



Advanced GMAW Process for Pipe Welding Applications

Technical Assessment

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Technical Assessment, December 2001

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ABSTRACT

During the last few years, advanced welding equipment has been developed with fuzzy logic microprocessor technology and waveform control for gas-metal arc welding (GMAW). This equipment allows arc conditions to be fine tuned for material thickness, wire diameter and material type. The equipment reacts quickly to changes in welding conditions to permit high-quality, high-deposition welding using a demand-pulsed short arc mode. The advanced equipment generated interest in developing procedures for welding of heavy sections with solid wire to provide higher productivity rates, shorter outage duration, and reduced man-rem exposure. For overlay applications the process could minimize burn through and reduce shrinkage with a higher deposition. The nominal pipe wall thickness that this process was targeted for is approximately ½-in., which, for example, would cover up to Schedule 120 for 6-in. pipe.

In prior Repair and Replacement Application (RRAC) programs the Lincoln Power Wave 450/STT was identified as the preferred power supply for open butt welding applications with solid wire. The evaluations with the Lincoln power supply resulted in reproducible open butt root welds for all position applications, joint geometry requirements and Procedure Qualifications per ASME Section IX for carbon steel, stainless steel and 2 ¼ CrMo (P5) plate materials. The advantages here is minimized burn thru, less shrinkage and relatively higher deposition.

As a follow-up to the evaluation RRAC members requested that further development of the process be conducted for manual and automatic pipe welding applications, which would include RT verification, shrinkage evaluation (compared to FCAW and SMAW) and welding guidelines. The results of the welding development are documented in this Technical Assessment.

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1

INTRODUCTION

During the last few years, advanced welding equipment has been developed with fuzzy logic microprocessor technology and waveform control for gas-metal arc welding (GMAW). This equipment allows arc conditions to be fine tuned for material thickness, wire diameter and material type. The equipment reacts quickly to changes in welding conditions to permit high-quality, high-deposition welding using a demand-pulsed short arc mode. The advanced equipment generated interest in developing procedures for welding of heavy sections with solid wire to provide higher productivity rates, shorter outage duration, and reduced man-rem exposure. For overlay applications the process could minimize burn through and reduce shrinkage with a higher deposition. The nominal pipe wall thickness that this process was targeted for is approximately ½-in., which, for example, would cover up to Schedule 120 for 6-in. pipe.

In prior Repair and Replacement Application (RRAC) programs the Lincoln Power Wave 450/STT (Figure 1-1) was identified as the preferred power supply for open butt welding applications with solid wire. The evaluations with the Lincoln power supply resulted in reproducible open butt root welds for all position applications, joint geometry requirements and Procedure Qualifications per ASME Section IX for carbon steel, stainless steel and 2 ¼ CrMo (P5) plate materials. The advantages here is minimized burn thru, less shrinkage and relatively higher deposition.

As a follow-up to the evaluation RRAC members requested that further development of the process be conducted for manual and automatic pipe welding applications, which would include RT verification, shrinkage evaluation (compared to FCAW and SMAW) and welding guidelines. The results of the welding development are documented in this Technical Assessment.

Section 2 describes the overall test matrix, Section 3 includes the test results of the GMAW demonstrations, Section 4 lists conclusions and Appendix A documents the welding guidelines or tutorial.

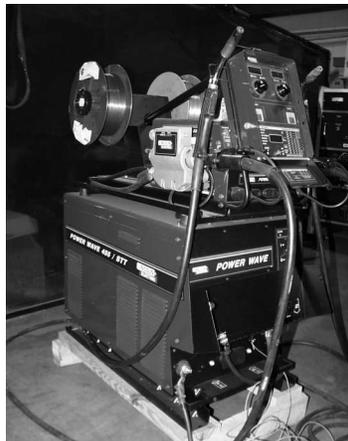


Figure 1-1. Lincoln Power Wave 455/STT Equipment

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TEST PROGRAM

A test program was established to evaluate and demonstrate GMAW process for pipe welding applications. The program first looked at transferring technology developed for GMAW qualifications on thick section plate material to manual GMAW pipe welding applications. To verify the GMAW process radiographic testing (RT) would be used to compare the quality to GTAW and SMAW processes. With successful demonstration of GMAW for manual pipe welding applications the technology would be further demonstrated with automated systems. Available pipe tracks and carriages (i.e. Pipeliner) would be used to adapt the process for automated welding application. Finally with the procedures established in the process demonstration a training manual would be developed for utility pipefitter/welders. Three tasks were outlined to accomplish the scope of this activity:

- Manual GMAW pipe welding demonstration
- Automated GMAW pipe welding demonstration
- Welding Guidelines

Manual GMAW Pipe Welding Demonstration

Manual demonstration of the Lincoln Powerwave 450 STT will be conducted on pipe to compare the process with GTAW, FCAW and SMAW process.

Open Root V-groove Welds

Manual demonstration of the Lincoln Powerwave 450 STT will be conducted on 6-in. schedule 120 pipe (.562-in. wall) to verify the process on pipe. A standard V-groove configuration shown in Figure 2-1, will be used for all open root welding evaluations. Initial welds will be made with parameters established in 2000 RRAC program for mechanical test specimens on thick section plate. RT evaluation will be used to verify the welding process in the 2G and 6G positions (Figure 2-2). The goal will be to demonstrate two successive RTs, with the same relative quality as GTAW/SMAW. The test matrix is included in Table 2-1. Parameters and welding techniques will be documented to assist in developing guidelines for training of pipefitter/welders.

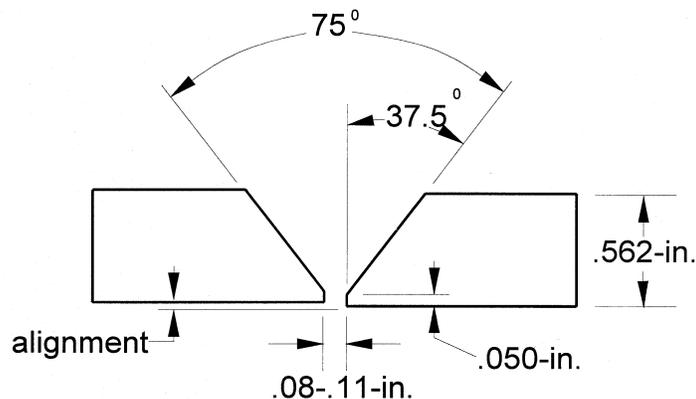


Figure 2-1. V-groove configuration for open root evaluations.

Utility Demonstration

As a follow on to the initial welding demonstration, participating utilities will use technology to independently verify the GMAW process on pipe welds. The goal will be to produce successive acceptable RTs with manual welding with a typical pipefitter/welders. The process will be repeated with a second utility welder.

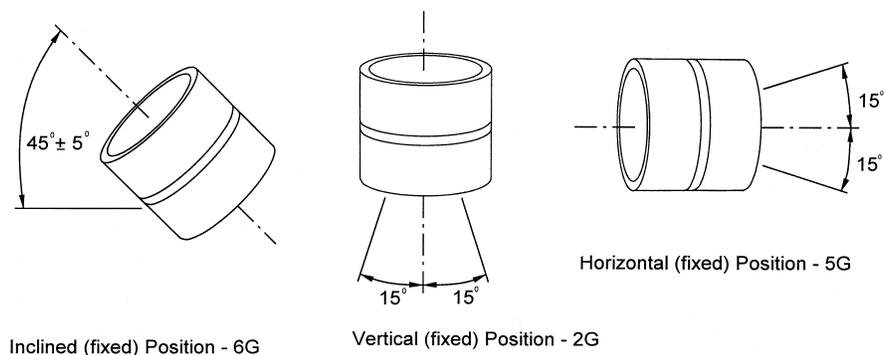


Figure 2-2. Welding Positions

Overlay Welds

The GMAW process will be evaluated for weld shrinkage by applying a standard weld overlay on identical pipe specimen with manual GMAW and FCAW, SMAW and automatic GMAW processes (Table 2-1). Each process will be used to apply a two layer overlay approximately 1.5-inches wide on the center of a set length of schedule 120 pipe (.562-inch wall) as seen in Figure 2-3. Axial shrinkage will be measured at the completion of each layer for all processes.

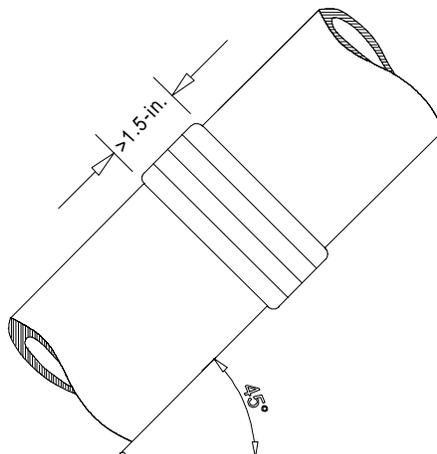


Figure 2-3. Schematic of overlay weld configuration.

Automated GMAW pipe welding demonstration

The Lincoln Powerwave 455/STT will be coupled with a manipulator system (i.e. Pipeliner, Bug-O system) to demonstrate the process for automatic applications. The v-groove welding and overlay specimens (Figure 2-2) will be duplicated as described above and in Table 2-1. The goal will be to demonstrate acceptable RT with the same relative quality as GTAW/SMAW and compare axial shrinkage with the manual processes (FCAW, SMAW, GMAW)

Table 2-1. Test Matrix for Evaluating the Lincoln Powerwave 455/STT

Process	Location	Application	Position	Quantity	Test
Manual GMAW	RRAC	V-Groove	2G	2	RT
Manual GMAW	RRAC	V-Groove	6G	2	RT
Manual GMAW	Utility	V-Groove	2G	2	RT
Manual GMAW	Utility	V-Groove	6G	2	RT
GMAW	RRAC	Overlay	6G	1	Shrinkage
FCAW	RRAC	Overlay	6G	1	Shrinkage
SMAW	RRAC	Overlay	6G	1	Shrinkage
Automatic GMAW	RRAC	V-Groove	2G	2	RT
Automatic GMAW	Vendor	V-Groove	6G	2	RT

Welding Guidelines

A training manual will be assembled with the data collected in the v-groove and overlay evaluations described above. The training manual will be used to transfer technology to utility pipefitter/welders. Information to be included in the manual will consist of welding terminology, fitup, process familiarization, weld procedures (i.e. tack welding, root welding, fill and cap passes).

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GMAW PIPE WELDING DEMONSTRATION

Manual demonstrations of the Lincoln Powerwave 450 STT were conducted 6-in. schedule 120 pipe specimens. Both overlay welds and v-groove welds were completed to assess the GMAW process for open root welding applications and to compare the process with other manual welding processes. Welding techniques and parameters were documented to assist with developing a training manual during the welding demonstrations. Automatic GMAW welding was also demonstrated with the technology to verify the capabilities of the equipment.

This section is divided into five tasks; *Open Root V-Groove Welds, Utility Demonstration, Overlay Welds, Automatic GMAW Welding and Guidelines-Training Manual*

Open Root V-groove Welds

The evaluation of the GMAW process with solid wire was conducted with the Lincoln Power Wave 450/STT power supply and Lincoln wire feeder (Figure 3-1) on carbon steel pipe material (SA-516, Grade 70). Additional weld modes (programs) were added to the welding power supply during the course of the welding evaluations to increase the capabilities of the equipment.

The development work consisted of parameter development including machine settings, joint geometry evaluation and welding technique for welding open root pipe welds. RT testing was conducted per ASME Section IX specifications to verify weld quality. Various welding positions were selected (Figure 2-1), to assure welding in all positions could be accomplished. In all cases, 0.045-in. diameter solid wire (ER70S-6, Lincoln L-56 70-6) was used for all passes (root, hot, and fill passes). A downhill welding progression was used for all root pass welds, and uphill and downhill progression was used for the hot and fill passes, depending on the Program setting. No backing gas was utilized with the carbon steel (SA-516, Grade 70) material.

A number of manual open root v-groove welds were completed with the Lincoln Powerwave 455/STT system. Initial welding parameters matched the specifications developed for qualifying thick section plate. As, new weld programs became available through Lincoln Electric Company; other parameter variations were evaluated. Table 3-1 lists the welding parameters used for various welding modes. Parameters were not altered for welding position. Detailed parameters and welding techniques were documented during the welding evaluations and will be included in the welding guidelines section (Appendix A).

Manual demonstration of the Lincoln Powerwave 450 STT were conducted on 6-in. schedule 120 pipe (.562-in. wall) with a standard V-groove configuration (Figure 2-1). All specimens were RT tested for acceptability (Table 3-2). At least two specimens for each condition in Table 3-2 were considered acceptable per RT evaluation.



Figure 3-1. Demonstration of open root V-groove (5G Position).

Table 3-1. Welding Specifications for Open Root V-Groove Welds

Program	Wire Speed (in/min)	Arc Control	Trim	Gas	Travel Speed (in/min)	Layer
Mode 119	120	5-10	.60	100% CO ₂ @ 25 cfh	6-7	Root and Tack Welds Downhill weld progression
Mode 117 STT Mode	120 (.045-in.)	5-10	.60	100% CO ₂ @ 25 cfh	6-7	Hot and Fill Passes Downhill weld progression slight weave
Mode 22 Pulse Spray Mode	135 (.045-in.)	+5	.98	92/8 Argon/ CO ₂ @ 25 cfh	6-7	Hot and Fill Passes Uphill weld progression slight weave
Mode 5 CV Mode	215 (.045-in.)	Off	1.05	75/25 Argon/ CO ₂ @ 25 cfh	6-8	Hot and Fill Passes Uphill weld progression slight weave

Table 3-2. RT Evaluations for GMAW

Quantity	Position	Process	Test Evaluation	Comments
2	2G	Manual GMAW	RT	Small round indications near tack welds and stop and starts (acceptable)
2	6G	Manual GMAW	RT	Small round indications near tack welds and stop and starts (acceptable)
2	6G	Automatic GMAW	RT	Very clean, a few small round indications

Utility Demonstration

As a follow on to the initial welding demonstration, participating utilities were supplied welding parameters and technical support to reproduce open root welding with the GMAW process. The utility pipewelder results were not available at the time this progress report was completed, but will be included in the next progress report.

Overlay Welds

Overlay welds were applied on pipe sections to evaluate weld shrinkage relative to welding process and deposition rate. Two layer overlays (Figure 2-3) were applied in the 6G position with identical pipe specimen with GMAW, FCAW, SMAW and automatic GMAW processes (Table 2-1). Welding specifications for each process evaluated for weld shrinkage is documented in Table 3-3. Parameters are similar to the cap passes used for the v-groove welding evaluation. All overlays were welded double up with the exception of the root pass which was welded downhill. The FCAW process was considered to perform the best for all position welding and had the best bead appearance for the manual processes (Figure 3-2). The automatic GMAW process had the overall best appearance (Figure 3-3). The manual SMAW and GMAW processes are illustrated in Figure 3-4 and 3-5, respectively.

The resulting axial shrinkage was measured at the completion of each layer and is documented in Table 3-4. The axial shrinkage was similar for the GMAW, FCAW and the GMAW-AU processes. The axial shrinkage caused by the SMAW process was twice that of the other processes.

Table 3-3. Welding Specifications for Overlay Specimens

Process	Position	Program	Wire Feed Speed (in/min)	Arc Control	Voltage/ amperage	Trim	Travel Speed (in/min)	Comments
GMAW NC-10	6G	Mode 22	135	+5		105	6-8	.045-in. Lincoln L-56 70-6 92A-8CO2
FCAW NC-11	6G	Mode 5	215	OFF	160 amps 22.4 volts	22.5V	6-8	.045-in. Lincoln Elite-71 75A/25CO2
SMAW NC-12	6G	3/32-in. 7018	N/A	N/A	100 amps 27-30 volts		6-8	3/32-in. Lincoln Jet-LH 78MR

Table 3-4. Shrinkage Evaluation for overlay weld specimens

Process	Position	Location	Overall Length in.	1st layer in.	Shrinkage in.	2 nd layer in.	Shrinkage in.
				(build up)	(ave.)	(build up)	(ave.)
GMAW Overlay NC-10	6G	0	5.914	5.897	.017	5.895	.017
		90	5.925	5.910	.015	5.910	.015
		180	5.954	5.932 (.160)	.022 (.019)	5.932 (.300)	.022 (.020)
		270	5.976	5.953	.023	5.948	.028
GMAW Overlay (auto.)	6G	0	4.310			4.290	.020
		90	4.342			4.318	.024
		180	4.202			----- (.300)	---- (0.22)
		270	4.273			4.250	.023
FCAW Overlay NC-11	6G	0	5.891	5.878	.013	5.873	.018
		90	5.908	5.894	.014	5.894	.014
		180	5.922	5.900 (.130)	.022 (.016)	5.891 (.260)	.031 (.021)
		270	5.954	5.939	.015	5.933	.021
SMAW Overlay NC-12	6G	0	5.927	5.886	.041	5.881	.046
		90	5.920	5.883	.037	5.871	.049
		180	5.987	5.956 (.160)	.031 (.036)	5.951 (.320)	.036 (.044)
		270	5.969	5.933	.036	5.922	.047

Note: All Overlays were welded double up with the exception of the root weld.

Note: Overlays were approximately 1 1/2-in wide by 2 layers by full circumference

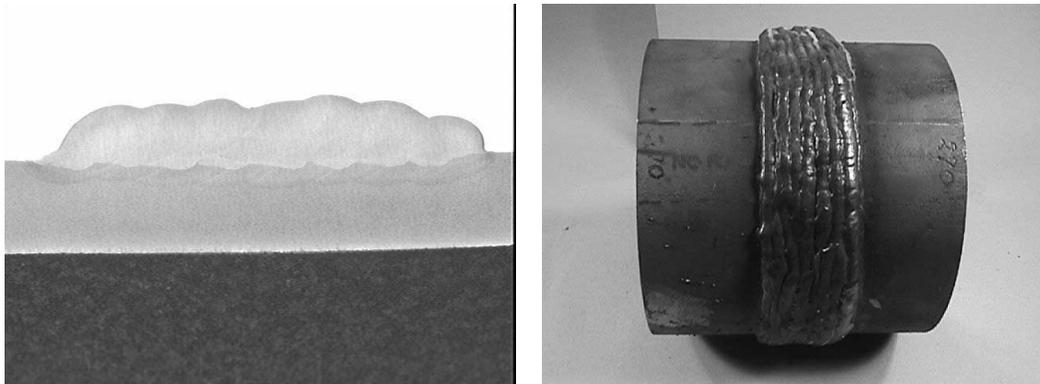


Figure 3-3. Overlay weld specimen with the manual FCAW process.

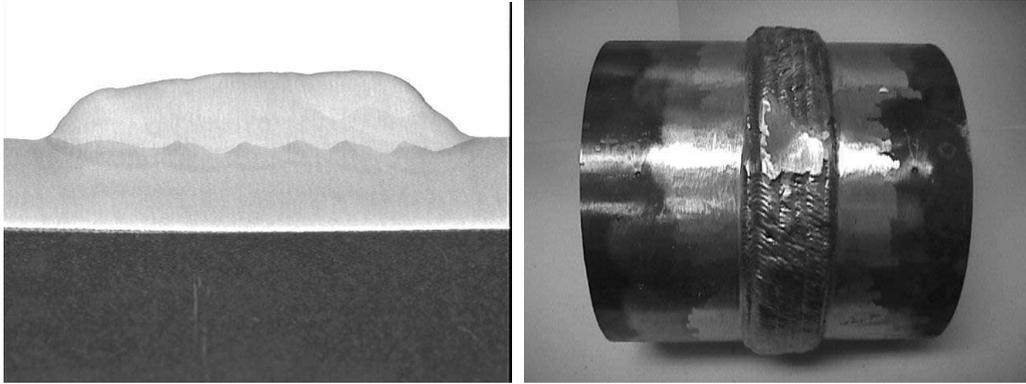


Figure 3-4. Overlay weld specimen with the GMAW-AU process (Courtesy of PCI-Energy).

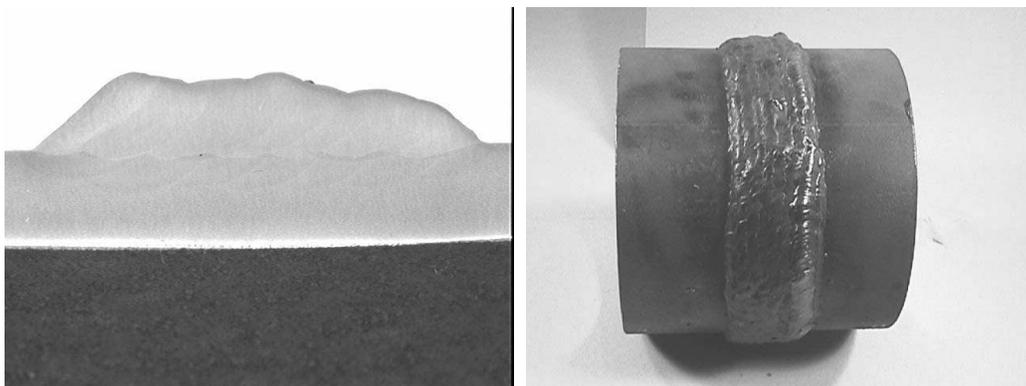


Figure 3-5. Overlay weld specimen with the SMAW process.

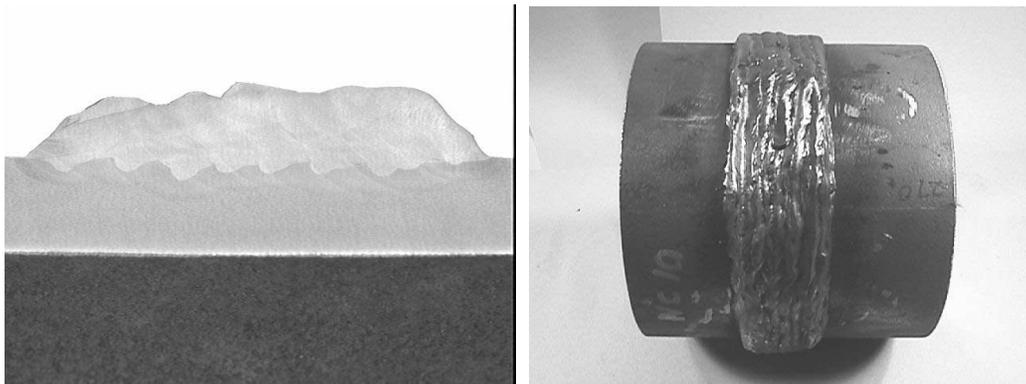


Figure 3-6. Overlay weld specimen with the GMAW process.

Automatic GMAW Welding

The Lincoln Powerwave 455/STT was further evaluated for automatic welding applications. The system was first coupled with the Magnatech Pipeliner II system for evaluating root welding capabilities (Figure 3-7). A number of root welds were applied to 12-inch pipe specimens with welding parameters identical to the manual welding parameters and similar joint fitup and

geometry (Figure 2-1). Limitations of the Pipeliner's control system did not allow for complete 360-degree welds to be completed, at this time. PCI Energy utilized their proprietary track system coupled with the Lincoln Powerwave 455/STT to complete both v-groove welds and overlay weld specimens.

The overlay welds were specified to match the manual overlay welds, which consisted of two layers approximately 1.5-inches wide welded in the 6G position. The results were reported with the manual welds in Table 3-4. Figure 3-8 illustrates typical root weld quality of the automatic GMAW system.

Welding specifications for the automatic welding process are documented in Table 3-5. The overlay parameters are similar to the cap passes used for the v-groove welding evaluation. All the GMAW-AU overlay welds were welded double up with the exception of the root pass, which was welded downhill. All RT evaluations of the automatic process were considered acceptable and were reported in Table 3-2 with the manual welding evaluations.

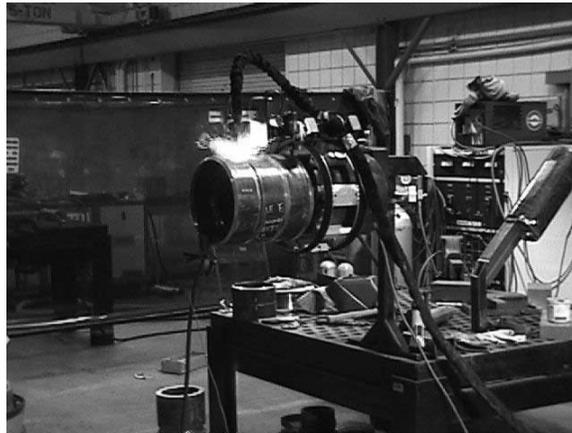


Figure 3-7. Automatic setup with Pipeliner II and Lincoln Powerwave 455/STT.

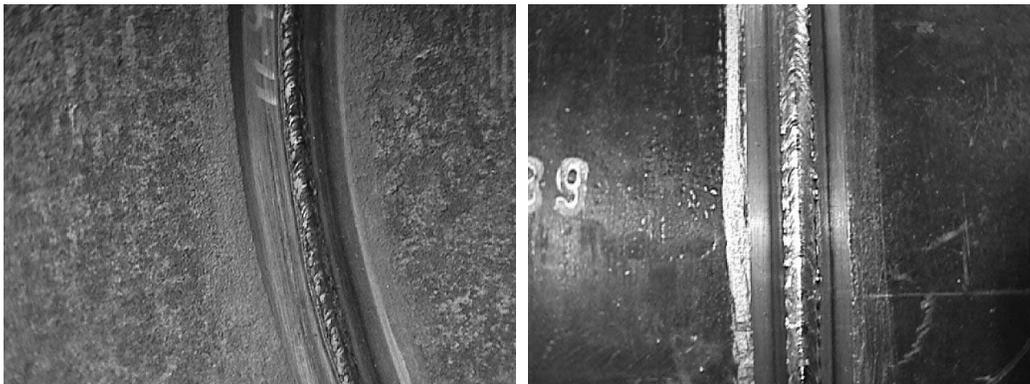


Figure 3-8. Typical appearance of root weld (ID and OD view).

Table 3-5. Welding Specifications for automatic GMAW process (Courtesy of PCI-Energy).

Process	Position	Program	Wire Feed Speed (in/min)	Arc Control	Trim	Travel Speed (in/min)	Comments
GMAW Overlay	6G	Mode 8	216	off	1.03	5.5	½-in. oscillation .045-in.wire 75A/25CO2 grind all starts
GMAW V-groove	6G	Root, Mode112	260	off	1.06	5.5	<1/4-in. oscillation .045-in.wire 75A/25CO2
		Fill, Mode 12	210-212	off	1.06	5.5	75A/25CO2

Guidelines-Training Manual

The Lincoln Power Wave 455/STT was evaluated through welding trials and RT Evaluations in the manual and automatic welding modes. The welding parameters and techniques were documented throughout the welding evaluations and are illustrated in the Welding Guidelines attached in Appendix A. The welding guidelines are intended to be used as a training manual for utility pipewelders. The welding guidelines will be updated to include utility comments in the next progress report.

4

CONCLUSIONS

The Lincoln Powerwave 455/STT was evaluated for manual pipe welding applications with an open root v-groove, overlay repair applications, and automatic welding applications. The basic conclusions are listed below:

- Acceptable RT evaluations were achieved with manual welding in 2G and 6 G positions.
- Welding parameters and techniques were documented for technology transfer to utility pipefitters/welders.
- Overlay welds were completed with FCAW, SMAW, GMAW and GMAW-AU to evaluate axial shrinkage.
 - FCAW, GMAW and GMAW-AU produced similar axial shrinkage (~.021-in over 6-inches).
 - SMAW produced had approximately .044-inches of shrinkage over 6-inches.
- Automatic welding was completed with Pipeliner II system and PCI Energy system with excellent results for both the overlay configuration and open root V-groove.
- Welding training manual was developed with techniques and parameters developed in the welding demonstrations (Appendix A).
- Technology transferred to participating utilities for further evaluations.

A APPENDIX - MANUAL GMAW PIPE WELDING GUIDELINES FOR LINCOLN POWERWAVE 455

The guidelines for full penetration open root welding with the GMAW process is divided into 4 lesson plans. The lesson plans (1-4) should be completed in approximately 4-6 hours. Lesson plan can be duplicated for different material and welding positions. Actual welding practice time should be less than 40-hours.

Lesson 1: GMAW Process Review

Objectives: Familiarization with basic terminology, design and set-up of open root v-groove welds. Student/Trainee should be able to measure and verify that the joint preparation (groove geometry) matches working drawings or written instructions. Lesson 1 is divided into two tasks; 1) GMAW Equipment Review and 2) Welding Process Description

Time: 1 hour review time

GMAW Equipment Review

Gas Metal Arc Welding Process (GMAW) - Commonly know as MIG or wire welding. Basic components of the Lincoln 455 Powerwave are shown in Figure L1-1.

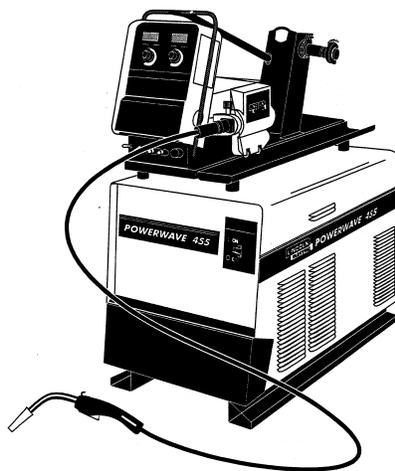


Figure L1-1 Components of the Lincoln Powerwave 455, GMAW system.

Mode – Mode is a setting that allows the machine to optimally perform according to welding process, welding position, material thickness, and wire diameters. The modes available with the Lincoln Powerwave 455 are listed below:

CV Mode: GMAW and FCAW processes. A preprogrammed voltage is set for each wire feed speed. Preset voltage can be altered by the Wire feeder's voltage control.

Pulse GMAW Mode: Pulse settings for GMAW process. Pulse parameters are adaptively controlled to accommodate changes in the stickout length.

STT Mode: STT Mode is a current control process and is neither a CC or a CV process. The current is altered very quickly to changes in the arc. Often referred to as the short circuit mode.

Arc Control – Inductance or Wave Control. Arc control is adjustable between -10.0 and 10.0. Arc control may vary depending on the welding Mode as described below:

CV Mode: ARC CONTROL adjusts the inductance, which directly relates to the heat input to the weld. Increasing the arc control number lowers the inductance resulting in a colder arc. Decreasing the arc control number increases the inductance resulting in a wider hotter arc.

Pulse GMAW Mode: ARC CONTROL adjusts the pulse frequency. Typically used for fine tuning for various weld positions. Increasing the arc control number raises the pulse rate. Decreasing the arc control number decreases the pulse rate.

STT Mode: ARC CONTROL is a coarse adjustment in the heat input to the weld. Increasing the arc control number produces a more fluid puddle (potentially spatter). Decreasing the arc control number makes a colder weld (potential wire stubbing).

Trim – Controllable between 0.500 and 1.500. TRIM may vary depending on the welding Mode as described below:

CV Mode: TRIM controls the welding voltage.

Pulse GMAW Mode: TRIM is an adjustment of the arc length. A TRIM setting greater than 1.000 increase the arc length. A TRIM setting of less than 1.000 decreases the arc length.

STT Mode: TRIM is a fine adjustment of heat input to the weld.

Wire Feed Speed – The wire feed speed is the main control over all other welding variables. The welders can control the WFS to vary weld size, penetration, heat input, etc.

Welding Process Description

Welding Position – The welding position is based on the position of the pipe and is the pipe is held stationary or rotated. Welding positions are described below and illustrated in Figure L2-1.

Horizontal pipe position: 1G if pipe is rotated, 5G if pipe is in a fixed position

Vertical pipe position: 2G, Inclined at $\pm 15^\circ$

Inclined pipe position: 6G, pipe in fixed position, inclined at a $45^\circ \pm 5^\circ$

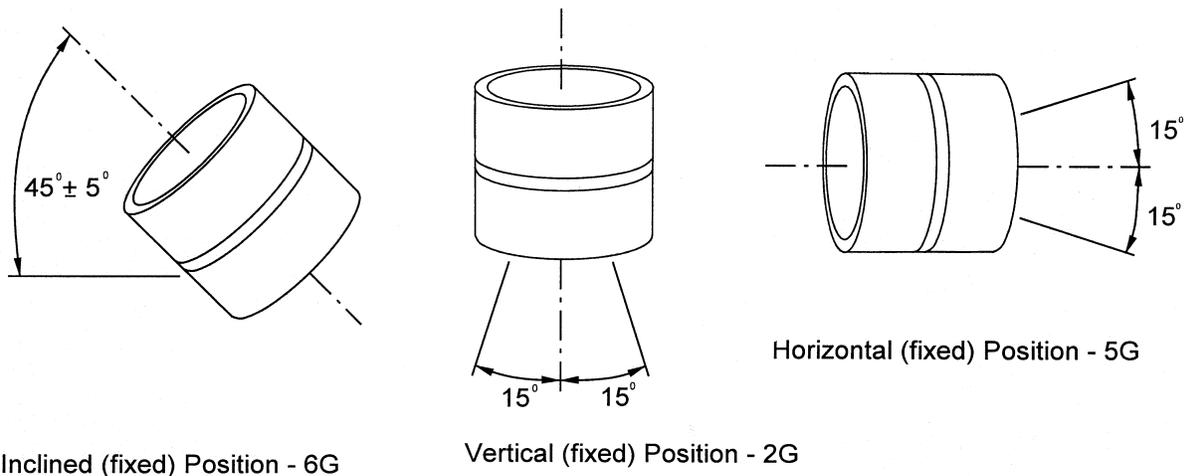


Figure L1-2 Pipe Welding Positions

Joint Preparation – The weld preparation for a full penetration pipe weld using the GMAW process typically consists of a single V-groove configuration with an open root. Details of the joint preparation are described below and correspond to Figure L1-3.

1. *Groove Angle* – Total included angle between the two sections of pipe. Typically 75-degrees
2. *Bevel Angle* – The angle prepared on one section of the pipe. Measured from a plane perpendicular to the prepared surface of the pipe. Typically 37.5 degrees.
3. *Root opening* – The opening or distance between the two workpieces. Root opening typically 0.08-in. up to 0.11-in.
4. *Land Thickness* - The length of the surface of the workpiece adjacent to the root. Typically 0.070-in.
5. *Groove Surface or Face* – Surface of the workpiece included in the groove.
6. *Pipe or Plate Wall Thickness* – Overall thickness of the pipe or plate being joined.

- 7. *Root Face or Land Face* – The portion of the groove face that is adjacent to the root opening.
- 8. *Alignment* – Distance the surface of one pipe section is offset from the other.

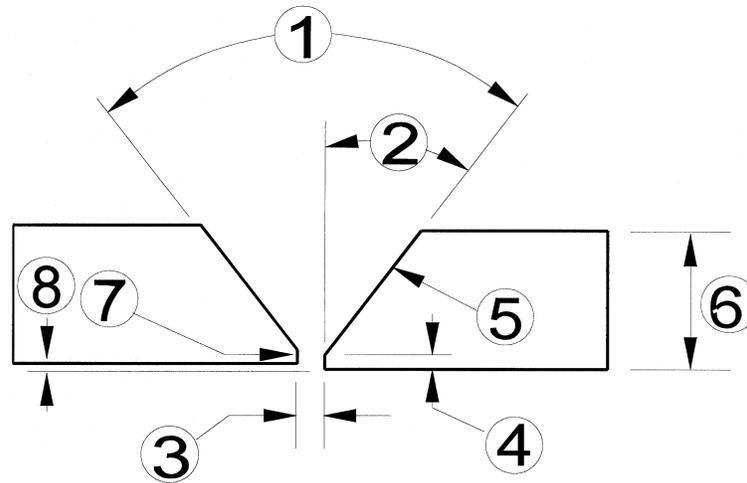


Figure L1-3. Weld Joint Design (numbers correspond to descriptions in the Joint Preparation Section)

Shielding – The protective gas used to protect the molten puddle from atmospheric contamination. Could also refer to gas purging. 100% CO₂ is typically used for short arc applications including the root welds. Alternative gases such 92% Argon and 8% CO₂ are used when pulse spray modes are used.

Weld Passes – Weld passes are divided into layer of progression including tack welds, root weld, hot pass, fill passes and cap passes. Details of the weld passes are described below and correspond to Figure L1-4.

8. *Tack Weld* – Tack welds are considered part of the root weld and should be sufficient in size and number to maintain the root opening and joint alignment.

8. *Root Weld* – The root pass is the first weld pass applied to completely bridge the gap between the pipe. For the GMAW process the root weld will typically be an open root weld (no backing ring). An attempt is made to make the root pass continuous between tack welds for manual welding.

9. *Hot Pass* – The hot pass is typically a single weld pass that fuses the root weld and both groove faces together. A split hot pass has been beneficial for 2G welding and where the root opening is larger than normal.

10. *Fill Passes* – Weld passes between the hot pass and the cap passes.

11. *Cap Passes* – Typically welded in a similar manner as the fill passes. Must provide complete fill of joint cavity.

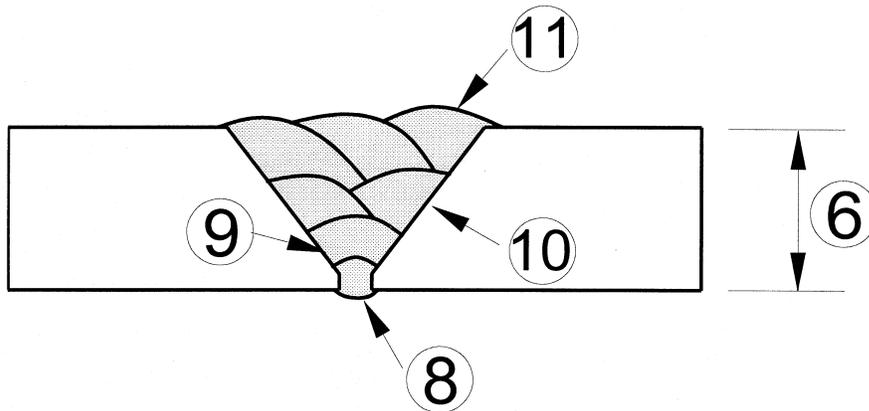


Figure L1-4 Bead Sequence and description (numbers correspond to descriptions in the Joint Preparation Section)

Weld Progression – Refers to the travel direction in which the weld is applied.

Downhill – welding with a downward progression typical of root welding and tack welds when utilizing the short circuit mode or STT mode.

Uphill – welding with a upward progression, typical of hot passes, fill and cap passes when utilizing pulse spray mode.

Travel Angle – Is the angle from a perpendicular line from the weld joint to the welding gun relevant to the travel direction. Typically referred as push angle or drag angle.

Push angle – The welding gun is pointing in the same direction of the travel.

Drag angle – The welding gun is pointing in the opposite direction of the travel.

Weld passes are divided into layers including tack welds, root weld, hot pass, fill passes and cap passes. Details of the weld passes are described below and correspond to Figure L1-4.

8. *Tack Weld* – Tack welds are considered part of the root weld and should be sufficient in size and number to maintain the root opening and joint alignment.

8. *Root Weld* – The root pass is the first weld pass applied to completely bridge the gap between the pipe. For the GMAW process the root weld will typically be an open root weld (no backing ring). An attempt is made to make the root pass continuous between tack welds for manual welding.

Weld Defect typical of GMAW welding include lack of fusion (LOF), Inclusions, Porosity, and Undercut.

Lack of Fusion (LOF) – Often referred to as incomplete fusion. LOF is when weld metal

is not completely fused to the base metal. LOF can be caused by excessive travel speed, low current poor joint preparation (interpass cleanup), poor bead placement.

Undercut – An underfill of the weld joint at the toes or root of the weld. Undercut can be caused by excessive welding parameters (i.e. current, voltage, travel speed), and inconsistent oscillation of welding gun.

Inclusions – Inclusions include oxides and slags. Inclusions can be caused by excessive travel speed, poor interpass cleaning and low voltage.

Porosity – Gas pockets in the weld metal. Porosity can be caused by inadequate shielding, excessive welding parameters (i.e. current, voltage, stickout, travel speed), and contaminants on or in the base metal.

Lesson 2: Tack Welds

Objectives: Teach set up procedures, tack welding techniques and terminology. At the completion of Lesson 2, welders should be able to set up and verify pipe joint geometry matches specifications, align and tack weld two sections of pipe and prepare pipe sections for root weld. This lesson is divided into three categories; 1) Terminology, 2) Setup, and 3) Welding

Time: 1.5 hours practice and demonstration of knowledge

Terminology

Tack welds are used to hold the root opening and maintain the pipe to pipe alignment while the root pass is being installed. Tack welds are considered a part of the root pass and should have the same quality as the root pass. Details of the root weld are described below and correspond to Figure L1-3 and Figure L2-1.

3. Root opening – A root opening that is too narrow can result in incomplete penetration. Excessive root open can be difficult to weld without melt through. The root opening is typically held by inserting a wire of the same dimension into the root opening. The wire is removed after the tacks are completed.

13. Root pass contour – The contour of the tack weld exposed to the OD surface, often referred to as the weld crown, is typically ground to reduce the convexity of the weld. A high crown often traps slag and makes it difficult to apply the root weld without inclusions and lack of fusion (LOF).

14. Root Surface – The root surface in the weld metal exposed to the ID surface. The geometry of the root surface can be concave (underfill) to convex. The shape of the root surface is governed by the degree of melt through, gravity, and welder technique. A slight convex root surface is desired.

15. Melt Through - Root reinforcement typically measured from the ID surface.

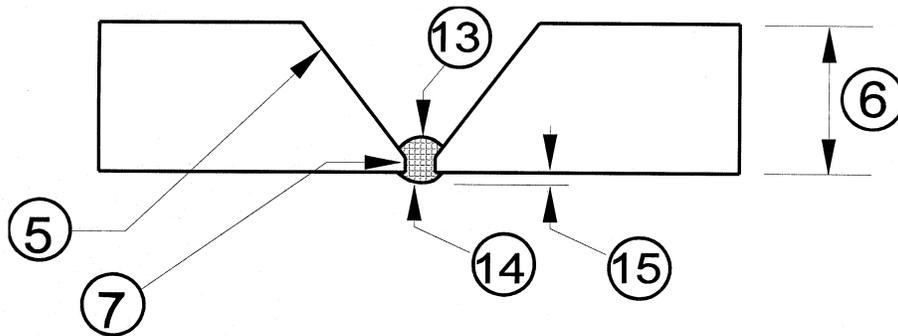


Figure L2-1. Tack weld and Root Weld Terminology

Setup

Demonstrate the ability to verify joint geometry (i.e. bevel angle, land, etc.) meets specifications prior to tack welding. Measure and record joint geometry in Table L2-1 (refer to Figure L2-2).

Set root opening, using a short section of wire or rod of appropriate diameter to maintain the gap while tacking the coupons together. Alignment of the pipe coupons should be held within 0.30-inch misalignment. Alignment for training coupons can be accomplished by using v-blocks, or pipe clamps. A minimum number of tacks should be utilized and tacks should be located to allow a continuous weld from one tack to the next. All tack locations and length of the tacks should be marked on the pipe prior to welding.

For 6-inch pipe coupons a minimum of 4 tacks, 90-degrees apart is recommended. Tacks 90-degrees apart corresponds to a 4 to 5-inch weld distance between tacks, which most welders can easily accomplish without stopping. Tacks should be located at the 0, 90, 180, and 270 location (0 at top and 180 at the bottom of the pipe) for pipes positioned in the 5G and 6G position, so the welder doesn't have to reposition himself in the middle of the root weld. The first two tacks should be placed approximately 180 degrees apart and root gap should be adjusted if necessary before remainder of tacks is applied. To assure tacks do not break during the root weld a tack length between $\frac{3}{4}$ and 1-inch is recommended. Also, shorter tacks may result in an overlap of the root weld at the starts and stops on the tack welds. The overlap could produce excessive weld build up, which could potentially result in LOF or inclusion.

Note: $\frac{1}{2}$ -in. plate coupons with similar joint preparation as the pipe coupons can be used for initial practice welds. Plate coupons will allow easy inspection of joint geometry, root face and cross section of root weld.

Table L2-1 Joint Geometry Verification (Figure 2-2)

	Target Dimension	Actual Dimension	After tack weld
1. Groove Angle	75-degrees		
2. Bevel Angle	37.5-degrees		
3. Root opening dimension	0.8 to 0.11-inches		
4. Land Thickness	0.050-0.070-inches		
6. Wall thickness	0.562-inches		
8. Pipe alignment	0.0-inches		

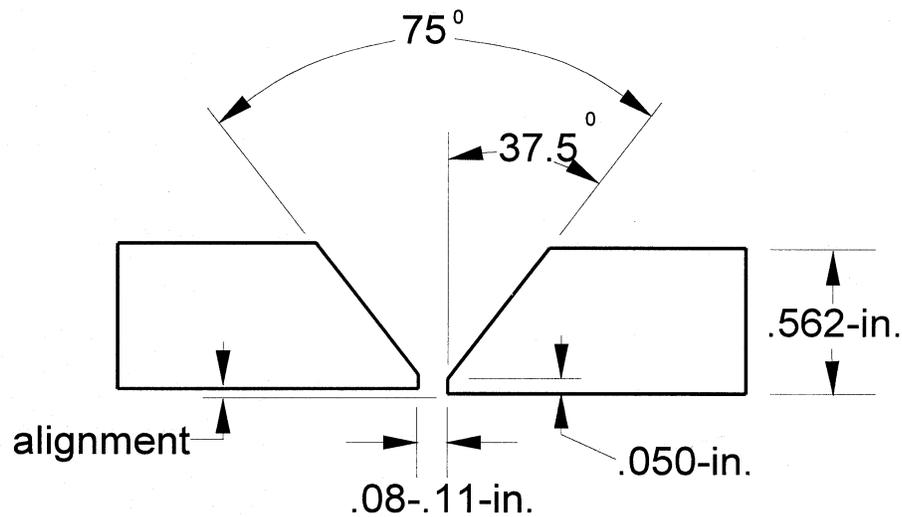


Figure L2-2. Typical Weld Joint Dimensions

Welding

Set up and tack 6-in. schedule 120 (.5-in. wall) coupons with specified root opening and alignment. Typical root welding parameters are referenced in Table L2-2.

Table L2-2. Welding Specifications for Tack Welds

Program	Wire Speed (in/min)	Arc Control	Trim	Gas	Travel Speed (in/min)	Technique
Mode 119	120	5-10	.60	100% CO ₂ @ 25 cfh	6-7	Tack at 0, 90, 180 and 270. Minimum ¼-in. in length. Slight oscillation

Welding Technique

The tack weld should be initiated on the groove face as illustrated in Figure L2-3. Starting the weld on the groove face allows the weld to be eased into the root opening and bridge the gap without excessive melt through or wire stubbing (whiskers). Similar to the start, the tack weld should be terminated on the groove face, to eliminate the crater at the end of the weld. Typical tack weld is shown in Figure L2-4. The weld crater is a potential source of porosity and cracks that affect the subsequent weld layers. The excess weld metal on the groove face will be blended or ground away prior to welding the root weld. Weld progression should be downhill when applicable (i.e. 90 and 270-degree locations for 5G and 6G pipe positions). The torch angle can be perpendicular to the root opening or oriented with a slight drag angle (up to 15-degrees). A slight oscillation of the weld torch is used to control the weld puddle and weld geometry (i.e. melt through and root face contour). Typically no more than 1/16-in. oscillation is necessary for tack welds.

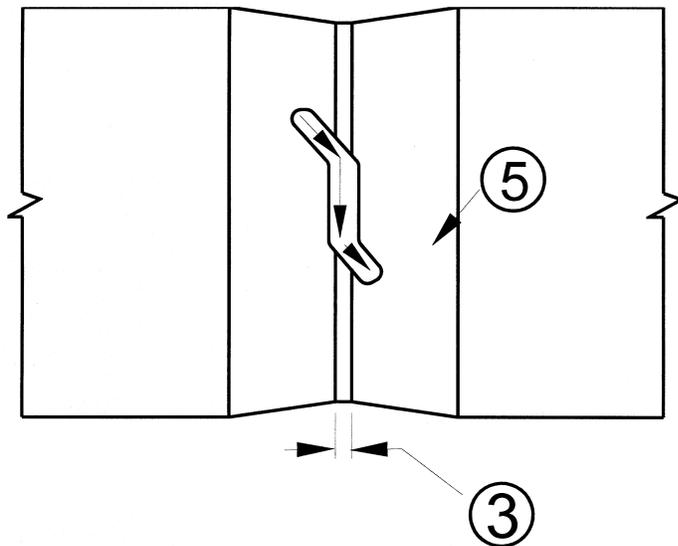


Figure L2-3. Tack weld progression



Figure L2-4. Typical appearance of a tack weld with weld initiation on groove face

The cross section of the tack weld should be similar to anticipated root weld. A convex root surface with minimal reinforcement is desired. The resulting tack weld should have an overall thickness, before cleanup, of approximately 3/16-inch. The TRIM setting on the power supply can be adjusted to help control the melt through. Figure L2-5 illustrates the effects of TRIM on the ID reinforcement. Lower trim increases ID reinforcement, while a higher trim produces a more concave geometry.

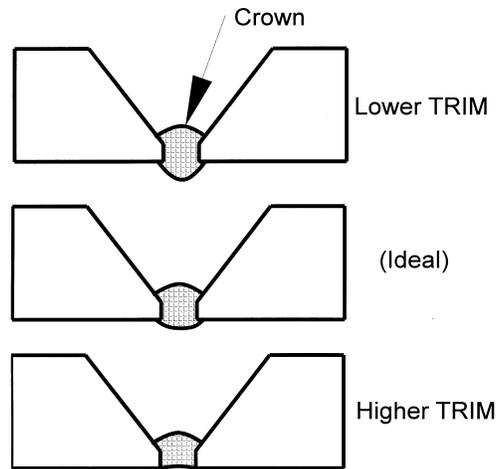


Figure L2-5. Cross section of typical tack/root welds in relation to the TRIM setting.

Cleanup

Proper preparation of the tack weld before the root weld is applied is important and can significantly reduce weld defects (i.e. LOF) at the tack locations. Preparation of the tack welds should include grinding and wire brushing to remove slag, and to blending the crown with the groove face. Figure 2-6 illustrates the desired contour (cross section) of the tack welds.

The tack welds should also be of an appropriate length to allow both ends to be taper ground and to allow starting and stopping of the root weld to be applied without overlapping. Recommended taper is approximately 3:1 (Figure L2-7) and should be feathered to a knife-edge. The taper will allow the welder to ease into the open gap and maintain a constant melt through with the root weld. Tack welds 3/4 to 1-inch in length is typically sufficient (Figure L2-8).

Root weld should not be welded out until instructor has inspected for proper cleanup and preparation for root weld.

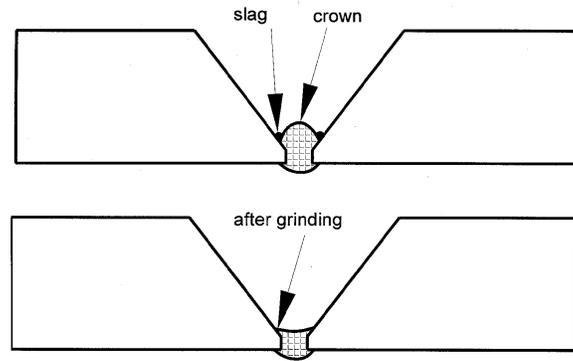


Figure L2-6. Tack Cleanup and Preparation

- 4. Land Thickness
- 6. Pipe Wall Thickness
- 8. Tack Length
- 9. 3:1 Taper

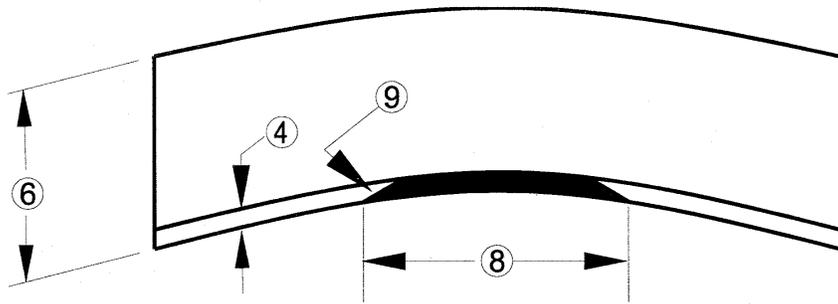


Figure L2-7. Tack Weld Taper (~3:1).

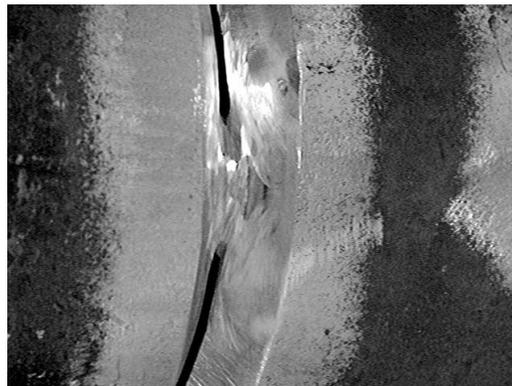


Figure L2-8. Tack Weld after post-weld cleanup.

Lesson 3: Root Pass

Objectives: Teach basic root weld techniques and requirements. At the completion of this lesson the welder should be familiar with equipment setup and capable of completely welding out the root of a 6-in. Schedule 120 pipe coupon. This lesson is divided into three categories ; 1) Terminology, 2) Setup and 3) Welding

Time: 1.5 hours practice and demonstration of knowledge

Terminology

Root welds should have the same quality and geometry as described for the tack welds. Details of the root weld are described below and correspond to Figure L1-3 and Figure L2-1.

3. Root opening (Figure L1-3) – A root opening that is too narrow can result in incomplete penetration. Excessive root open can be difficult to weld without melt through. The tack welds typically hold the root opening.

13. Root pass contour – The contour of the tack weld, often referred to as the weld crown, is typically ground to reduce the convexity of the weld. A high crown often traps slag and makes it difficult to apply the root weld without inclusions and lack of fusion (LOF).

14. Root Surface (Figure L2-2) – The root surface in the weld metal exposed to the ID surface. The geometry of the root surface can be concave (underfill) to convex. The shape of the root surface is governed by the degree of melt through, gravity, and welder technique. A slight convex root surface is desired.

15. Melt Through - Root reinforcement typically measured from the ID surface.

Setup

Test coupon should meet required dimensions (root opening) and alignment specified in Lesson 2. The 6-in. schedule 120 coupons prepared in Lesson 2 with tack welds completed should be utilized for root weld demonstration. Check tack weld cleanup to make sure the appropriate taper and surface preparation was completed.

Note: ½-in. plate coupons with similar joint preparation as the pipe coupons can be used for initial practice welds. Plate coupons will allow inspection of joint geometry, root face and cross section of root weld with minimal effort.

Welding

Set up and complete root pass on the 6-in. schedule 120 (.5-in. wall) coupons with tack welds already in place. Root welding parameters are referenced in Table L3-1. The welding parameters used for the root weld are typical of the tack weld parameters.

Table L3-1. Welding Specifications for Root Weld

Program	Wire Speed (in/min)	Arc Control	Trim	Gas	Travel Speed (in/min)	Technique
Mode 119	120	5-10	.60	100% CO ₂ @ 25 cfh	6-7	Slight oscillation, continuous from tack to tack, downhill weld progression

Welding Technique

The welder should be in a position to allow a continuous root weld between tacks to be performed without having to reposition during welding. Weld progression should be downhill when applicable (i.e. 5G and 6G pipe positions). The torch angle can be perpendicular to the root opening or oriented with a slight drag angle (up to 15-degrees). The root weld should be initiated on the groove face (Figure L3-1) above the tapered area. The weld should proceed down the taper and ease into the root opening and bridge the gap with a melt through consistent with the tack weld. Similar to the start, the root weld should be terminated above the tapered area on the groove surface on the next tack. This will eliminate the crater at the stops and reduces excessive melt through at the starts of the weld. This technique typically eliminates weld defects (i.e. porosity, cracks, inclusions, LOF) at the start and stop locations. Figure L3-2 shows a typical root weld with weld initiation and termination on the groove face.

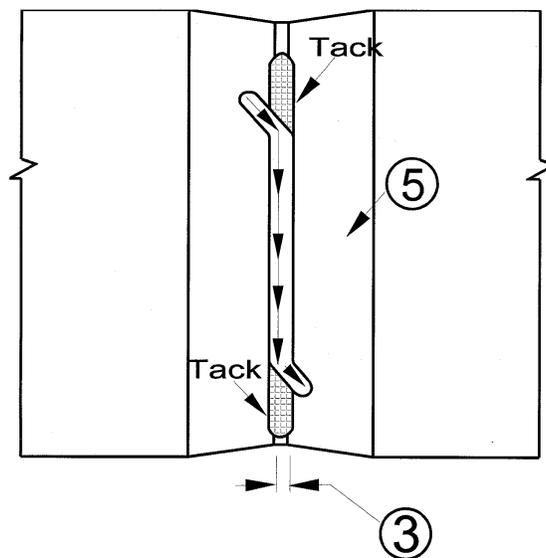


Figure L3-1. Root Weld Progression

A slight oscillation of the weld torch is used to control the weld puddle and geometry (i.e. melt through and root face contour). Typically no more than 1/16-in. oscillation is necessary for root welds with standard root opening of .08 to .11-inch. Root openings up to .156 may need to lower trim and a slight increase in the oscillation. Root openings up to 0.25-in. may require lower trim, lower wire feed speed and an increase in the oscillation.

If the root weld is terminated prior to the next tack. The termination should be prepared with a taper grind similar to the tack welds. The weld should be restarted in the same manner and terminated on the next tack.

The cross section of the root weld should be consistent with the tack weld geometry. A convex root surface with minimal reinforcement is desired. The TRIM setting on the power supply can be adjusted to help control the melt through. Figure L2-5 illustrates the effects of TRIM on the ID reinforcement. Lower trim increases ID reinforcement, while a higher trim produces a more concave geometry. The ID melt through and weld bead geometry should coincide with the center drawing in Figure L2-5.

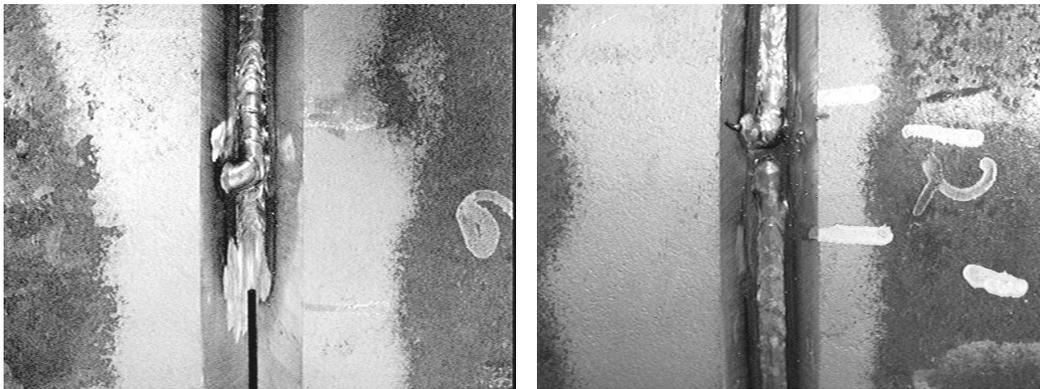


Figure L3-2. Termination and Initiation of Root Weld on Groove Face

Cleanup

The crown of the root pass is typically convex (similar to the tack welds, Figure L3-2) and creates a narrow cavity with the groove face. The narrow cavity may trap slag and makes it difficult to weld the hot pass without LOF and inclusions. The toes of the root weld should be cleaned up by grinding and/or wire brush to remove slag and severity of the transition from the root weld to the groove face. The excess weld metal caused by the starts and stops at the tack locations should also be ground or blended into the groove face. This will allow a continuous hot pass to be performed without interruptions. Typical appearance of root weld cleanup at tack location is shown in Figure L3-3.

The root pass should be consistent around the entire groove and should be evaluated by the instructor prior to continuing with the hot pass.



Figure L3-3. Start and stop location at tack weld before and after preparation for hot pass.

Lesson 4: Hot pass and Fill Pass

Objectives: Teach basic weld techniques to assist welder in equipment setup and welding techniques to apply the hot pass and fill passes. At the completion of this lesson the welder should be capable of completing the hot pass, fill passes and cap passes with successful RT evaluation. This lesson is divided into three categories; Terminology, Setup and Welding.

Time: 2.5 hours practice and demonstration of knowledge

Terminology

Definition of machine Modes are listed below since the remainder of the welding (hot passes, fill passes, cap passes) can be completed with different machine settings.

CV Mode: GMAW and FCAW processes. A preprogrammed voltage is set for each wire feed speed. Preset voltage can be altered by the Wire feeder's voltage control.

Pulse GMAW Mode: Pulse settings for GMAW process. Pulse parameters are adaptively controlled to accommodate changes in the stickout length.

STT Mode: STT Mode is a current control process and is neither a CC nor a CV process. The current is altered very quickly to changes in the arc. Often referred to as the short circuit mode.

Descriptions of the weld passes are described below and correspond to Figure L4-1.

8. *Root Weld* – The root pass is the first weld pass applied to completely bridge the gap between the pipe. For the GMAW process the root weld will typically be an open root weld (no backing ring). An attempt is made to make the root pass continuous between tack welds for manual welding.

9. *Hot Pass* – The hot pass is typically a single weld pass that fuses the root weld and both groove faces together. A split hot pass has been beneficial for 2G welding and where the root opening is larger than normal.

10. *Fill Passes* – Weld passes between the hot pass and the cap passes.

11. *Cap Passes* – Typically welded in a similar manner as the fill passes. Must provide complete fill of joint cavity.

6. *Pipe Wall Thickness*

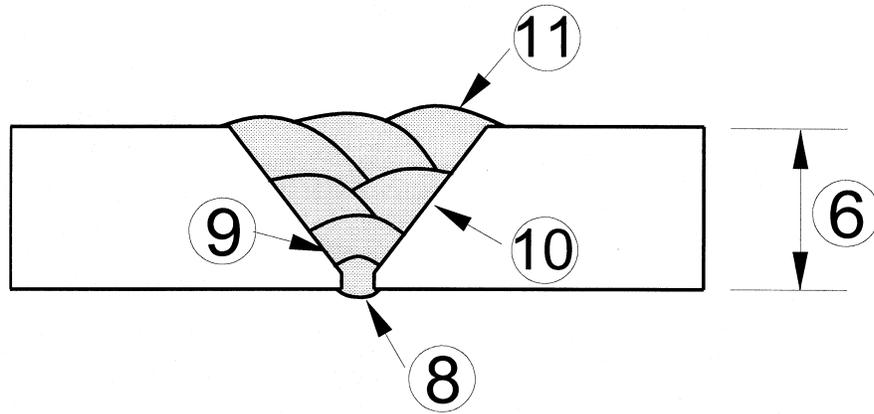


Figure L4-1. Bead Sequence and description

Setup

The hot pass through the cap passes are typically welded with similar parameters, machine settings and techniques. The machine settings, shielding gases and techniques will differ from those used for the root pass and tack welds. Before welding verify the machine settings and gas selection (i.e. type and flow rates).

The hot, fill and cap passes can be completed in the CV Mode (GMAW or FCAW), Pulse GMAW Mode, STT Mode. Pulse GMAW is recommended for the highest quality weld deposit and minimal interpass cleaning. Welding progression with the STT Mode is downhill (Figure 4-2) and uphill with the CV Mode and Pulse GMAW Mode.

No matter what mode selected, bead placement is critical to assure the joint cavity is completely filled without excessive OD buildup, LOF and inclusions. Correct bead placement can also significantly reduce interpass cleaning and grinding. Starts and stops of the weld beads should be altered to avoid stacking the stop and start locations through the complete weld thickness.

The hot pass is typically completed with a single pass, although in some welding positions (i.e. 2G position) a split hot pass may be beneficial with the STT Mode.

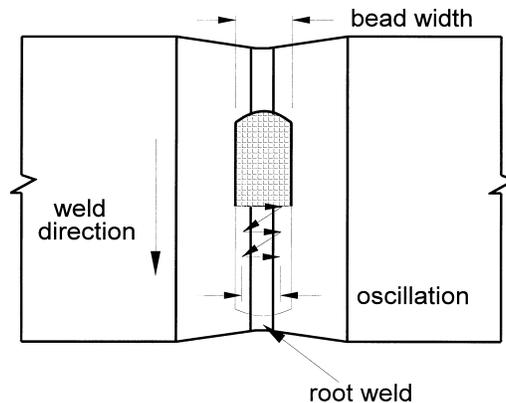


Figure L4-2. Bead Oscillation and Weld Direction for the STT Mode.

Welding

Set up and complete hot pass, fill passes and cap passes on the 6-in. schedule 120 (.5-in. wall) coupons with root welds already in place (Lesson 3). Welding parameters are referenced in Table L4-1. Note: ½-in. plate coupons with similar joint preparation as the pipe coupons can be used for initial practice welds.

Table L4-1. Welding Specifications for Hot pass through Cap Passes.

Program	Wire Speed (in/min)	Arc Control	Trim	Gas	Travel Speed (in/min)	Technique
Mode 117 STT Mode	120 .045-in.	5-10	.60	100% CO ₂ @ 25 cfh	6-7	Downhill weld progression slight weave
Mode 22 Pulse Spray Mode	135 .045-in.	+5	.98	92/8 Argon/ CO ₂ @ 25 cfh	6-7	Uphill weld progression slight weave
Mode 5 CV Mode	215 .045-in.	Off	1.05	75/25 Argon/ CO ₂ @ 25 cfh	6-8	Uphill weld progression slight weave

* Mode 5 voltage is controlled by the Trim

Welding Technique

The welder should be in a position to complete as long a weld bead as possible without stopping. The torch angle can be perpendicular to the root opening or oriented with a slight drag angle (up to 15-degrees for the STT Mode and up to a 15-degree push angle for CV and Pulsed GMAW Modes.

Hot Pass

The hot pass should tie together the root weld with both groove faces (Figure L4-1). If a split bead is used the first hot pass should cover approximately one half the root weld. If necessary the first hot pass should be wire brushed and ground to assure the second bead can successfully tie in with the root weld, other groove face and first hot pass. For a single hot pass, the weld torch is oscillated from one toe of the root weld to the other (approximately 1/8 to 3/16-inch depending on the size of the root pass) as seen in Figure L4-2.

Fill Passes

The remaining fill passes and cap passes need to completely fill the groove cavity without excessive OD build up. Bead sequence should be carefully planned in an alternating pattern as seen in Figure L4-1. Each bead location should make sure an adequate geometry remains for the subsequent weld beads. If a narrow cavity is formed between weld beads or between the groove face and the weld bead, LOF or inclusions (i.e. slag) could result. An effort should be made to grind out the area to eliminate or improve the geometry before welding continues.

The oscillation for fill passes is approximately 0.25-inches, with a resulting weld bead size of approximately .4 to .5-inches for the STT Mode. Oscillation and bead size may be slightly larger with the Pulse GMAW and CV Mode. A typical ½-inch thick pipe with a 37.5-degree bevel will consist of 5 to 7 total passes with the Pulse GMAW Mode and CV Mode, compared to 9-11 passes with the STT Mode.

Cleanup

Interpass cleaning and grinding should be completed to remove poor geometry created by weld bead placement and to remove slag. The start and stop locations within each layer should also be ground and tapered to accept the subsequent weld bead. This assures a good tie in with the subsequent weld and removes any defects associated with the weld crater (i.e. porosity, crater cracks). After each layer is complete the stop and starts should be cleaned up with a grinder before the next layer is initiated. The degree of grinder and cleanup depends on the weld bead geometry and may not be necessary in many cases. Figure L4-3 illustrates typical cleanup of hot pass prior to initiating the fill pass sequence.

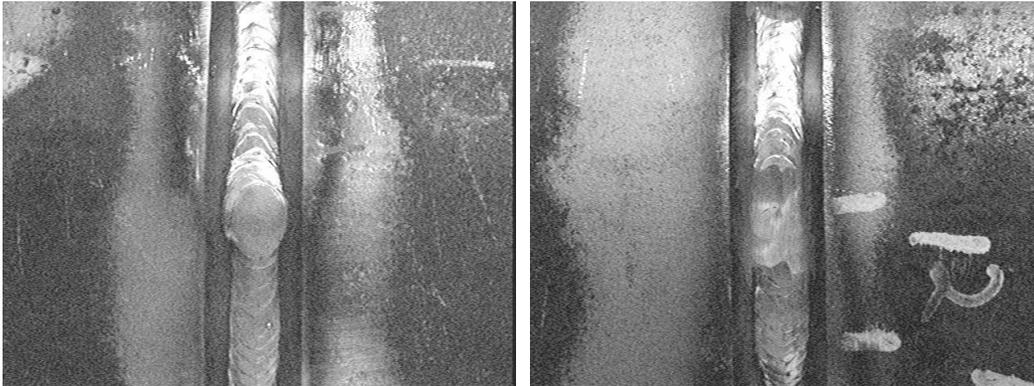


Figure L4-3. Start and stop location of hot pass before and after preparation for fill passes.

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