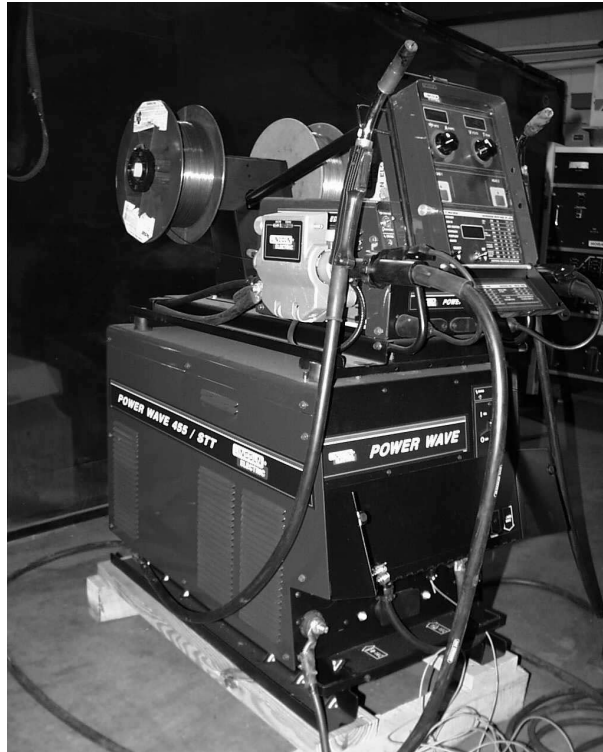


Evaluation of Solid Wire Advanced GMAW for Heavy Section and Piping Replacement

1001299



Evaluation of Solid Wire Advanced GMAW for Heavy Section and Piping Replacement

1001299

Service Document, December 2000

EPRI Project Manager

Greg Frederick

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

EPRI • 1300 W.T. Harris Blvd., Charlotte, North Carolina 28262 • PO Box 217097, Charlotte, North Carolina 28221 • USA
800.313.3774 • 704.547.6176 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

EPRI

NOTICE: THIS REPORT CONTAINS PROPRIETARY INFORMATION THAT IS THE INTELLECTUAL PROPERTY OF EPRI, ACCORDINGLY, IT IS AVAILABLE ONLY UNDER LICENSE FROM EPRI AND MAY NOT BE REPRODUCED OR DISCLOSED, WHOLLY OR IN PART, BY ANY LICENSEE TO ANY OTHER PERSON OR ORGANIZATION.

This is an EPRI Level 2 report. A Level 2 report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

ORDERING INFORMATION

Requests for copies of this report should be directed to the EPRI RRAC, 1300 W.T. Harris Blvd., P.O. Box 217097, Charlotte, NC 28221, (704)547-6176.

Electric Power Research Institute and EPRI are registered service marks of the Electric Power Research Institute, Inc. EPRI. ELECTRIFY THE WORLD is a service mark of the Electric Power Research Institute, Inc.

Copyright © 2000 Electric Power Research Institute, Inc. All rights reserved.

CITATIONS

This document was prepared by

EPRI
Repair and Replacement Applications Center (RRAC)
1300 W.T. Harris Blvd.
Charlotte, NC 28262

Principal Authors
G. Fredrick
S. Findlan
M. Newman

New York Power Authority
James A. Fitzpatrick Nuclear Plant
Lake Rd. E.
Oswego, NY 13126

Principal Investigator
N. Chapman

AmerenUE
Callaway Nuclear Plant
P.O. Box 620
Fulton, MO 65251

Principal Investigator
Steve McCracken

This document describes research sponsored by EPRI.

The publication is a corporate document that should be cited in the literature in the following manner:

Evaluation of Solid Wire Advanced GMAW for Heavy Section and Piping Replacement, EPRI, Charlotte, NC: 2000. 1001299.

ABSTRACT

During the past 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 has generated interest in the development of procedures for welding of heavy sections with solid wire to provide higher productivity rates, shorter outage duration, and reduced man-rem exposure. The nominal wall thickness targeted for this process is approximately ½-in., which, for example, would cover up to Schedule 120 for 6-in. pipe.

A 1999 Repair and Replacement Application (RRAC) program funded through Subscriber Requested Assistance (SRA) provided by NYPA and AmerenUE was conducted to evaluate the merits of advanced GMAW welding equipment for pipe root welding with solid wire. The results of the testing were promising in that successful, reproducible, open butt root welds had been completed using the Lincoln STT power supply. To our knowledge, this power supply represents the only present day power supply capable of all position open-butt GMA root welding. Some questions still remained concerning the joint geometry (optimum root opening and land), maximum material thickness and material limitations, but the results were very encouraging. The results of the evaluation were presented with members of the RRAC at the April 1999 RRAC Issues meeting.

As a follow-up to the evaluation RRAC members requested that further development of the process be conducted with the second generation Lincoln Power Wave 455/STT. The objective of the program was to develop a Procedure Qualification (PQR) for an open root, GMAW plate weld for thickness up to 1-in. thick, SA-516 Grade 70 material in accordance with ASME IX. Once this objective was reached other materials were also addressed including stainless steel and 2¼Cr-1Mo (P5A) materials for the same purpose. The effect of spatter and whiskers on the ID surface of carbon and low alloy piping were also evaluated as part of this program.

The overall outcome of the program indicated that short arc GMAW with the Lincoln Power Wave 455/STT could be used on thick section components with careful control of welding technique and machine settings. The intent of this report is to communicate the results of the procedure development and mechanical testing for each material and thickness.

ACKNOWLEDGEMENTS

This report describes research sponsored by EPRI-RRAC subscribers listed below.

Scott Presler
Steve McCracken
Richard Corbit
Mike Schwartzwalder
Peter Cerve
Jimmy Mark
Jerome Nordby and Philip Flenner
John Polacheck
Tom Alley
Jean Louis Guilloteau
Richard Rogoski
John Torbert and Jagdish Gupta
Neal Chapman
Michael Jones
James Grewe
George Field and Ming Lau
Michael Sullivan
Richard Ciemiewicz
Edward Gerlach
Paul Norris and Marty Sims
Jon Rupert and Dana Couch
Evan Dalasta and Stuart Myers

Alliant Energy Corp.
AmerenUE
AmerGen
American Electric Power
Commonwealth Edison
Consolidated Edison
Consumers Energy
Detroit Edison
Duke Power Co.
Electricite de France
FirstEnergy Corp.
Amergen
New York Power Authority
Niagara Mohawk Power Corp.
Omaha Public Power District
Ontario Power Generation, Inc.
Pacific Gas & Electric Co.
PECO Energy Co.
PP&L, Inc.
Southern Nuclear Operating Co.
Tennessee Valley Authority
TXU Electric

CONTENTS

1 INTRODUCTION.....	1-1
2 TEST PROGRAM AND RESULTS.....	2-1
2.1 Carbon Steel Procedure Development.....	2-2
2.1.1 5/8-in. Carbon Steel Qualification – Lincoln STT II.....	2-2
Mechanical Test Results	2-2
2.1.2 Set-up of Lincoln Power Wave 455/STT	2-3
2.1.3 5/8-in. Carbon Steel Qualification – Lincoln Power Wave 455/STT	2-5
Mechanical Test Results	2-5
2.1.4 3/4-in. Carbon Steel Qualification – Lincoln Power Wave 455/STT	2-6
Mechanical Test Results	2-7
2.1.5 1.0-in. Carbon Steel Qualification – Lincoln Power Wave 455/STT	2-8
Mechanical Test Results	2-9
2.2 Stainless Steel Procedure Development.....	2-11
2.2.1 1/2-in. Stainless Steel Qualification – Lincoln Power Wave 455/STT	2-11
Mechanical Test Results	2-11
2.3 2¼Cr-1Mo (P5A) Alloy Steel Procedure Development	2-13
2.3.1 3/4-in. 2 ¼ Cr-1Mo (P5A) Alloy Steel Qualification – Lincoln Power Wave 455/STT	2-13
Mechanical Test Results	2-13
3 ADDITIONAL ROOT WELDING EVALUATIONS.....	3-1
4 CONCLUSIONS.....	4-1

LIST OF FIGURES

Figure 1-1 Lincoln STT II Power Supply	1-2
Figure 1-2 Lincoln Power Wave 455/STT	1-2
Figure 2-1. Modified 3G Welding Position	2-1
Figure 2-2. Side Bends (4) and Face Bend (1) for Test Plate N-1, 5/8-in. (455/STT)	2-6
Figure 2-3. Tensile Specimens (2) for Test Plate N-1, 5/8-in. (455/STT)	2-6
Figure 2-4. Side Bends (4) and Face Bend (1) for Test Plate N-2, 3/4-in. (455/STT)	2-8
Figure 2-5. Tensile Specimens (2) for Test Plate N-2, 3/4-in. (455/STT)	2-8
Figure 2-6. Side Bends (4) and Face Bend (1) for Test Plate N-3, 1-in. (455/STT)	2-10
Figure 2-7. Tensile Specimens (2) for Test Plate N-3, 1-in. (455/STT)	2-10
Figure 2-8. Side Bends (4) and Face Bend (1) for Test Plate NS-4, 1/2-in. (455/STT)	2-12
Figure 2-9. Tensile Specimens (2) for Test Plate NS-4, 1/2-in. (455/STT)	2-12
Figure 2-10. Side Bends (4) and Face Bend (1) for Test Plate N-5, 3/4-in. (455/STT)	2-14
Figure 2-11. Tensile Specimens (2) for Test Plate N-5, 3/4-in. (455/STT)	2-15
Figure 3-1. Cross section of spatter for hardness tests for Test Plate N-5, 3/4-in., 2¼Cr-1Mo Plate.	3-1
Figure 3-2. Micro-hardness indentations at spatter locations on cross section (left) and on the surface (right).	3-2

LIST OF TABLES

Table 2-1. Procedure Qualification Welding Parameters using the STT II on 5/8" plate.....	2-2
Table 2-2. Weld Bend Test Results on 5/8-in. test specimen (STT II).....	2-3
Table 2-3. Set-up evaluation for root pass welding.....	2-4
Table 2-4. Procedure for Power Wave 455/STT.....	2-5
Table 2-5. Procedure Qualification Welding Parameters using the Power Wave 455/STT on 5/8-in. Plate in 3G (Plate N-1).	2-5
Table 2-6. Weld and Tensile Test Results on 5/8-in test specimen (455/STT).....	2-6
Table 2-7. Procedure Qualification Welding Parameters using the Power Wave 455/STT on 3/4-in. Plate in modified 3G position (Plate N-2).	2-7
Table 2-8. Weld and Tensile Test Results on 3/4-in test specimen (455/STT).....	2-7
Table 2-9. Procedure Qualification Welding Parameters using the Power Wave 455 STT on 1" Plate in modified 3G position (Plate N-3).....	2-9
Table 2-10. Procedure Qualification Welding Parameters using the Power Wave 455 STT on 1" Plate in modified 3G position (Plate N-3A).....	2-9
Table 2-11. Weld and Tensile Test Results on 1-in. test specimen (455/STT).....	2-10
Table 2-12. Weld and Tensile Test Results on 1-in. test specimen (455/STT).....	2-10
Table 2-13. Procedure Qualification Welding Parameters using the Power Wave 455/STT on 1/2-in. Plate in modified 3G position (Plate NS-4).	2-11
Table 2-14. Weld and Tensile Test Results on 1-in. test specimen (455/STT).....	2-12
Table 2-15. Procedure Qualification Welding Parameters using the Power Wave 455/STT on 3/4-in. Plate in Modified 3G Position (Plate NCR-5).	2-13
Table 2-16. Weld and Tensile Test Results on 3/4-in. test specimen (455/STT).....	2-14
Table 3-1. Micro-hardness measurements associated with adhered spatter.	3-2

1 INTRODUCTION

During the past 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 has generated interest in the development of procedures for welding of heavy sections with solid wire to provide higher productivity rates, shorter outage duration, and reduced man-rem exposure. The nominal wall thickness targeted for this process is approximately ½-in., which, for example, would cover up to Schedule 120 for 6-in. pipe.

A 1999 Repair and Replacement Application (RRAC) program funded through Subscriber Requested Assistance (SRA) provided by NYPA and AmerenUE was conducted to evaluate the merits of advanced GMAW welding equipment for pipe root welding with solid wire. The results of the testing were promising in that successful, reproducible, open butt root welds had been completed using the Lincoln STT power supply Figure 1-1. To our knowledge, this power supply represents the only present day power supply capable of all position open-butt GMA root welding. Some questions still remained concerning the joint geometry (optimum root opening and land), maximum material thickness and material limitations, but the results were very encouraging. The results of the evaluation were presented with members of the RRAC at the April 1999 RRAC Issues meeting.

As a follow-up to the evaluation RRAC members requested that further development of the process be conducted with the second generation Lincoln Power Wave 455/STT (Figure 1-2). The objective of the program was to develop a Procedure Qualification (PQR) for an open root, GMAW plate weld for thickness up to 1-in. thick, SA-516 Grade 70 material in accordance with ASME IX. Once this objective was reached other materials were also addressed including stainless steel and 2¼Cr-1Mo (P5A) materials for the same purpose. The effect of spatter and whiskers on the ID surface of carbon and low alloy piping were also evaluated as part of this program.

The overall outcome of the program indicated that short arc GMAW with the Lincoln Power Wave 455/STT could be used on thick section components with careful control of welding technique and machine settings. The intent of this report is to communicate the results of the procedure development and mechanical testing for each material and thickness.

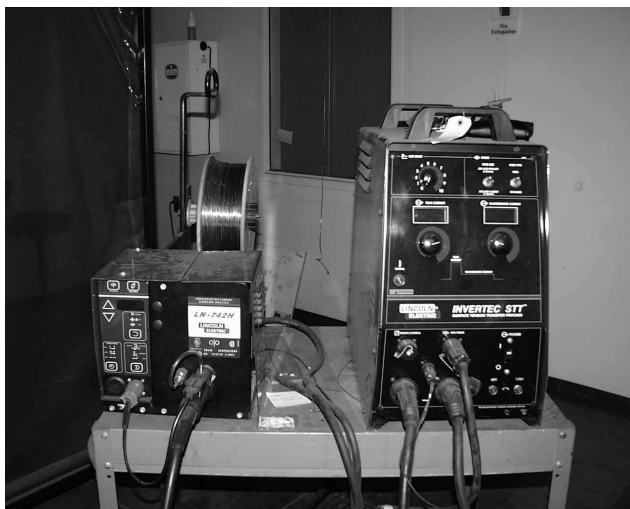


Figure 1-1 Lincoln STT II Power Supply



Figure 1-2 Lincoln Power Wave 455/STT

2 TEST PROGRAM AND RESULTS

The evaluation of short arc welding with solid wire was conducted on two welding power supplies, Lincoln STT II and Lincoln Power Wave 455/STT. The Lincoln STT II was initially used, until the Power Wave 455/STT was delivered as a prototype welding power supply. Modification to the welding power supply was made by the manufacturer during the evaluation to accommodate short falls in the prototype equipment. The development work consisted of parameter development including machine settings, joint geometry evaluation and welding technique for each material evaluated. Mechanical testing was conducted per ASME Section IX specifications to verify weld quality. In some cases face and/or root bends were also completed in addition to side bends, although not required by Section IX, to supplement the acceptance criteria.

A modified 3G (vertical) welding position was selected for the PQR development, as seen in Figure 2-1, to qualify the procedure in all positions. Original intentions were to evaluate carbon steel (SA-516, Grade 70) although as testing progressed additional materials were also evaluated including Type 304 stainless steel and 2¼Cr-1Mo steel (P5A). In all cases, 0.045-in. diameter solid wire was used for each pass (root, hot, and fill passes) with a downhill welding progression. No backing gas was utilized with the carbon steel (SA-516, Grade 70) or 2¼Cr-1Mo (P5A) welds. An argon backing gas was introduced for the stainless steel material. No preheat was used for the carbon steel or the stainless steel welds. The 2 ¼ Cr-1Mo (P5A) material required a 455°F preheat. Based on material the test program was divided into three sections, *Carbon Steel Procedure Development*, *Stainless Steel Procedure Development* and *2 ¼Cr-1Mo (P5A) Material Procedure Development*.

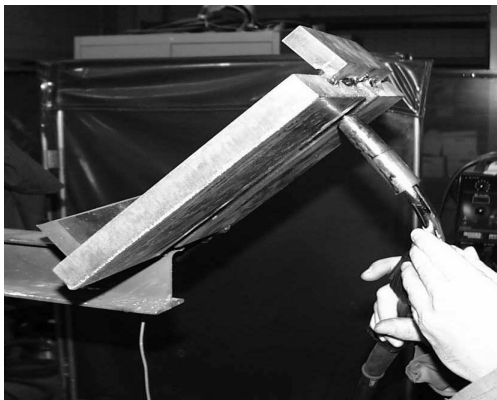


Figure 2-1. Modified 3G Welding Position

2.1 Carbon Steel Procedure Development

Evaluation of manual GMAW carbon steel was initiated prior to the release of the Lincoln Power Wave 455/STT, requiring initial tests to be conducted with the Lincoln STT II. Based on equipment and material thickness the carbon steel section was divided into 5 sections including;

- 5/8-in Carbon Steel Qualification – Lincoln STT II
- Set-up of Lincoln Power Wave 455/STT
- 5/8-in. Carbon Steel Qualification – Lincoln Power Wave 455/STT
- 3/4-in. Carbon Steel Qualification – Lincoln Power Wave 455/STT
- 1.0-in. Carbon Steel Qualification – Lincoln Power Wave 455/STT.

2.1.1 5/8-in. Carbon Steel Qualification – Lincoln STT II

Two manual GMAW qualifications were performed using SA-516, Grade 70, 5/8-inch thick plate using the Lincoln STT II Welding Power Supply (prior to receiving the Power Wave 455/STT). Different root openings of 0.085- and 0.115-inch were utilized for the two welds, along with a 0.062 land and a weld joint beveled with 37-1/2 degree side wall. The welds were performed using a 0.045-inch diameter, ER70S-6 solid wire (SFA 5.18, ESAB SpoolArc 86, Heat Number 186373) in the 3G-Modified welding position as seen in Figure 2-1. A downhill progression was employed for the qualification along with a 100% CO₂ shielding gas (at 40cfm). No backing gas was employed.

A total of 10 weld beads were deposited to complete each of the two weldments. Parameters for the first plate weld is shown in Table 2-1. Similar parameters were employed for the second plate weld. The fill passes were held to approximately 1/8 to 3/16-inch oscillation. As a result the actual bead width was maintained between 0.410- and 0.610-in.

Table 2-1. Procedure Qualification Welding Parameters using the STT II on 5/8" plate

Welding Pass	Peak/Background Current	Wire Feed Speed (in/min)	Voltage	Tail Out	Travel Speed (in/min)
Root Pass	375/43	160	16.7	Off	13-14
Hot Pass	375/70	160	20.2	8.5	6-7
Fill Passes 3 –10	375/70	160	20.2	8.5	6-7

Mechanical Test Results

Mechanical testing, including root, side, and face bends, was performed on the SA-516, Grade 70, 5/8-inch thick weldments per ASME Section IX specifications. Tensile tests were not performed on these specific test plates. All test results are reported in Table 2-2.

Table 2-2. Weld Bend Test Results on 5/8-in. test specimen (STT II).

Test Plate Number	Face Bend Results	Side Bend Results	Root Bend Results
Test Plate #1 -- #90253	Passed (2)	Passed (4)	Passed (2)
Test Plate #2 -- #90252	Passed (2)	Passed (4)	Passed (2)

As described above, two successful GMAW open root butt weld qualifications were performed for on 5/8-inch thick, SA516 Grade 70 plate. The qualifications were performed in the 3G modified welding position, thus qualifying the process for all-position welding, in accordance with ASME Section IX. Suggested welding technique, machine settings and joint geometry resulting from these weld tests are listed below:

- Narrow oscillation is required to maintain an appropriate high heat input.
 - An oscillation of approximately 1/8-in. is recommended.
 - Actual bead width should be maintained between .400 to .500-in.
- Root opening of .085 and .115-in. were both considered acceptable per test results, a .115 to .120-in. root opening is recommended.
- Land thickness of .062 to .075-in. is recommended.
- Tail out setting is adjustable from 0 to 10. Higher the tailout number the greater the heat input.
 - Tail out range for fill and hot pass is recommended at 8.5 to 9.5
 - Tail out should be set in the off position for the root pass.

2.1.2 Set-up of Lincoln Power Wave 455/STT

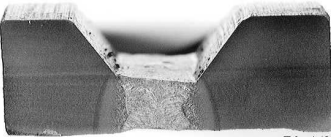
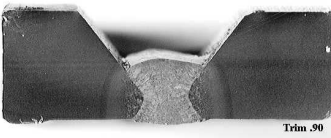
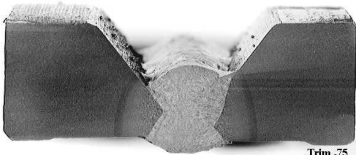
A prototype Lincoln Power Wave 455/STT power supply was incorporated into the program as soon as available. The new generation power supply offered the same welding capabilities as the original STT II, with the addition of welding schedules (programs) and synergic control of the background and tailout features. The 455/STT combines the background and tailout into one control called trim and the arc control knob now controls the peak current. The 455/STT also offers a dual wire feed capability for FCAW and GMAW setup for greater flexibility.

To establish a relationship with parameters used with the STT II and the Power Wave 455/STT a number of test welds were conducted to compare the bead geometry and the root and fill passes. Table 2-3 illustrates the variation in the root pass based on the trim setting. Recommendations for machine settings, joint geometry and welding technique are listed below. These settings were used as a starting point for the remainder of the qualification welds conducted with the 455/STT power supply. Table 2-4 lists the recommended machine settings and welding parameters that were recorded during one of the weld trials with the new power supply. Additional information on the weld qualifications is provided in the following:

- Joint geometry
 - Root opening .090 to .125-in.
 - Land thickness .060 to .070-in.

- Welding technique
 - Gun orientation: 90 degrees or perpendicular to the weld joint.
 - Narrow oscillation is required to maintain appropriate heat input, similar to the STT II
 - Less than ¼-in manual oscillation is recommended, with a resulting bead width of less than ½-in.
- Machine Settings
 - Arc Control must be set in the OFF position to achieve appropriate ID buildup (no concavity of root surface or suckback) for welding the root pass.
 - Trim setting of 0.75 is recommended (See Figure 2-3).
 - Higher trim setting (1.2, .90) will produce a flatter bead appearance and increase concavity of root surface on the ID (Table 2-3).

Table 2-3. Set-up evaluation for root pass welding.

Specimen	Trim /Wire Feed Speed	Bead thickness (in.)	Comment
 Trim 1.10	1.2 /160	1.10-in.	Flat bead geometry, slight concavity of root surface
 Trim .90	.90/160	.161-in.	Convex bead geometry, slightly convex root surface
 Trim .75	.75/160	.275-in.	Convex bead geometry, ID build up

Note: Similar observations were made for all materials evaluated.

Table 2-4. Procedure for Power Wave 455/STT.

Welding Pass	Program	Wire Feed Speed (in/min)	Arc Control	Voltage	Trim	Travel Speed (in/min)
Root Pass	119	155 -165	Off	20-21	.75 – 1.0	8-10
Hot Pass	117	155 -165	4.5 - 5.0	20-21	1.50 (max.)	8-10
3-12 Fill Passes	117	155 -165	4.5 - 5.0	20-21	1.50 (max.)	8-10

2.1.3 5/8-in. Carbon Steel Qualification – Lincoln Power Wave 455/STT

A manual GMAW qualifications was performed using SA-516, Grade 70, 5/8-inch thick plate using the Lincoln Powerwave STT-455 Welding Power Supply. A root opening of 0.075-in. was utilized for the weld, along with a 0.062-in. land and a weld joint beveled with 37-1/2 degree side wall. The welds were performed using an 0.045-in. diameter, ER70S-6 solid wire (SFA 5.18, ESAB SpoolArc 86, Heat Number 186373) in the 3G-Modified welding position. A downhill progression was employed for the qualification along with a 100% CO₂ shielding gas (at 40cfm). No backing gas was employed.

A total of 12 weld beads were deposited to complete the weldment. Parameters for the first plate weld is shown in Table 2-5. Manual oscillation was maintained at approximately ¼-in. for all fill passes. As a result, the actual bead width was maintained between 0.40- and 0.50-in.

Table 2-5. Procedure Qualification Welding Parameters using the Power Wave 455/STT on 5/8-in. Plate in 3G (Plate N-1).

Welding Pass	Program	Wire Feed Speed (in/min)	Arc Control	Voltage	Trim	Travel Speed (in/min)
Root Pass	119	160	off	20-21	1.15	8-9
Hot Pass	117	160	4.5	20-21	1.5	8-9
3-12 Fill Passes	117	160	4.5	20-21	1.5	13-14

Mechanical Test Results

Mechanical testing, including side bends and tensile tests, were performed on the SA-516, Grade 70, 5/8-in. thick weldment per ASME Section IX specification. Face bends were also performed (though not required by Section IX) to supplement the acceptance of the test results. All test

results were acceptable and are reported in Table 2-6. The bends and tensile specimens are shown in Figure 2-2 and 2-3. As demonstrated from the mechanical test results, the weld quality produced with the Lincoln STTII could be reproduced with the Lincoln Power Wave 455/STT.

Table 2-6. Weld and Tensile Test Results on 5/8-in test specimen (455/STT).

Test Plate Number	Face Bend Results	Side Bend Results	Tensile Results
Test Plate N-1	Passed (1)	Passed (4)	87,900 Weld metal 88,200 Weld metal



Figure 2-2. Side Bends (4) and Face Bend (1) for Test Plate N-1, 5/8-in. (455/STT)



Figure 2-3. Tensile Specimens (2) for Test Plate N-1, 5/8-in. (455/STT)

2.1.4 3/4-in. Carbon Steel Qualification – Lincoln Power Wave 455/STT

A manual GMAW qualification was performed using SA-516, Grade 70, 3/4-in. thick plate, using the Lincoln Powerwave STT-455 Welding Power Supply. A root opening of 0.075-in. was

utilized for the weld, along with a 0.062-in. land and a weld joint beveled with 37-1/2 degree side wall. The welds were performed using an 0.045-in. diameter, ER70S-6 solid wire (SFA 5.18, ESAB SpoolArc 86, Heat Number 186373) in the 3G-Modified welding position. A downhill progression was employed for the qualification along with a 100% CO₂ shielding gas (at 40cfm). No backing gas was employed.

A total of 20 weld beads were deposited to complete the weldment. Parameters for the first plate weld is shown in Table 2-7. Manual oscillation was maintained between 1/8 and 3/16-in for all fill passes. As a result, the actual bead width was maintained between 0.40- and 0.50-in.

Table 2-7. Procedure Qualification Welding Parameters using the Power Wave 455/STT on 3/4-in. Plate in modified 3G position (Plate N-2).

Welding Pass	Program	Wire Feed Speed (in/min)	Arc Control	Voltage	Trim	Travel Speed (in/min)
Root Pass	119	160	off	20-21	.75	8-9
Hot Pass	117	160	5.0	20-21	1.50	8-9
3-20 Fill Passes	117	160	5.0	20-21	1.50	8-9

Mechanical Test Results

Mechanical testing, including side bends and tensile tests, was performed on SA-516, Grade 70, 3/4-inch thick weldment per ASME Section IX specifications. A face bend was performed, though not required by Section IX to supplement the acceptance of the test results. All test results are reported in Table 2-8. The bends and tensile specimens are shown in Figure 2-4 and 2-5.

The tensile tests met the minimum specified tensile requirements and 2 of the 4 side bends and the face bend were considered acceptable (Figure 2-4 and 2-5). The side bend failures were a result of poor tie in at the hot pass. The poor tie in the hot pass was not observed through out the entire length of the weldment and was not prevalent in previous tests. It was decided at this point to continue with the 1-in. thick weldment, which was already in progress.

Table 2-8. Weld and Tensile Test Results on 3/4-in test specimen (455/STT).

Test Plate Number	Face Bend Results	Side Bend Results	Tensile Results
Test Plate N-2	Passed (1)	Passed (2)	77,700 Parent metal
		Failed (2) Lack of Fusion	75,800 Parent metal

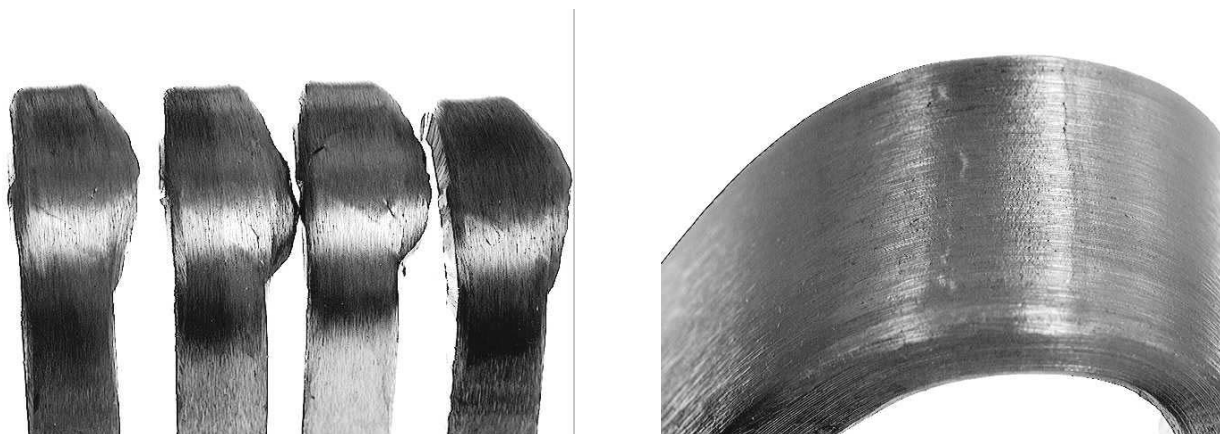


Figure 2-4. Side Bends (4) and Face Bend (1) for Test Plate N-2, 3/4-in. (455/STT).



Figure 2-5. Tensile Specimens (2) for Test Plate N-2, 3/4-in. (455/STT)

2.1.5 1.0-in. Carbon Steel Qualification – Lincoln Power Wave 455/STT

Two 1-in. thick weld coupons (N-3 and N-3A) were welded with Lincoln Power Wave 455/STT using the parameters shown in Table 2-9 and 2-10. Weld N-3A was completed on A36 material, and Weld N-3 was completed on SA516, Grade 70 material. A root opening of 0.075-in. was utilized for both welds, along with a 0.062-in. land and a weld joint beveled with 37-1/2 degree side wall. The welds were performed using an 0.045-in. diameter, ER70S-6 solid wire (SFA 5.18, ESAB SpoolArc 86, Heat Number 186373) in the 3G-Modified welding position. A downhill progression was employed for the qualification along with a 100% CO₂ shielding gas (at 40cfm). No backing gas was employed.

Weld N-3 was welded at machine setting optimized for root and fill passes (program 119 and 117 respectively, Table 2-9) and with welding techniques originated from previous weld tests. Weld N-3A was used to determine if larger weld beads (greater manual oscillation width) and identical root pass and fill pass machine settings (Program 119 and 1.25 trim setting, Table 2-10) could be used to speed up the welding process. Arc control remained in the off position for the root pass (typical) for both welds. N-3A was completed with 11 total passes and N-3 was completed in 38 passes. Both welds were tested per ASME IX specifications.

Table 2-9. Procedure Qualification Welding Parameters using the Power Wave 455 STT on 1" Plate in modified 3G position (Plate N-3)

Welding Pass	Program	Wire Feed Speed (in/min)	Arc Control	Trim	Travel Speed (in/min)
Root Pass	119	160	Off	.75	8-9
Hot Pass	117	160	5.0	1.50	10
3-38 Fill Passes	117	160	5.0	1.50	10

Table 2-10. Procedure Qualification Welding Parameters using the Power Wave 455 STT on 1" Plate in modified 3G position (Plate N-3A)

Welding Pass	Program	Wire Feed Speed (in/min)	Arc Control	Trim	Travel Speed (in/min)
Root Pass	119	160	Off	1.25	---
Hot Pass	119	160	3.0	1.25	---
3-11 Fill Passes	119	160	3.0	1.25	---

Mechanical Test Results

Mechanical testing, including side bends and tensile tests, was performed on both 1-in. thick weldments. Face bends were also performed, though not required by Section IX, to supplement the acceptance criteria. All test results are reported in Table 2-11, for plate N-3 and N-3A. The bends and tensile specimens are shown in Figure 2-6 and 2-7 for plate N-3.

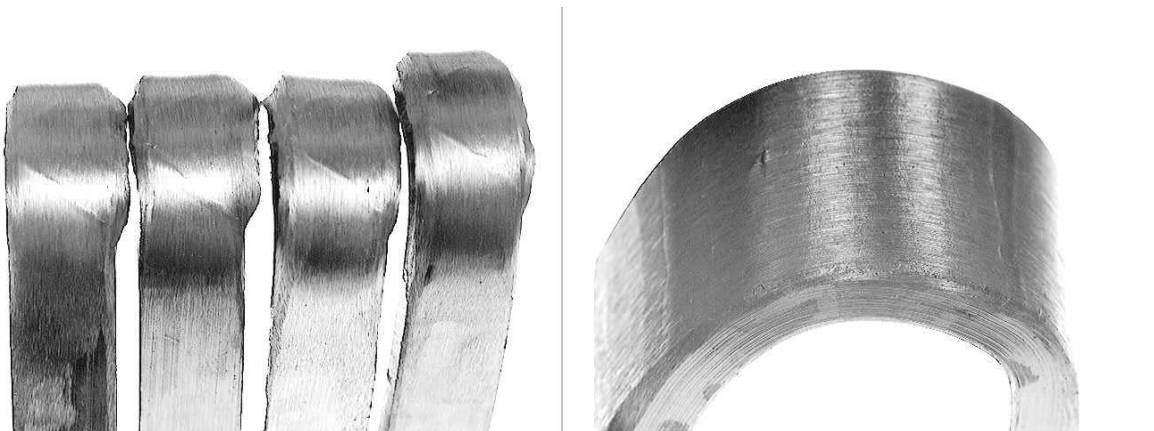
Weld specimen N-3, which was completed with techniques and machine setting predetermined from prior successful weld tests, provided tensile tests that exceeded the minimal specified tensile requirements and acceptable side and face bends (Figure 2-6 and 2-7). Weld plate N-3A, which was welded with non-conforming machine settings and weld techniques, produced lack of fusion on the side wall, resulting in bend test failures. Tensile tests for N-3 and N-3A were both acceptable. The test results confirmed that a narrow oscillation, which restricts the overall bead width, was necessary to provide the optimal heat input to tie in the side walls.

Table 2-11. Weld and Tensile Test Results on 1-in. test specimen (455/STT).

Test Plate Number	Face Bend Results	Side Bend Results	Tensile Results
Test Plate N-3	Passes (1)	Passed (4)	77,000 parent metal 77,900 parent metal

Table 2-12. Weld and Tensile Test Results on 1-in. test specimen (455/STT).

Test Plate Number	Face Bend Results	Side Bend Results	Tensile Results
Test Plate N-3A	Failed (1)	Failed (3) Passed (1)	73,100 parent metal 72,600 parent metal

**Figure 2-6. Side Bends (4) and Face Bend (1) for Test Plate N-3, 1-in. (455/STT).****Figure 2-7. Tensile Specimens (2) for Test Plate N-3, 1-in. (455/STT)**

2.2 Stainless Steel Procedure Development

2.2.1 1/2-in. Stainless Steel Qualification – Lincoln Power Wave 455/STT

A manual GMAW qualifications was performed using Type 304L Stainless Steel, 1/2-in. thick plate using the Lincoln Powerwave STT-455 Welding Power Supply. A root opening of 0.100-in. was utilized for the weld, along with a 0.040-in. land and a weld joint beveled with 37-1/2 degree sidewall. The welds were performed using a 0.045-in. diameter, Sandvik Type 308L solid wire, Heat Number S471342 in the 3G-Modified welding position. A downhill progression was employed for the qualification along with a 90% Helium, 7.5% Argon and 2.5% CO₂ shielding gas (at 40cfm). An argon backing gas was also employed.

A total of 14 weld beads were deposited to complete the weldment. Parameters for the weld are shown in Table 2-13. Manual oscillation was maintained between 1/8 and 3/16-in for all fill passes. As a result, the actual bead width was maintained between 0.40- and 0.50-in.

Table 2-13. Procedure Qualification Welding Parameters using the Power Wave 455/STT on ½-in. Plate in modified 3G position (Plate NS-4).

Welding Pass	Program	Wire Feed Speed (in/min)	Arc Control*	Voltage/ amperage	Trim*	Travel Speed (in/min)
Root Pass	137	120	Off	18-19 / 98	1.00	6-7
Hot Pass	129	160	4.0	21-22 / 124	1.10	7-8
3-14 Fill Passes	129	160	4.0	21-22 / 124-128	1.10	10-11

* New Control board

Mechanical Test Results

Mechanical testing, including side bends and tensile tests, was performed on the ½-in. thick Type 304/308L stainless steel weldment. A face bend was also performed, though not required by Section IX, to supplement the acceptance criteria. All test results are reported in Table 2-14. The bends and tensile specimens are shown in Figure 2-8 and 2-9.

All bend tests (side and face) were acceptable and the tensile tests exceeded the minimum specified tensile requirements. Adjustments or alteration from the weld procedures originated from the carbon steel weld tests are listed below:

- Program 137 was recommended by the manufacture for stainless steel welds

- After further evaluation on stainless materials, Program 117 (same as carbon steel setting) is recommended.
- Due to the arc characteristics on the stainless steel material
 - Root opening was increased to .100-in. (.075-in. used for carbon steel)
 - Land was reduced to .040-in. (.062-in. used for carbon steel)
 - Trim setting was increased to 1.00 for root pass and 1.10 for hot and fill passes.
 - Arc control was set OFF for root pass (typical) and at 4.0 for hot and fill passes.

Table 2-14. Weld and Tensile Test Results on 1-in. test specimen (455/STT).

Test Plate Number	Face Bend Results	Side Bend Results	Tensile Results
Test Plate NS-4	Passes (1)	Passed (4)	91,200 parent metal 91,600 parent metal

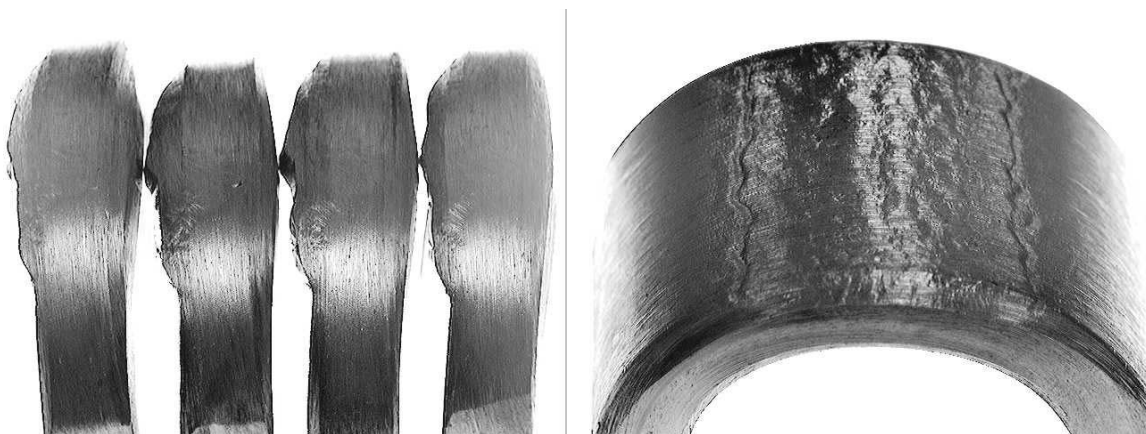


Figure 2-8. Side Bends (4) and Face Bend (1) for Test Plate NS-4, 1/2-in. (455/STT).



Figure 2-9. Tensile Specimens (2) for Test Plate NS-4, 1/2-in. (455/STT)

2.3 2¼Cr-1Mo (P5A) Alloy Steel Procedure Development

2.3.1 3/4-in. 2 ¼ Cr-1Mo (P5A) Alloy Steel Qualification – Lincoln Power Wave 455/STT

A manual GMAW qualification was performed using 2 ¼ Cr-1Mo, .750-in. thick plate using the Lincoln Powerwave STT-455 Welding Power Supply. A root opening of 0.100-in. was utilized for the weld, along with a 0.065-in. land and a weld joint beveled with 37-1/2 degree sidewall. The welds were performed using a 0.045-in. diameter, ER90S-B3 solid wire in the 3G-Modified welding position. A downhill progression was employed for the qualification along with a 90% Helium, 7.5% Argon and 2.5% CO₂ shielding gas (at 40cfm). No backing gas was employed. A preheat temperature of 455°F was maintained.

A total of 23 weld beads were deposited to complete the weldment. Parameters for the weld are shown in Table 2-13. Manual oscillation was maintained between 1/8 and 3/16-in for all fill passes. As a result, the actual bead width was maintained between 0.420- and 0.475-in.

Table 2-15. Procedure Qualification Welding Parameters using the Power Wave 455/STT on 3/4-in. Plate in Modified 3G Position (Plate NCR-5).

Welding Pass	Program	Wire Feed Speed (in/min)	Arc Control*	Voltage/ amperage	Trim*	Travel Speed (in/min)
Root Pass	137	120	3.0	16.8/100	.85	7-8
Hot Pass	129	155	6.0	22/130	1.30	6-7
3-23 Fill Passes	129	155	7.0	21-22/130	1.30	6-8

* New Control board

Mechanical Test Results

Mechanical testing, including side bends and tensile tests, was performed on .750-in., 2¼Cr-1Mo weldment. Face bends were also performed, though not required by Section IX to supplement the acceptance criteria. All test results are reported in Table 2-16. The bends and tensile specimens are shown in Figure 2-10 and 2-11.

All bends (side and face) were acceptable and tensile tests exceeded the minimum specified tensile requirements. Adjustments or alteration from the carbon steel and stainless steel welding procedures for the 2¼Cr-1Mo steel are listed below:

- Program 137 and 129 was recommended by the manufacture for CrMo steel
 - Further evaluations are needed to determine the optimal program setting, although similar to stainless steel Program 117 showed promise.
- Due to the arc characteristics and sluggish weld pool
 - A higher trim setting of .95 is recommended (.75 typical for carbon steel)
 - Root opening was opened up to .100-in. (same for stainless steel, .075-in. for carbon steel)
 - Land was reduced to .040-in. (same for stainless steel, .062-in. for carbon steel)
 - Arc Control was altered between 3 and 7.0 during welding of test coupon, Setting of 4-4.5 was found to be acceptable.
- Bead width between .420-.475-in. was achieved with similar welding techniques used with the carbon and stainless steel welds (narrower than SS and carbon steel welds).

Table 2-16. Weld and Tensile Test Results on 3/4-in. test specimen (455/STT).

Test Plate Number	Face Bend Results	Side Bend Results	Tensile Results
Test Plate NCR-5	Passes (1)	Passed (4)	76,400 parent metal 74,400 parent metal

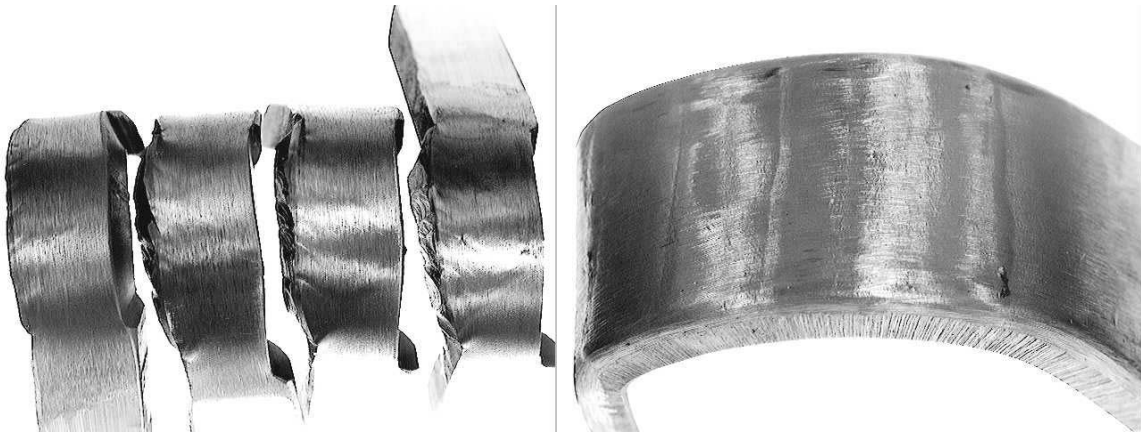


Figure 2-10. Side Bends (4) and Face Bend (1) for Test Plate N-5, 3/4-in. (455/STT).



Figure 2-11. Tensile Specimens (2) for Test Plate N-5, 3/4-in. (455/STT)

3 ADDITIONAL ROOT WELDING EVALUATIONS

The influence of spatter and whiskers on the ID surface of the low alloy piping (P5A) was also evaluated. The effect of spatter was evaluated by measuring the hardness associated with the adhered spatter ball and the adjacent material. Whiskers were evaluated by measuring the average length of wire, which penetrated through the ID and remained attached to the root pass. As a note: It was very difficult to produce whiskers and spatter with the welding procedures developed in the prior weld tests. Extreme variations in welding technique were required to generate the weld coupons with spatter and whiskers present.

To evaluate the effects of spatter, a cross section of the P5A weldment was cut at the location of a spatter ball adhered to the surface (Figure 3-1). Micro-hardness values were measured on the surface of the plate across the spatter ball into unaffected base metal, and into the thickness of the material just below the spatter ball. The spatter ball was polished flush to the surface to allow hardness measurements across the surface. The micro-hardness measurements were taken at 0.2-mm increments from the location of the spatter until values matched the base material. Figure 3-2 shows the location of the hardness measurements below the spatter ball and across the surface of the plate. The hardness values are listed in Table 3-1.

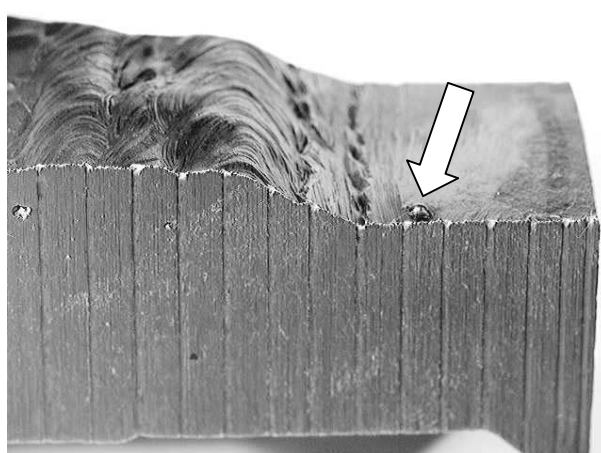


Figure 3-1. Cross section of spatter for hardness tests for Test Plate N-5, 3/4-in., 2¼Cr-1Mo Plate.

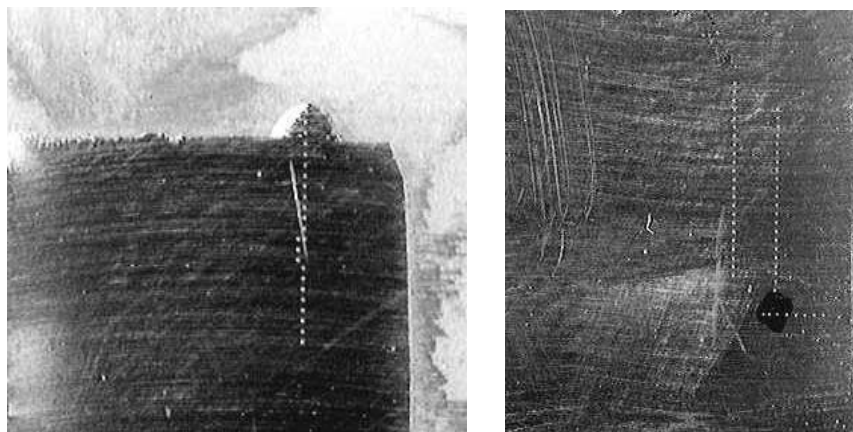


Figure 3-2. Micro-hardness indentations at spatter locations on cross section (left) and on the surface (right).

Table 3-1. Micro-hardness measurements associated with adhered spatter.

Surface Measurements			Cross-section Measurements		
Location	Hardness Vickers	Distance from fusion line	Location	Hardness Vickers	Distance from fusion line
	(Indenter:HV0.5)	(mm)		Indenter:HV0.5	(mm)
Spatter	402	+.6	Spatter	343	+.5
Spatter	371	+.4	Spatter	343	+.3
Spatter	350	+.2	Spatter	356	+.1
Fusion Line	245	0	Fusion Line	296	0
Base Metal	207	-.2	Base Metal	195	-.1
Base Metal	189	-.4	Base Metal	189	-.3
Base Metal	189	-.6	Base Metal	201	-.5
Base Metal	189	-.8	Base Metal	189	-.7
			Base Metal	201	-.9
			Base Metal	189	-1.1

Personnel unfamiliar with the GMAW process and the Lincoln Power Wave 455/STT produced welds with no whiskers on the ID surface of the root weld. Non-conforming machine settings and welding techniques were necessary to produce the whiskers. Whiskers (unmelted lengths of welding wire) produced under these conditions were measured at lengths between 0.12-in. to 0.65-in. long. It was determined that the presents of whiskers on the ID surface would be limited even under the worst welding conditions.

Hardness of the spatter balls was measured at 304-402 Hardness Vickers (HV0.5), which is considerably harder than the base metal. The base metal was measured at 190-200 Hardness Vickers (HV0.5). The hardness at the fusion line between the spatter ball and the base material fell between the hardness measurement of the base material and spatter ball (245-296 Hardness Vickers). The hardness value 0.2-mm removed from the fusion line in any direction was consistent with typical values measured in the base material.

4 CONCLUSIONS

The Lincoln Power Wave 455/STT and the Lincoln STTII were evaluated through welding trials and procedure qualifications (ASME Section IX) to determine appropriate welding techniques and parameters. Mechanical testing used to evaluate this equipment, included the required side bends and tensile tests, and optional face and root bends, have provided the acceptance criteria needed to use the process in the intended range of 3/8-in to 1/2-in nominal wall thickness. Key results of the weld tests and parameter/technique development are listed below:

- Weld productivity was increased:
 - Single welding machine for root, hot and fill passes
 - Deposition inherently greater with the GMAW process compared to GTAW and SMAW
- Successful welding procedure qualifications in the modified 3G (vertical) position were performed for stainless steel, carbon steel and P5A materials in the following thickness:
 - 5/8-in. thick carbon steel
 - 1-in. thick carbon steel
 - 1/2-in. thick Type 304 stainless steel
 - 3/4-in. thick 2 1/4Cr-1Mo (P5A) materials
- Minimal training should be required for most certified pipe welders to utilize the process
 - Maintain close adherence to welding parameter ranges
 - Machine settings (programs) critical
 - Welding technique requires narrow manual oscillation
- Root welding evaluations were successful in that there was minimal amount of spatter and no whiskers produced along the ID surface of any of the qualification welds.
 - Evaluations of spatter balls indicated that this welding process would not introduce additional welding related anomalies.

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

EPRI. Electrify the World

© 2000 Electric Power Research Institute (EPRI), Inc. All rights reserved. Electric Power Research Institute and EPRI are registered service marks of the Electric Power Research Institute, Inc. EPRI. ELECTRIFY THE WORLD is a service mark of the Electric Power Research Institute, Inc.

1001299



Printed on recycled paper in the United States of America