat Treatment	As-welded	As-welded

Mechanical properties of weld deposits

Tensile Strength, MPa (ksi)	(80 - 100)	590 (86)
Yield Strength, 0.2% Offset, MPa (ksi)	(68 min.)	480 (70)
Elongation %	20 min.	28
Average Impact Energy Joules @ -29 °C (ft-lbs @ -20 °F)	(20 min.)	62 (46) 60,61,66 (44,45,48)
Average Hardness, HRB	Not Required	91

Chemical composition of weld deposits (weight %)

C	0.12 max.	0.05
Mn	1.60 max.	1.55
Si	0.80 max.	0.66
S	0.025 max.	0.008
P	0.030 max.	0.016
Cr	0.15 max.	0.05
Ni	0.75 - 1.10	0.84
Mo	0.35 max.	0.01
Cu	0.35 max.	0.13
Ti+V+Zr	0.05 max.	0.01

Electrode composition (weight %)	F8A2-ENi1K-Ni1-H8 Requirements	Electrode Results
C	0.12 max.	0.08
Mn	0.80 - 1.40	1.02
Si	0.40 - 0.80	0.63
S	0.020 max.	0.009
P	0.020 max.	0.009
Ni	0.75 - 1.25	0.94
Cu (Total)	0.35 max.	0.13

Diffusible Hydrogen (per AWS A4.3)	F8A2-ENi1K-Ni1-H8 Requirements	RESULTS
Electrode Size		5/32 inch
Polarity		DC+
Nominal Voltage, V		28
Nominal Current, A		525
Diffusible Hydrogen, mL/100g	8 max.	2
Abs. Humidity (gr moisture/lb dry air)		72

1. This certificate complies with the requirements of EN 10204, Type 2.2.
2. The electrode size required to be tested for this classification is 5/32 inch. All other sizes manufactured will also meet these requirements.
3. Radiographic Inspection: Met requirements.
4. Strength values in SI units are reported to the nearest 10 MPa converted from actual data. Preheat and interpass temperature values in SI units are reported to the nearest 5 degrees.

Product: **Lincolnweld® 960® Flux / Lincolnweld® LA-75 Electrode**
Classification: **F8A2-ENi1K-Ni1-H8**
Specification: **AWS A5.23:2011, ASME SFA-5.23**
Date **May 13, 2016**

Toronto Cunningham — May 13, 2016
Toronto Cunningham, Certification Supervisor — Date

Marie Quintana — May 16, 2016
Marie Quintana, Director, Consumable Compliance — Date

Figure 2-5: This Is a Typical Flux/Electrode Certificate of Conformance.

Choose the correct flux based on application and performance. For high-strength welds or when welding on highly restrained joints, choose a flux/wire combination with a lower diffusible hydrogen level, which is designated by the number following -H in the flux/wire classification.

For information on electrode composition or on weld metal limits, click on a flux/wire combination to see the test results.

Consult with a Lincoln Electric technical sales representative to help you make the best flux/wire selection for an application, or visit: www.lincolnelectric.com.

2.4 PROCESS VARIABLES SELECTION

There are a number of ways to implement SAW. These different techniques require distinct equipment and specific procedures to achieve a quality weld.

The SAW process is accomplished using these methods:

- Semi-automatic: Manual or by-hand/mechanized control.
- Fully mechanized.
- Fully automated control, including hard automation/robotics.
- Multiple electrode welding (two or more independent electrodes).
- Configured Twin-Electrode process, also known as Tiny Twinarc.

Specialized equipment is required for different SAW operations. While specialized equipment may be necessary for different SAW applications, the following components are always required:

- Power source
- Wire feeder
- Control panel
- Control cables
- Electrode leads
- Work leads

Lincoln Electric can provide equipment and consumables for all submerged arc welding needs, including the following components:

» Drive rolls
» Wire reels
» Contact nozzle assemblies
» Contact tips
» Mounting hardware
» Manipulators/positioners
» Seam trackers and oscillators

Table 2-3: Electrode/Work Cable Diameters Based on Amperage

Recommended Welding Cable Sizes - Rated 167° F (75° C)*						
Current (amps)	Duty Cycle (%)	Combined Lengths of Electrode and Work Cables				
		0 to 50 ft. (0 to 15.2 m)	51 to 100 ft. (15.5 to 30.5 m)	101 to 150 ft. (30.8 to 45.7 m)	151 to 200 ft. (46 to 61 m)	201 to 2.5-0 fl. (61.3 to 76.2 m)
125	30	6 (13.3mm²)	5 (16.8mm²)	3 (26.7mm²)	2 (33.6mm²)	1 (42.4mm²)
150	40	6 (13.3mm²)	5 (16.8mm²)	3 (26.7mm²)	2 (33.6mm²)	1 (42.4mm²)
180	30	4 (21.1mm²)	4 (21.1mm²)	3 (26.7mm²)	2 (33.6mm²)	1 (42.4mm²)
200	60	2 (33.6mm²)	2 (33.6mm²)	2 (33.6mm²)	1 (42.4mm²)	1/0 (53.5mm²)
225	30	3 (26.7mm²)	3 (26.7mm²)	2 (33.6mm²)	1 (42.4mm²)	1/0 (53.5mm²)
250	30	3 (26.7mm²)	3 (26.7mm²)	2 (33.6mm²)	1 (42.4mm²)	1/0 (53.5mm²)
250	60	1 (42.4mm²)	1 (42.4mm²)	1 (42.4mm²)	1 (42.4mm²)	1/0 (53.5mm²)
300	60	1 (42.4mm²)	1 (42.4mm²)	1 (42.4mm²)	1/0 (53.5mm²)	2/0 (67.4mm²)
350	60	1/0 (53.5mm²)	1/0 (53.5mm²)	2/0 (67.4mm²)	2/0 (67.4mm²)	3/0 (85.0mm²)
400	60	2/0 (67.4mm²)	2/0 (67.4mm²)	2/0 (67.4mm²)	3/0 (85.0mm²)	4/0 (107.2mm²)
400	100	3/0 (85.0mm²)	3/0 (85.0mm²)	3/0 (85.0mm²)	3/0 (85.0mm²)	4/0 (107.2mm²)
500	60	2/0 (67.4mm²)	2/0 (67.4mm²)	3/0 (85.0mm²)	3/0 (85.0mm²)	4/0 (107.2mm²)
600	60	3/0 (85.0mm²)	3/0 (85.0mm²)	3/0 (85.0mm²)	4/0 (107.2mm²)	2x2/0 (70mm²)
600	100	3/0 (85.0mm²)	3/0 (85.0mm²)	4/0 (107.2mm²)	2x2/0 (70mm²)	2x3/0 (95mm²)
650	60	3/0 (85.0mm²)	3/0 (85.0mm²)	4/0 (107.2mm²)	2x2/0 (70mm²)	2x3/0 (95mm²)
700	100	3/0 (85.0mm²)	3/0 (85.0mm²)	2x3/0 (95mm²)	2x3/0 (95mm²)	2x4/0 (120mm²)
800	100	3/0 (85.0mm²)	2x3/0 (95mm²)	2x3/0 (95mm²)	2x3/0 (95mm²)	2x4/0 (120mm²)
1000	100	3x3/0 (95mm²)	3x3/0 (95mm²)	3x3/0 (95mm²)	3x3/0 (95mm²)	3x3/0 (95mm²)
1200	100	4x4/0 (120mm²)	4x4/0 (120mm²)	4x4/0 (120mm²)	4x4/0 (120mm²)	4x4/0 (120mm²)
1500	100	5x4/0 (120mm²)	5x4/0 (120mm²)	5x4/0 (120mm²)	5x4/0 (120mm²)	5x4/0 (120mm²)

* Values are for operation at ambient temperatures of 104°F (40°C) and below. Applications above 104°F (40°C) may require cables larger than recommended, or rated higher than 167°F (75°C).

Semi-Automatic

Hand held or semi-automatic is the most basic, lowest-cost way to begin SAW. The required SAW equipment consists of a power source, a wire feeder, a welding gun (or torch), along with all the necessary cables. Semi-automatic SAW is limited to using 1/16 in. (1.6 mm), 5/64 in. (2.0 mm), or 3/32 in. (2.4 mm) diameter wires. The inability to watch or see the arc makes hand-held SAW challenging, but with practice and training, semi-automatic SAW can be quite successful.

Wire Feeders

Multi Process Welder

Flux Tank and Cart

Squirt Gun and Cable

Figure 2-6: Semi-automatic Welding Equipment

Fully Mechanized/Automatic

The most common use of SAW consists of fully mechanized or automated equipment. The equipment required for automated SAW is the same as the semi-automatic process, with the exception of the hand-held welding gun. During a mechanized/automated submerged arc weld, the hand-held weld gun is replaced by a fixed head/contact assembly that is permanently attached to a travel carriage that consistently moves the arc down the weld fixture.

Figure 2-7: Automatic Welding – Single-Electrode Equipment

Accessories tor Wire Feeders

Some of the most common accessories required for wire-fed SAW processes include flux hoppers, wire straighteners and contact assemblies. While some of these accessories are included with the wire feeders as part of the original purchase, others may be added or upgraded to the assembly. Wire diameters, wire-feed speeds, intended amperage, joint design, etc. will determine what accessories may be needed.

Figure 2-8: Flux Hopper

Figure 2-9: Positive Contact Assembly

Figure 2-10: Contact Assembly

Figure 2-11: Wire Straightener

Providing for Linear Motion

To achieve linear motion for a welding torch, implement one of these methods:

1. Use a Lincoln Electric TC-3 travel carriage (see Figure 2-12).
2. Use a self-contained tractor.
3. Use gantries and manipulators.
4. Use a travel sled to move work piece.

Lincoln Electric TC-3 Travel Carriage

This carriage may be used with any of the automatic combinations. Travel beams and suitable fabrication details are available in the TC-3 instruction manual (IM 278).

Self-Propelled Automatic Submerged Arc Tractors

The Lincoln Electric LT-7 and Lincoln Electric Cruiser® are two SAW tractors capable of manual steering, as well as track-guided steering. Both tractors may be configured to self-track horizontal lap, horizontal fillet, and flat-positioned fillet welds.

» The LT-7: May be used with any traditional constant current or constant voltage DC output welders.

» The Cruiser: This tractor is designed specifically for operation with the Power Wave® AC/DC 1000® SD subarc welder.

Figure 2-12: TC-3 Travel Carriage

Figure 2-13: LT-7 Tractor

Figure 2-14: Cruiser® Tractor

Gantries and Manipulators

The most efficient way to automate SAW is to use a gantry or manipulator to move the electrode to the work, or move the work under the electrode. These fixtures are specifically built to maximize productivity, enhance quality, and create a safer work environment.

Fully Automated, Hard Automation, and Robotics

Fully automated welding cells can be configured into a simple, push-button operation wherever maximum productivity and minimal operator input are required.

Figure 2-15: Lincoln Electric Pantheon® Column and Boom Mechanized Submerged Arc Welding System

A

B

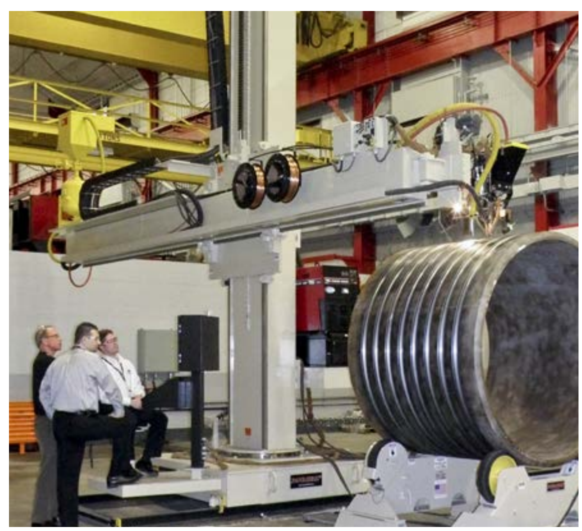


Figure 2-16: A, Robotic SAW; B, Hard Automation

Multiple Electrode Welding

Whenever the deposition rates of single-electrode welding do not meet the required productivity levels, adding more electrodes can help achieve the desired goals. The most common use of multiple electrodes is tandem arc welding, described in Section 6 of this guide.

Tiny Twinarc®

The Tiny Twinarc welding process is most commonly used to make high-speed horizontal fillet welds. It has excellent puddle follow through, which allows the process to be used at elevated travel speeds. See Section 7 of this guide for more information.

Figure 2-18: A Tiny Twinarc® Welding Cell

A

B

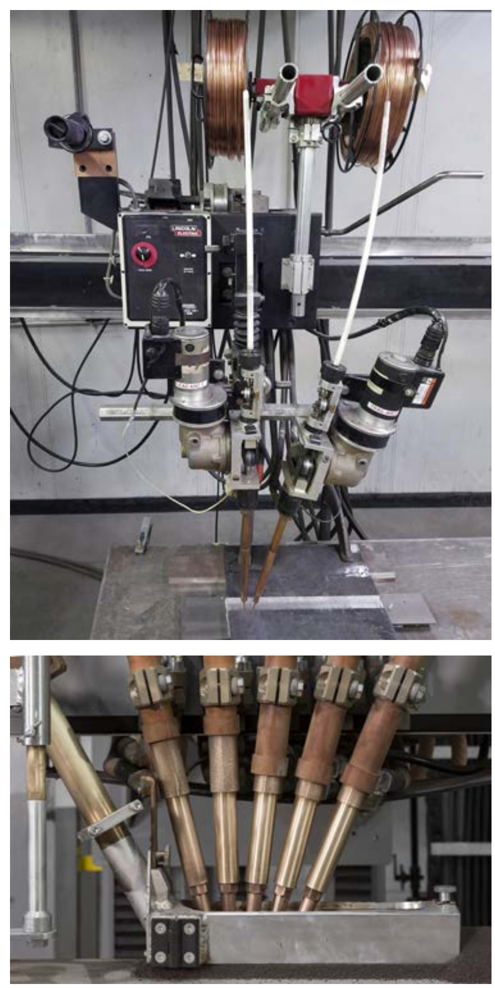


Figure 2-17: A, Tandem Arc SAW Cell; B, Five Arc SAW Welding Cell

2.5 RELATED EQUIPMENT: FLUX RECOVERY

- Unfused flux, dust, fines, and small pieces of slag are drawn into the flux separator.
- Recovered flux will fall into the lower flux hopper.
- Dust, fines, and slag pieces are separated and collected for disposal.
- Recovery units will maximize flux utilization.
- Avoid picking up any contaminants, such as mill scale, oil, water, grinding dust, cutting dross, etc.
- Keep recovered flux sealed and dry.
- Use magnetic separators when neccessary.

2.6 MODE SELECTION

Type of Control: Constant Current vs. Constant Voltage

Constant Current Welding (CC):

- Pre-set current
- Pre-set voltage
- Variable wire feed speed (WFS)
- Use with large diameter wires
- Consistent penetration

Constant Voltage (CV) Welding:

- Pre-set WFS
- Pre-set voltage
- Variable current
- Use with smaller diameter wires
- Consistent deposition

Figure 2-19: Flux Recovery System

Type of polarity: positive vs. negative vs. alternating current.

Direct Current Electrode Positive (DCEP) (Figure 2-20):

- Referred to as reverse polarity
- Used in most applications
- Highest penetration
- Lowest deposition
- Heat concentrated into the work piece
- Most stable arc

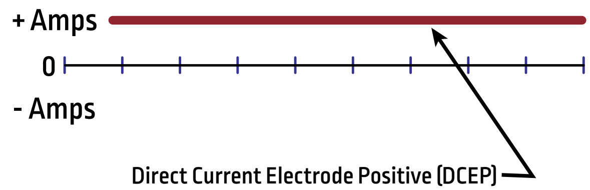


Figure 2-20: Direct Current Electrode Positive (DCEP)

Direct Current Electrode Negative (DCEN) (Figure 2-21):

- Referred to as straight polarity
- Lowest penetrating
- Highest deposition rates
- Heat concentrated into the electrode
- Least stable arc
- Commonly used for hardfacing and overlay applications

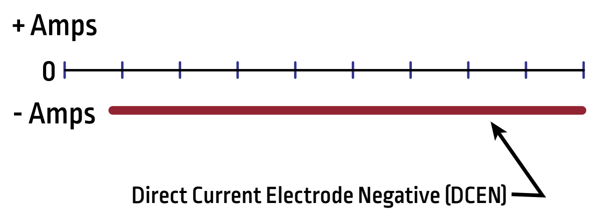


Figure 2-21: Direct Current Electrode Negative (DCEN)

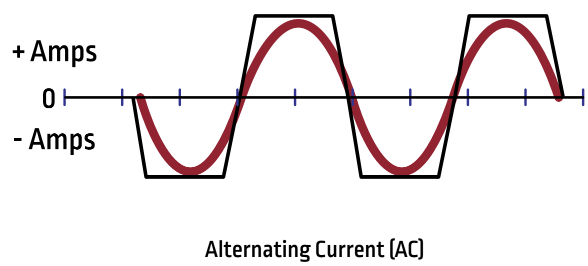


Figure 2-22: Alternating Current (AC) Shown in Both Sine Wave and Square Wave

Alternating Current (AC) (Figure 2-22):

- Good balance of DCEP and DCEN properties
- Will reduce possibility of arc blow
- Balances deposition and penetration
- Power Wave® AC/DC 1000® SD subarc welder AC mode allows for manipulation of AC output
- Often used in multi-arc systems

2.7 TYPES OF WELDS (WELD POSITION)

The welding position in the SAW process is limited by the use of flux. Containing the flux around the welding arc is key to producing a consistent and quality weld. If the flux spills or moves away from the arc, welding quality will quickly deteriorate. Figure 2-22 shows weld positions 1F, 1G, 2F, and 2G, which are the only viable welding positions for SAW.

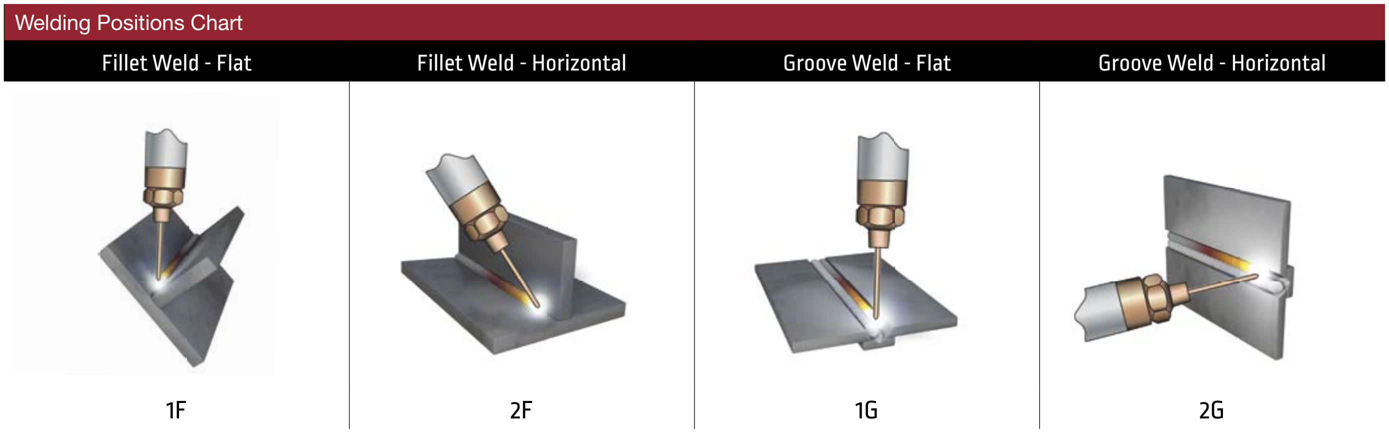


Figure 2-23: Shown are the Four General Welding Positions

Groove Weld (1G)

A groove weld is a joint type created by joining two workpieces with a groove angle (beveled) cut on the adjoining surfaces. The surfaces can have dissimilar prep, but may still be joined in a groove configuration. See Figure 2-24 for an example of a 1G groove weld.

Horizontal Groove (2G Supported)

A 2G horizontal groove weld may be referred to as a 3 o'clock weld. Using SAW in this position requires careful control of the supported flux. The liquid weld metal will fall out of the joint if the flux falls out of the joint. See Figure 2-25 for a 2G horizontal groove weld.

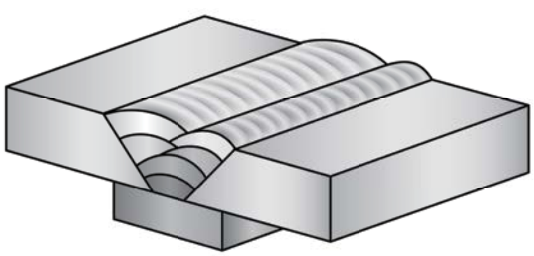


Figure 2-24: Groove Weld

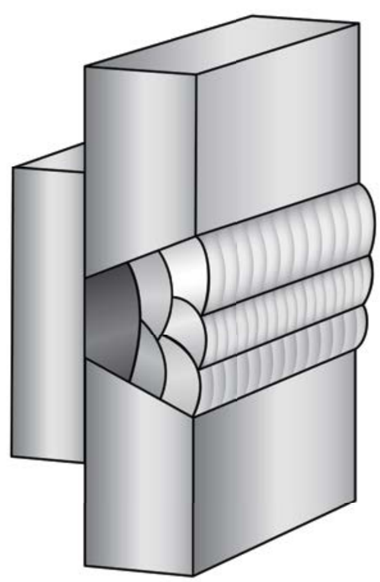


Figure 2-25: Horizontal Groove Weld

Flat Fillet (1F)

A 1F flat fillet is also referred to as a trough weld, referencing the way the workpieces are configured. Turning a T-joint 45˚, so the root of the joint is the lowest point of the weld, is the easiest way to contain the puddle and allow for the highest deposition rates. See Figure 2-26 for an example of a 1F flat fillet weld.

Horizontal Fillet (2F)

A 2F horizontal fillet is also a T-joint, but it is not turned on its axis and it is positioned on the bottom member's surface. Figure 2-27 is an example of a 2F horizontal fillet weld.

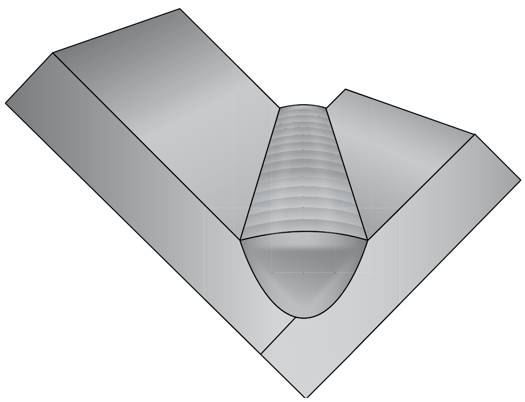


Figure 2-26: Flat Fillet Weld

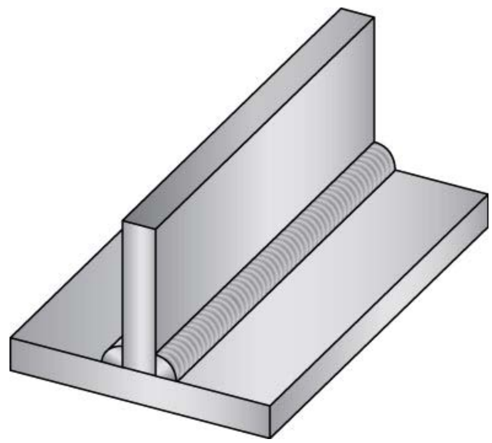


Figure 2-27: Horizontal Fillet Weld

Complete Joint Penetration

Complete Joint Penetration (CJP) is a condition in a groove weld where the weld metal protrudes through the joint thickness. Attaining CJP is usually required (unless specified) and requires careful attention to procedures and parameters (see Figure 2-28).

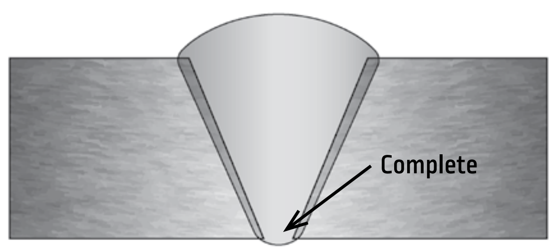


Figure 2-28: CJP Weld

Partial Joint Penetration

Partial Joint Penetration (PJP) welds can vary from 1% – 99% penetration, with typical ranges 60% – 80%. Whenever a code allows for PJP welds, the minimum amount of penetration should be specified. See Figure 2-29 to view a PJP weld.

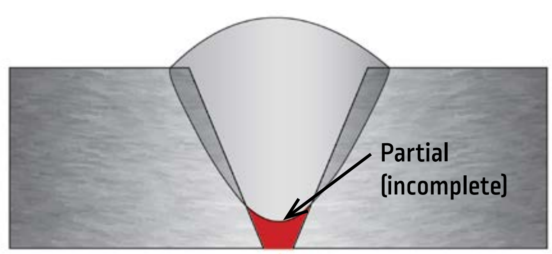


Figure 2-29: PJP Weld

2.8 HEAT INPUT

Heat Input

Heat input is the energy applied per unit length of a weld. Heat input is typically measured in kJ/in. To calculate heat input in kJ/in, use the following formula:

$$\frac{\text{Amps x Volts x 60}}{\text{Travel Speed in/min (mm/min) x 1000}} = \text{kJ/in. (kJ/mm)}$$

Controlling heat input will also help control distortion and affect mechanical properties.

2.9 WIRE FEED SPEED GEAR RATIO SELECTION

In order to accommodate a wide range of wire feed speeds, the Lincoln Electric wire feeder motor has the ability to run multiple gear ranges.

Table 2-4: Wire Feed Rates

Gear Box	Wire Feed Speed Range ipm (m/min)	Wire Size Range in (mm) Solid
142:1	10 – 200 (0.4 – 5.0)	3/32 – 7/32 (2.4 – 5.6)
95:1	10 – 300 (0.4 – 7.6)	1/16 – 1/8 (1.6 – 3.2)
57:1	40 – 500 (1.3 – 12.7)	1/16 – 3/32 (1.6 – 2.4)

Notes

Because variables in design, fabrication, and in-service conditions may affect the results obtained in applying the information contained within this section, the testing and serviceability of a product or structure is the responsibility of the builder and user.

The simplest form of submerged arc welding is single-electrode welding. The lowest cost and least complex setups contain one power source, one wire feeder and one controller with one wire (electrode) feeding through it. Every application is different and has its own challenges. The purpose of this section is to explain the theory and logic used when making single-electrode welds.

3.1 JOINT DESIGN AND FIT-UP CONSIDERATIONS

Subarc can be a deep penetrating process. To avoid burn through, the plates being welded must be uniformly edge prepared, fit-up properly, or the welding procedure modified to use lower currents, faster travel speeds, changing polarity (DCEN or AC), or increased contact tip to work extension.

Experience, knowledge, and research are all required before ever striking an arc with the submerged arc process. Many variables can be adjusted to reduce burn through, or in contrast, increase penetration levels, if needed. Changes to joint design and fit-up will affect all of these variables.

3.2 FLUX AND ELECTRODE SELECTION

Lincoln Electric produces many fluxes and electrodes that, when properly selected, will produce the desired results. Refer to the following bulletins in selecting the best combinations:

» C1.50 *Filler Metal Selector Guide*: This addresses selecting filler metal to match specific steels.

» C1.10 *Welding Consumables Catalog*: This provides specific information on the flux and electrode combination.

3.3 CLEANLINESS

Contaminants such as oil, grease, paint, rust, scale or moisture can cause porosity. Due to the large volume of gases generated from zinc-based primers during welding, weld joints contaminated by these primers can result in severe porosity. When choosing to not remove primers, it is recommended that practice welds be made on the material.

Therefore:

1. Use only clean, rust-free electrodes.
2. Screen recycled flux to remove large particles of slag or other debris.
3. If recycled flux is contaminated with excess fine mill scale, remove it with a magnetic separator.
4. Remove heavy rust, scale, oil, grease, or moisture from the joint area.
5. With contaminants present, use lower weld speeds to allow gas to escape.
6. Preheat the weld area to degrease and drive off moisture and condensation.
7. Grind or shot blast work area to remove contaminants.

3.4 WORK POSITION

Subarc welding may be done in the flat or horizontal position. The one exception occurs when welding thin plate, usually 1/4 in. (6.4 mm) or less where a downhill angle of up to 15˚ may be used to increase travel speed and control penetration. The weld may be positioned for either horizontal or flat (see Figure 3-1).

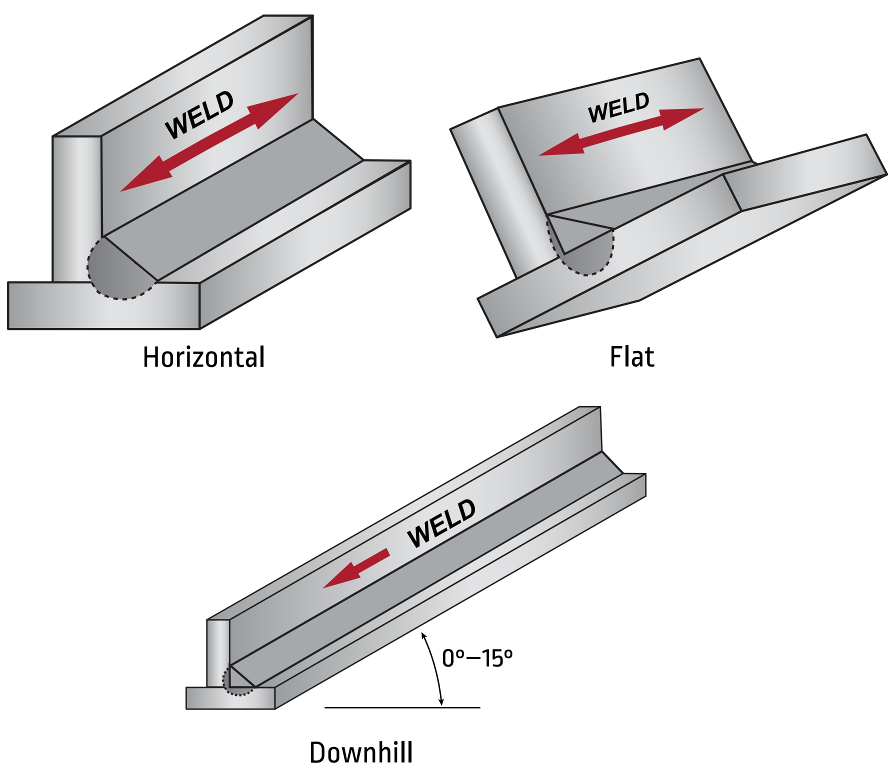


Figure 3-1: Horizontal, Flat and Downhill Welds

3.5 PREHEAT

Preheat may be required when welding alloyed, high-strength, and higher carbon steels. It may also be specifically required when welding to various codes. Thick plates and rigid joints may also require preheating to ensure sound, crack-free welds. Note that on joints that require multiple weld passes, interpass temperature (temperature between passes) should be maintained as specified in the WPS.

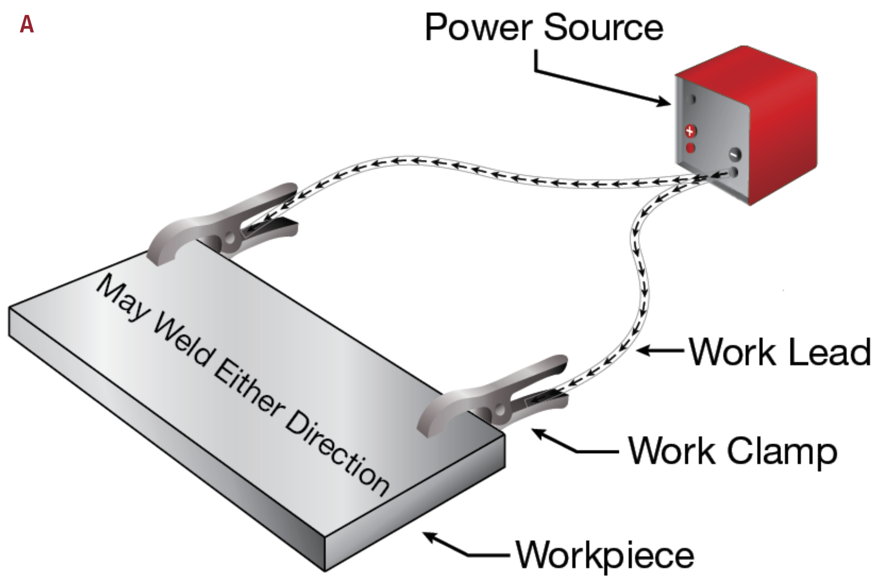
The minimum required preheat may be specified by code requirements. AWS code D1.1 contains preheat tables. The easiest way to determine preheat is to use a preheat and interpass temperature calculator like the one shown in Figure 3-2, which may be purchased from the James F. Lincoln Arc Welding Foundation at www.jflf.org.

Figure 3-2: Preheat and Interpass Calculator

3.6 WORK LEAD CONNECTIONS

The best weld results are usually obtained by welding away from the work lead connection. Clamp the work lead directly to the work, preferably to both plates if possible (see Figure 3-3). A poor connection can cause arc instability, arc blow, porosity and poor bead shape. This is especially true when welding with DCEN polarity. In many cases, better results are achieved by using two work leads, one at each end of the weldment.

A



B

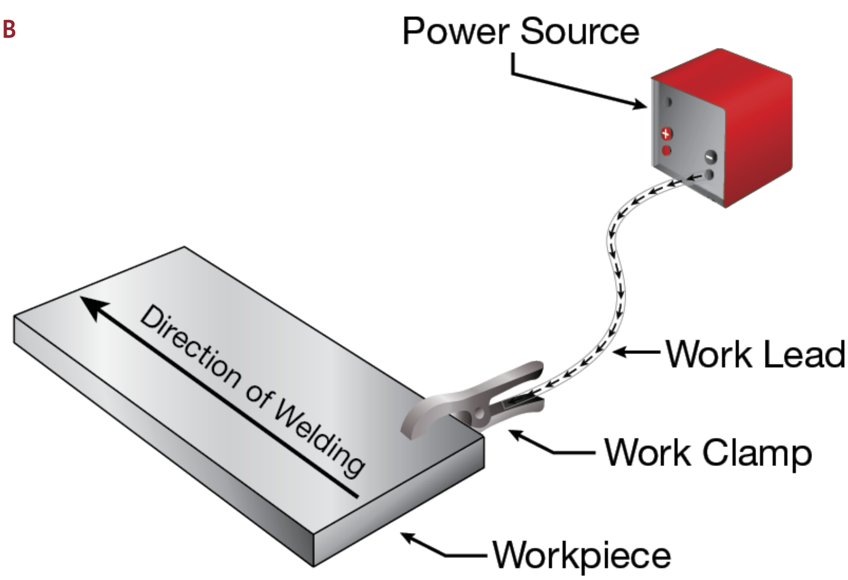


Figure 3-3: A, Setup for Welding in Either Direction; B, Setup for Welding in One Direction

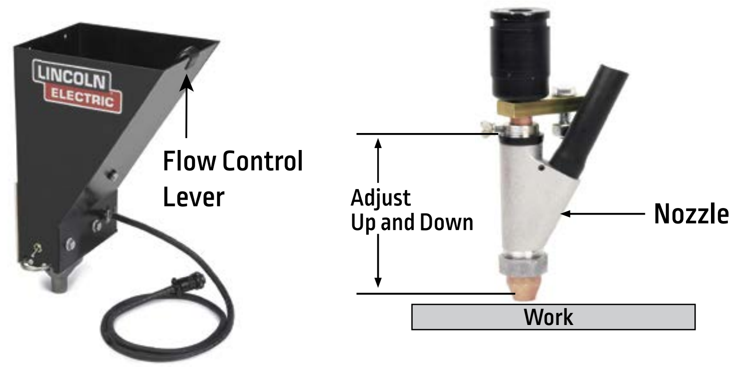


Figure 3-4: Equipment for Supplying Flux

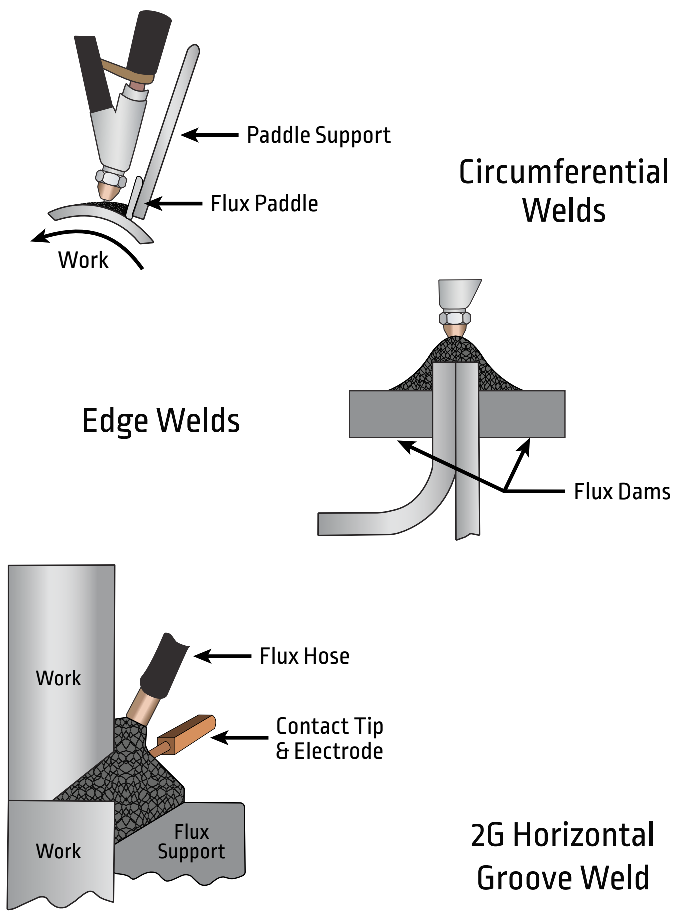


Figure 3-5: Flux Paddles, Dams and Other Supporting Devices

3.7 FLUX COVERAGE

Flux depth should be just enough to bury the arc. A good indicator is when just a flicker of light may be seen on the electrode. Too little flux will cause excessive flash-through and result in weld porosity. This could also be very uncomfortable for the operator. Too much flux may cause narrow and humped beads, which will result in poor appearance and make slag removal difficult.

WARNING

Direct viewing of flash-through or skin exposure to flash-through can result in UV radiation burns. Proper clothing and eye protection should be used.

For semi-automatic welding, flux placement and coverage is controlled by the semi-automatic gun. For automatic welding, flux flow depth can be controlled by adjusting the height of the nozzle above the work piece (see Figure 3-4). It is better controlled, and it will work in all cases, by utilizing the flux flow control lever.

A 2G horizontal groove weld is also commonly referred to as a “3 o’clock” weld. “3 o’clock” welds require dams to hold the flux in place (see Figure 3-5). It is important that the flux particles surrounding the arc puddle not be moving until the weld has solidified. Non conductive, fire-resistant materials work very well as damming paddles on round-abouts.

3.8 ELECTRODE SIZE — SEMI-AUTOMATIC WELDING

For hand-held semi-automatic submerged arc welding, electrode sizes are limited to 5/64 in. (2.0 mm) and 3/32 in. (2.4 mm) diameters. Each size requires a set of guns, feed cables, guide tubes, and drive rolls.

The 5/64 in. (2.0 mm) size works well on 12-gauge (2.6 mm) and thicker material. The Lincoln Electric hand-held SAW gun and cable are lightweight and flexible, which allows easy positioning and guidance.

A 3/32 in. (2.4 mm) electrode will allow use of higher current, resulting in a higher deposition rate. Hand-held SAW guns are available with mechanized control travel speeds that can significantly reduce the weight the operator must carry (see Figure 3-6).

Figure 3-6: Guns and Power Pack: A and B, Lincoln Electric SAW Guns; C, Power Pack (for Travel Speed Control)

3.9 ELECTRODE SIZE — AUTOMATIC WELDING

If all other process variables are held constant, changing electrode diameter will have the following effects.

1. Increasing diameter, decreases penetration
2. Increasing diameter, decreases deposition
3. Increasing diameter, increases current carrying capability

See Figure 3-7: The photo shows three separate beads, all made using direct current electrode positive (DCEP) polarity, 650 amps, 32 volts, and 24 ipm (0.6m/min) travel speed. The drastic difference in the bead shape is purely the result of a change in wire diameter.

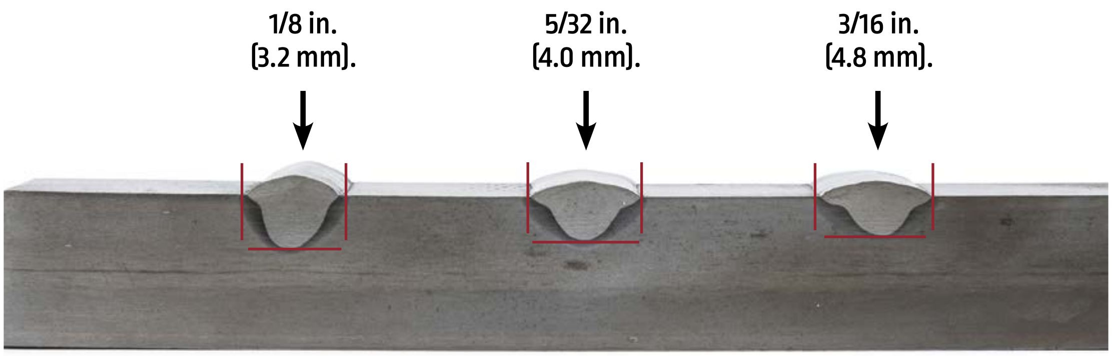


Figure 3-7: Shows the Relationship Between Wire Diameter and Bead Size. Penetration Profile DCEP, Amperage 650 A, Voltage 32V, and Travel Speed 24 IPM (0.6 m/min); Left, 1/8 in. (3.2 mm); Center, 5/32 in. (4.0 mm); Right, 3/16 in. (4.8 mm). Red Lines Indicate Penetration Profile.

3.10 CURRENT

If all procedure variables are held constant, changing current can have the following effects:

» Increasing current (amps) increases penetration and electrode meltoff rate. (See Table 3-1 on page 59 for meltoff rate calculation factors based on wire feed speed.)

» Excessively high currents produce an unstable arc, undercut or a high, narrow bead.

» Excessively low currents produce an unstable arc and very poor bead shape. (See Figure 3-8 and Figure 3-9 to see the effects of amperage on bead shape and size.)

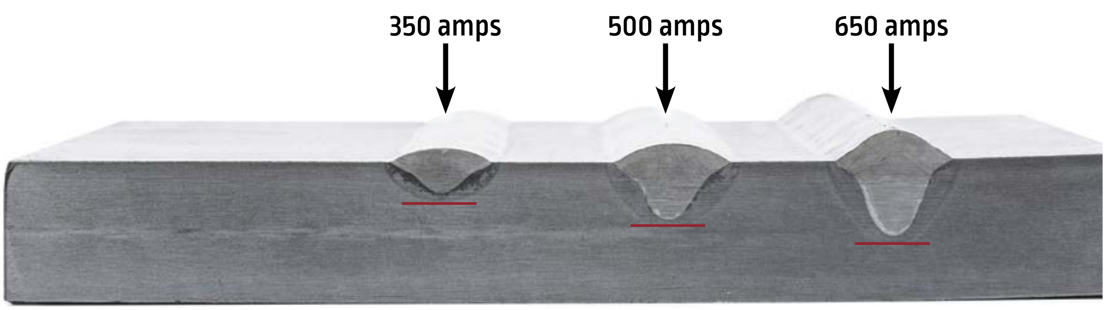


Figure 3-8: Shows the Penetration Related to Amperage. Penetration Profile 3/32 in. (2.4 mm) Wire on DCEP, Travel Speed 24 IPM (0.6 m/min), Voltage 35V; Left, 350 amps; Center, 500 amps; Right, 650 amps. Red Lines Indicate Depth of Penetration.

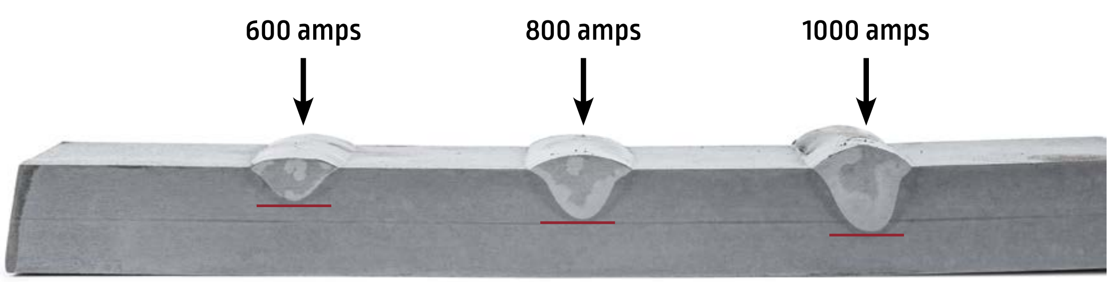


Figure 3-9: Shows the Penetration Related to Amperage. Penetration Profile 3/16 in. (4.8 mm) Wire on DCEP, Travel Speed 30 IPM (0.8 m/min), Voltage 34V; Left, 600 amps; Center, 800 amps; Right, 1000 amps. Red Lines Indicate Depth of Penetration.

3.11 VOLTAGE

Voltage is primarily used to control bead shape. Voltage, or more accurately *arc voltage*, should always be measured from the contact assembly to the work, since it is arc voltage, *not* power source voltage that affects the weld.

Cable lengths, cable routing and inductance can all affect arc voltage. If all other procedure variables are held constant, changing voltage has the following effects:

1. Increasing voltage:
    - Increases arc length.
    - Produces flatter and/or wider weld beads.
    - Improves slag removal on square edge butt and fillet welds.
    - Increases overall flux consumption.
    - Depending on type of flux, may increase resistance to porosity.
    - When fit-up is poor, it helps bridge small gaps.
    - Decreases penetration.
    - Decreases resistance to arc blow porosity.
2. Excessively high voltages:
    - Produce a hat-shaped bead, which is prone to cracking.
    - Result in poor slag removal.
    - Produce concave-shaped fillet weld, which may result in centerline cracking.
    - Increased risk of arc blow and arc blow porosity.
    - Can cause undercut.
    - Can lead to arc flashing.
3. Lowering the voltage:
    - Produces a narrower arc cone, which increases penetration.
    - Helps resist arc blow.
    - Improves slag removal in deep groove welds.
    - Helps produce an acorn-shaped bead, which is less prone to cracking.
    - Can increase cracking due to poor depth to width ratio at high current.

4. Excessively low voltage:
   - Can produce excessively high, narrow bead shapes.
   - Poor slag removal.
   - May cause unstable arc.
   - Increase risk of trapped slag.

See Figure 3-10 and Figure 3-11 for examples of voltage changes on bead shape.

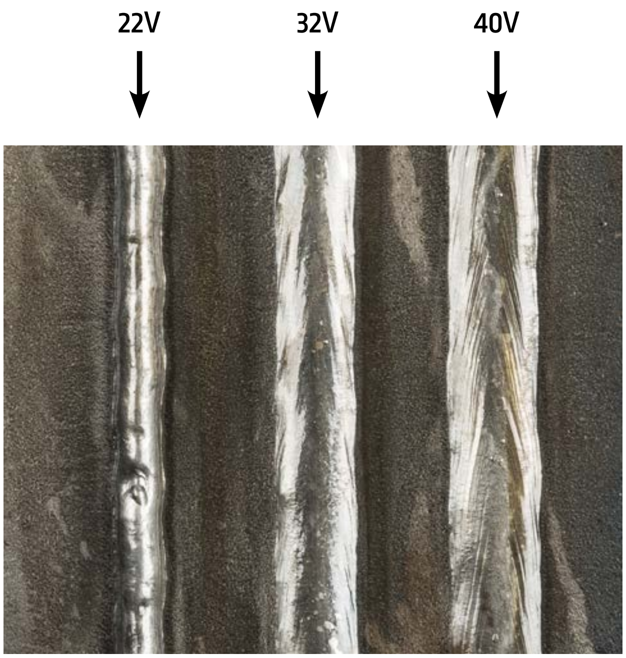


Figure 3-10: 3/32" (2.4mm) Wire on DCEP, Amperage 500, Travel Speed 24 IPM (0.6 m/min); Left, 22V; Center, 32V; Right, 40V.

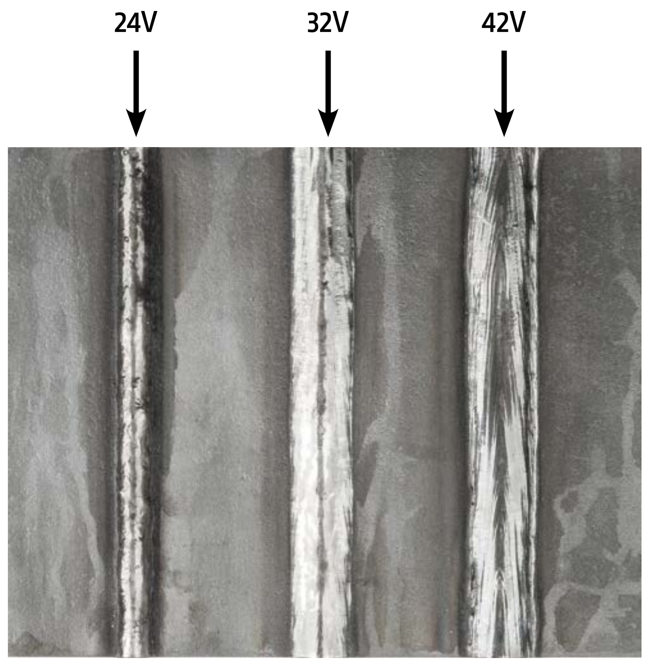


Figure 3-11: 3/16" (4.8mm) Wire on DCEP, Amperage 850, Travel Speed 30 IPM (0.8 m/min); Left, 24V; Center, 32V; Right, 42V.

Voltage – Suggested Initial Setting

Figure 3-12 on page 51 is based on DCEP procedures with 1-1/2 in. (38 mm) CTWD. Note that the graph's voltages are based on contact assembly to work lead values, not power source terminal values.

For AC polarity, increase by 2 or 3 volts.

For procedures with greater CTWD, a significant increase in voltage may be necessary (see Figure 3-12 on page 51).

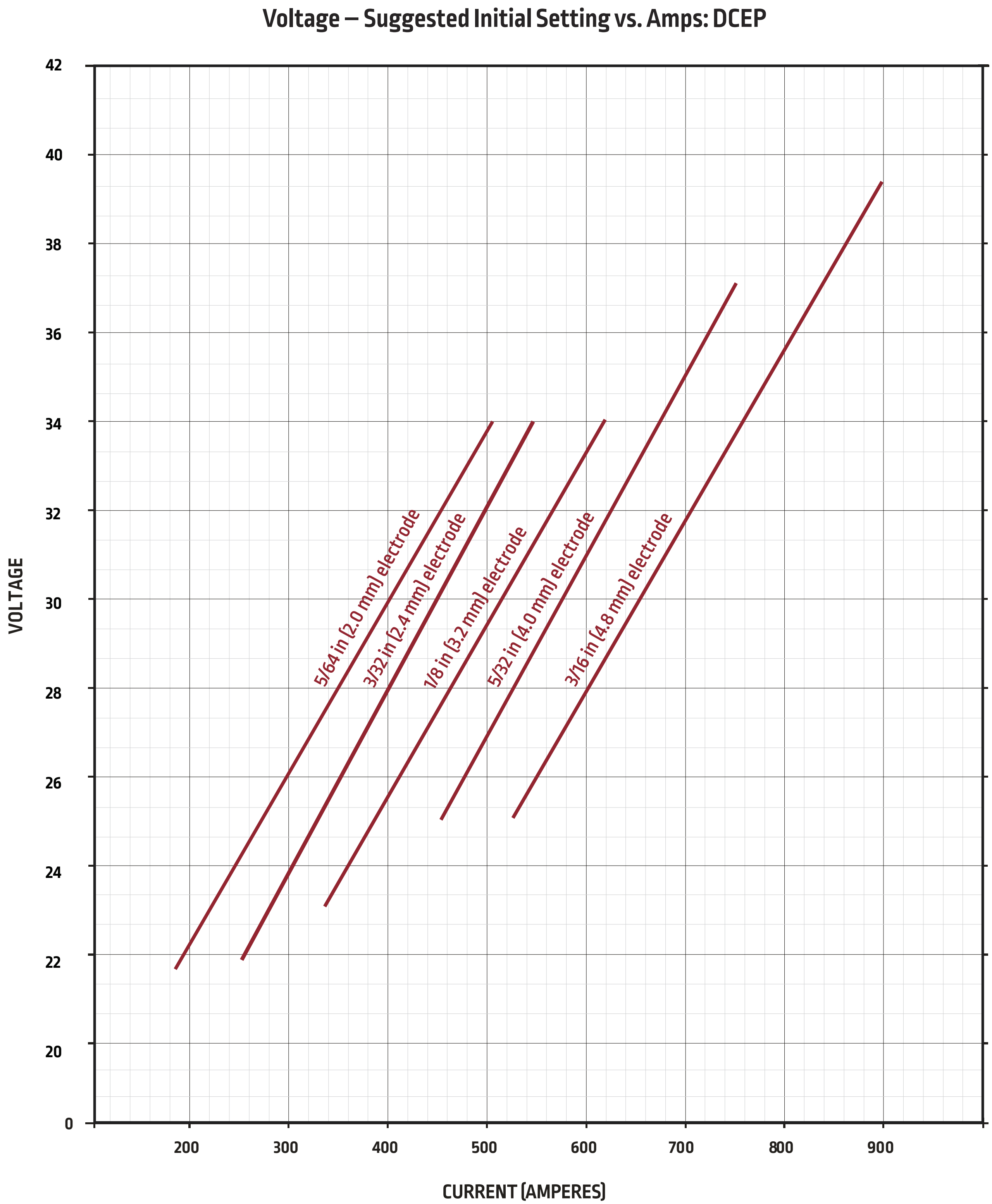


Figure 3-12: Voltage Starting Point vs. Amps: DCEP

3.12 TRAVEL SPEED

Changing the travel speed, like changing the current, will change weld size and penetration. The volume of a cross-sectional area of 3/8 in. (10 mm) fillet weld per pass, usually works well. (See Figure 3-13 and Figure 3-14 for the effects of travel speed on bead shape and penetration.)

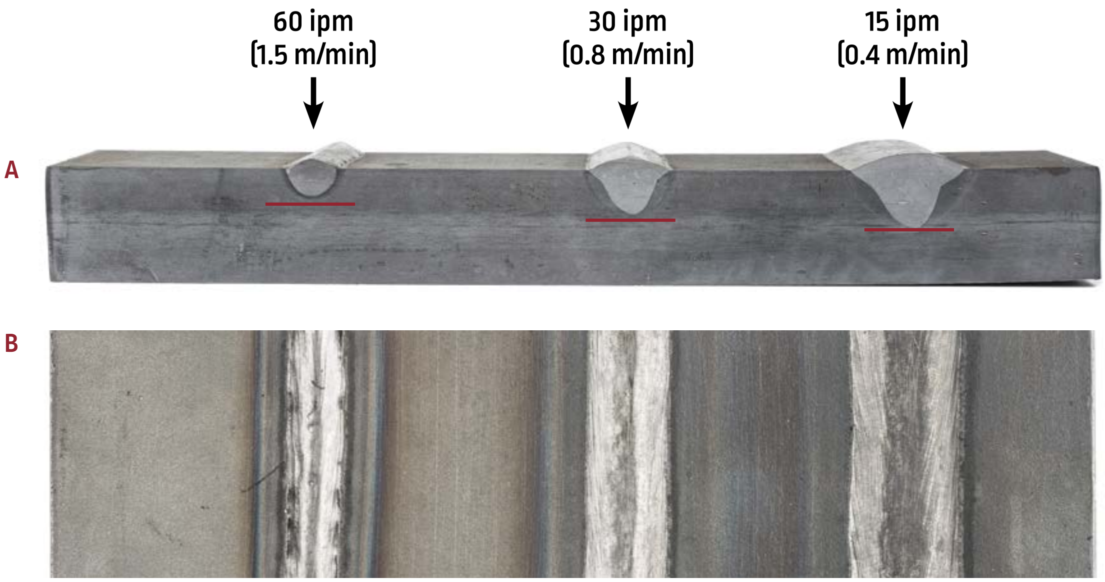


Figure 3-13: Shows Penetration Related to Travel Speed. A, Penetration Profile 3/16 in. (4.8 mm) Wire on DCEP, Amperage 850 A, Voltage 34V; Left, 60 IPM (1.5 m/min); Center, 30 IPM (0.8 m/min); Right, 15 IPM (0.4 m/min). A, Red Lines Show Depth of Penetration; B, Top View of Figure 3-14 A.

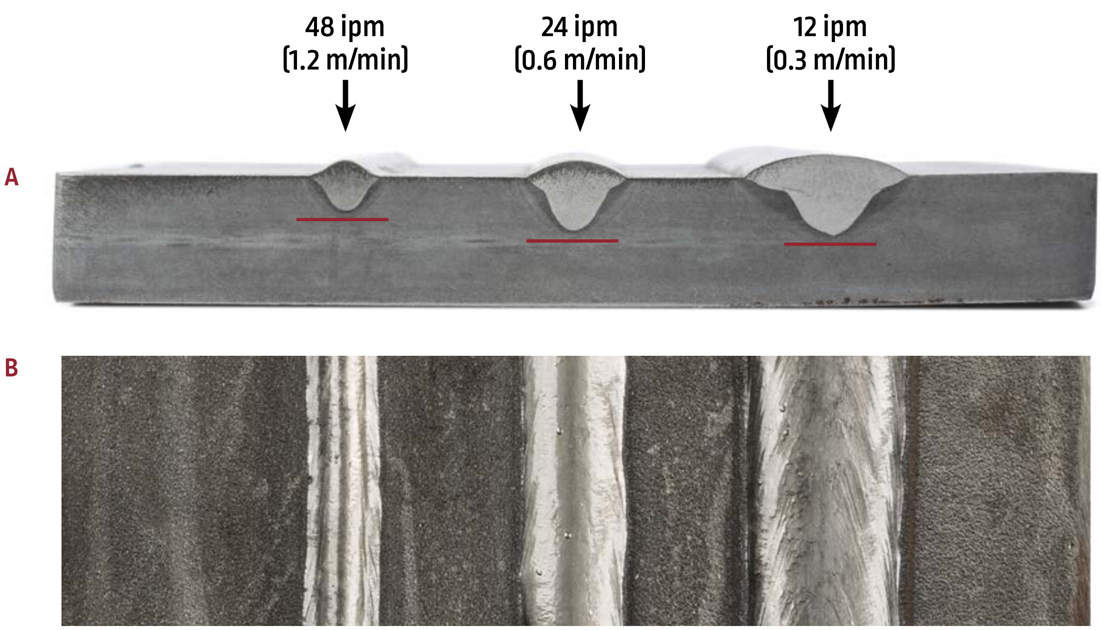


Figure 3-14: Shows Penetration Related to Travel Speed. A, Penetration Profile 3/32 in. (2.4 mm) Wire on DCEP, Amperage 500 A, Voltage 32V; Left, 48 IPM (1.2 m/min); Center, 24 IPM (0.6 m/min); Right, 12 IPM (0.3 m/min). A, Red Lines Show Depth of Penetration; B, Top View of Figure 3-16 A.

If the other variables are held constant, changing travel speed has the following effects:

1. Increasing the travel speed may increase the tendency for undercut and uneven bead shapes.
2. Slower travel speeds give gases time to escape the molten weld, reducing the potential for porosity and gas marks (pockmarks).
3. Insufficient travel speeds may cause:
   - Hat-shaped beads that can increase or cause cracking (see Figure 3-15). For other types of cracks and discontinuities, see Section 9.
   - Arc flashing through the flux, which increases the risk for weld porosity.
   - A large molten puddle that flows around the arc resulting in a rough surfaced bead and slag entrapment.
   - The arc to ride on the puddle, resulting in less penetration.

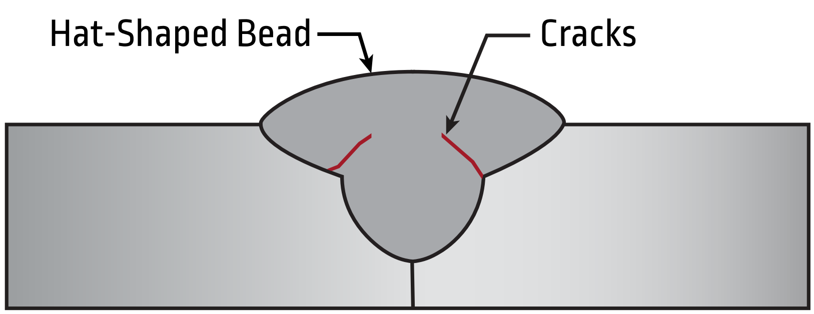


Figure 3-15: Hat Cracks

3.13 CONTACT TIP TO WORK DISTANCE (CTWD)

Contact tip to work distance is the most easily measured variable between the electrode and the work piece. Often incorrectly referred to as electrical stickout (ESO), ESO is actually the distance from the contact tip to the arc. ESO is not easily measurable, especially in a submerged arc application. Nominal CTWD is typically 8 times electrode diameter. CTWD is an important factor that affects melt-off rate:

If welding in a constant current (CC) mode, the wire feed speed (WFS) will change:

1. If CTWD is increased, WFS will increase.
2. If CTWD is decreased, WFS will decrease.

If welding in a constant voltage (CV) mode (constant wire feed speed), the amperage will change:

1. If CTWD is increased, amperage will decrease.
2. If CTWD is decreased, amperage will increase.

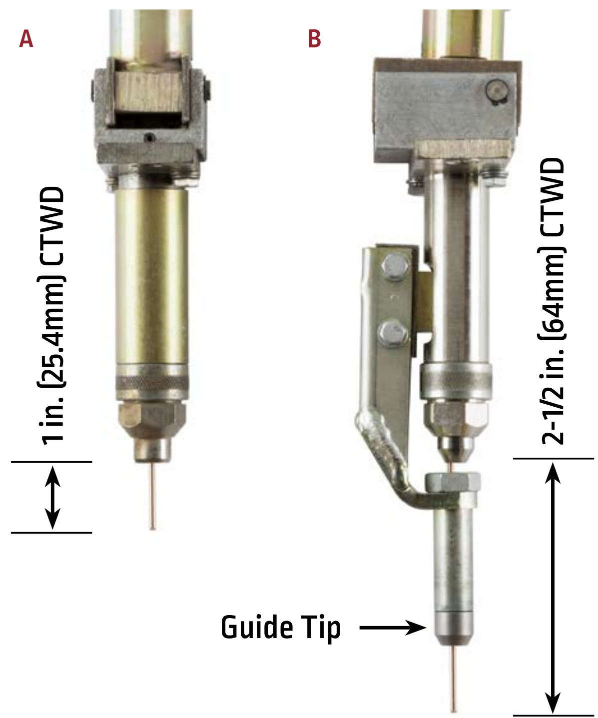


Figure 3-16: A, Positive contact assembly; B, Linc-Fill Long Stickout Extension mounted on a positive contact assembly.

3.14 DEPOSITION RATES

Deposition rates can be increased significantly by utilizing electrical stickout equipment and procedures. Using a positive contact assembly welding torch and an ESO guide tube assembly, CTWD can be increased up from 3 in. (75 mm) to 5 in. (125 mm). (See Figure 3-16.)

3.15 POLARITY: DCEP VS. DCEN

If welding is to be done using DC current, it is generally recommended that DCEP be used as it produces the most stable arc. At the same current, DCEP produces smooth welds and greater arc penetration than with DCEN. To minimize the possibility of porosity and/or hot cracking for high-carbon, sulfur or phosphorous steels, DCEN may be preferable because of its lower base metal dilution.

At equal current and CTWD settings, meltoff rate for DCEN is about 33% greater than for DCEP. This is useful for:

1. Fillets on plates free of rust and primer coating.
2. Hard facing and build-up applications.
3. Linc-Fill™ applications.

3.16 AC WELDING

Conventional AC power sources deliver a 50 or 60 hertz sine wave output. The current passes through the zero point twice each cycle (see Figure 3-17), or the arc goes out and must re-initiate 120 times per second. Very little time is spent at peak current where the arc is stable (see Figure 3-17 and Figure 3-18).

For constant electrode diameter and current, AC polarity gets higher deposition rate then DCEP. (See deposition rate curves, page 60-65.)

Solid state and digital technology has allowed for development of square wave AC, or a typical square wave (see Figure 3-18). Notice two very important characteristics:

1. The time it takes for amperage from positive to negative is much shorter for the square wave.
2. Time at peak current is greater resulting in greater arc stability and a higher deposition rate.

The result is a consistent, stable arc. The output is software controlled and provides useful functions such as unbalancing the wave form, shifting wave frequency, and offsetting wave zero point.

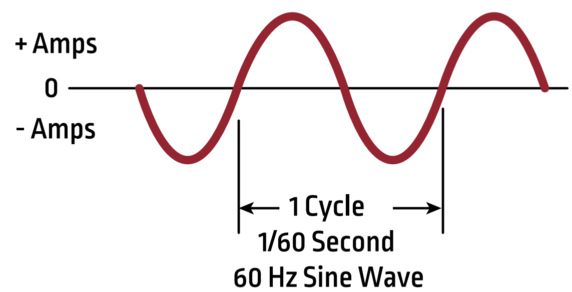


Figure 3-17: 60 Hz Sine Wave

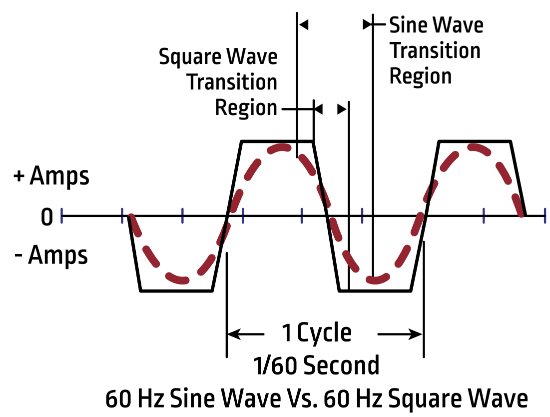


Figure 3-18: Sine Wave vs. Square Wave

3.17 UNBALANCED AC SQUARE WAVE

This allows the amount of time the arc spends in the positive vs. the negative part of the cycle to be adjusted. This can be helpful in increasing or decreasing penetration (CV modes) as well as increasing or decreasing the deposition rate (CC modes) to control the amount of deposit being made. Balance is always expressed as a percentage of the positive portion of the waveform (see Figure 3-19).

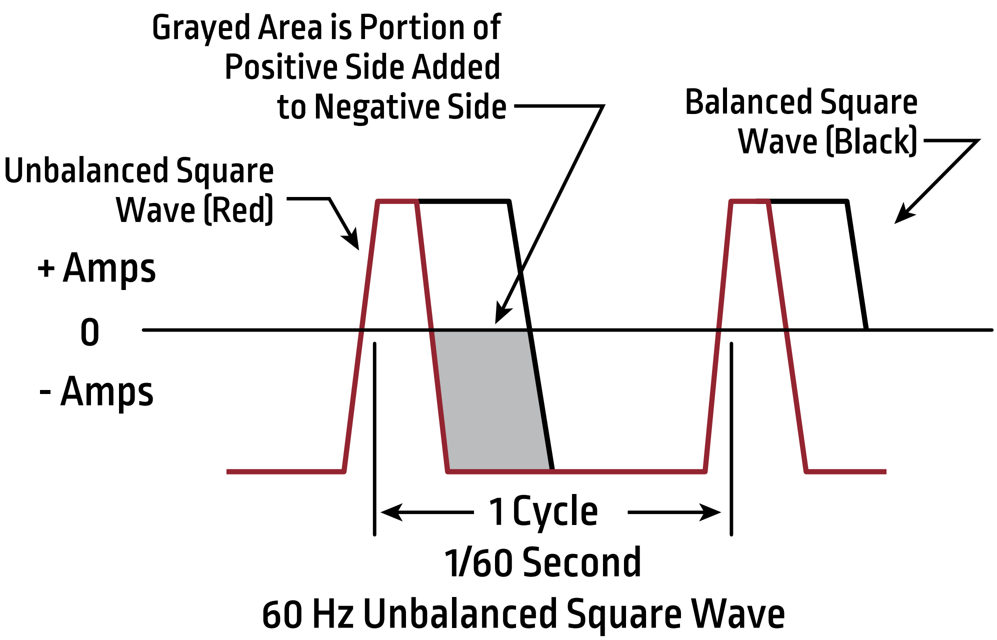


Figure 3-19: Unbalanced Square Wave Cycle

In other words:

1. At 50% balance, the wave is evenly split between positive and negative.
2. At 25% balance, 25% of the cycle is positive and 75% negative.
3. Any increase in balance increases the DCEP portion of the wave.

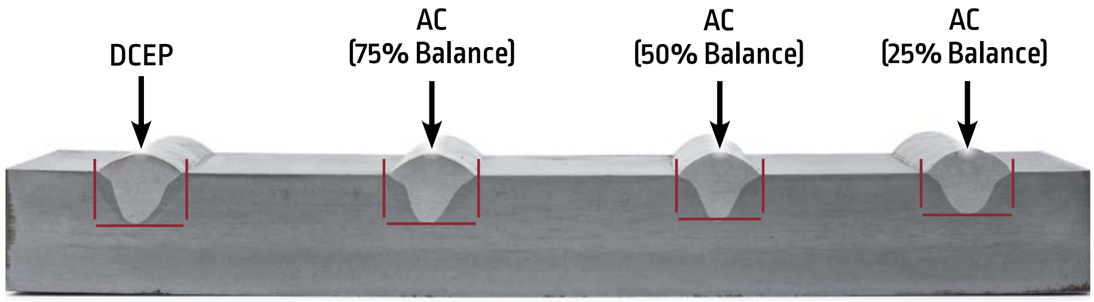


Figure 3-20: Shows Effects of Balance on Penetration and Bead Shape with Four Welds Made Using Identical Parameters Except for Balance. From Left to Right, DCEP; AC (75% Balance); AC (50% Balance); AC (25% Balance). Red Lines Indicate Penetration Profile.

Figure 3-20 shows four weld beads all run at a travel speed of 16 inches per minute (ipm) (0.406 mpm), 650 amps, and 28 volts. The bead widths above are the result of:

1. DCEP CC
2. AC CC 75%
3. AC CC 50%
4. AC CC 25%

3.18 WAVE FREQUENCY

In Figure 3-21, conventional sine waves (red) are shown with square waves (black). Balance is shown as neutral (50%) and no offset (see Figure 3-22 on Page 58) is included. As shown, RMS current and voltage are identical for all three curves.

Frequency is defined as the number of AC cycles per second. Wave Frequency control aids in arc stability. It can also have a small effect on deposition rate. Higher frequencies can reduce arc interactions in multiple arc systems. Lower frequencies help overcome inductance problems from long cable lengths.

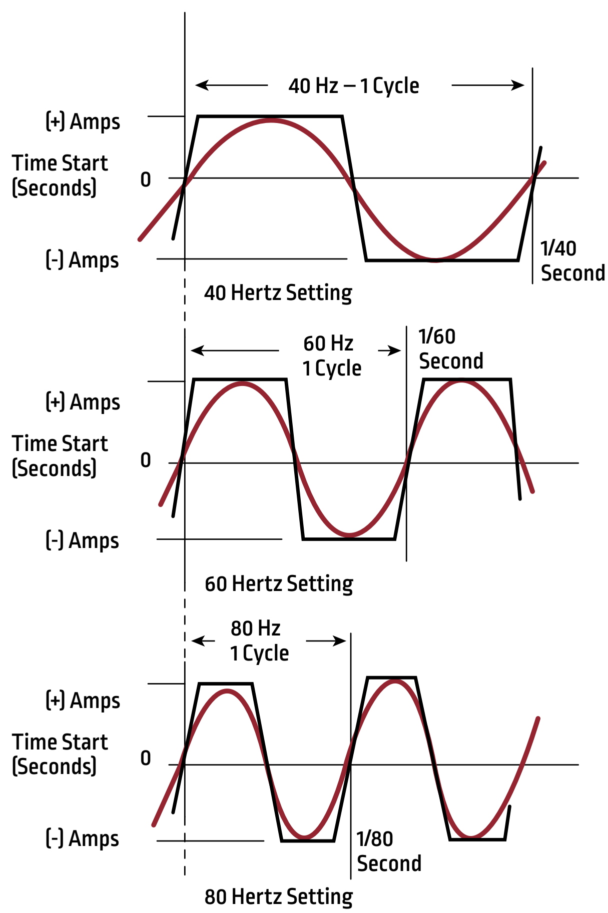


Figure 3-21: AC Waveforms of Different Frequency

3.19 SQUARE WAVE OFFSET

Offset controls a positive or negative shift of the current wave form with respect to the 0 crossing and is variable from -25 to +25.

In constant current, negative offset contributes to increasing deposition rates toward the values obtainable with DCEN welding, yet without the problems frequently encountered with the latter (see Figure 3-22). Positive offset values will decrease deposition rates. (See Figure 3-23 on page 59 to see the effects of offset.)

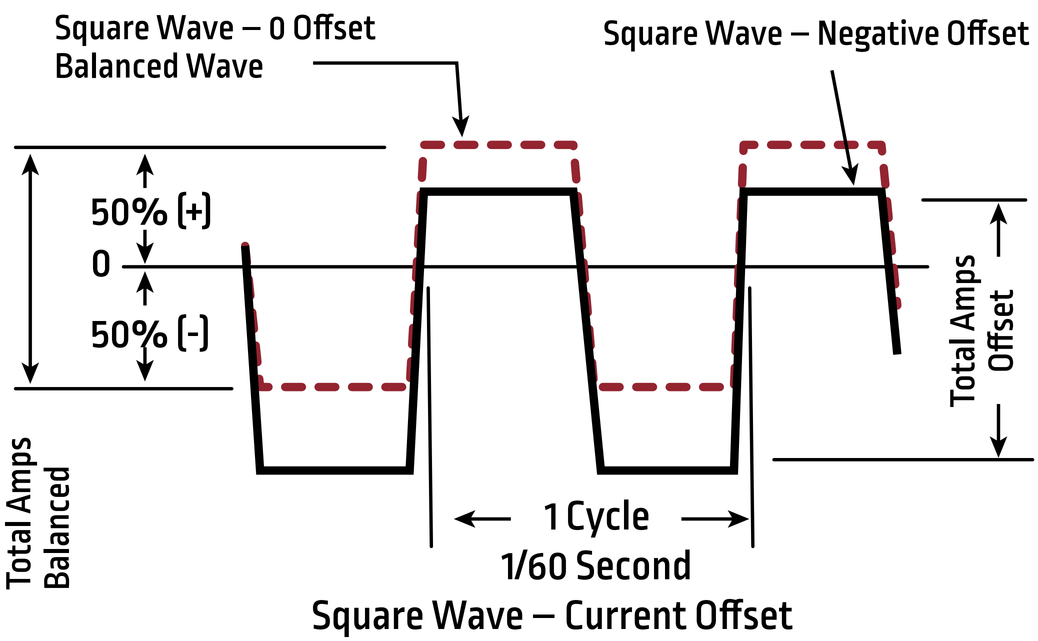


Figure 3-22: Square Wave Offset

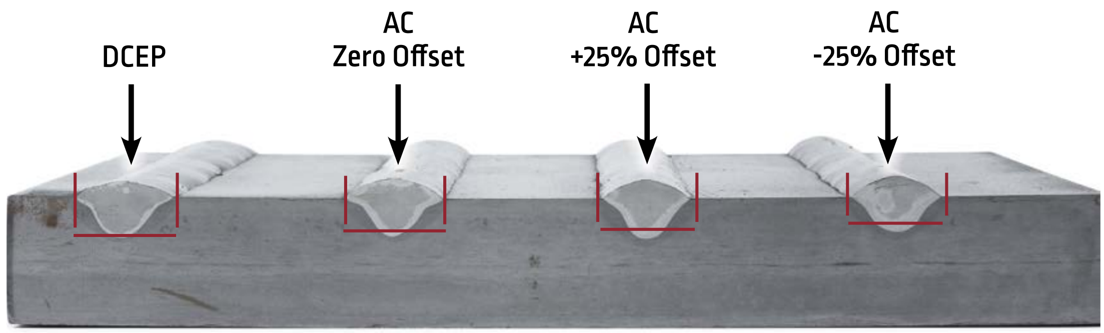


Figure 3-23: Shows the Effects of Offset on Penetration and Bead Shape with Four Welds Made Using Identical Parameters, Except for Offset. From Left to Right, DCEP; AC with Zero Offset; AC with +25% Offset; AC with -25% Offset. Red Line Shows Penetration Profile.

3.20 MELT OFF CALCULATION AND CHARTS

Table 3-1: (A) Wire Diameter Multipliers for Standard Units

Diameter (in)	Multiplier (lbs/hr)
1/16	0.052
5/64	0.081
3/32	0.115
1/8	0.210
5/32	0.325
3/16	0.470

(B) Wire Diameter Multipliers for Metric Units

Diameter (mm)	Multiplier (kg/hr)
1.6	0.947
2.0	1.480
2.4	2.131
3.2	3.773
4.0	5.919
4.8	8.508

When wire feed speed (WFS) is measured in (A) Inches Per Minute (ipm), the multiplier can be used to calculate deposition rate in LBS/HR. When WFS is measured in (B) Meters Per Minute (mpm), the multiplier can be used to calculate deposition rate in KG/HR.

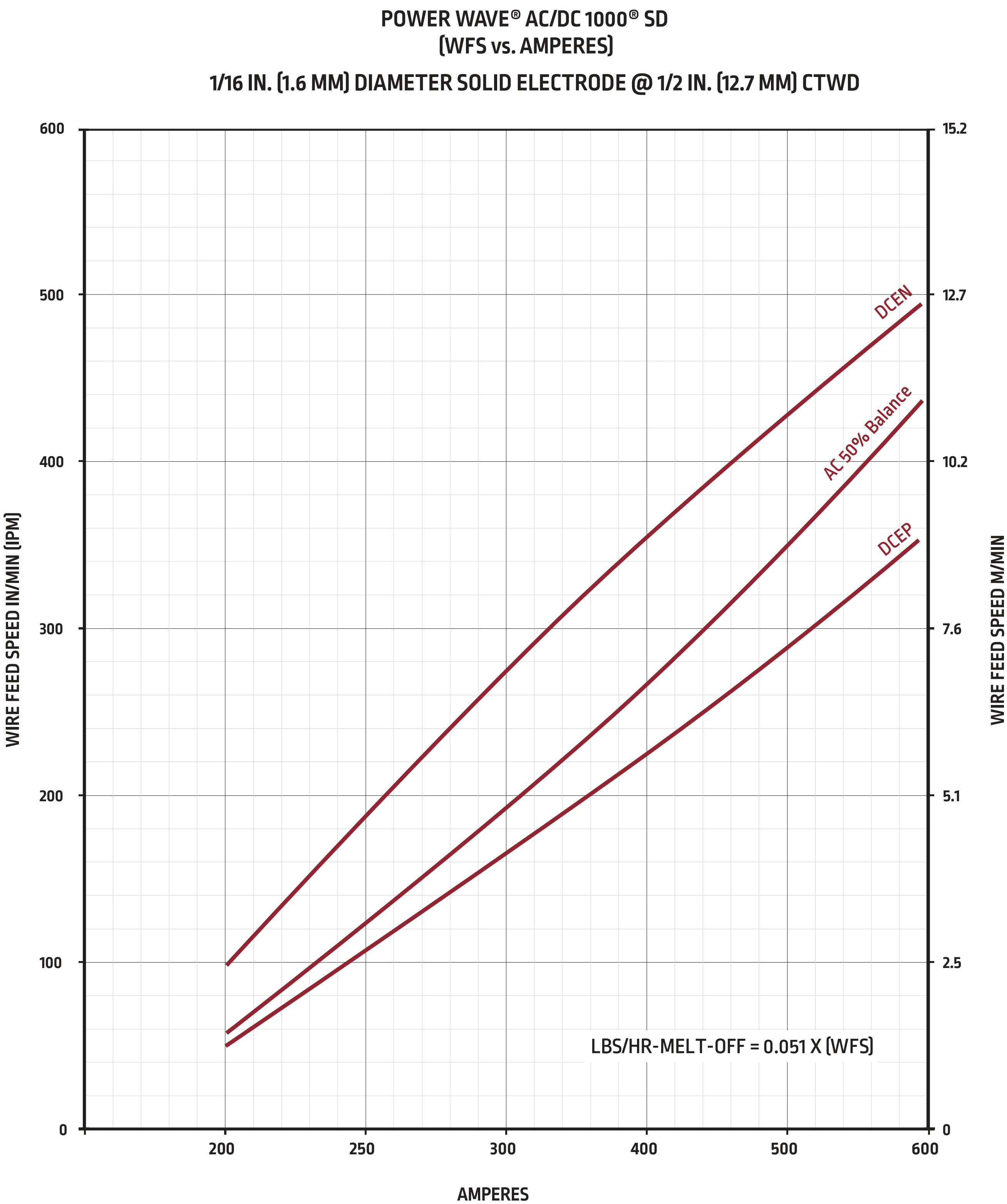


Figure 3-24: 1/16 In. (1.6 mm) Diameter Solid Electrode @ 1/2 In. (12.7 mm) CTWD

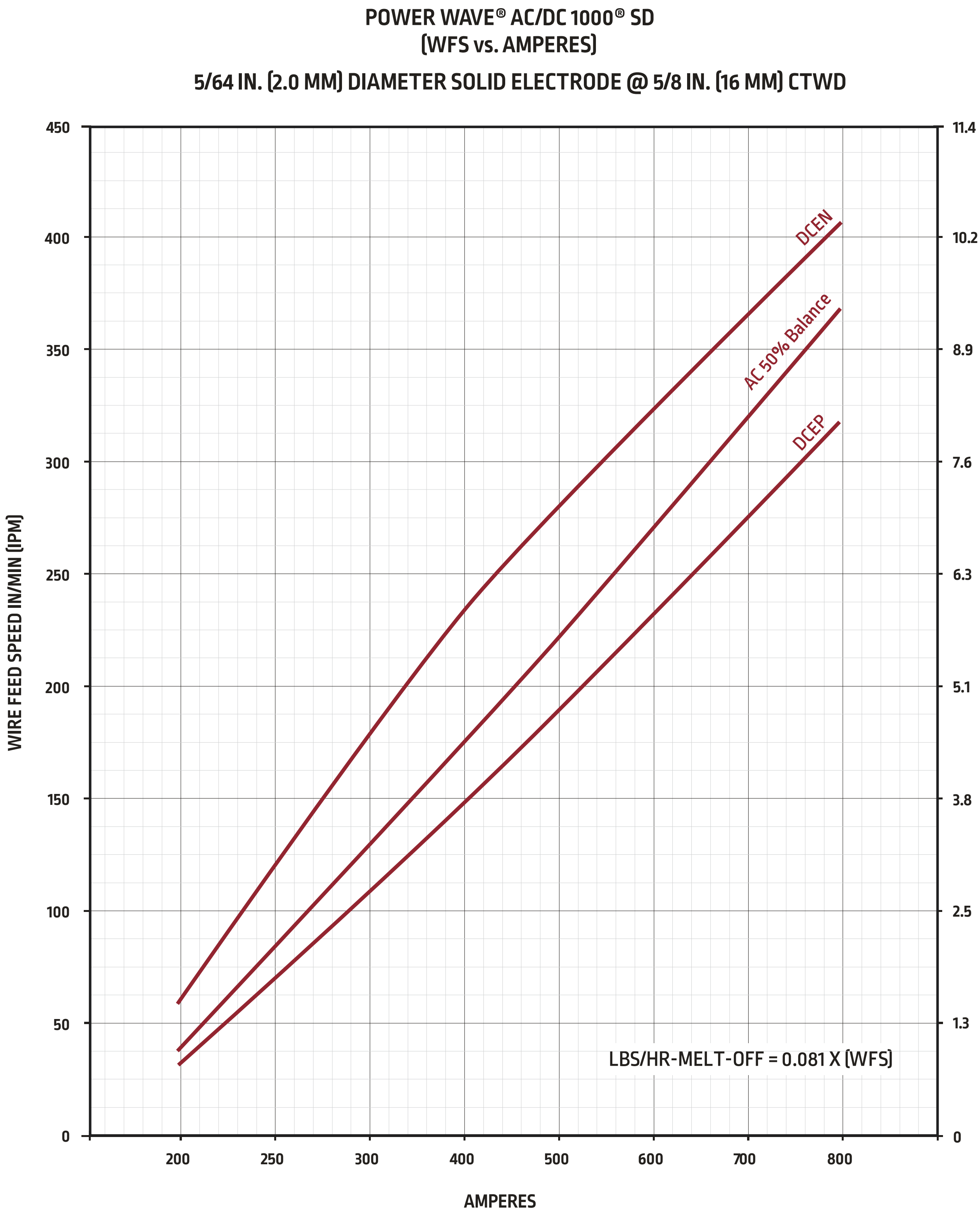


Figure 3-25: 5/64 In. (2.0 mm) Diameter Solid Electrode @ 5/8 In. (16 mm) CTWD

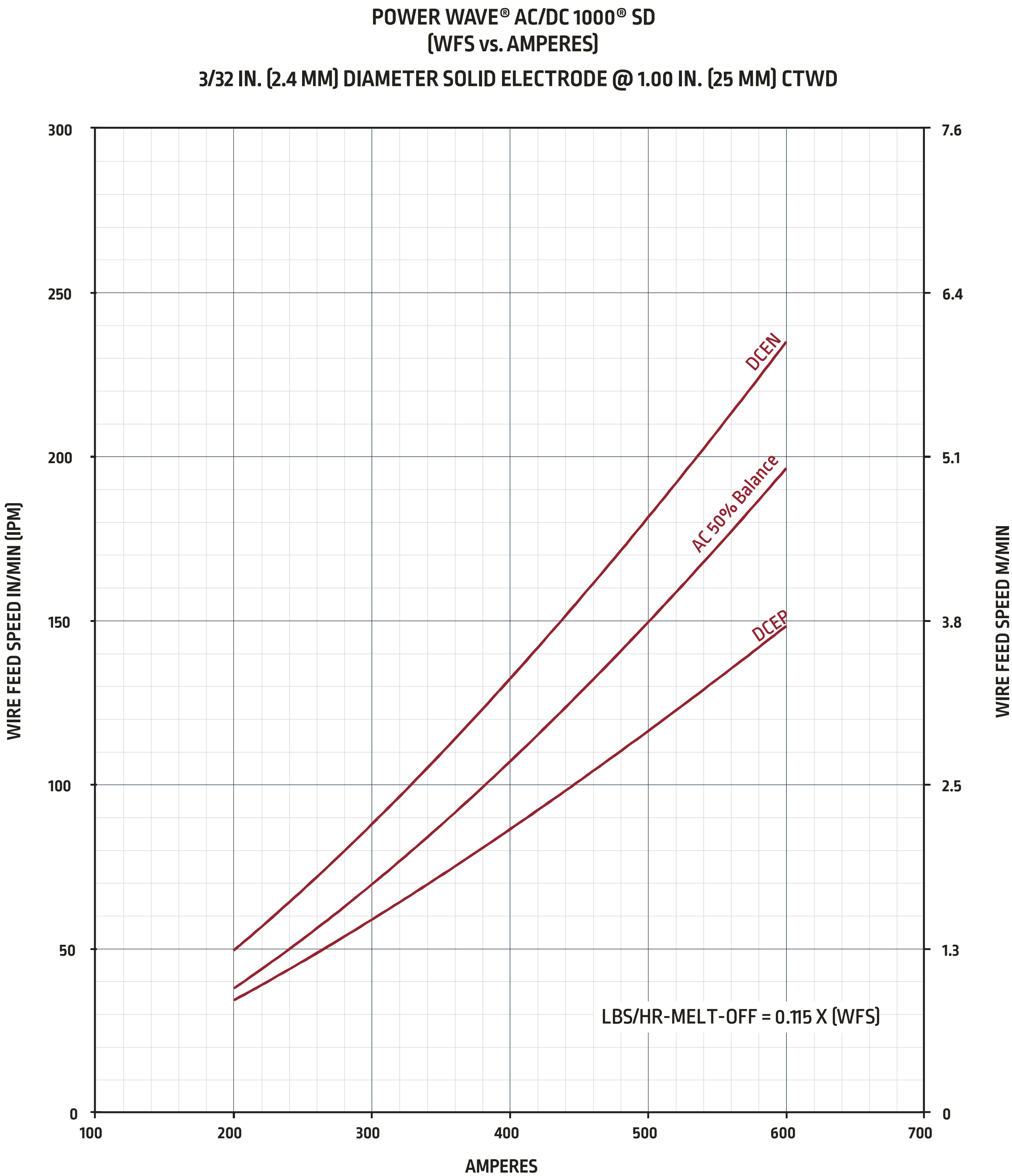


Figure 3-26: 3/32 In. (2.4 mm) Diameter Solid Electrode @ 1.00 In. (25 mm) CTWD

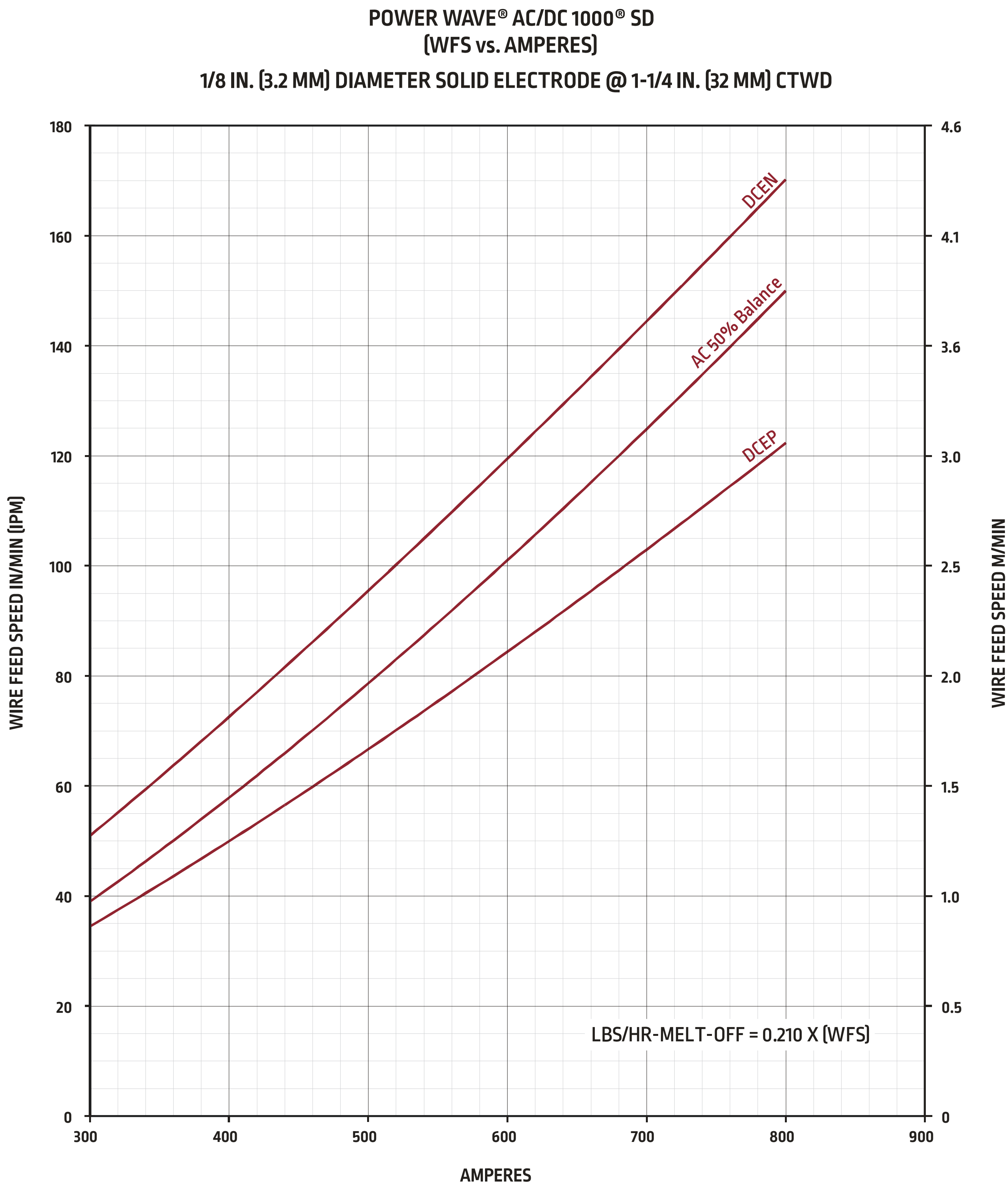


Figure 3-27: 1/8 In. (3.2 mm) Diameter Solid Electrode @ 1.25 In. (32 mm) CTWD

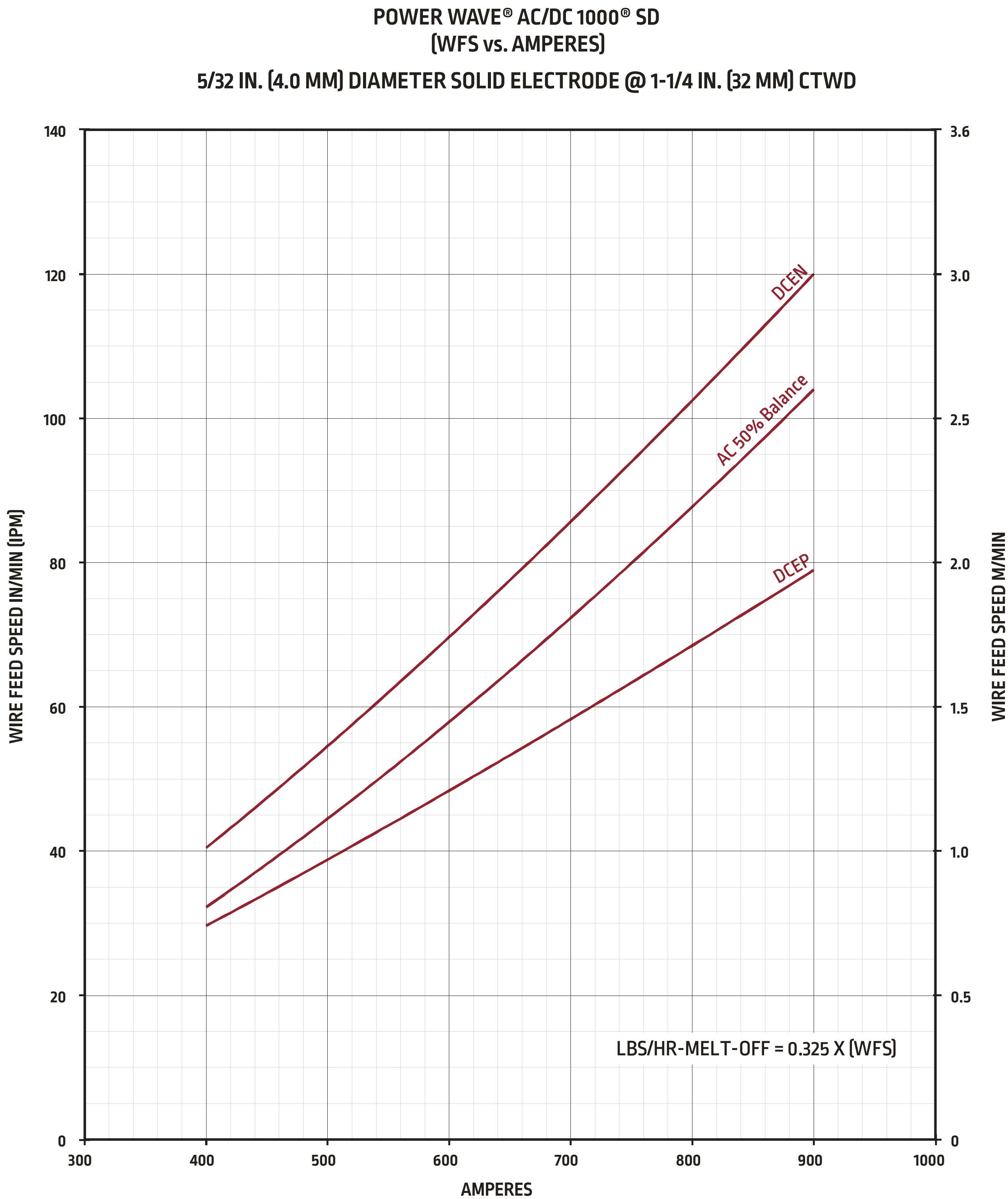


Figure 3-28: 5/32 In. (4.0 mm) Diameter Solid Electrode @ 1-1/4 In. (32 mm) CTWD

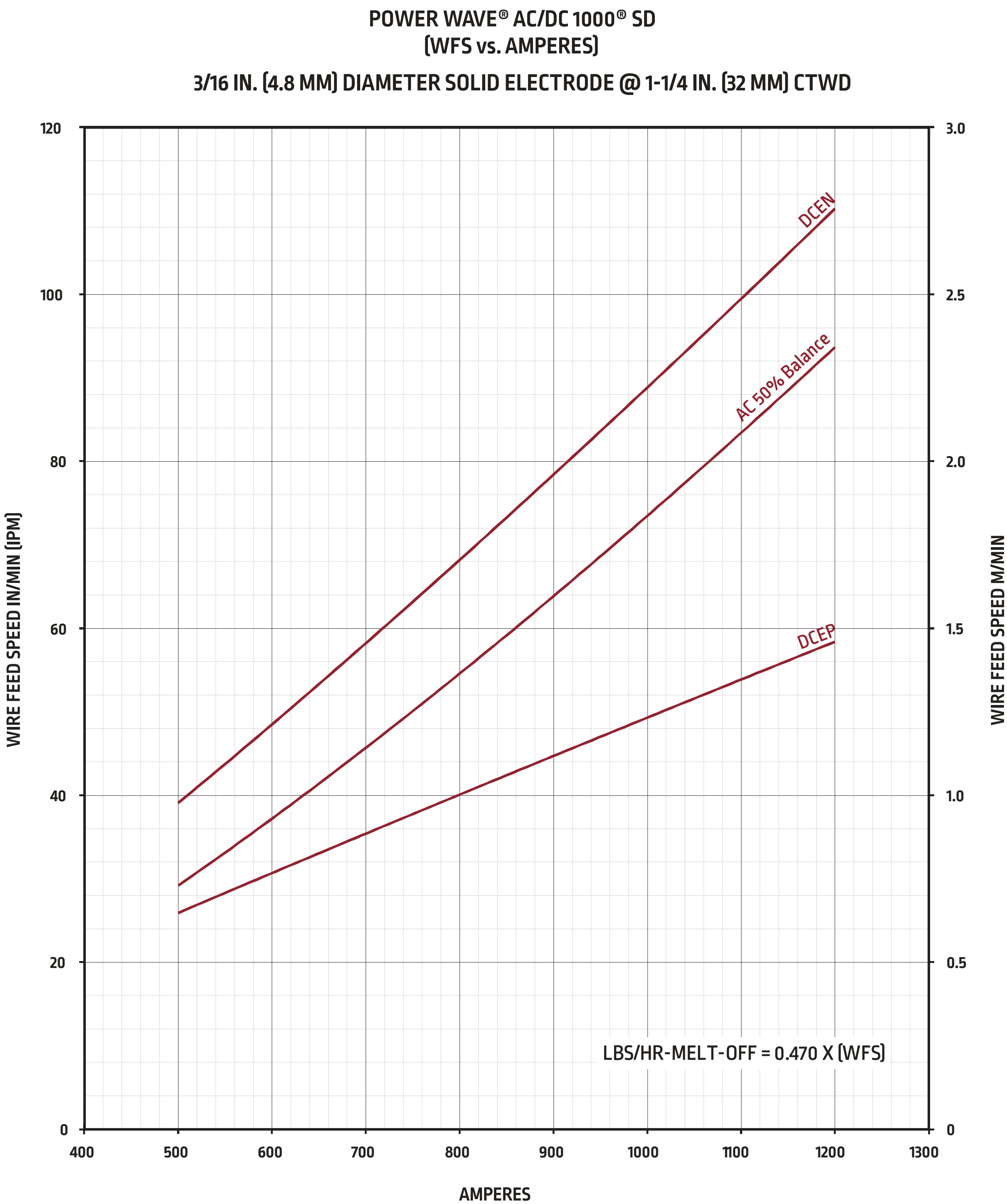


Figure 3-29: 3/16 In. (4.8 mm) Diameter Solid Electrode @ 1-1/4 In. (32 mm) CTWD

Notes

4.1 PREPARATION

Requirements and best-practice suggestions in this section apply to all SAW applications.

1. Always use clean, dry flux.
2. Welding surface edges should be free of rust, primers, organic coatings, solvents, and lubricants.
3. Securely clamp or tack-weld the workpiece to maintain the original joint fit-up during welding.
4. Mating surfaces should be free of cutting dross (see Figure 4-1).
5. Prepare sheared edges so torn edge portion face(s) are together and face up (see Figure 4-1).

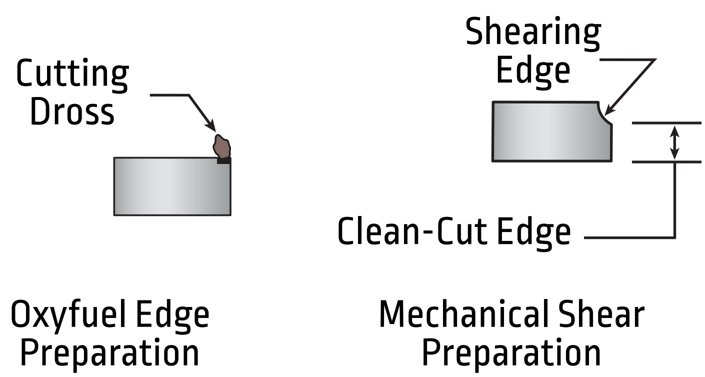
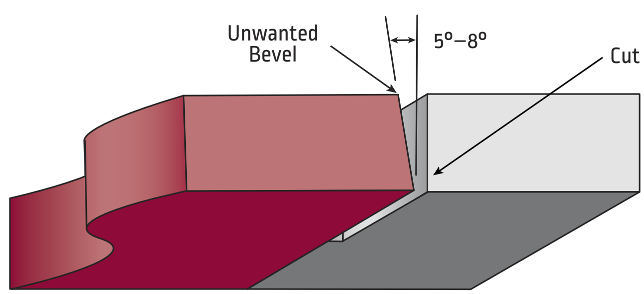


Figure 4-1: Edge Preparation

Plasma cutting presents two unique considerations:

1. Poor practices may lead to the surface picking up nitrogen during cutting, which may cause weld porosity. The cut face may need to be ground to solve this problem.
2. There is usually an unwanted angle of 5˚ – 8˚ on only one side and it should be considered as a slight fit-up bevel (see Figure 4-2).



Direction of cut should be selected so bevel is on the scrap side (shown in red). If this is not feasible, then the wide part of the bevel should be fit on the top side to avoid possible burn-through.

Figure 4-2: Plasma Cutting

4.2 SHEET METAL

While it is somewhat arbitrary, sheet metal is considered to be any thickness less than 1/4 in. (6.4 mm). Controlling distortion and preventing burn through are principal concerns when submerged arc welding on sheet metal. To control distortion, the work must be rigidly supported. A backup bar is also important to avoid burn through. Backup bars may be steel or copper (see Figure 4-3).

If using a steel strip for the backup, it will become part of the finished weld assembly. To avoid distorting edges and curling away from the sheets, intermittent tack welding can be helpful. Also, the use of a slight gap between the plates (less than the electrode diameter) may be beneficial to control penetration and reinforcement.

If the additional backside steel (backing) is unacceptable, then a copper backing should be used. The copper bar may be a flat bar, a bar with a small groove or a larger groove filled with clean flux. The back bead will have the best overall shape with a flux-filled groove.

When using a copper backing bar with a flux-filled groove, special care should be taken to avoid getting flux between the flat part of the backing bar and the plates to be welded. The current path is usually through this bar and if so, the surfaces of the steel and copper should be clean for the sake of electrical contact. The work should be securely clamped down to the copper backing bar to avoid metal run-out defects on the backside weld.

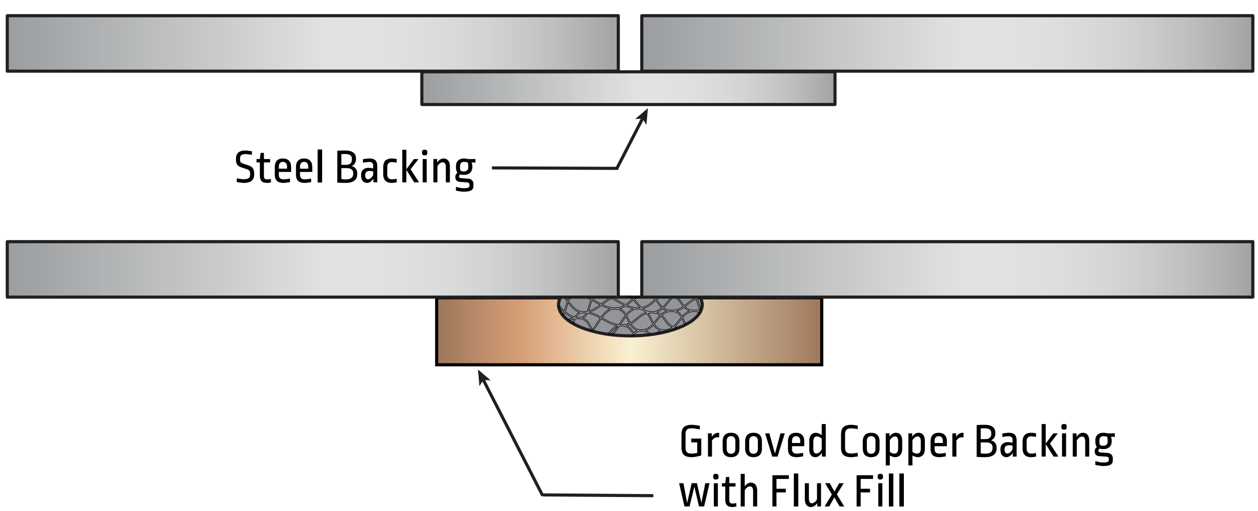


Figure 4-3: Steel and Copper Backing

4.3 JOGGLE JOINT

This weld preparation is frequently used in the fabrication of cylindrical objects and is commonly used with sheet metal. The thickness of metal is dependent on the available forming capacity to produce the joggle.

A joggle joint (see Figure 4-4) uses one plate edge to create a formed edge, which serves as the backing for the weld joint. The plates must be tightly clamped or tack welded to hold both fit-up and weld seam alignment.

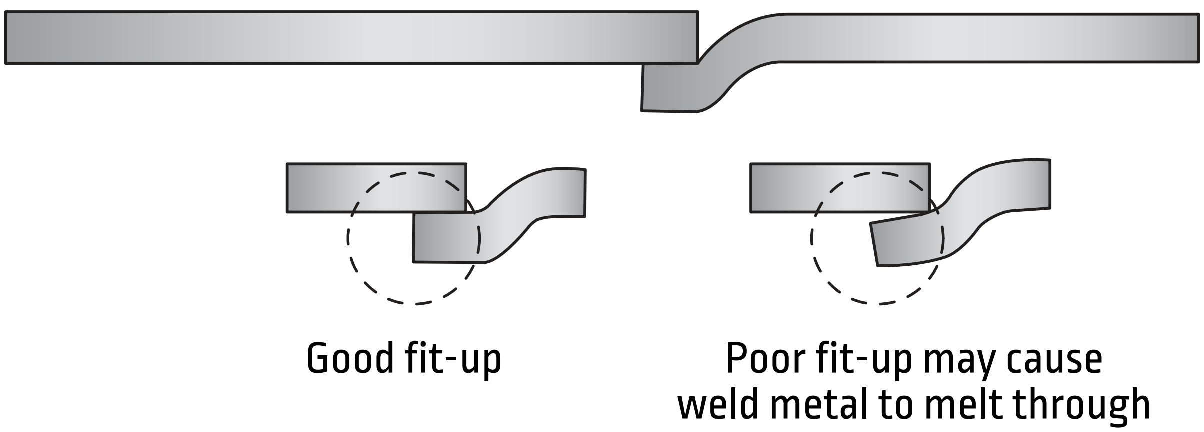


Figure 4-4: Top, Typical Joggle Joint. Bottom Left, Good Fit-up. Bottom Right, Poor Fit-up.

The quality of fit-up and cleanliness of the joint will determine if a joggle joint will need one or two passes to meet complete joint penetration.

If fit-up is poor and scale and rust are within the joint, then two passes will be required. The first pass will be to penetrate all the way to the corner of the joint, which may result in some intermittent porosity. The second pass will consume most of the first pass, eliminate the porosity, and leave behind a smooth cap layer.

If fit-up is optimum, and the material to be welded is free from rust, scale or other contaminants, then a joggle joint may be welded in one pass.

4.4 SQUARE EDGE BUTTS

One hundred percent fusion through the thinner plate thickness (t) is required to produce full weld strength when making square-edge butt welds.

Plates up to 5/8 in. (16 mm) in thickness can be butted tightly and then welded with one pass from each side. With properly sheared or flame-cut edges, 60% thickness penetration is practical on the first side. A potential penetration of 75% – 80% thickness is possible if plate edges are machined and tightly fitted together.

When the edges are tightly butted together, particularly on plates over 1/2 in. (12.7 mm) thickness, the buildup bead on top of the joint may become excessive and show irregular edges. This can be reduced by slightly beveling the edges or fitting a slight gap between the plates. Care should be taken to avoid atmospheric contamination (see Figure 4-5).

Gaps of any kind increase penetration for an otherwise good procedure. As a rule of thumb, if the gap is wide enough for loose flux to spill through (see Figure 4-6), either a backing bar or a seal bead is required to support the flux.

Seal beads may be made with manual electrode, GMAW or gas shielded FCAW processes:

1. For 1/2 in. (13 mm) plate thickness and thicker seal beads should be placed on the second pass side (see Figure 4-7 on page 71).
2. For thinner plate, seal beads and/or tack welds should be placed on the first side (see Figure 4-7 on page 71).

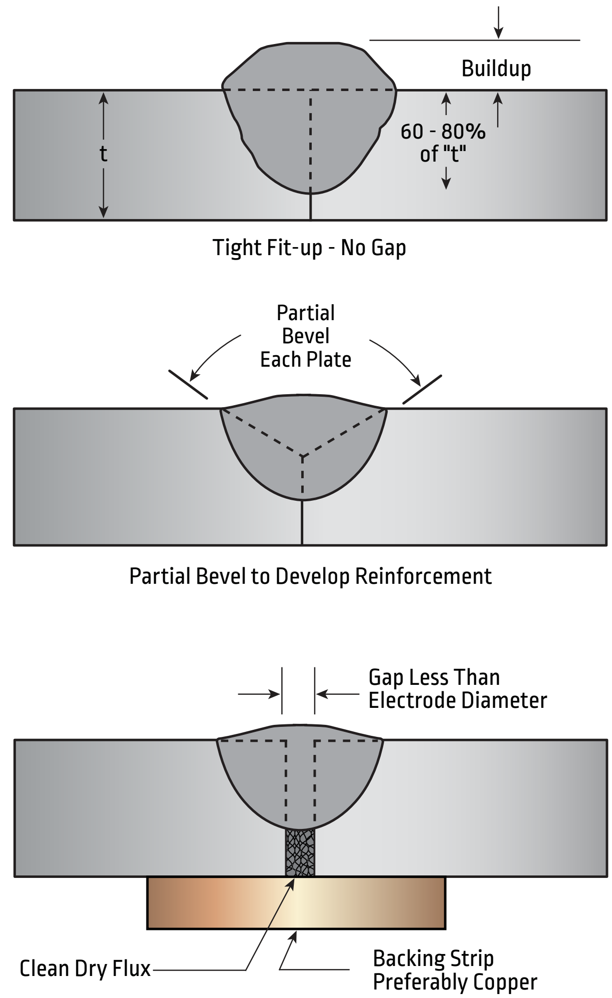


Figure 4-5: Butting Edges Together

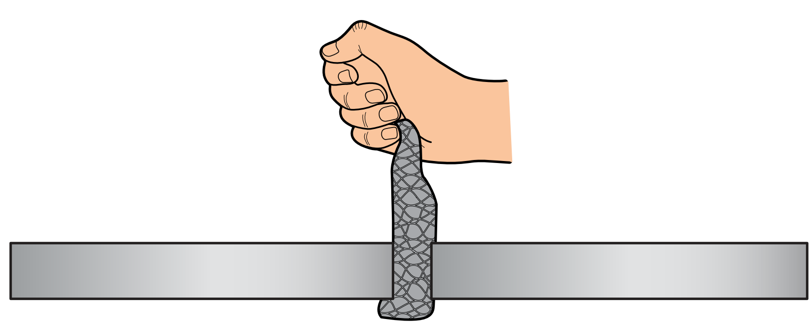


Figure 4-6: Filling Gap

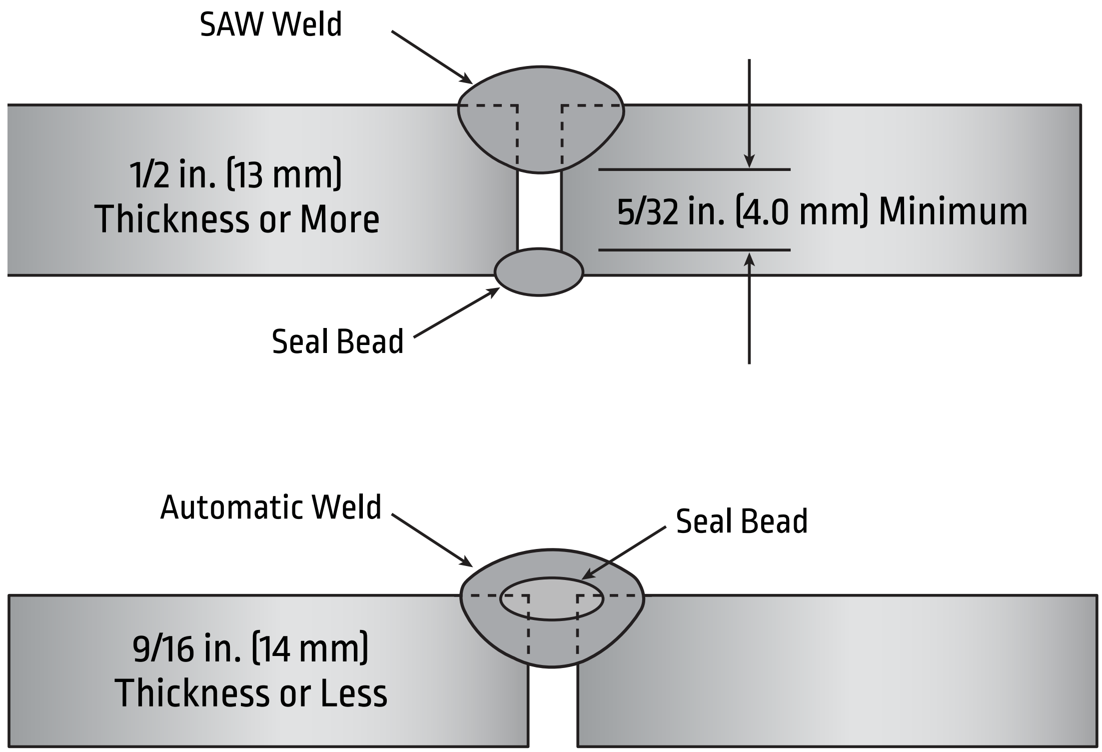


Figure 4-7: Seal Beads

CAUTION: When there is a chance for flux or gas to be trapped between the weld being made and the back of the joint, porosity can result. The porosity may be internal, root porosity or surface porosity. To eliminate this problem, penetration into the backing weld or plate is necessary. Penetration can also be reduced to allow at least a 5/32 in. (4.0 mm) space between the weld and the backing.

For steel up to 1/2 in. (12.7 mm) thick, full penetration welds can be made from one side using a gap and a steel or grooved copper backup bar. The steel backing bar remains as a permanent part of the weldment or can be machined off (see Figure 4-8). This is the same process as was described for sheet metal.

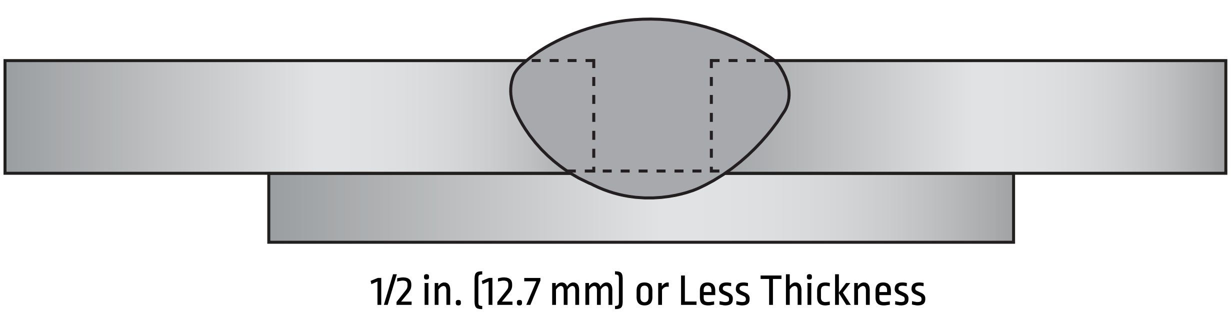


Figure 4-8: Backing Bar

4.5 MULTIPLE PASS DEEP-GROOVE WELDS

The first pass of a deep-groove weld requires the same consideration of possible burn through and penetration as a square-edge butt weld. The root face of the joint serves as a backing bar. If one hundred percent fusion is required, the backside of the joint requires welding. This side can be treated as a square-edge joint. Typically these joints are prepared with a land (as shown in Figure 4-9) if a backing bar is not used.

The shape and depth of the groove(s) makes it easy for the flux depth to become too deep. This can affect bead shape and make slag removal difficult. The depth should be just enough to cover the arc with a slight flicker of light up the backside of the electrode.

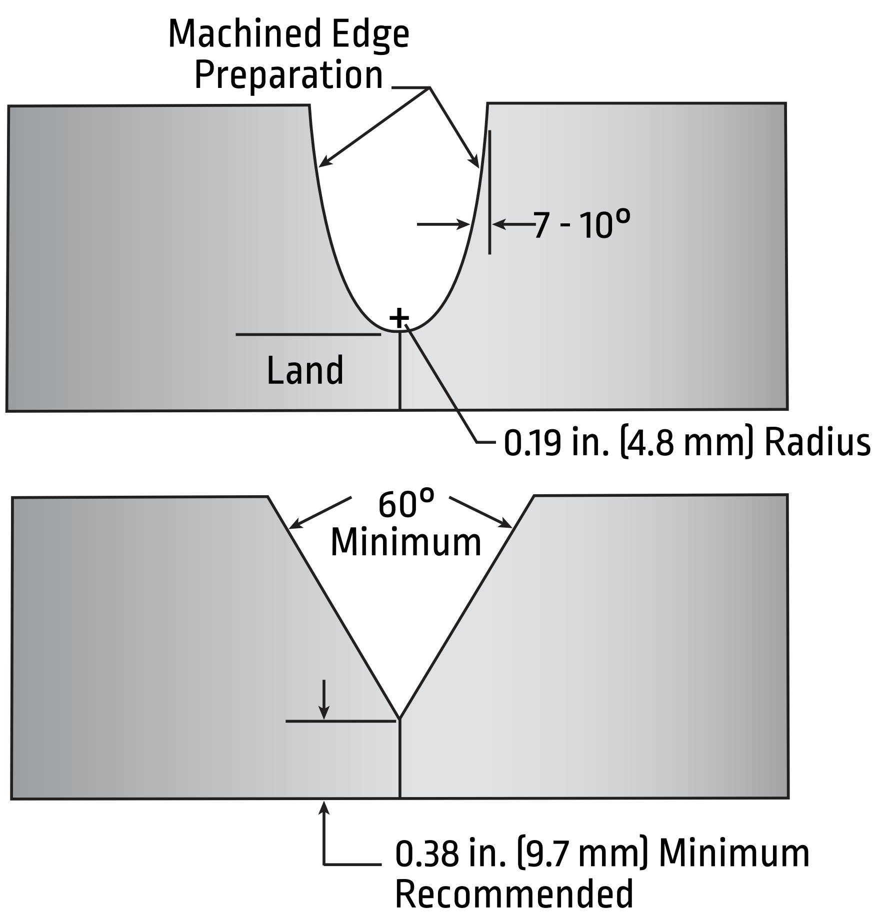


Figure 4-9: Examples of Prequalified Joint Designs AWS D1.1

Slag removal can become a problem if the weld puddle is allowed to become too wide and/or too deep. Excessively wide beads can also become crack sensitive as described in Section 9-3. Proper bead placement and split layers are the best way to produce sound, easily cleaned welds that can improve weld toughness (see Figure 4-10).

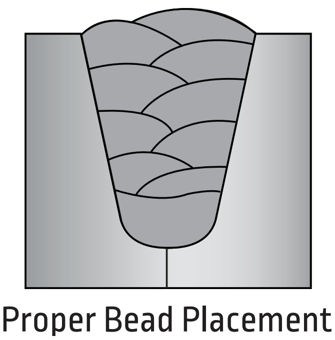


Figure 4-10: Multiple Pass Welds

Electrode placement in Figure 4-11 is critical in these deep groove joints:

1. Too close to the side wall of the bevel will cause undercut and make slag removal very difficult.
2. Too far from the side wall of the bevel can result in a very convex bead, again making slag removal difficult and easy to trap slag in the weld.

Placement of approximately one electrode diameter from the sidewall works in most cases. Using the weld toe from the previous bead as a guide, line up the electrode within a wire diameter of the toe to keep bead placement consistent Check CTWD after each completed layer to ensure the desired length is maintained.

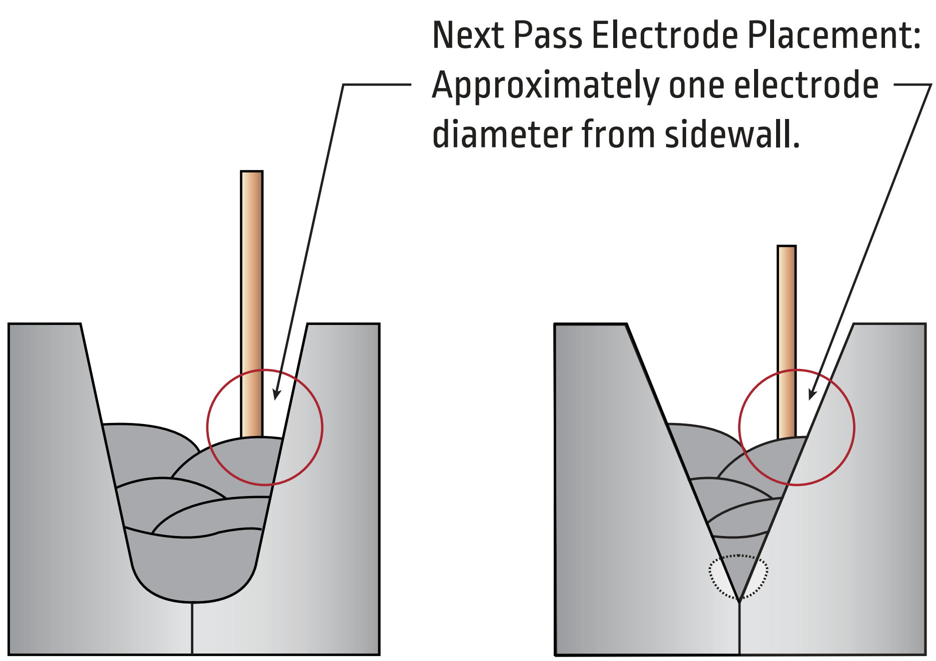


Figure 4-11: Proper Electrode Placement in a Single U-groove and Single V-groove Butt Joint.

4.6 RUN-ON / RUN-OFF TABS

On joints where the weld must run to the end of the plates, some means of restraining the metal so it doesn't spill off the end must be provided. Run-off tabs are the most commonly used method. The arc is started on one run-off tab tacked to the start end of the weld and is stopped on the second tab at the end of the weld. The tabs are large enough so the entire bead on the work itself is properly shaped. Run-off tabs must be wide enough to support the flux and be sealed at the bottom to prevent burn through. Run-off tabs should conform to groove joint configuration. They are removed after the weld is complete.

It is important the run-on/run-off area of the tab replicate the seam geometry as closely as possible. Three acceptable means of attaching tabs are shown in Figure 4-12, Figure 4-13 and Figure 4-14.

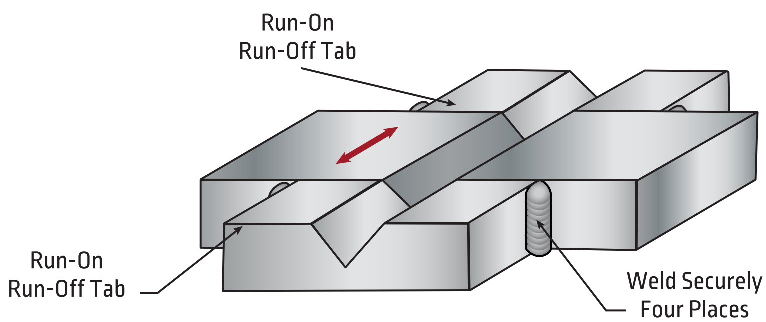


Figure 4-12: Method 1: Run On/Off Tabs Should Be Prepared with the Same Joint Geometry as the Plate to be Welded and Similar in Thickness.

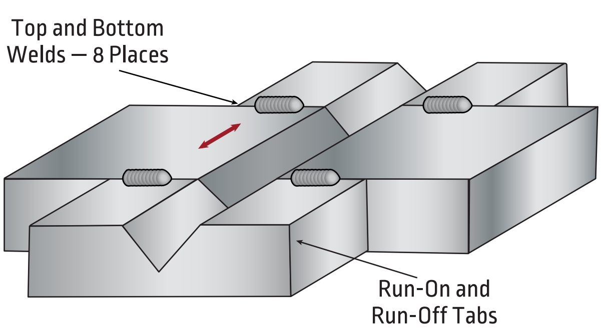


Figure 4-13: Method 2

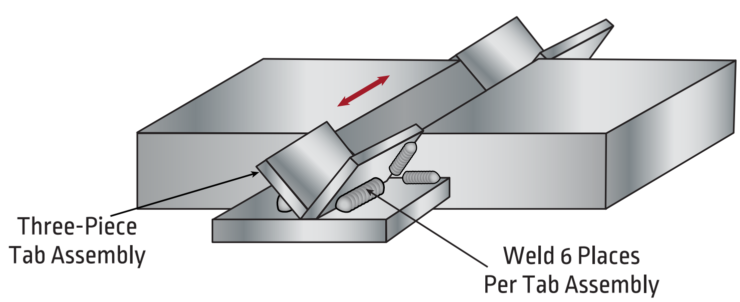


Figure 4-14: Method 3

4.7 FILLET WELDS

Common considerations with making fillet welds:

1. Potential for arc blow.
2. Bead size, shape and penetration.

Potential for Arc Blow

Fillet welds can be subject to arc blow when using DC current, with DCEN being the most sensitive. Careful grounding and the direction of welding going away from the ground is usually best. Arc blow can result in poor bead shape, undercut, and severe porosity. If possible, a large tack weld at the weld end can be helpful (see Figure 4-15). If possible, AC may eliminate this problem.

Figure 4-16 shows two different solidification, centerline cracks. One crack is the result of excess penetration, while the other crack is a result of an excessively concave bead shape. Both cracks are examples of depth (D) to width (W) ratio shrinkage cracking. For other types of cracks and discontinuities, see Section 9.

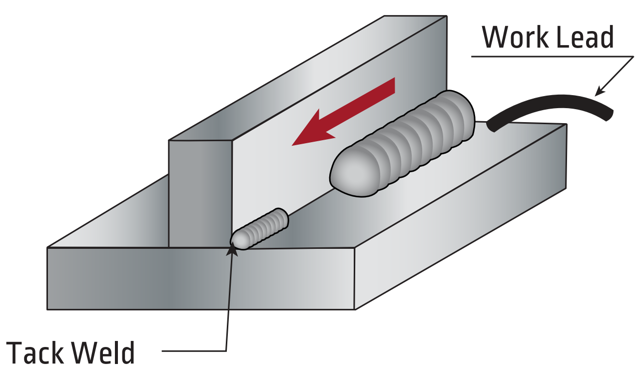


Figure 4-15: Tack Weld Position

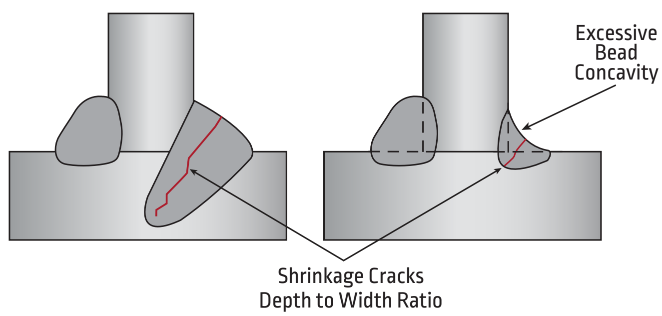


Figure 4-16: Shrinkage Cracks

Bead Shape and Penetration

All fillet welds are a combination of the visible fillet weld and the melted root (arc penetration) of the parent plates. The fillet is usually sized by measuring the visible portion of the weld. The key features of a fillet weld are leg size, throat, convexity, and root penetration.

4.8 PENETRATION FILLETS: DCEP VS. DCEN

By requiring less filler metal and perhaps higher travel speeds, deep penetration DCEP fillets can reduce weld costs below conventional DCEN fillets. The strength of a given fillet weld is determined by the effective throat of the weld.

NOTE: If welding must comply with some specific code specification, making penetration fillet welds may not be permitted.

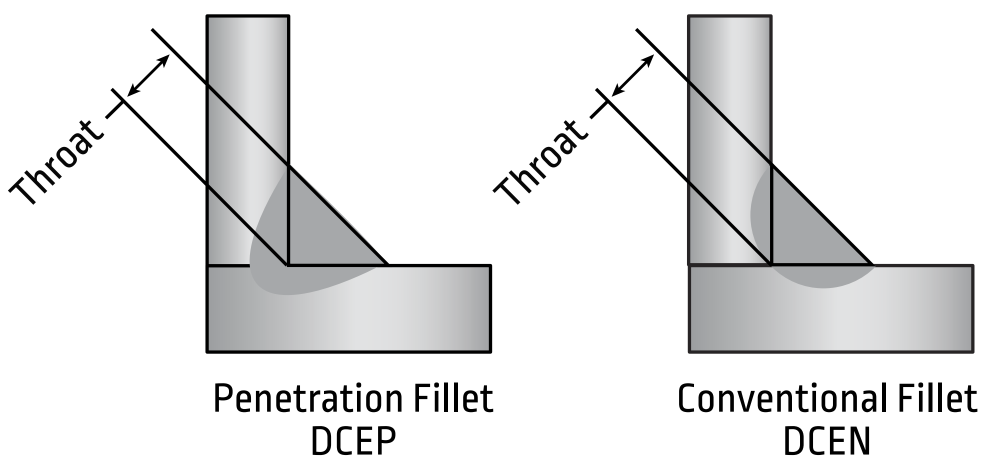


Figure 4-17: Equal Strength Fillet Welds

4.9 HORIZONTAL FILLET WELDS

The largest acceptable single pass horizontal fillet weld is generally a 5/16 in. (7.8 mm) fillet. Trying to make a larger fillet usually results in poor bead shape, resembling the weld below (see Figure 4-18). For more information about undercut, overlap or other discontinuities, see Section 9.

Larger horizontal fillet welds can be made with multiple passes. A 3/8 in. (10 mm) fillet weld is usually made in two passes and a 1/2 in. (12.5 mm) weld is made in six passes (see Figure 4-19).

NOTE: In many third-party welding codes, a 5/16 in. (7.8 mm) is the largest single-electrode, single pass, prequalified weld allowed in the horizontal position. This includes the AWS Structural Codes. There is no size restriction for welds made in the flat position.

Setup: Automatic Horizontal Fillet Welds

Typical setup for single pass welds is shown in Figure 4-20 on page 78.

Contact tip to work distance (CTWD) will vary depending on the electrode diameter and the desired weld size. A good rule of thumb to use when determining proper CTWD of any weld is to multiply the wire diameter times eight. For example, a 5/32 in. (4.0 mm) diameter wire should typically be set at 1-1/4 in. (32 mm). A slight electrode drag angle (see Figure 4-21 on page 78) can be helpful in making larger welds.

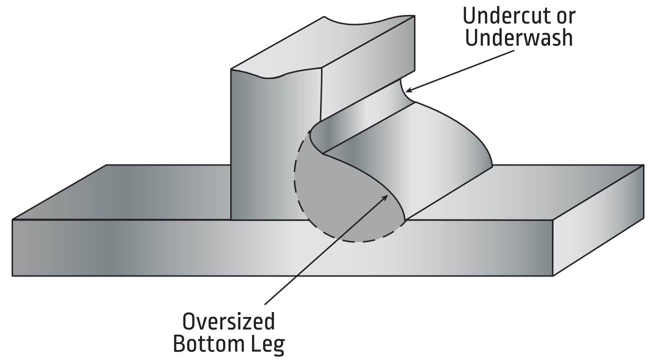


Figure 4-18: Horizontal Fillet #1

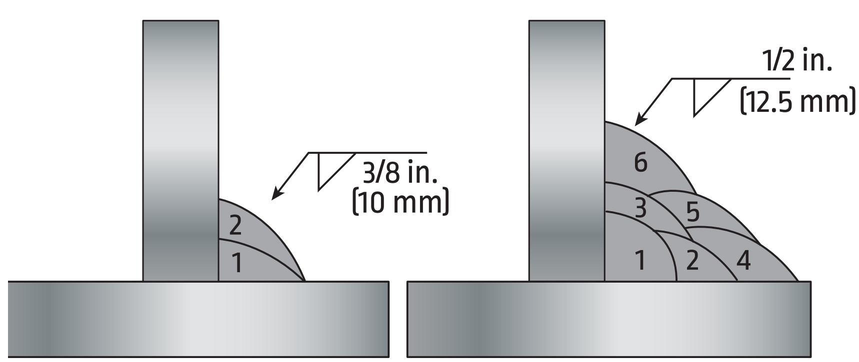


Figure 4-19: Horizontal Fillet #2

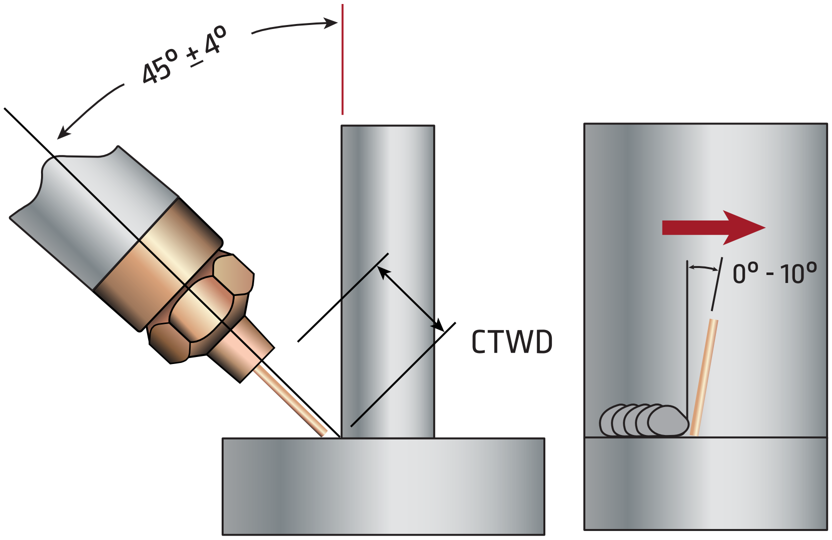


Figure 4-20: Electrode Positioning—Single Pass Horizontal Fillet

Multiple pass horizontal fillets will require some electrode repositioning for each layer and pass (see Figure 4-21). Electrode diameter and flux/electrode combination will affect the actual electrode placement. On larger multiple pass welds, unfused flux can be used to form a dam on the lower passes to help support the current pass. The fourth pass should establish the bottom leg to correct size, 1/2 in. (12.5 mm).

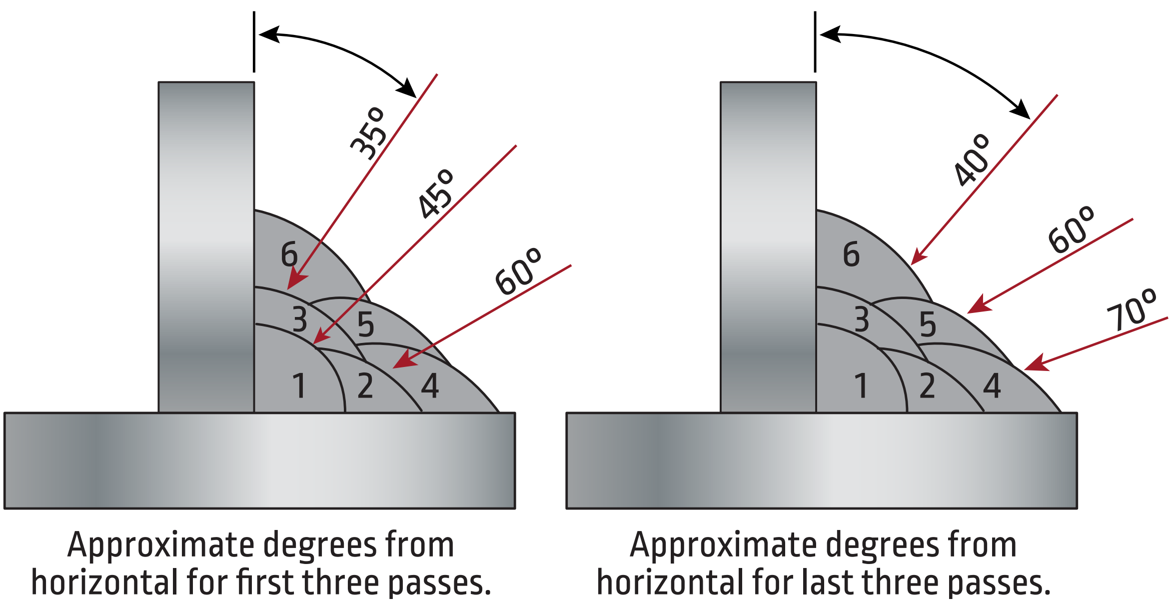


Figure 4-21: Electrode Positioning—Multiple Pass Horizontal Fillet

4.10 FLAT POSITIONED FILLET WELDS

The same guidelines that apply to a horizontal fillet weld, apply to flat positioned fillets, except that it is possible to make a 1/2 in. (12.5 mm) single arc weld in one pass. A slight drag angle should be used. A 2˚– 3˚ uphill joint angle position may prove helpful on larger welds. This process keeps molten slag from running ahead of the puddle. The CTWD must be maintained during weld travel (see Figure 4-22).

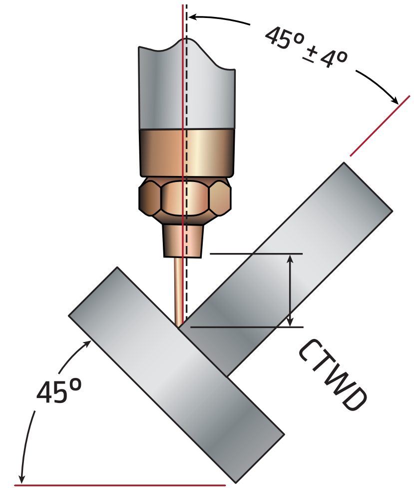


Figure 4-22: Electrode Positioning - Single Pass Flat Fillet

4.11 EQUIPMENT FOR ALL HORIZONTAL FILLETS AND LAP WELDS

When welding with fully automatic equipment, use of a curved nozzle assembly, like the one shown in Figure 4-23, may be beneficial. This nozzle is recommended to keep the flux hopper in a nearly vertical position for most welds of this type. Since the flux hopper is mounted to the drive roll faceplate, use of standard straight nozzles require the drive roll faceplate to be rotated to the appropriate angle. This also rotates the flux hopper. The hopper should not be rotated more than 40˚ from the vertical, or flux feeding can become erratic.

Use straight contact nozzle assemblies for lap welds with electrode angle setups 0˚ – 30˚ from vertical.

Installing the flux control lever on the flux hopper is very helpful for controlling the amount of flux delivered to the weld in progress (see Figure 3-5 on page 45).

Figure 4-23: Curved SAW Nozzle

4.12 LAP WELDS

There are two major requirements for all lap welds, regardless of the material thickness of the plates to be welded:

1. Plate fit-up must be tight. Gaps in fit-up will cause an undersized weld on thick top plates and a scalloped or undercut top edge on thin plates.
2. Abutting surfaces should be free of all coatings, especially organic-based, as well as heavy mill scale and rust.

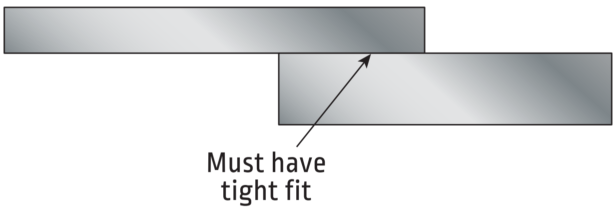


Figure 4-24: Lap Weld Fit-Up

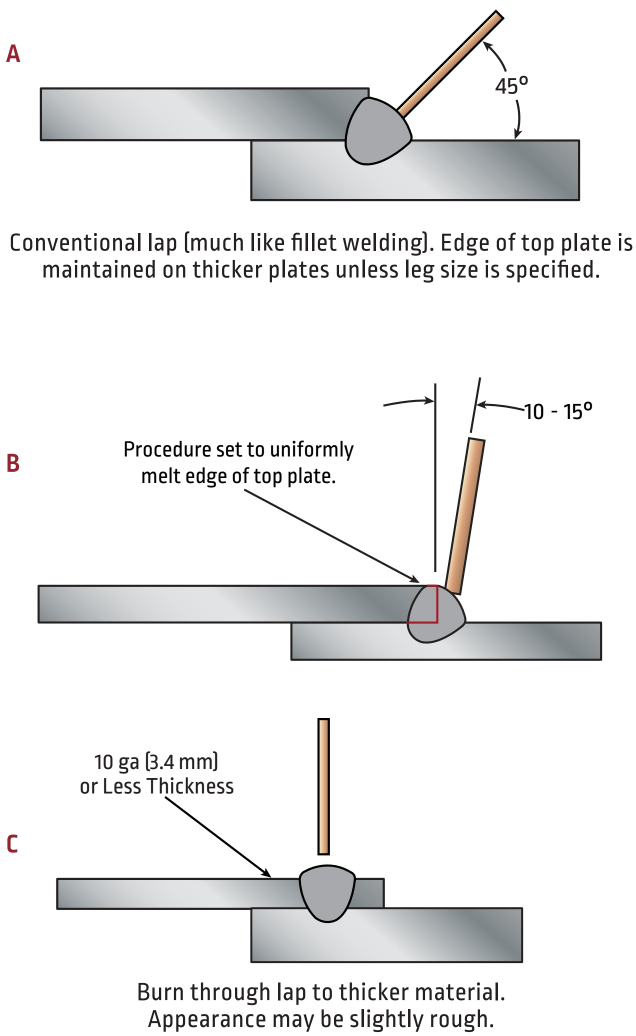


Figure 4-25: 3 Variations of Lap Welds

Figure 4-24 and Figure 4-25 provide more information on lap weld fit-up, different types of lap weld fit-up, different types of lap welds and the process of melting the edge of a lap weld to fit weld size.

Sometimes the desired weld is sized such that it is slightly less than the top plate thickness. This can result in a top plate edge that appears to be scalloped and/or undercut. This can occur when the top plate thickness is just slightly greater than the specified weld size. The procedure can be set to just uniformly melt the top edge corner (see Figure 4-25 B). Be sure to check the specific requirements of the welding code for the application.

4.13 PLUG WELDS

A true plug weld is a weld made without any manipulation of the arc during welding. Depending upon the thickness of the plates to be welded, a 3/4 in. (19 mm) diameter hole is about the largest practical size that can be filled without some manipulation of the arc. Top plate thickness up to 1/2 in. (12.5 mm) can readily be welded. For thicker plates, CTWD changes can cause changes in voltage and current that may be undesirable.

The use of fully automatic equipment is highly recommended to take advantage of preset arc-strike, arc-run and crater-fill.These welds are usually timed to assure proper fill, including the crater. Using the wire feed speeds/current charts is helpful in establishing a good procedure.

While these welds can be made semi-automatically, skill is required by the welder to provide multiple, identical welds.

The copper flux retaining ring should be just tall enough to provide a suitable flux depth, which will vary with top plate thickness. The diameter should be large enough to provide for uniform flux spread over the weld diameter and crater. An example of a copper flux ring is shown in Figure 4-26.

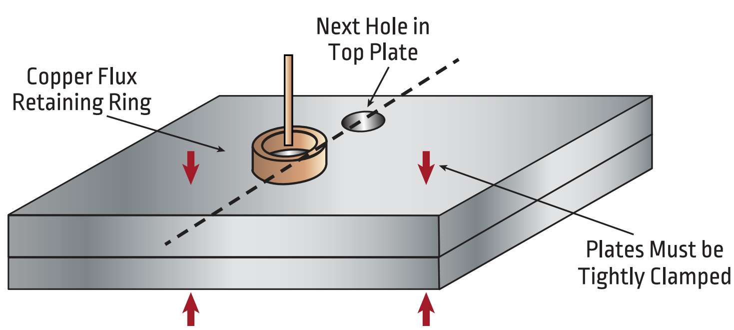


Figure 4-26: Plug Weld

Notes

5.1 DESCRIPTION AND CHALLENGES

A circumferential weld is a distinct type of weld produced around the rotational surface of a cylindrical work piece. Circumferential welds are most often used to fabricate pipes or tanks. Circumferential (or roundabout) welds differ from flat and horizontal welds in three major ways:

1. Molten flux and weld metal have a tendency to spill off the work and the smaller the diameter of work, the greater the tendency for this spill to occur.
2. Ease of slag removal is very important:
    - To ensure good tie-in at the start and finish ends of single pass welds.
    - To facilitate continuous welding without interruption between passes and layers of multiple pass welds.
3. To avoid affecting the finished bead shape, it is critical to control molten slag and/or weld metal to avoid sag or spillage from the weld puddle.

The following factors are important to avoid problems noted above:

» Location of the electrode on the circumference away from top dead center or bottom dead center.

» Tight control of the welding procedure.

» Supporting the loose flux, especially on smaller diameter work.

» Using a flux that creates a slag that solidifies rapidly.

» Maintain proper electrode position and angle, relative to the joint. A 90˚ angle or a slight drag angle, is desirable to maintain good bead shape.

» Maintain correct CTWD, sometimes erroneously referred to as “stickout.”

Figure 5-1: Spiral Welded Pipe

5.2 EFFECT OF ELECTRODE POSITION ON CIRCUMFERENCE

Figure 5-2 (A) shows the desired weld result when the electrode is correctly located on the circumference and the correct welding procedure is utilized.

Figure 5-2 (B) shows the undesirable result when too little O.D. electrode displacement is used, or too much I.D. displacement, even if the correct procedure is used.

Figure 5-2 (C) shows the undesirable result when too much O.D. displacement is used, or too little I.D. displacement is used.

Figure 5-3 shows the approximate distance (D) of the electrode placement from the vertical centerline. Note that this dimension is measured to the tip of the electrode with the electrode set to the correct CTWD.

NOTE: These figures all show the work rotation to be clockwise. If the rotation is counter-clockwise, measurements will be to the opposite direction.

Travel speed plays a major role in in recommended displacements. For example, an increase in travel speed may require an increase in electrode displacement.

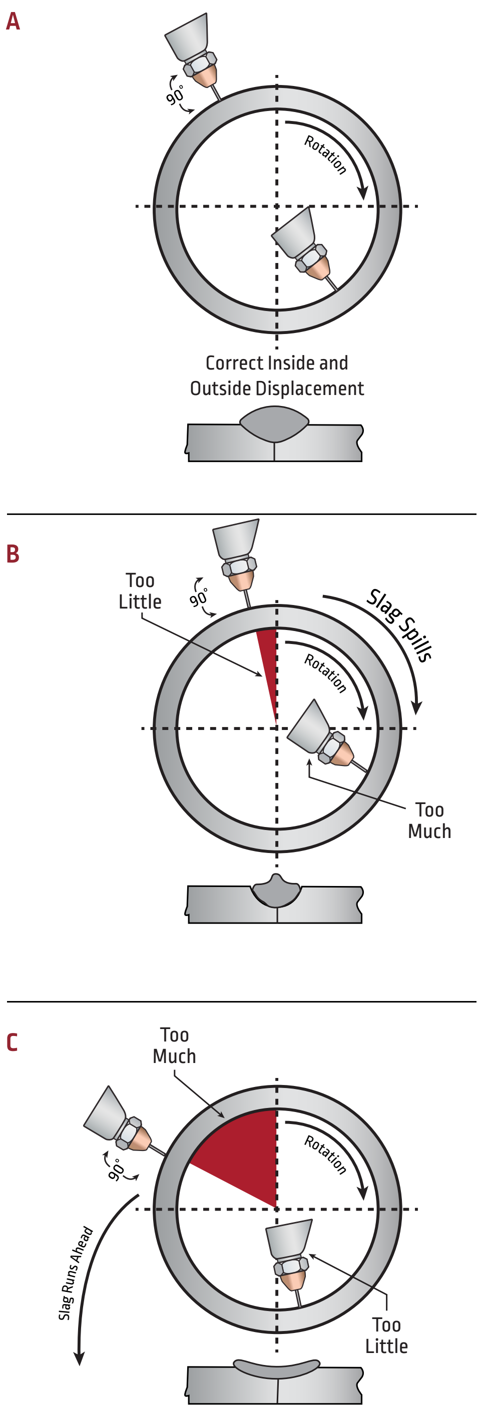
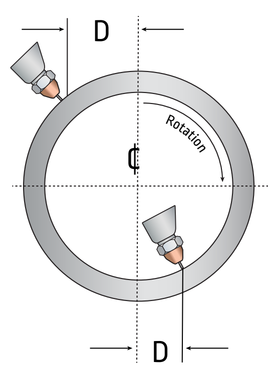


Figure 5-2: Shows Effect of Electrode Displacement on Bead Shape



Girth Diameter	Electrode Displacement "D" Range
in (mm)	in (mm) from vertical centerline
1–3 (25–76)	3/8 – 3/4 (9.5–19.1)
3–18 (76–457)	3/4 – 1 (9.5–19.1)
18–36 (457–914)	1-1/4 – 1-1/2 (31.7–38.1)
36–42 (914–1067)	1-1/2 – 1-3/4 (38.1–44.4)
42–48 (1067–1219)	1-3/4 – 2 (50.8–63.5)
48–72 (1219–1829)	2 – 2-1/2 (50.8–63.5)
Over 72 (1829)	3 (76.2)

Figure 5-3: Suggested Electrode Displacement

5.3 EFFECT OF PROCEDURE VARIABLES

Regardless of the electrode position on the work, if the weld puddle is too large for the diameter of the work, slag and weld metal will spill because there has not been adequate time for the puddle to solidify. Factors that directly affect the weld puddle size include:

1. Welding current
2. Travel speed
3. Electrode diameter
4. Voltage (slag volume is proportional to voltage)

Deposition rate and travel speed are especially important in controlling bead size and shape. For a given welding procedure, reducing the current (deposition rate) and/or increasing the travel speed reduces the volume of weld metal placed in the joint. A good starting point, especially on smaller diameter work, is to use a deposition rate (lbs/hr) that is numerically the same or less than the joint diameter in inches. This linear rule of thumb does not apply to metric values. For example, when welding a 14 in. diameter pipe, a good starting point is 14 lbs/hr. deposition rate and 14 inches per minute travel speed.

5.4 CIRCUMFERENTIAL FILLET AND LAP WELDS

When making fillet and lap welds that are fitted circumferentially, there are two primary considerations:

1. Locate the point of weld on the circumference as if it were going to be a butt weld.
2. Position the electrode at that point as if it were going to be a horizontal fillet or lap weld.

5.5 FLUX DELIVERY

Flux should be delivered just ahead of the electrode and arc, or around the electrode. Care should be taken to deliver the flux in a smooth, consistent manner. There are two usable devices for flux delivery (see Figure 5-4).

Figure 5-4: Shows Flux Delivery Methods; Left, Lincoln Electric Contact Assembly that Delivers Flux around the Electrode; Right, Lincoln Electric Contact Assembly that Delivers Flux Ahead of the Arc

The amount of flux delivered should be just enough to cover the arc with just a slight flicker of light above the flux pile and along the electrode. By utilizing the contact tube assembly, flux volume can be controlled by sliding the flux cone body assembly up or down. With the nozzle, it is recommended the flux hopper have a sliding flux adjustment installed.

To avoid flux spillage with any nozzle assembly, a flux-supporting device should be incorporated. The device must be electrically insulated and include a flexible fabric pad, such as high-temperature fiberglass that is in contact with the work surface. (A typical device is shown in Figure 5-5.) Controlling the flow and direction of the flux is paramount to controlling the weld metal puddle. If the flux spills uncontrollably, the weld metal will not solidify in the desired location and be subjected to lack of shielding and atmospheric contamination.

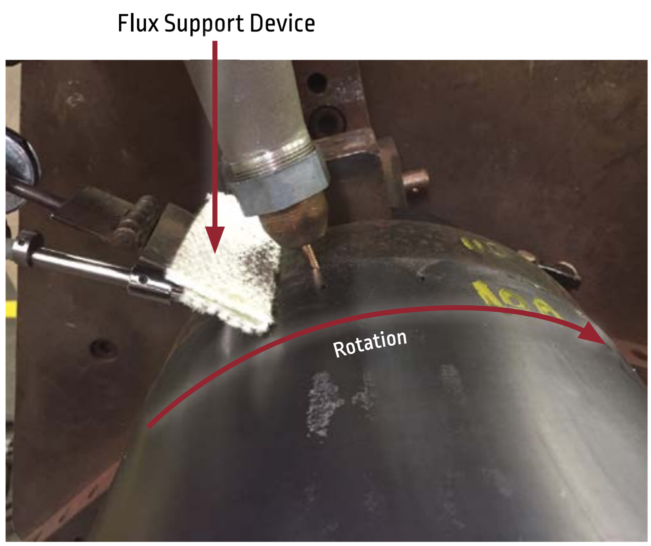


Figure 5-5: Flux Support Device

5.6 SLAG REMOVAL

Slag removal is especially important on circumferential welds in order to ensure good tie-in between the start and finish ends of a weld pass or layer. Factors that directly affect slag removal are:

1. Flux selection
2. Procedure (especially arc voltage)
3. Temperature (weld seam proximity)
4. Bead shape and placement
    - **NOTE:** Split pass layers typically give better slag removal than single pass layers (see Figure 5-6).
    - To ensure good slag removal on thinner-walled material requiring only two or three passes, the pass before the last pass should wash just to the top (see Figure 5-7).

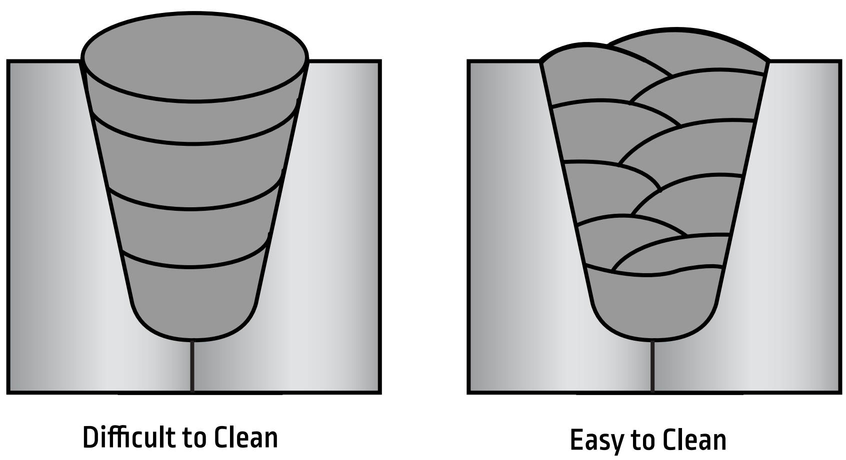


Figure 5-6: Influence of Bead Shape on Slag Removal

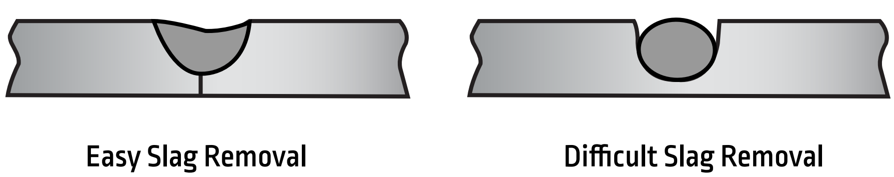


Figure 5-7: Bead Shape before Final Cap Pass

The depth of flux coverage can increase the difficulty of removing slag. It can also result in misplacing bead location as well as trapping slag in corners of the weld pass. Flux depth should be just enough to cover the arc and allow a slight flicker of light. Excess flux depth may also result in reducing contact tip life and, in some cases, damage the nozzle itself (see Figure 5-8).

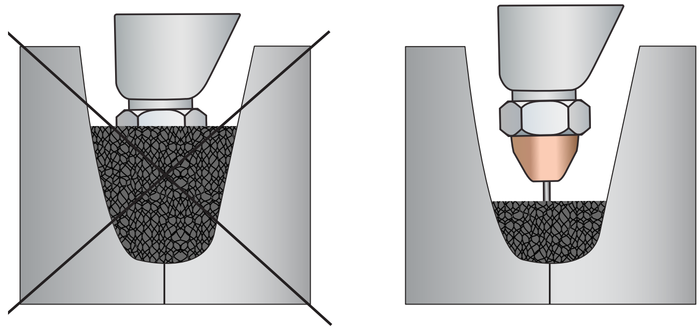


Figure 5-8: Flux Depth

5.7 FLUX COLLECTION AND RECYCLING

Circumferential welds can involve long, continuous welds requiring large amounts of flux. It is highly recommended that some form of flux recovery system be used to capture and clean the flux, and to remove slag particles. On some welds, a properly configured vacuum system can be used for this purpose. If this is not practical, then a screened pan may be employed to capture both slag and unfused flux. This flux should be run through a screen and magnetic separator before reusing. Flux that has fallen onto a floor, or perhaps lodged in a fixture, should be discarded. If recycled flux is to be stored for future use, it should be treated as described in *Section 10: Submerged Arc Flux Storage, Re-Drying and Recycling*.

5.8 WELDING GROUND

Grounding a fixture frame to complete the welding circuit is a very poor practice and should be avoided. Grounding to any stationary portion of a fixture results in having to carry welding current through bearings. This can result in an erratic ground as well as shorten bearing life. If the work piece is attached to a rotating shaft, copper or copper-graphite sliding shoes may be utilized. At the point of attachment, the shaft must be free of rust, oil or paint. The best grounds may be commercially available rotating grounds with suitable current rating, or a brush ground system with multiple brushes to carry the current (see Figure 5-9).

Figure 5-9: Grounding Brushes Mounted to a Bracket.

Notes

6.1 INTRODUCTION

This section is specifically focused on two-electrode tandem arc welding. There are many applications using three, four or more electrodes combined to form one weld pool, but that is beyond the scope of this document. Contact your local Lincoln Electric representative if you need additional information about multiple arc welding. A typical tandem arc setup is displayed in Figure 6-1. A standard tandem arc setup will include two power sources, two spools of electrodes, two wire feeders, two contact assemblies and two arcs, all feeding into one puddle. Because two electrodes feeding into the same weld carry higher total currents than a single-electrode, many applications that can be successfully welded with single-electrode automatic equipment can be more economically welded with tandem arc multiple-electrode methods.

The higher currents generated by two electrodes will increase deposition rates and speeds, reduce distortion due to increased speeds, and reduce welding costs.

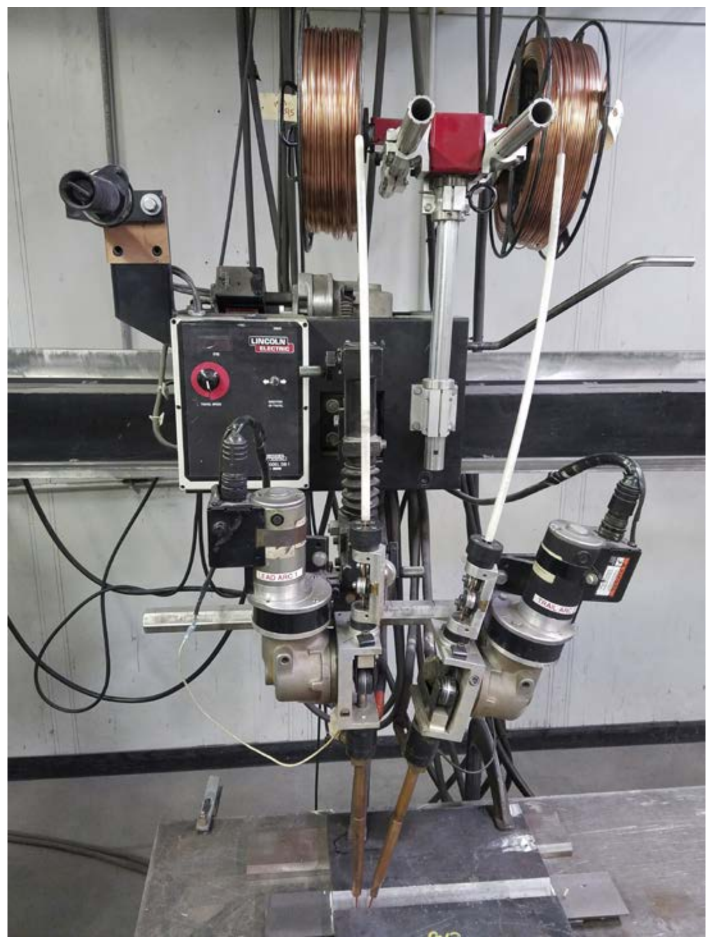


Figure 6-1: Tandem Arc Setup

6.2 TANDEM ARC ADVANTAGES

1. Tandem arc offers a range of 25% – 100% higher deposition rates and travel speeds than a single-electrode and can be useful for a range of applications such as:
   - Multiple pass welds.
   - Single pass butt welds on 10-gauge and thicker steel.
   - Single pass 1/4 – 1/2 in. (6.4 – 12.7 mm) horizontal fillets and laps.
   - Single pass 1/4 – 3/4 in. (6.4 – 19.1 mm) flat fillets.
   - Large diameter (24 in. (0.6 m) minimum) circumferential welds.
2. Provides the best option when welding into a flat flux backing.

Figure 6-2: DC-AC Double Electrode Tandem Arc Setup

6.3 LIMITATIONS OF TANDEM ARC WELDING

The combination of high travel speed, a larger weld puddle, more involved weld setups and higher equipment costs, makes multiple arc welding impractical for the following applications:

» Short welds and small diameter roundabouts.

» Installations where frequent setup changes are required.

» Low-volume jobs that will not justify equipment costs.

6.4 DC-AC TANDEM ARC WELDING WITH CONVENTIONAL EQUIPMENT

In every tandem arc setup, there are two wires (arcs) feeding into one puddle. They are designated as lead and trail. The lead wire is used to penetrate into the material being welded. The trail wire is used to fill and cap the weld. With prior knowledge being that maximum penetration comes from DCEP and the primary role of the lead arc being penetration, a typical tandem setup uses DCEP on the lead. To avoid arc deflection, the trail wire is run on AC.

Conventional equipment setup for this process has been an NA-3 or NA-5 automatic head and DC power source for the lead arc and an NA-4 automatic head and a CC type AC power source for the trail electrode. (See Figure 6-3.)

NA-3

DC-1000

NA-4

NA-5

AC-1200

Figure 6-3: Typical DC-AC Tandem Arc Welding Equipment

6.5 TANDEM ARC WELDING WITH THE POWER WAVE® AC/DC 1000® SD SUBARC WELDER

The Power Wave® AC/DC 1000® SD subarc welder (Figure 6-4) has greatly simplified the tandem arc process and added powerful versatility in comparison to earlier tandem arc welding systems. AC-AC setups are simplified and maximized using this greater technology. The same power source can be used for DC+, DC-, and a variety of AC configurations.

For procedure enhancement and/or fine-tuning purposes, the frequency, balance and offset functions of the Power Wave® AC/DC 1000® SD subarc welder may be useful.

Several major characteristics of the Power Wave® AC/DC 1000® SD subarc welder make it easy to implement a tandem arc welding process:

Figure 6-4: Power Wave® AC/DC 1000® SD

» Three-phase input power makes it easy to install without possibly unbalancing primary power input lines.

» Phase angle relationship between the lead and trail power sources is easily changed. This is discussed in Section 6.6.

» Since arc ignition is always with DCEP, arc striking problems that at times plagued earlier AC-AC tandem arc systems are minimized.

» Since all mode-output settings are controlled on the MAXsa® 10 front panel with the mere push of a button or turn of a knob, there is no need for complex hardware configuration changes at the power source.

Any operator unfamiliar with the operation and functionality of the Power Wave® AC/DC 1000® SD subarc welder should consult the operational guide.

6.6 INTRODUCTION TO PHASE ANGLE

The electrical phase angle existing between two independent AC-AC arcs working in tandem (i.e., tandem arc) has a recognizable effect on how each arc acts and how each arc affects the weld pool. Arc stability, bead shape, penetration and bead edge appearance are all influenced by the interaction of the arcs.

Phase angle is the angular separation of AC current paths. For example, normal industrial three-phase power is separated by 120˚. AC-AC welding circuits involve two separate single-phase circuits. While each circuit is an independent circuit, they can and do interact with each other. Common phase relationships that may exist in arc welding circuits are shown in Figure 6-5 A, B, and C. The solid curve and the dashed-line curve each represent a separate and independent arc.

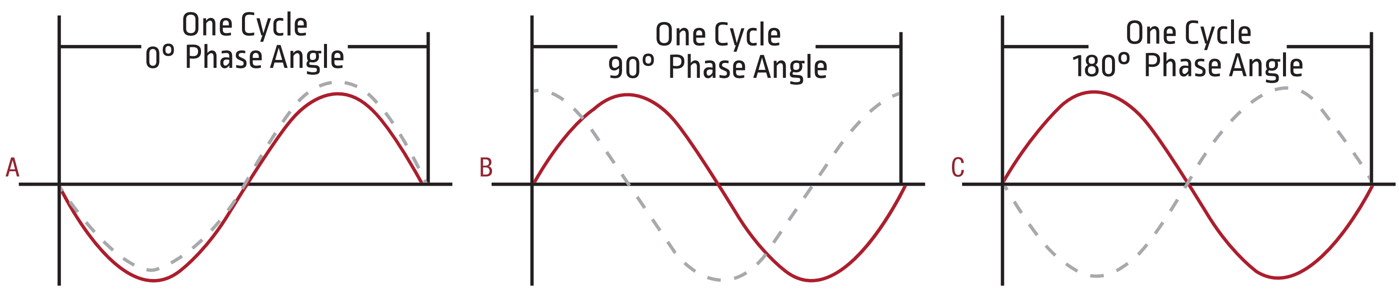


Figure 6-5: Three Examples of Separate and Independent Arcs

To understand the relationship in arc welding circuits represented, note the following:

- Graph A: The current is maximum and minimum at the same time and the polarity of each arc is always the same. In this case, the arcs will both extinguish at the same instant and the ground current will always be the sum of the two independent currents.
- Graph B: The current in one phase is always at maximum value when the other phase is at zero. In other words, one arc is always on. This adds significantly to the stability of the tandem arcs. When equally balanced arcs are being used, it usually creates the most stable operation and generally results in the best surface appearance.
- Graph C: The current is maximum and minimum in each arc at the same time but the polarity of each arc is always opposite. This is most useful when unbalanced and offset arcs are being employed.

For an example of how phase angle can affect a fillet weld, see Figure 6-6. The only difference in producing these two 1/4 in. (6.4 mm) fillets is a change from a 90˚ – 180˚ phase angle. When welding with an AC-AC balanced waveform, the proper angle is 90˚. Any other phase angle can cause arc instability. Figure 6-6 represents the difference between a correct angle of 90˚ and an incorrect angle of 180˚. The following Table 6-1 contains the proper phase angles for various wave balances.

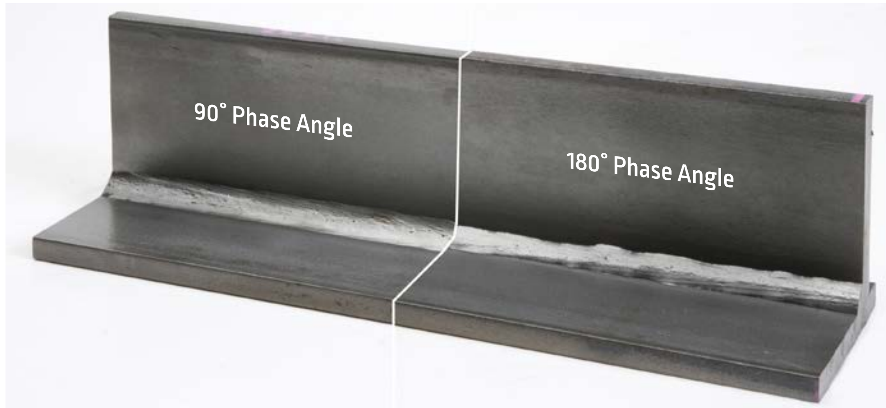


Figure 6-6: Phase Angle Effect on Arc Welds

Table 6-1: AC Arc Balance

AC Arc 1 Balance	AC Arc 2 Balance	Phase Angle Between the Arcs
50%	50%	90
75%	75%	190
25%	25%	190
35%	35%	180
65%	65%	180

This chart shows settings for phase angle when using AC-AC tandem arc welding with the Lincoln Electric Power Wave® AC/DC 1000 SD®.

6.7 WORK CURRENT CONSIDERATIONS

Ground current can be a rather complex topic, but knowledge of a few fundamentals will help the reader understand how ground current relates to tandem arc welding, especially if ground current is being monitored and common work leads are being used. If all of the work leads are bundled together and a calibrated tong-meter is used, the observed value will not necessarily be the arithmetic sum of the amperage values set for each electrode because there is interaction between the arcs.

Figure 6-5 on page 95 depicts the following relationships (assuming the current on each electrode is the same):

» Figure 6-5 on page 95, A: Both curves are in phase, hence the resultant value of the ground current will be double the current flowing across each electrode.

- Figure 6-5 on page 95, B: This example presents an entirely different situation and is similar to what is most common in tandem arc welding circuits. The ground current will not be twice the set value for each electrode, but some value that will be greater than the value for each electrode, but less than twice the set value. Actually, it will be twice the value where the two curves cross each other.
- Figure 6-5 on page 95, C: At any point, the value of each curve is equal, but of opposite polarity, therefore the ground current will be zero.

6.8 TANDEM ARC ELECTRICAL CONSIDERATIONS

AC-AC tandem arc welding can be susceptible to unwanted inductance and/or electrical noise interference, especially as the arc frequency is increased. Giving consideration to electrode-cable routing, control-cable routing, and sense-lead location will ensure minimum electrical interference with control functions.

Key considerations:

- Separate the control and electrode cables for the lead and trail arcs as far from each other as possible.
- Keep control cables and sense leads away from ground and electrode welding cables.
- Do not run cables through metal, magnetic, or current-carrying tubes or channels (this includes tubular or channel sections used for manipulator booms).
- For the highest effectiveness, the sense leads should be attached to the work piece as far away from the work cable connection point as possible (if specifically welding away from the work ground, attach this lead to the finish end of the work piece).
- Keep sense leads out of the path of current.
- **NOTE:** Reference Service Manual 2.51 (measuring amps and volts).

For most tandem arc applications, a spacing of 5/8 – 3/4 in. (15 – 19 mm) is optimum. The angle of the trail electrode, relative to the lead electrode, has an effect on both the final bead shape and the overall stability of both arcs. This should be considered as a process variable. An angle of 10˚ – 12˚, as shown in Figure 6-9 on page 98, is most desirable. Arc instability and poor bead shape can be a result of non-optimal electrode angles and spacing.

6.9 COMMON TANDEM ARC MECHANICAL DEFINITIONS

Successful tandem arc welding results when electrical as well as mechanical requirements are carefully set and followed. The common mechanical requirements for all tandem arc procedures are listed on the following pages.

Contact Tip to Work Distance (CTWD)

Often mistakenly referred to as electrical stickout, CTWD has one precise meaning:

» It is the distance from the contact tip to the top of the surface where the weld is to be made.

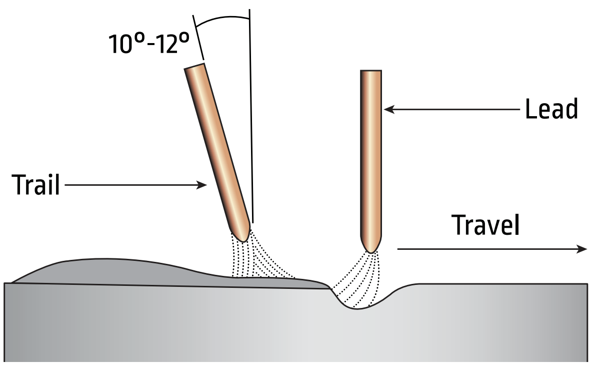


Figure 6-7: Common Angle

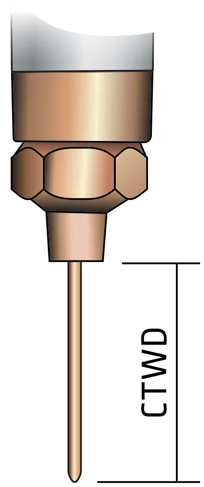


Figure 6-8: Contact Tip to Work Distance (CTWD)

Electrode Spacing (Figure 6-9)

This is the distance between the electrode center lines at the CTWD distance. For many tandem arc setups, a 5/8 – 3/4 in. (16 – 19 mm) distance will be ideal. Wider spacing results in less penetration and wider bead, reduced spacing produces more penetration than a narrow bead.

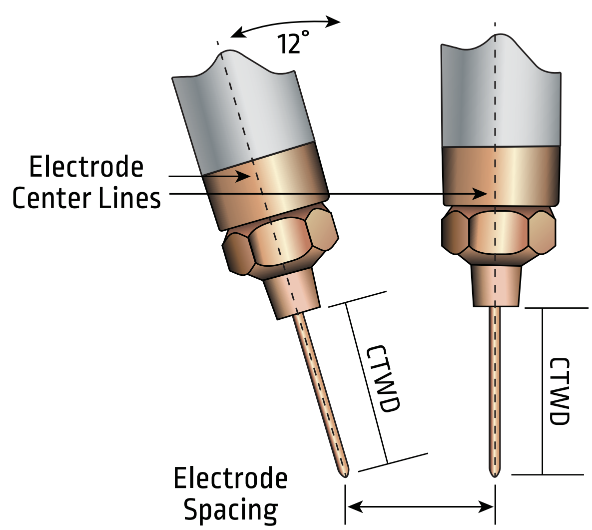


Figure 6-9: Electrode Spacing

Electrode Angles Along the Seam Relative to Direction of Travel (Figure 6-10)

These angles are referred to as Push or Drag angles. The lead electrode will usually be at 0˚ – 3˚ drag and the trail electrode will usually be set for 10˚ – 12˚ push. There are some exceptions to these parameters when involving small, high-speed welds.

Electrode Angle to Joint—Horizontal Fillet and Lap Welds (Figure 6-11)

This is always the angle between the electrode centerline and the horizontal plate of the assembly being welded. If the electrode is properly straightened, this angle can be measured to the contact nozzle.

Electrode alignment to Joint Line—Horizontal Fillet and Lap Welds (Figure 6-12)

On most single pass welds, the top of the electrode should aim at the joint line. On multiple pass welds, the tip of the electrode may be offset horizontally and vertically by “A” and/or “B”. Special large, single pass welds 3/8 – 1/2 in. (9.5 – 12.7 mm) do require being offset by both “A” and “B” dimensions.

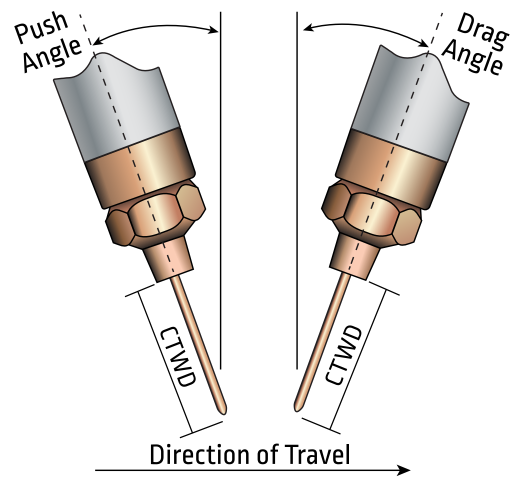


Figure 6-10: Electrode Angles along the Seam Relative to Direction of Travel

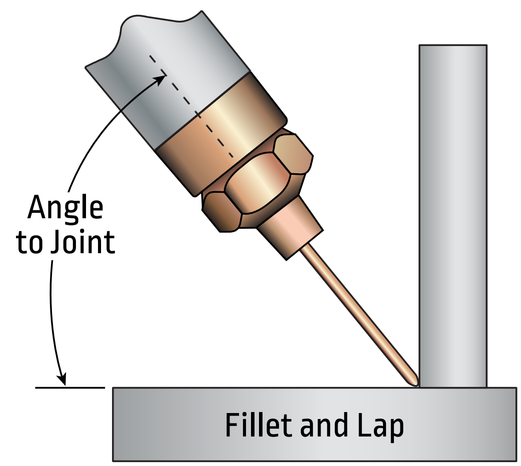


Figure 6-11: Electrode Angle to Joint—Horizontal Fillet and Lap Welds

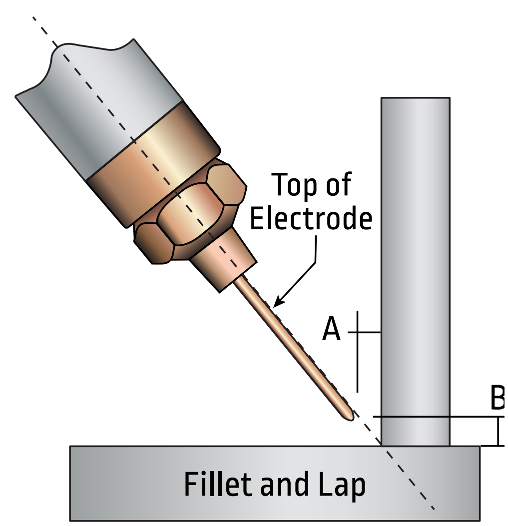


Figure 6-12: Electrode Location to Joint Line—Horizontal Fillet and Lap Welds

Electrode Location to Joint Line—Positioned Single Pass Fillets (Figure 6-13)

Normal position for these welds is to tip the weldment to 45˚, which means the electrode-to-horizontal angle will always be 90˚. In special instances where unequal leg fillets are desired, the electrode-to-horizontal angle may need to be something other than 90˚.

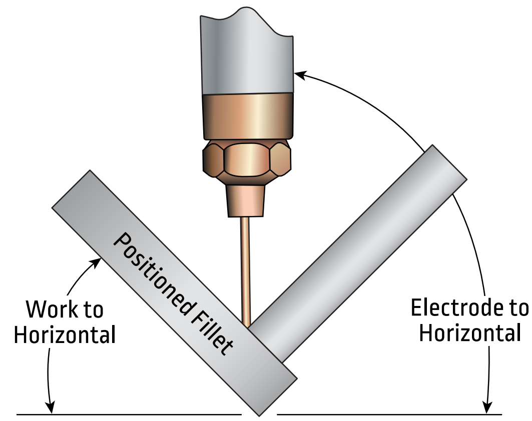


Figure 6-13: Electrode Location to Joint Line—Positioned Single Pass Fillets

Electrode Offset—Large Multiple Pass Positioned Fillets (Figure 6-14)

These welds may require offsetting the electrode centerline after the first pass. Offset dimension should be indicated as being right or left hand. Depending on the size of the finished fillet, it may be necessary to adjust the electrode-to-horizontal angle to ensure good edge wetting. The original CTWD distance should be maintained for each pass.

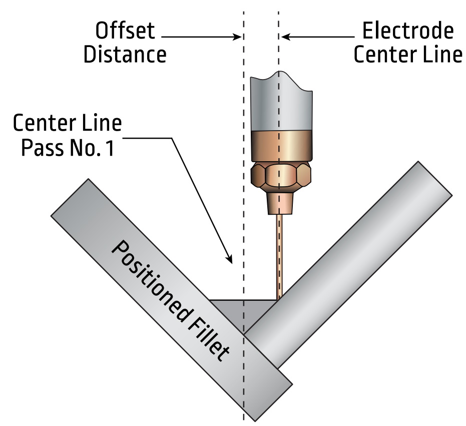


Figure 6-14: Electrode Offset—Large Multiple Pass Positioned Fillets

Electrode Location—Groove and Butt Welds (Figure 6-15)

Electrode alignment is on the joint line for assembly types for “C” and “D” and angle “A” is always 90˚. If the depth of the bevel in type “D” requires more than one pass, it should be treated like assembly “B”.

Assembly “B” represents any symmetrical prepared groove. Angle “A” is 90˚. If more than two to three passes are required, some electrode offset will be necessary.

Assembly “E” is representative of any non-symmetrical groove preparation. For the first few passes, angle “A” usually splits the included groove angle. Assemblies requiring multiple passes will require electrode offset and some adjustment of angle “A”.

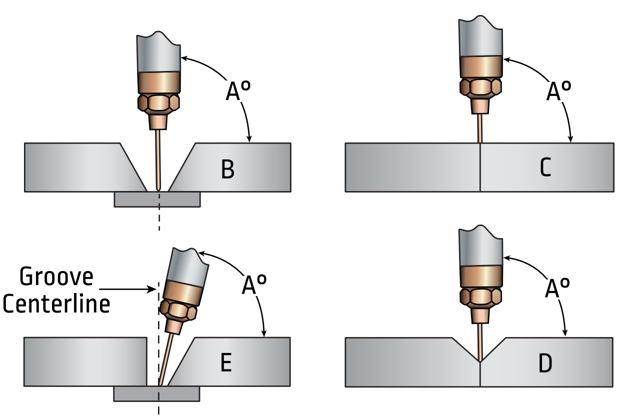


Figure 6-15: Electrode Location—Groove and Butt Welds

6.10 HORIZONTAL FILLET WELD SETUP

Similar to the careful setup procedures required to achieve horizontal fillet welds with a single-electrode to the joint, tandem arc setup involves a few additional steps. These next pages will cover setting two types of horizontal fillets, including the 5/16 in. (8 mm) and smaller, and the 3/8 – 1/2 in. (9.5 – 12.7 mm) single pass fillets, which cannot be made with a single-electrode in one pass.

Fillet Weld Setup 5/16 in. (8 mm) and Smaller

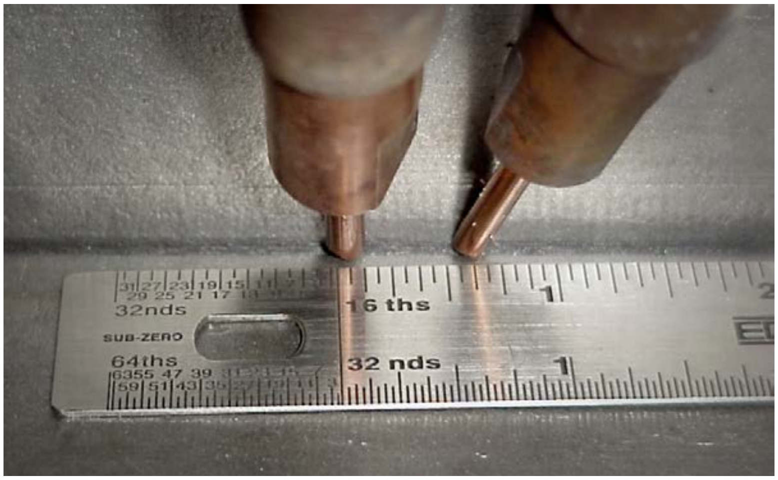


Figure 6-16: Horizontal Fillet Weld Spacing

Figure 6-16 depicts the typical spacing for horizontal fillet welds: 5/8 – 3/4 in. (16 – 19 mm). This spacing is fairly common for all fillet welds, except for the larger single pass welds.

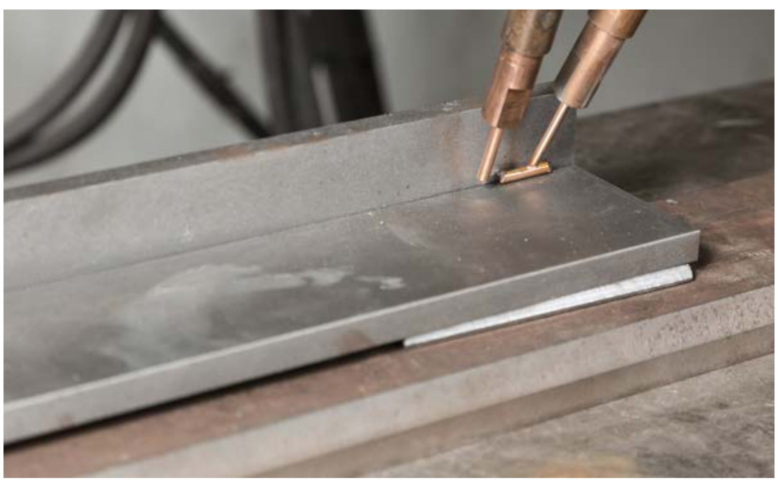


Figure 6-17: Horizontal Fillet Lead and Trail Arcs

Figure 6-17 depicts the orientation of lead and trail arcs to the weld joint line. While not dimensioned, note that the trail arc is set with a push angle. The push angle is usually 10˚ – 12˚.

Single Pass Fillets 3/8 – 1/2 in. (9.5 – 12.7 mm)

Making this size fillet in one pass is like making two passes simultaneously. Success is dependent on accurately setting mechanical and electrical details.

The setup pictured in Figure 6-18 is observed from the normal operating position. Right to left side beam carriage travel is being used and, while not apparent, both arcs are set at 1-1/2 in. (38 mm) CTWD. Note that the trail arc appears to be above the lower base plate of the assembly. The location of each electrode is shown in the following photographs. The lead electrode is usually 3/16 in. (4.8 mm) and the trail electrode 1/8 in. (3.2 mm) in diameter.

Figure 6-19 provides a view of the setup from the end looking along the weld seam. Note that each torch is at a different angle. The lead arc is positioned to produce the lower leg of the fillet, while the trail arc is positioned to complete filling the weld throat and generate the vertical leg. In a sense, this is a two-pass weld. The electrode spacing assures that the lower leg is solidified just enough to support the deposit of the trail arc. The slag from the lead arc is still soft enough to not interfere with the trail arc.

Figure 6-20 is the lead arc electrode position at correct CTWD. This is the distance from the joint line of the weld to the edge of the electrode closest to the joint line.

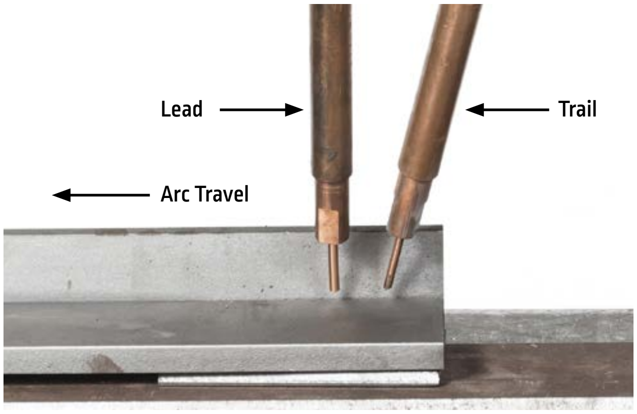


Figure 6-18: Setup Fillet Lead and Trail Arcs

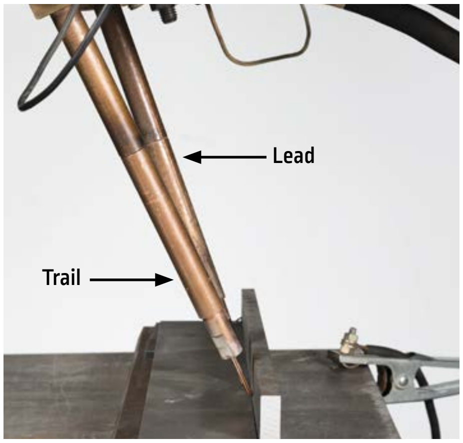


Figure 6-19: Setup along Weld Seam

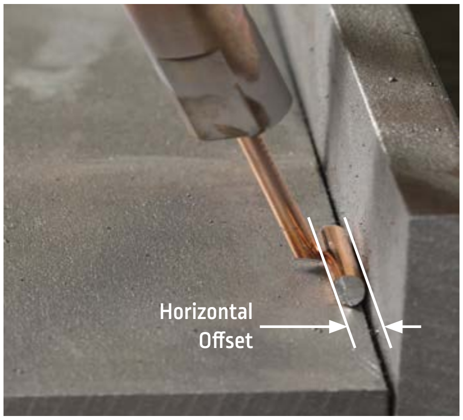


Figure 6-20: Lead at Correct CTWD

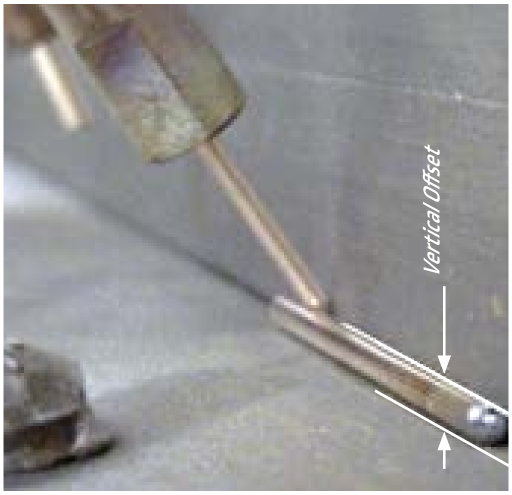


Figure 6-21: Location of Trail Arc

Figure 6-21 shows the location of the trail arc. Note that it is set at a distance above the horizontal plate. The inside of the electrode almost touches the vertical plate.

Figure 6-22 depicts both arcs properly set to make a fillet weld. For this type of large, single pass fillet, the mechanical setup dimensions need to be accurately set and the electrodes carefully straightened so that “wire wander” doesn’t become an issue.

A correct setup and welding procedure will result in a good final weld (see Figure 6-23).

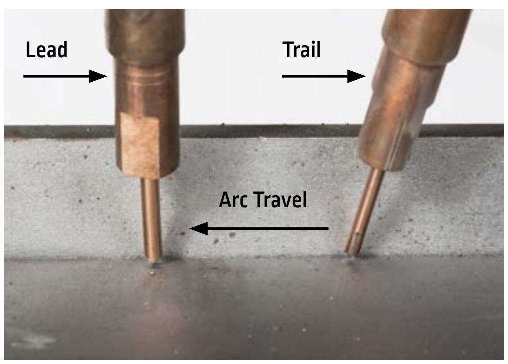


Figure 6-22: Location of Trail Arc

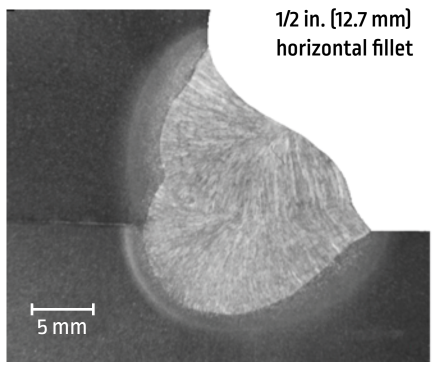


Figure 6-23: Macro Photo of a Tandem Arc 1/2 In. (12.7 mm) Fillet Weld

Notes

7.1 INTRODUCTION TO TINY TWINARC

Developed in the mid-1950s, Tiny Twinarc® setup is a submerged arc welding process that utilizes two small-diameter electrodes fed at high wire-feed speeds. The Tiny Twinarc process, when used to replace a conventional single-electrode, offers substantial welding economies for many applications. Faster travel speeds and higher usable deposition rates create the economies. The two wires, which are in close proximity, result in an elongated puddle that improves follow characteristics and enables faster travel speeds, while maintaining the proper weld bead shape.

Upgrading a submerged arc welding cell from a single-electrode configuration to a Tiny Twinarc two-wire configuration is a low-cost option for increasing productivity. Using the same power source, feeder, and controller, the two wires are simultaneously fed through a twinarc contact assembly into one puddle (see Figure 7-1).

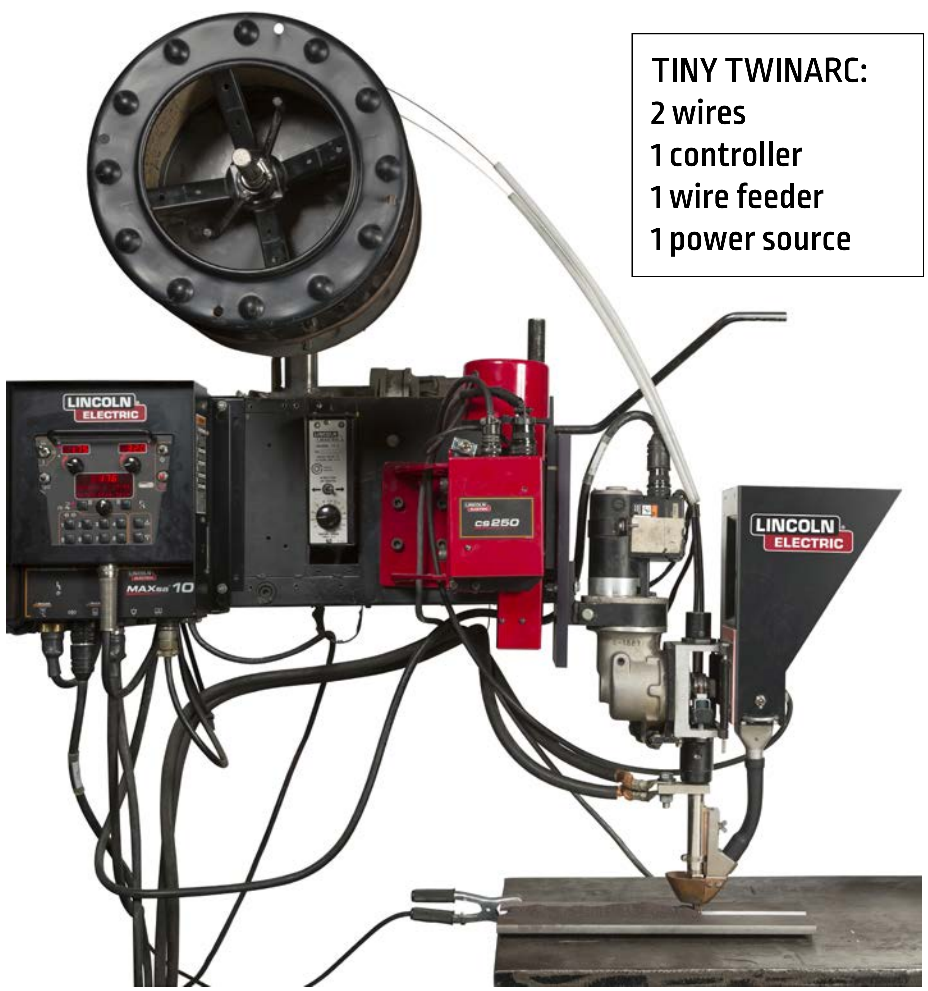


Figure 7-1: Tiny Twinarc Setup

7.2 BENEFITS

Tiny Twinarc conversion increases travel speeds, provides equal-or-better weld quality (depending on application) and requires minimal investment.

Tiny Twinarc advantages over the single arc process:

1. Offers higher deposition rates, with 40% potential increases.
2. Faster travel speeds can exceed 25% on light gauge material and 50 – 75% on heavier material.
3. Power consumption is lower per pound of weld metal.
4. Distortion is lessened by 5 – 50%.
5. Heat inputs are lower.
6. Minimal penetration is possible with light gauge material or thin seams.

NOTE: The Tiny Twinarc process results in low-heat input per pound of metal deposited, which aids in controlling distortion. It becomes especially important when welding high strength steels where the HAZ impacts deteriorate with increased heat input.

7.3 APPLICATIONS

The Tiny Twinarc process has applications in the manufacturing of pre-engineered buildings, earthmovers, excavators, cement mixers, railcars, code tanks and pressure vessels, thin-walled shells and many other welded products made of material ranging in thickness from 14 gauge (1.9 mm) to heavy plate.

This system is versatile and used on:

1. High speed, light gauge weldments
2. High deposition, heavy weldments
3. Larger circumferential welds
4. Flat fillets, horizontal fillets
5. Lap welds
6. Butt welds
7. Hardfacing applications

7.4 DEPOSITION RATE ADVANTAGES

Higher Current

With the single-arc process, raising the current to increase the deposition rate may result in poor bead shape, undercutting and/or excessive penetration. The Tiny Twinarc process makes use of higher currents by splitting the usable current between the two wires, which results in acceptable bead shape when running higher amperages (see Figure 7-2).

Resistance Heating

Another factor contributing to the Tiny Twinarc process' higher deposition rate is the high-current density resistance heating effect on the smaller diameter wires.

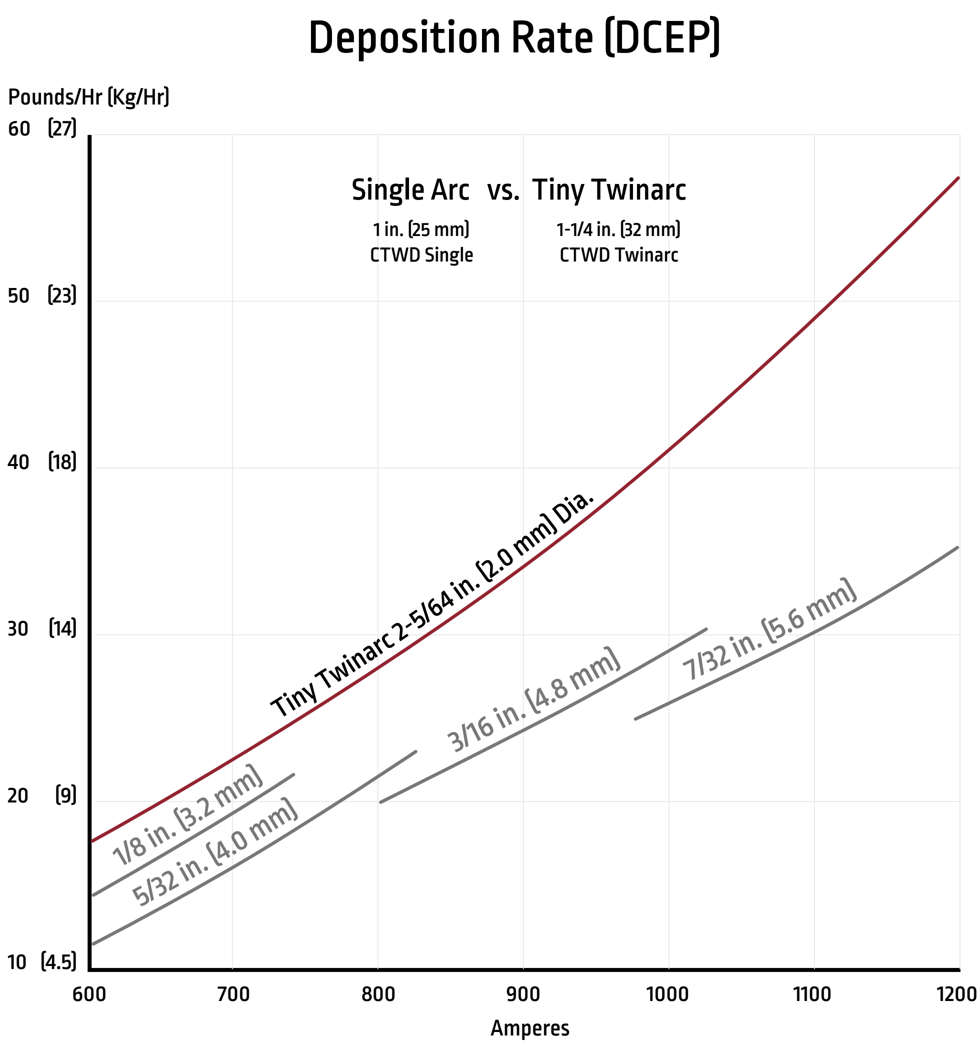


Figure 7-2: Deposition Rate Single Arc vs. Tiny Twinarc

7.5 TRAVEL SPEED

During conventional single arc operation, it is possible to increase the travel speed by increasing the welding current; however, bead shape, bead appearance, undercutting, or burn through will impose a limitation on the travel speed.

With the Tiny Twinarc process, the higher usable deposition rate results in travel speed increases, while still maintaining the desirable bead shape, bead placement, penetration and other advantageous welding characteristics.

The CTWD affects deposition rates and useable travel speeds. Use a shorter CTWD at higher travel speeds where a tighter, narrower arc is desired. Use a long CTWD to maximize deposition rates and aid electrode resistance preheating, which will increase melt-off rates.

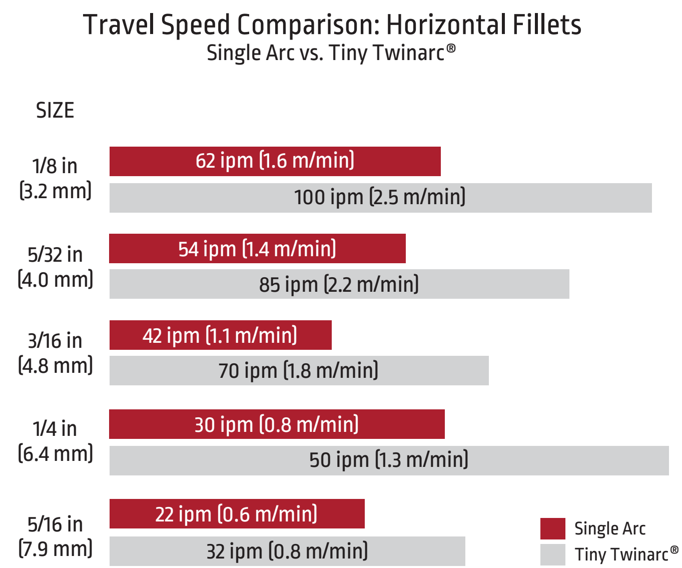


Figure 7-3: Travel Speed Comparison: Horizontal Fillets

7.6 FILLET WELDS

Horizontal Fillets

During the welding of horizontal fillets, the Tiny Twinarc process can increase travel speeds up to 68% for 1/8 in. (3.2 mm) – 5/16 in. (7.9 mm) fillets. (See Figure 7-3 and Figure 7-4.)

Flat Fillets

When it comes to welding flat fillets, the Tiny Twinarc process offers about a 50% increase in welding speed over the single-electrode process. (See Figure 7-5.)

Figure 7-4: Tiny Twinarc Weld of Horizontal Fillet

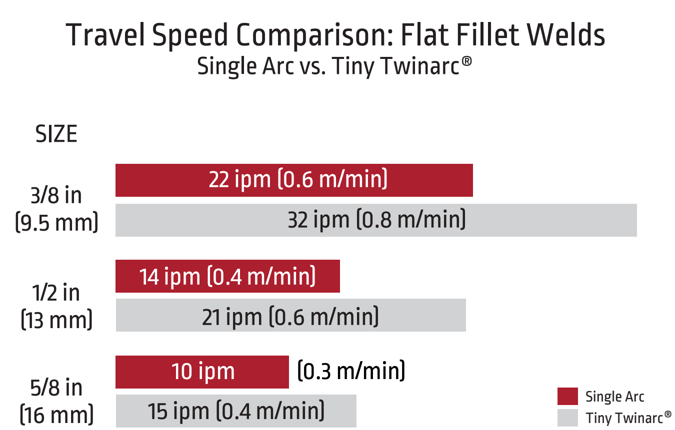


Figure 7-5: Travel Speed Comparisons: Flat Fillet Welds

7.7 LAP WELDS

Small lap welds made with the Tiny Twinarc process will result in welding speed increases of 43% – 70% higher than the single arc process. (See Figure 7-6.)

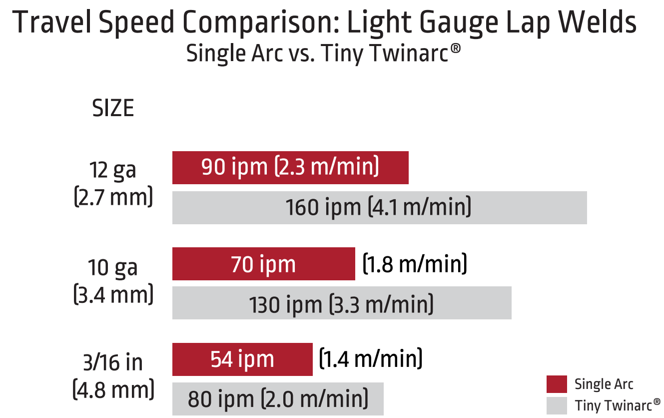


Figure 7-6: Travel Speed Comparison: Light Gauge Lap Welds

7.8 BUTT WELDS

Use the Tiny Twinarc process for prepared groove butt welds on code vessels and heavy-walled tanks. Make butt welds economically in the flat and 3 o'clock position. Increased speeds of 30% or more are practical. (See Figure 7-7.)

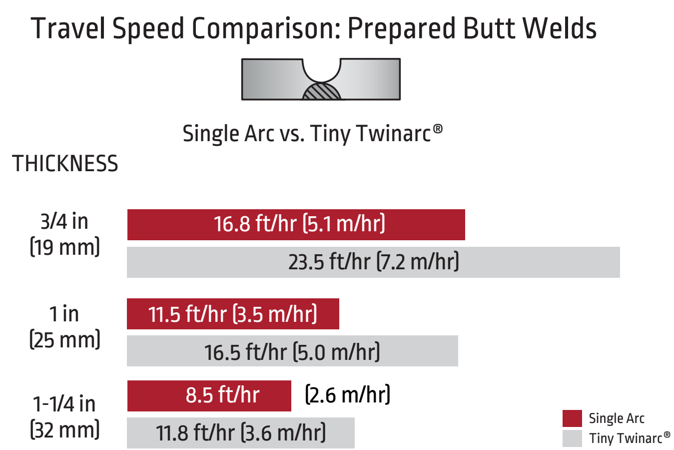


Figure 7-7: Travel Speed Comparison: Prepared Butt Welds

7.9 PROCEDURE RECOMMENDATIONS

To maximize penetration, rotate and lock the contact tip assembly in line with the direction of travel. To minimize penetration and increase bead width, rotate and lock the contact tip assembly perpendicular to the weld joint or seam.

Flux and Electrode Selection

Make the flux and electrode selections for the Tiny Twinarc application based on single-electrode applications. See Bulletin C1.10 for wire and flux combinations. Consult a Lincoln Electric representative for suggested welding procedures.

Polarity

DCEP is recommended for:

1. Obtaining best impact toughness
2. Producing deepest penetration
3. Obtaining highest radiographic quality
4. Enhanced high-speed light gauge applications
5. Improved resistance to arc blow

DCEN is recommended for:

1. Less crack sensitive bead shape—better depth/width ratio.
2. Reduced base plate admixture will reduct cracking tendencies in situations where alloying elements in the base plate contribute to weld metal cracking.
3. Higher deposition rate.
4. Opposing arc applications where minimal penetration and maximum deposition are required.
5. Making conventional fillet welds (1/4 in. (6.4) or greater) where penetration is not a concern.

Alternating Current (AC) is recommended for:

1. Balancing between penetration depth and deposition rate.
2. Maximizing travel speeds while maintaining good root and side wall fusion.
3. Highest resistance to arc blow.

Electrode Size

The electrode diameter selected for Lincoln Electric Tiny Twinarc procedures is a compromise between deposition rate, bead shape, flash through, penetration, etc.

The available diameter sizes are:

- 0.045 in. (1.1 mm)
- 0.052 in. (1.3 mm)
- 1/16 in. (1.6 mm)
- 5/64 in. (2.0 mm)
- 3/32 in. (2.4 mm)
- 1/8 in. (3.2 mm)

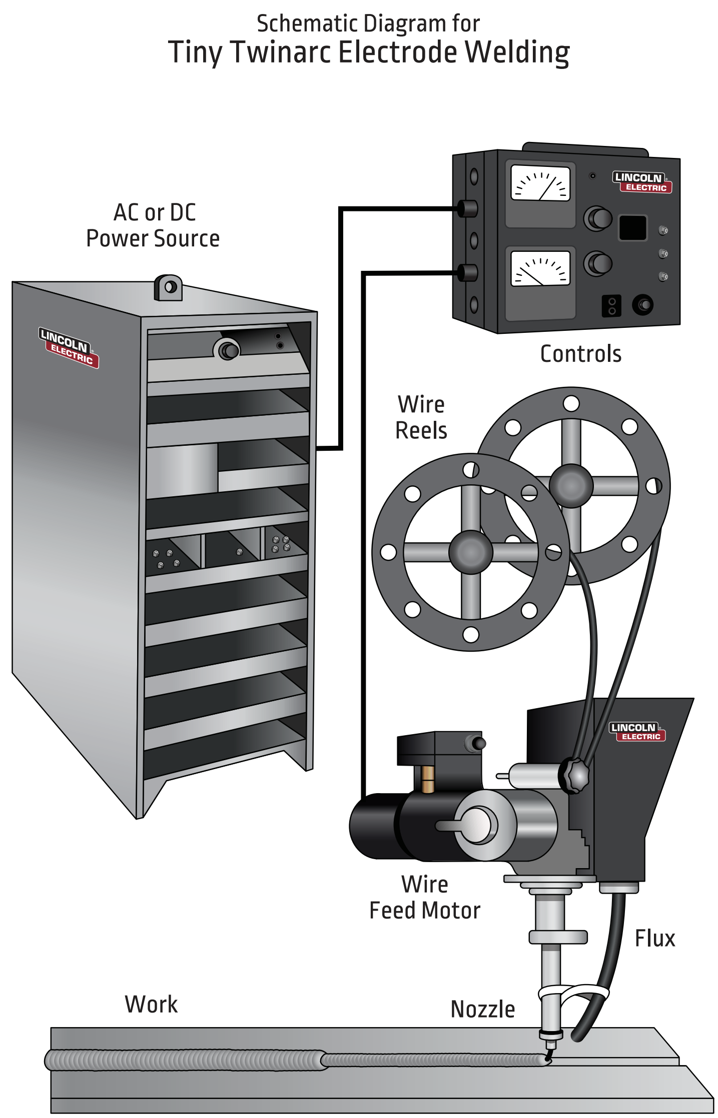


Figure 7-8: Schematic Tiny Twinarc

CV and CC Operation

A CV power source is preferred:

1. On high-speed applications.
2. For 3/16 in. (4.8 mm) and smaller horizontal fillets.
3. For 5/16 in. (7.9 mm) and smaller flat fillets.

A CC source is preferred on:

1. High deposition rate applications.
2. Maximum penetration.

7.10 EQUIPMENT RECOMMENDATIONS

The following equipment is recommended for new installations:

1. A CV or CC power source rated for the intended work.
2. Wire feeder with the proper gear ratio drive installed (95:1 will produce 10 – 300 ipm (0.4 – 7.6 mpm) and (57:1 will produce 40 – 500 ipm (1.3 – 12.7 mpm).
3. Two spools, coils, reels, or drums of wire.
4. Two contact tips of the correct diameter.
5. A Lincoln Electric Tiny Twinarc Torch Assembly (based on wire diameter and desired amperage range).
6. A wire straightener.

Figure 7-9: The Lincoln Electric Tiny Twinarc Contact Nozzle Can Feed Two Electrodes for High-speed Submerged Arc Welds on 14 Gauge (1.89 mm) to Heavy Plate.

Figure 7-10: The Lincoln Electric Tiny Twinarc Solid Wire Straightener Accommodates Wire Diameters 0.045 in. – 3/32 in. (1.2 through 2.4 mm). It Is Particularly Valuable on Longer CTWD Procedures.

Notes

8.1 INTRODUCTION TO HARDFACING APPLICATIONS

Benefits of Hardfacing

Hardfacing is a low-cost method of depositing wear-resistant surfaces on metal components to extend service life. Although used primarily to restore worn parts to usable condition, hardfacing is also applied to new components before placing into service.

In addition to extending the life of new or worn components, hardfacing provides the following benefits:

- Fewer replacement parts
- Reduced downtime
- Less expensive base metal
- Reduced overall costs

Figure 8-1: Mining Equipment Utilizes Hardfacing to Minimize Equipment Wear and Tear in Harsh Working Environments.

Build-Up and Hardfacing

Restoring worn parts frequently involves the following three steps:

1. Buttering: Used for a deposit that will dilute the carbon and alloy content of base metal.
2. Build-up: Rebuild seriously worn areas close to working size using tough, crack-resistant welding materials deposited in an unlimited number of layers.
3. Hardfacing: Wear-resistant surfaces deposited on the base metal or on build-up deposits extend service life. Hardfacing is usually limited to one, two, or three layers.

8.2 CONSUMABLE SELECTION

Welding material selection depends upon three major factors:

1. Base metal: Primarily affects the choice of build-up materials.
   a. Manganese steel is used for components subject to high-impact loading. Rebuild to size using manganese steel weld deposits.
   b. Carbon and alloy steel components are rebuilt to size using low-alloy steel weld deposits.
2. Types of wear: Consider the wear to be encountered when selecting the final hardfacing layers. These include:
   a. Metal-to-metal friction – Wear from steel parts rolling or sliding against each other with little or no lubrication.

b. Severe impact – Wear from severe pounding, which tends to deform, gouge, and crack the surface. Manganese steel deposits, which work harden in service, provide the greatest impact wear resistance.

c. Abrasion plus impact – Wear from gritty material or heavy pounding, which tends to chip or crack, as well as grind, away the surface.

d. Severe abrasion – Wear from gritty materials, which grind or erode the surface. Severe abrasion is often accompanied by heavy compression or moderate impact. Hard deposits resist abrasion and provide impact resistance.

e. Metal-to-earth abrasion – Wear from earth-like materials accompanied by moderate impact (pounding).

f. Corrosion – Chemical reaction/attack.

NOTE: In many, if not most cases, the effective wear is a result of a combination of two or more of the phenomena described in this section.

3. Arc welding method: The choice of arc welding method depends primarily upon the size and number of components, available positioning equipment, and frequency of hardfacing. Available methods are as follows:

   a. Manual welding – Using stick electrodes requires the least amount of equipment while providing maximum flexibility for welding in remote locations and all positions.

   b. Semi-automatic welding – Uses wire feeders and self-shielded, flux-cored Lincore® electrodes, which increase deposition rates over manual welding.

   c. Automatic welding – Requires the greatest amount of initial setup, but provides the highest deposition rates for maximum productivity. Accomplished with combinations of:

      i. Neutral flux and alloy wire

      ii. Alloy flux and mild steel wire

      iii. Self-shielded, flux-cored wire with or without flux

Figure 8-2: Hardfacing Consumables Family

8.3 APPLYING THE WELD DEPOSITS

Cleanliness

Remove dust, dirt, grease, oil, and other contaminants from weld surfaces.

Surface Preparation

Remove all existing hardfacing and any badly cracked, deformed, or hardened surfaces by grinding, machining or carbon arc gouging.

Deposit Thickness

Avoid excessive build-up of hardfacing deposits or they may crack and break off during service. For thick deposits, use the appropriate build-up materials before hardfacing.

Preheat and Interpass Temperature

The combination of alloy content, carbon content, massive size, and part rigidity creates a necessity to preheat in many build-up and hardfacing operations. Slow cooling may be needed. Use low- or minimum-preheat, low-heat input, and low interpass temperature on manganese steels.

Figure 8-3: Caster Roll Rebuilding Using Hardfacing SAW

Caution: Manganese steel becomes brittle if overheated. When a 100˚F – 200˚F (38˚C – 93˚C) preheat is required, do not allow interpass temperatures to exceed 500˚F (260˚C).

Caution: When preheating and welding, some alloy steel components require a specific heat treatment to perform properly in service. Contact the parts maker for information.

Distortion

A small amount of distortion can destroy the usability of some parts. Rigid bracing, pre-bending, skip welding, and other distortion control techniques may be required.

Welding Procedures

Obtain the recommended starting procedures from the appropriate Lincoln Electric product literature or from procedures and techniques, etc. in this manual. The procedures and techniques listed are general guidelines for specific applications. Final responsibility must be that of the builder/user.

Always refer to the product Safety Data Sheet (SDS), for any welding product before use. Product SDSs contain information about the product's potential physical and health hazards, as well as information to assist with the proper, safe use of the product. Adequate ventilation must be provided to ensure airborne exposures remain below applicable exposure limits. Use of respiratory protection is advised unless industrial hygiene exposure assessments indicate otherwise.

IMPORTANT: Special ventilation and/or exhaust required

Fumes from the normal use of certain hardfacing welding products contain significant quantities of components such as chromium and manganese, which can lower the 5.0 mg/m3 maximum exposure guideline for general welding fumes.

Before use, read and understand the Safety Data Sheet (SDS) and specific information printed on the product container.

Table 8-1: Electrode/Alloy Flux

Alloy Fluxes (Generally used with Lincolnweld L-60™)
Lincolnweld® A-96-S
Lincolnweld® H-535
Lincolnweld® H-560

Table 8-2: Alloy Electrode/Neutral Flux	
Alloy Electrodes* (Generally used with neutral fluxes Lincolnweld 801®, 802™, and 880™)	
Lincore® 30-S	Lincore® 410
Lincore® 32-S	Lincore® 410NiMo
Lincore® 35-S	Lincore® 424A
Lincore® 40-S	Lincore® 423L
Lincore® 42-S	Lincore® 423Cr
Lincore® 60-S	Lincore® 420
Lincore® 20	Lincore® 96S
Lincore® 8620	Lincore® 102W
Lincore® 4130	Lincore® 102HC

* All Lincore Subarc Electrodes are Metal Cored.

NOTE: See Publication C7.710 for more hardfacing information.

Notes

Discontinuities are an irregularity in the structure of a material. Not all discontinuities are a rejectable defect. A discontinuity is considered a rejectable defect if the effects of the discontinuity render the part or product unable to pass acceptance criteria or specifications. Careful examination of the code or standards is critical to determining whether a repair is needed or necessary.

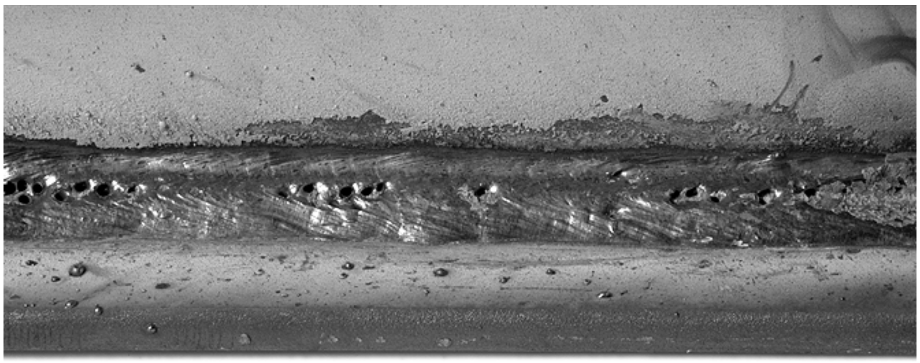


Figure 9-1: Metal Porosity

9.1 POROSITY CHARACTERISTICS

Weld porosity is the result of gases that become trapped in the weld metal during solidification. Porosity presents as voids in the weld which may or may not break the surface.

Many different conditions may lead to porosity. These conditions may be visible on the surface or obscured within the material.

These conditions include:

- Steel surface condition and cleanliness
- Surface coating
- Flux or electrode contamination
- Presence of moisture
- Cutting or gouging dross
- Nitrogen absorption on plasma cut face
- Incorrect flux pile height or lack of shielding

Flux contaminated by moisture, or other contaminants (such as floor sweepings) can result in porosity and other defects. Electrode moisture, rust, or internal moisture in cored electrodes can also be contributing factors.

9.1.1 SURFACE CONDITION OF MATERIAL

Material with light gray-colored scale that is tight to the surface can usually be welded without difficulty. Heavy or flaking scale is likely to create some porosity as well as uneven bead edges.

Rusty “red” scale usually contains a high moisture content. This condition should be totally removed from the mating surfaces. In preparation for square edged and groove welds, remove all scale and primer coatings from the weld area (see Figure 9-2).

When preparing fillet welds, it is important that the underside of the web member is clean (see Figure 9-3). When welding the web on both sides, the entire underside should be clean. For single side welds, clean the surface to the expected penetration depth.

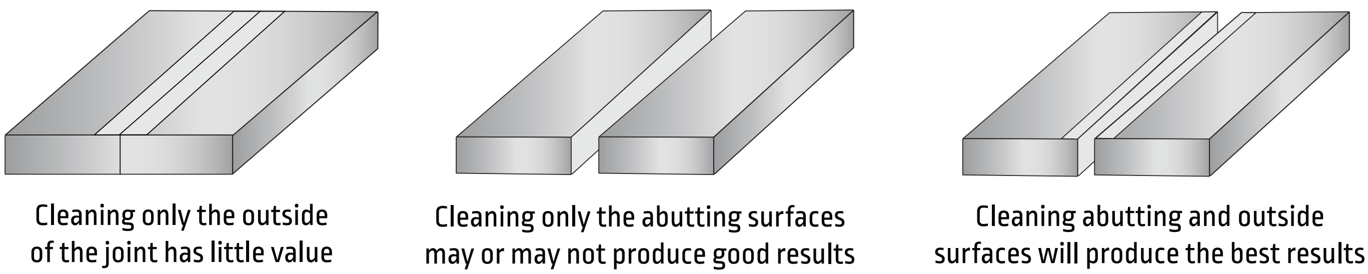


Figure 9-2: Recommended Surface Preparation

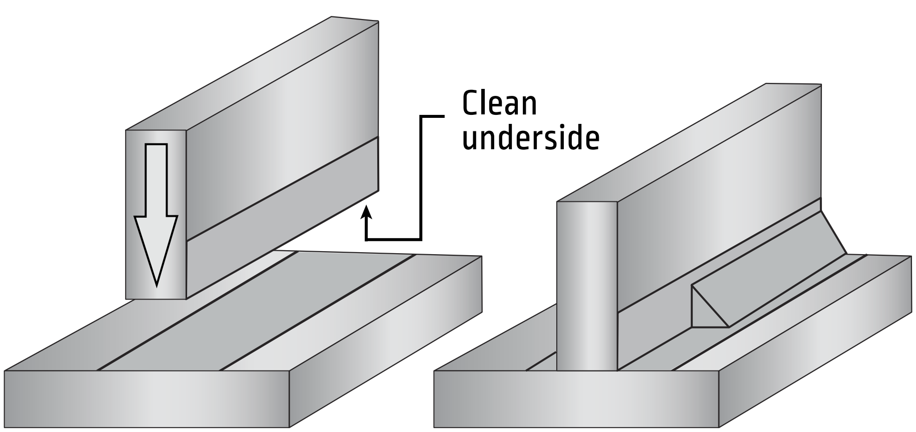


Figure 9-3: Recommended Surface Preparation

It is not necessary to clean every edge that is to be welded. Edges that have been prepared by machining or flame cutting can be welded without further cleaning if they are not rusty or oil coated (see Figure 9-4). Grinding of the surface will be required when plasma cutting operations leave a layer of dross containing dissolved nitrogen in the face of the cut.

Unprepared edges with normal, tight gray mill scale can be successfully welded using a silicon-killed electrode.

Power wire brushing and/or shot blasting will clean rust and red mill scale from the edges, while torch heating will eliminate moisture in the rust (see Figure 9-5). Although either process will substantially reduce porosity, both should be used for best results. To drive off residual moisture, put a flame torch about 1 – 2 feet (0.3 – 0.6 m) ahead of the arc while welding. Be sure the torch is hot enough to heat the plate to 300 – 500˚F (149 – 260˚C). Insufficient heat may leave some residual moisture that will cause subsurface porosity.

Degreasing and/or washing is frequently used to remove oil, grease, die lubricants and other similar materials. Rinse off all washing compounds and thoroughly dry surfaces before starting the weld. Some washing compounds leave behind a residual layer of contaminants that can also cause porosity (see Figure 9-6). Select a washing compound that is compatible with the welding process. Low silicon electrodes minimize porosity caused by organic compounds.

Surface Coatings

Various coatings are frequently used to protect the surfaces of the weld material, including zinc, aluminum, or epoxy-based primers. These coatings may produce large volumes of gas and can be especially troublesome to weld over. It is not uncommon for primed plates to have increased primer coating thickness on edges and corners. This condition can result in significant degassing, resulting in serious porosity. While some surface coatings are marketed as being weldable, care must still be taken to ensure requirements for weld quality are met.

Figure 9-4: Good Porosity-Free Welds Can Be Made on Machined and Flame-Cut Edges and on Uncut Edges that Have an Ordinary Amount of Mill Scale. See A, Machined Edges; B, Flame-Cut Edges; C, Uncut Edges.

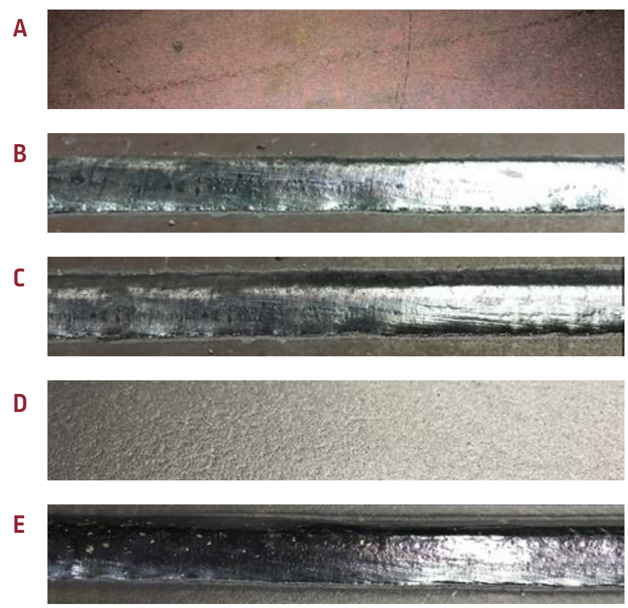


Figure 9-5: See A, Rusty Plate; B, Weld on Rusty Plate; C, Weld on Rusty Plate after Plate Was Pre-Heated to 400˚F (204˚C); D, Sand Blasted Plate; and, E, Weld on Sand Blasted Plate. By Power Brushing and/or Sand Blasting and Torch Heating, Even the Rustiest Plate Can Be Cleaned so that It Is Possible to Make a Good Porosity-Free Weld.

Figure 9-6: Porosity Caused by Oily Plates.

Some rust-preventive coatings are transparent, making the plate appear clean and uncoated. These coatings may still lead to gassing and possible porosity.

As is the case with rust and mill scale, surface coatings should be removed from abutting weld surfaces (see Figure 9-2 and Figure 9-3 on page 120).

9.1.2 CONTAMINANTS

Flux Contamination

Flux that is contaminated can cause porosity in the weld. The most common contaminants in flux are:

- Dirt
- Mill scale
- Moisture

Exposed welding flux may pick up moisture. Store flux according to the manufacturer's recommendations. For storage and handling of Lincoln Electric fluxes see Section 10.

Using flux recovery equipment that adequately removes slag, mill scale and dust will reduce the risk of porosity.

Avoid picking up mill scale with flux recovery equipment. Removing mill scale from flux requires the use of a magnetic separator in a flux recovery system.

Electrode Contamination

Do not use rusty electrodes. Improperly stored electrodes may rust, which may cause porosity, particularly when making high-speed welds on thin material. Rusty electrodes can cause excessive contact tip wear, arc instability and irregular electrode feeding.

9.1.3 INCORRECT FLUX PILE HEIGHT

Sufficient flux coverage is necessary to protect the molten metal from the atmosphere. By contrast, excessive flux depth may cause poor bead shape and increase the risk for weld metal defects.

Flux depth should be just enough to bury the arc. A good indicator is when just a flicker of light may be seen on the electrode. Too little flux will cause excessive flash through and result in weld porosity. Insufficient flux coverage is more apt to occur on circumferential welds than on flat welds (see Figure 9-7).

For small diameter circumferential welds, corner welds and multiple pass horizontal fillet welds, it is necessary to provide some mechanical means to support the flux around the arc (see Section 5).

Figure 9-7: Gas Pockets in the Weld Resulting from Insufficient Flux Coverage

9.1.4 WELD JOINTS WITH OPPOSING WELDS

When the opposing side of a weld joint is sealed by a previous weld, or continuous tack weld, incomplete joint penetration into the opposing weld or tack may result in porosity (see Figure 9-8).

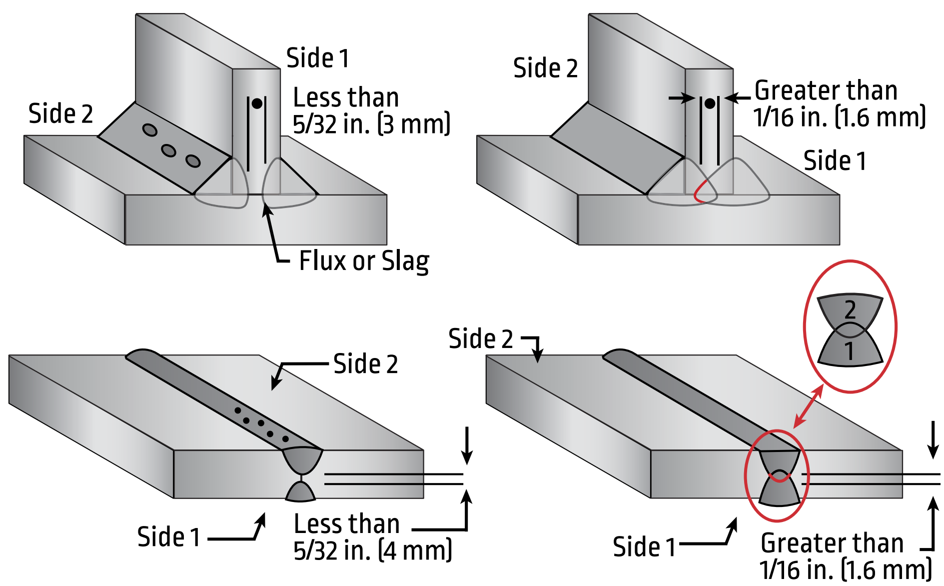


Figure 9-8: Opposing Weld Porosity

9.1.5 PRESS FIT JOINTS

Press fit parts are usually coated with a lubricant prior to joining the two parts together. The lubricant becomes a gas-producing contaminant that may cause porosity, generally in the form of large holes that appear at, or near, the end of the weld. It is best to allow a gap of up to 1/32 in. (0.8 mm). Another solution is to knurl one part to provide a path for gas to escape.

9.1.6 TRAVEL SPEED

Welding at high travel speeds tends to increase porosity because of faster weld cooling rates. Welding on direct current (DC) increases the risk of arc blow porosity. If controlling arc blow is ineffective, reducing speed and current may reduce porosity on these applications.

NOTE: Reducing travel speed generally reduces the risk of porosity. Slower speeds give gaseous materials longer time to escape from the molten weld metal.

9.1.7 ARC BLOW

DCEN polarity and small diameter electrodes are particularly susceptible to arc blow, which can cause porosity. It most frequently occurs on automatic high-speed welds on thin steel, but can also occur on heavier plate sections using complex joint designs.

Arc blow porosity typically occurs near the end of the weld. The following is a list of possible steps to minimize the risk of arc blow:

» Weld away from the work (ground) connection.

» Put a heavy tack weld at the finish end of the joint.

» Clamp the work lead firmly to the starting end of the workpiece and weld toward the closed end of the fixture or workpiece.

» Use Alternating Current (AC) if possible.

» Use long run-on/off tabs.

» Avoid residual magnetism.

» Reduce voltage.

» Review flux selection, as flux type will influence susceptibility to arc blow porosity.

» Keep the electrode as close to vertical as possible.

Any magnetic materials in the vicinity of the arc, including fixtures, can hold residual magnetism and contribute to arc blow.

9.2 POCKMARKING WITH SAW FLUXES

Pockmarks are depressions in the weld bead surface (see Figure 9-9), formed when gases that are escaping the liquid weld pool become trapped at the slag-metal interface.

Pockmarks can be caused by contaminants (i.e., rust, mill scale, and moisture), fluxes with fast freezing slag and fast cooling rates.

Reducing travel speeds, increasing voltage and using higher pre-heat temperatures may reduce or eliminate pockmarking. Pockmarks are not usually considered defects, nor do they indicate subsurface porosity. Pockmarks are not normally a rejectable discontinuity.

Figure 9-9: Pockmarking

9.3 CRACKS

Cracks are a fracture in a material's structure. Cracks typically initiate at a stress riser within the weldment. Cracks are generally categorized as hot or cold cracks. Hot cracks occur while the weld metal is solidifying. Cold cracks occur near ambient temperatures. In relation to welding, cold cracks are typically associated with Hydrogen. Cracks may be described as longitudinal cracks or transverse cracks.

Longitudinal Cracks (Figure 9-10)

Longitudinal cracks are typically located parallel to the weld axis. Longitudinal cracks are often solidification cracks caused by improper depth-to-width ratio, low melting point contaminants, or a concave weld surface. Utilizing a depth-to-width ratio of 1:1 to 1.4:1, limiting excessive penetration, decreasing travel speed, and proper material selection will reduce the risk of longitudinal cracking.

Transverse Cracks (Figure 9-11)

Transverse cracks occur perpendicular to the weld axis. One cause of a transverse crack is shrinkage stress in low-ductility weld metal. A few other causes are copper contamination and hydrogen.

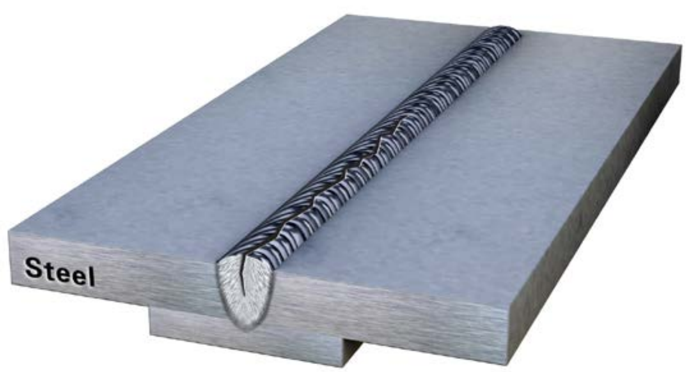


Figure 9-10: Longitudinal Cracks

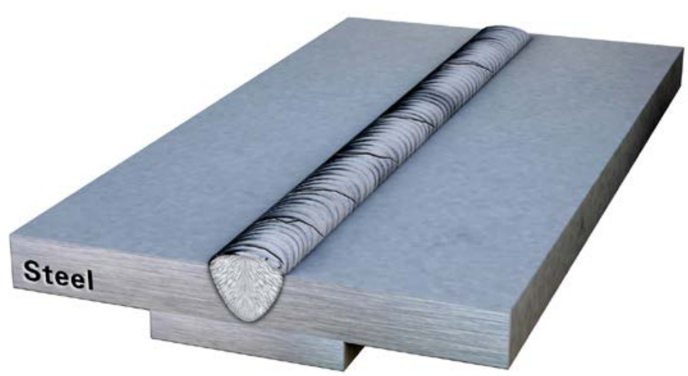


Figure 9-11: Transverse Cracks

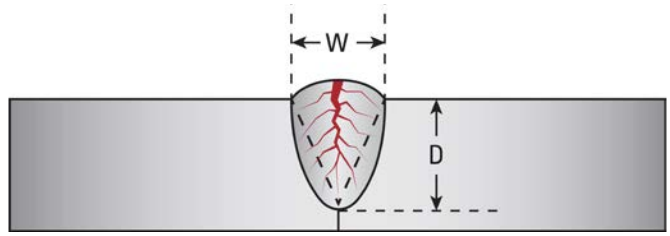


Figure 9-12: Centerline Cracks

Heat Affected Zone Crack (Figure 9-13) and Underbead Cracking (Figure 9-14)

Heat affected zone (HAZ) and underbead cracks are types of cold cracks. These cracks are generally short and can be longitudinal or transverse. HAZ cracks are typically caused by a combination of conditions, which include; presence of hydrogen, susceptible microstructure, and high residual stress.

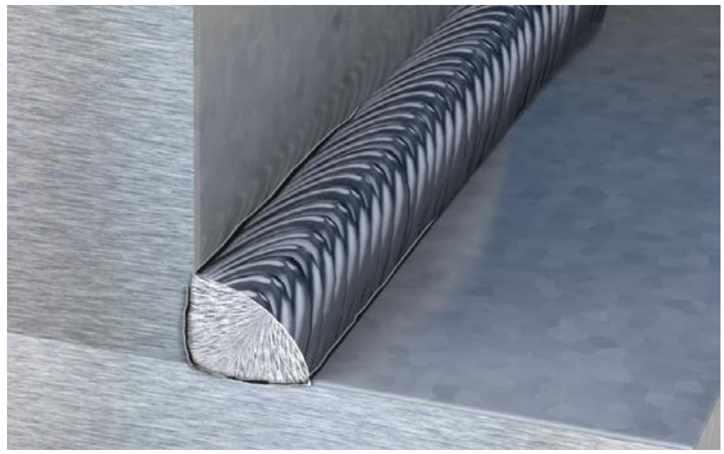


Figure 9-13: HAZ Cracks

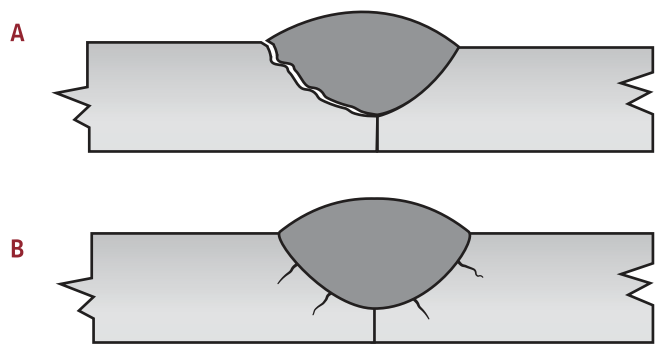


Figure 9-14: Typical Fusion Boundary and HAZ Crack Orientation.

Solidification Cracking

Depth-to-Width Ratio (Figure 9-15)
Weld deposits that are too deep and narrow are more susceptible to solidification cracking due to the solidification pattern and increased stresses imposed on the centerline of the weld during solidification (see Figure 9-12). A depth-to-width ratio of 1.1 to 1.4 is generally recommended to minimize crack susceptibility.

Hat Cracking (Figure 9-16 on page 127)
Hat cracks can occur at sharp transitions along the fusion boundary of the weld deposit due to stresses during solidification. Eliminating sharp transitions can be accomplished by adjusting welding parameters, torch angles/configuration and joint design.

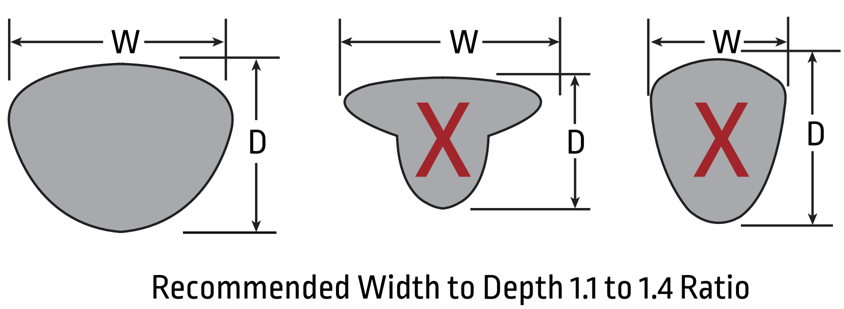


Figure 9-15: Depth-to-Width Ratio

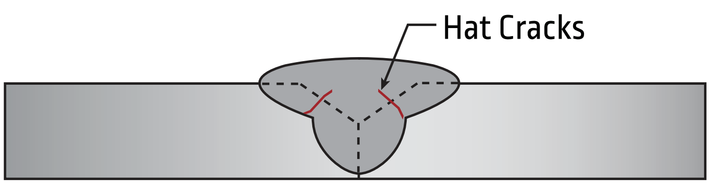


Figure 9-16: Hat Shaped Cracks

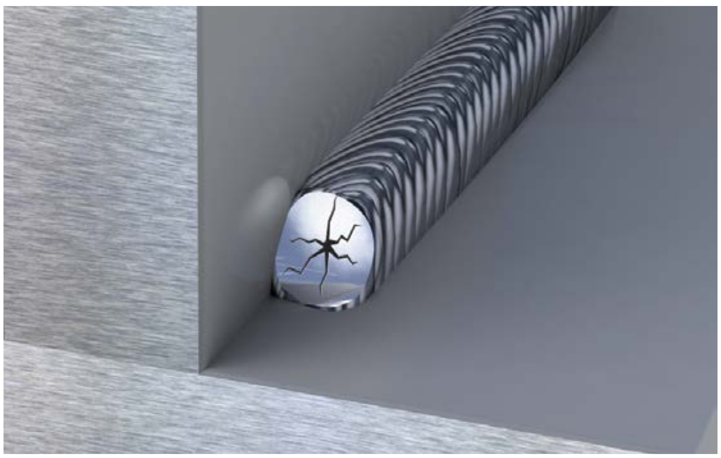


Figure 9-17: Crater Cracks

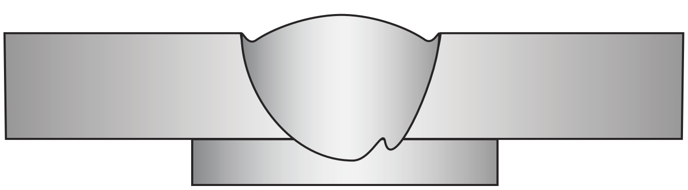


Figure 9-18: Undercut

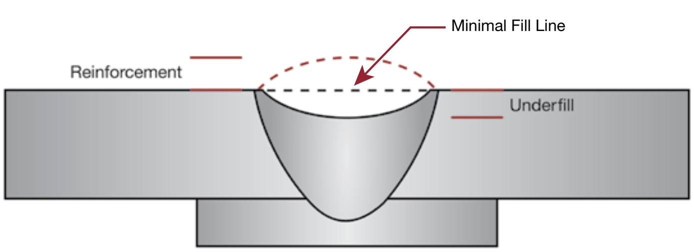


Figure 9-19: Underfill

Crater Cracks (Figure 9-17)

Inadequate filling of the crater at the end of a weld can result in solidification cracking due to high shrinkage stresses in the solidifying concave crater. The greatest risk with crater cracks is the possibility of propagation into the rest of the weld. Proper crater fill procedures will minimize the risk. Run-off tabs can be used and removed to eliminate craters from the welded part.

9.4 ADDITIONAL TYPES OF DISCONTINUITIES

Undercut (Figure 9-18)

Undercut is a defect that appears as a groove in the parent metal directly along the edges of the weld or weld toes. Undercut is typically caused by improper welding procedure, excessive voltage, or both. Undercuts can act as stress risers. Always check the welding code prior to inspection.

Underfill (Figure 9-19)

Underfill is a condition where the weld face surface of a groove weld extends below the adjacent surface of the base metal. Discontinuity can be eliminated by adjusting the welding parameters.

Excessive Weld Reinforcement in a Groove Weld (Figure 9-20)

Weld reinforcement is the portion of the weld deposit that projects above (or below) the surface of the joint. Always check the welding code prior to inspection. Weld reinforcement is controlled by welding procedures. Adjusting deposition rate and bead dimensions will control reinforcement.

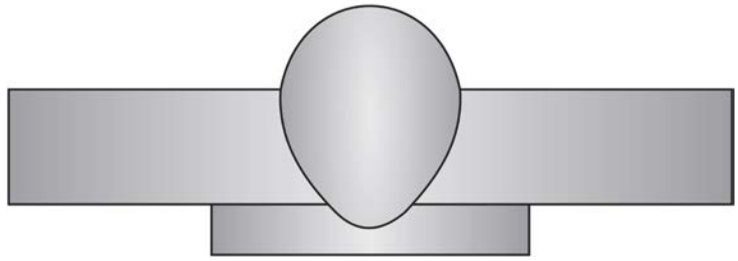


Figure 9-20: Excessive Reinforcement

Slag Inclusions (Figure 9-21)

Slag inclusions are the result of slag trapped in the weld metal. Slag inclusions can be found in any welding process that uses flux to shield the arc. Improper welding techniques or improper joint design cause slag inclusions.

Figure 9-21: Slag Inclusions

Incomplete Joint Penetration Or Lack of Penetration (LOP) (Figure 9-22)

Incomplete joint penetration is a lack of penetration or tie-in at the root of a groove weld. Penetration is controlled by welding parameters, mainly current. Increasing current will increase penetration. Joint design and welding technique can also influence penetration.

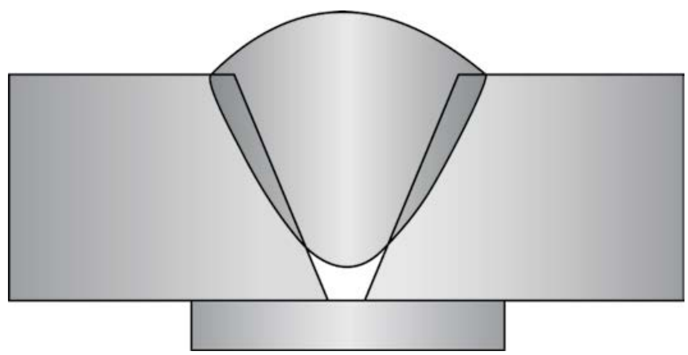


Figure 9-22: Incomplete Joint Penetration

Figure 9-23: Fillet Weld Gauge

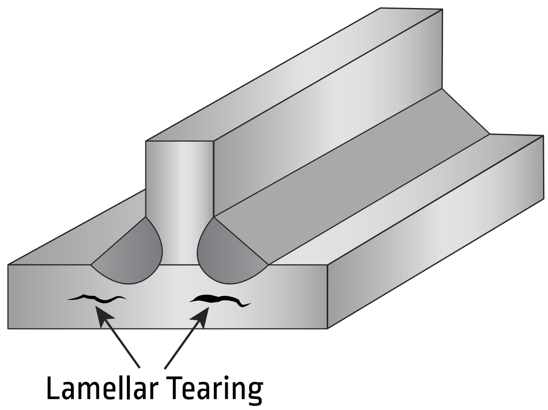


Figure 9-24: Lamellar Tearing

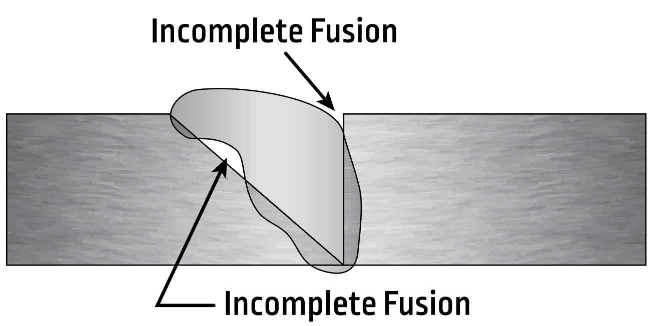


Figure 9-25: Incomplete Fusion

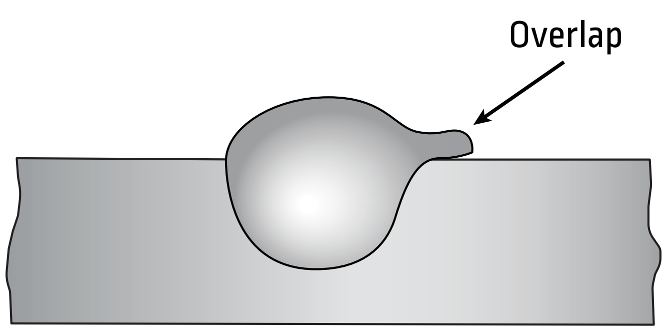


Figure 9-26: Overlap

Lamellar Tearing (Figure 9-24)

A lamellar tear is a step-like crack in the base metal that typically occurs parallel to the plate surface. The tear is a result of dispersed, planar-shaped, nonmetallic inclusions located parallel to the metal surface. Tensile stresses weaken the inclusion base metal through-thickness and the fracture surface typically propagates from one lamellar plane to another. Lamellar tearing is most common in heavier sections of steel.

Incomplete Fusion (Cold Lap) (Figure 9-25)

A lack of weld fusion to the base metal, or adjacent weld deposit, is a sign of incomplete fusion. The causes of incomplete fusion are improper welding technique, poor joint design and inadequate cleaning or preparation.

Overlap (Figure 9-26)

Overlap occurs when additional weld metal protrudes beyond the weld toe or weld root. Overlap causes a mechanical notch next to the weld and it is a rejectable discontinuity. Prevent overlap by adjusting travel speed or improving base metal preparation.

Notes

10.1 FLUX CARE AND HANDLING

For detailed instructions on Lincoln Electric flux care and handling, please refer to the most recent version of C1.10 available at lincolnelectric.com.

Submerged arc welding fluxes and other low-hydrogen welding products must be dry to perform properly. Lincoln Electric fluxes that are in the original unopened bags will remain dry if proper attention is paid to good storage conditions.

Hermetically sealed packages, such as metal drums, plastic pails or the Sahara Ready Bag (SRB), when undamaged, will ensure the moisture levels of the flux do not change from the time of manufacture. Lincoln Electric fluxes in hermetically sealed packages can be used directly from these packages with the assurance that the flux will deliver the diffusible hydrogen level to which it is certified.

When welding flux storage bags are opened or punctured, the flux should be removed and stored in closed containers to ensure it remains dry. Moisture contamination of exposed flux can occur through condensation of moisture from the surrounding air.

Figure 10-1: Unopened Bag of Flux

The condensation of moisture can also occur on steel plates and any other materials stored in the same location. Condensation can be especially severe under humid conditions, especially when the air temperature drops, particularly after sundown. Relative Humidity (RH) is the amount of water vapor in the air expressed as a percentage of the maximum amount that the air can hold at a given temperature.

When open bags are exposed to air or when sealed bags are stored in especially damp conditions, the flux may experience contamination due to condensation. Depending on the amount of moisture, weld quality can be negatively impacted when:

1. Moisture reduces the ability of low-hydrogen welding to resist underbead cracking with hardenable base steel (possible delayed cracking).
2. Moisture causes internal porosity. Detection of porosity may require x-ray inspection or destructive testing.
3. A relatively high moisture content causes visible external porosity or pockmarking.
4. **NOTE:** Moisture can also cause excessive slag fluidity, a rough weld surface and slag removal problems.

As is the case with all arc welding processes, careful analysis of material condition is required to achieve a successful weld. Certain conditions in the material to be welded can result in the development of porosity, which may be visible on the surface or contained internally.

It is critical to pay attention to the quality of flux being utilized for welds. Flux contaminated by moisture, or other contaminants such as floor sweepings, can result in both porosity and other discontinuities. Secure flux and wire storage is essential to beginning the submerged arc welding process with the level of confidence required to create quality welds.

10.2 DISPOSAL OF SUBARC SLAG

The U.S. Government standard leaching test for landfill materials has determined that Lincoln Electric submerged arc slag is not a hazardous waste and may be placed into landfills.

10.3 CRUSHED SLAG

Slag formed during the welding process that is subsequently crushed for use as a welding flux is defined as a crushed slag. This is different from a recycled flux, which was never fused into a slag and can often be collected from a clean surface and reused without crushing. Ingredients for use in welding fluxes are very carefully chosen to cleanse the weld metal, protect it from atmospheric contamination, stabilize the arc, allow for ease of slag removal from the weld metal and provide an appropriate slag viscosity and freezing range for the intended applications. When flux is melted by a welding arc, many chemical reactions occur. Some of the specific elements contained in the slag may be the same, but their chemical form will be different.

Cleansing the weld metal is one of the most important functions of the flux. This is especially important for oxides and sulfides that would otherwise be dissolved in weld metal, or be present in the form of inclusions. To achieve this, the fluxing agents must be in the correct chemical form. For example, manganese, ferromanganese, manganese silicon, manganese oxide and manganese silicate will all appear as Mn when the flux is analyzed by the most commonly used chemical analysis methods (e.g., X-ray fluorescence). However, each of these forms of Mn will provide a very different level of cleaning and alloying to the weld metal. In addition, each has different melting characteristics which will influence the operability of the flux. Melted flux is mixed with molten weld metal, and impurities in the weld metal are captured in the slag. When slag is ground for subsequent use, the same original compounds are not available for cleansing the weld metal and the slag is intrinsically higher in harmful impurities.

The flux and its slag generally have significantly different melting points and viscosities. This is due to the form of the oxide, silicide, fluoride, metal, etc. Further, after melting, materials that are included in flux to stabilize and shield the arc are no longer available in their original form. The change in these compounds upon melting will often detrimentally affect the slag removal and operability of the fluxes, resulting in lower travel speeds and productivities. Slag is typically 20% more dense than an agglomerated flux. This will promote segregation of any blends of this slag with the original welding flux. It can also significantly increase the consumption of welding flux, increase the slag to metal ratio, and affect the bead shape.

Notes

TEACH YOUR TRADE.

WE'LL DO THE REST.

CUSTOMER ASSISTANCE POLICY

The business of The Lincoln Electric Company is manufacturing and selling high quality welding equipment, consumables, and cutting equipment. Our challenge is to meet the needs of our customers and to exceed their expectations. On occasion, purchasers may ask Lincoln Electric for information or advice about their use of our products. Our employees respond to inquiries to the best of their ability based on information provided to them by the customers and the knowledge they may have concerning the application. Our employees, however, are not in a position to verify the information provided or to evaluate the engineering requirements for the particular weldment. Accordingly, Lincoln Electric does not warrant or guarantee or assume any liability with respect to such information or advice. Moreover, the provision of such information or advice does not create, expand, or alter any warranty on our products. Any express or implied warranty that might arise from the information or advice, including any implied warranty of merchantability or any warranty of fitness for any customers' particular purpose is specifically disclaimed.

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

Subject to Change – This information is accurate to the best of our knowledge at the time of printing. Please refer to www.lincolnelectric.com for any updated information.

THE LINCOLN ELECTRIC COMPANY
22801 St. Clair Avenue ● Cleveland, OH ● 44117-1199 ● U.S.A.
PH: +1.216.481.8100 ● www.lincolnelectric.com

LINCOLN® ELECTRIC

Publication C5.50 Issue Date 11/19