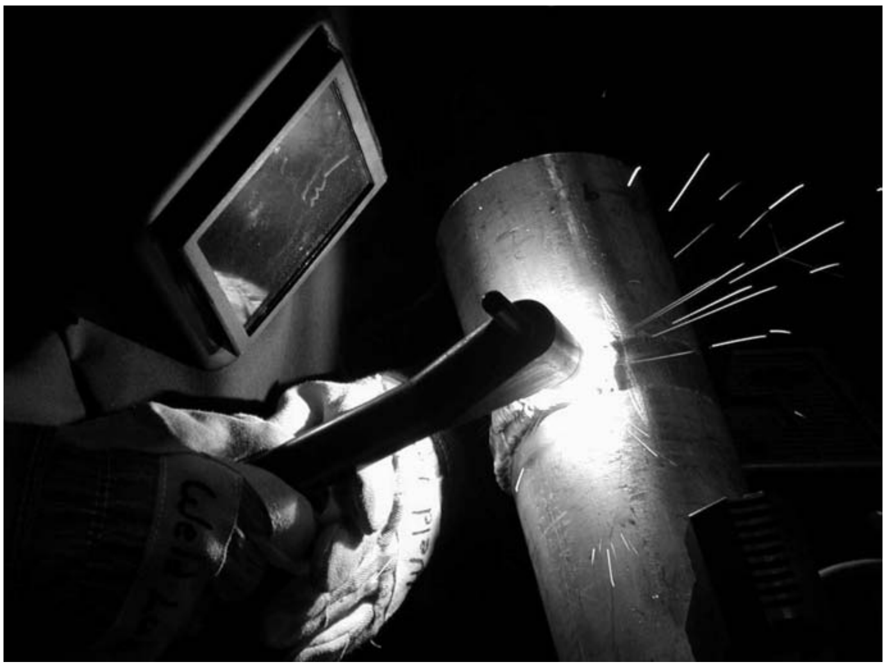
Onsite Plasma Welding Technology and Equipment Development

RRAC Task 88

1001437



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Technical Review, March 2001

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ABSTRACT

Automated Plasma Transfer Arc Welding (PTAW) with powder feed capabilities is commonly used for applying hardfacing alloys for new installations and for replacement valves. Although, the complexity of the PTAW equipment and its inability to operate in all positions (with powder), has limited the use of PTAW for manual repair and in-situ hardfacing applications. With a variety of hardfacing and corrosion resistant alloys readily available in the powder form, the PTAW process is an effective and economical process for applying hardfacing materials. The PTAW process with powder filler has the ability to obtain high quality deposits with a very low dilution rate and excellent material properties with a minimum number of weld layers.

The purpose of this program was to evaluate and promote the use of manual powder PTAW for the repair of specific power plant components. The primary goal was to develop and evaluate PTAW equipment for manual welding application and to use the technology to develop welding practices.

Various plasma welding systems, powder feeders and weld torches were evaluated in this program for out-of position welding, shielding capabilities and ease of operation. Welding with Alternating Current (AC) was also evaluated to minimize weld dilution for hard to weld alloys. The PTAW process was compared to conventional welding processes through the development of Procedure Qualification Records (PQR) and the corresponding weld soundness criteria per ASME requirements. The soundness criteria consisted of as-deposited weld metal chemistry evaluation, 5X visual examination of cross sections, surface hardness measurements and liquid penetrant testing (PT).

The program resulted in successful weld qualifications in the 6G position, with Stellite 21 and Norem 02A on 4-in. Schedule 80, stainless steel pipe. Due to the successful results a second phase of the program will evaluate manual PTAW for the in-situ repair of components originally installed with powder hardfacing alloys.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Automated Plasma Transfer Arc Welding (PTAW) with powder feed capabilities is commonly used for applying hardfacing alloys for new installations and for replacement valves. Although, the complexity of the PTAW equipment and its inability to operate in all positions (with powder), has limited the use of PTAW for manual repair and in-situ hardfacing applications. With a variety of hardfacing and corrosion resistant alloys readily available in the powder form, the PTAW process is an effective and economical process for applying hardfacing materials. The PTAW process with powder filler has the ability to obtain high quality deposits with a very low dilution rate and excellent material properties with a minimum number of weld layers.

The purpose of this program was to evaluate and promote the use of manual powder PTAW for the repair of specific power plant components. The primary goal was to develop and evaluate PTAW equipment for manual welding application and to use the technology to develop welding practices. A second phase of this program will be used to demonstrate the manual repair technology on original equipment installed with powder PTAW hardfacing.

Various plasma welding systems, powder feeders and weld torches were evaluated in this program for out-of position welding, shielding capabilities and ease of operation. Welding with Alternating Current (AC) was also evaluated to minimize weld dilution for hard to weld alloys. The PTAW process was compared to conventional welding processes through the development of Procedure Qualification Records (PQR) and the corresponding weld soundness criteria per ASME requirements. The soundness criteria consisted of as-deposited weld metal chemistry evaluation, 5X visual examination of cross sections, surface hardness measurements and liquid penetrant testing (PT).

2
TEST PROGRAM

PTAW welding torches are commonly available for various applications, although only a few systems are commercially available with powder feed capabilities. The commercial powder feed systems are typically designed for high deposition and welding in the flat position. The goal of this program was to evaluate commercially available systems and to develop a prototype system that can accommodate welding out-of-position for localized repair applications. The system requirements for the manual PTAW system included:

- Consistent (uninterrupted) powder feed capabilities for all positions
- Low-profile torch design for accessibility into grooves and transition areas and for welder visibility
- Light-weight torch assembly for manual operation

A secondary objective was to evaluate PTAW capabilities with alternating current (AC) for critical applications requiring low dilution and minimal heat input.

A schematic of a typical PTAW torch with powder feed is shown in Figure 2-1. The orifice used for feeding the powder alloy can be continuous (as shown) or individual orifices oriented between the shielding gas and the plasma gas, typically directed at the leading and trailing edge of the weld puddle.

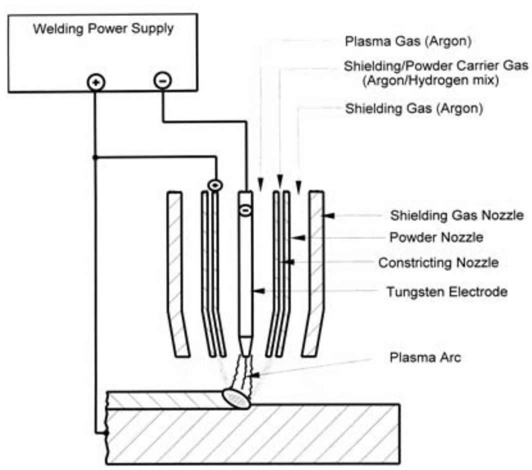


Figure 2-1 Typical PTAW Powder Torch Assembly

2.1 PTAW Torch Development

To improve the PTAW capabilities for manual powder applications a standard torch assembly was modified to reduce the overall body size and shielding configuration, to improve welder visibility and torch accessibility into transition zones or repair cavity. Modifications of the plasma torch are limited to the shielding gas nozzle and the powder nozzle since the constricting nozzle and tungsten electrode configuration must remain constant to maintain the columnar arc typical of plasma welding. Improvements to the torch body concentrated around a tapered shielding gas nozzle with a smaller diameter and a greater powder nozzle extension length while maintaining an appropriate level of gas flow. The shielding gas nozzle can not be removed entirely because the gas flow through the constricting nozzle is typically not sufficient to shield the weld puddle from atmospheric contamination.

Modified gas diffusers were manufactured from various materials including aluminum and porous copper. The aluminum gas diffusers basically housed a series of screens to diffuse the gas flow as seen in Figure 2-3. The aluminum housing was tapered to the contour of the powder nozzle and shortened to increase the extension length of the powder nozzle (Figure 2-3) and to improve welding visibility. The outer surface of the aluminum housing was covered with an insulating coating to reduce the potential of arcing between the torch body and work piece.

Figure 2-3. Aluminum shielding gas nozzle with internal diffuser

To reduce the overall size of the gas diffuser even further a porous copper material was used in place of the aluminum housing and screen diffuser configuration. The porous copper material allowed the gas to be diffused directly through the material eliminating the need for screens and the outer aluminum housing. The mesh size and surface quality after machining was evaluated for the optimum gas flow properties. The surface areas where the gas enters and exits the gas nozzle where often machined to the final dimensions with EDM to assure the surface texture wasn’t damaged. Normal machining techniques smeared the surface of the copper nozzle causing the gas flow to be masked or redirected.

To confine the gas flow direction the OD of the porous copper was coated with nonconductive material such as high temperature ceramic or epoxy (Figure 2-4). The coating also eliminated the grounding potential of the gas nozzle to the work piece. Both the gas diffusers were evaluated through a series of welds to determine the optimum gas flow rates. Both the copper and the aluminum gas diffuser configurations provided sufficient gas coverage of the molten puddle and were considered viable alternatives.

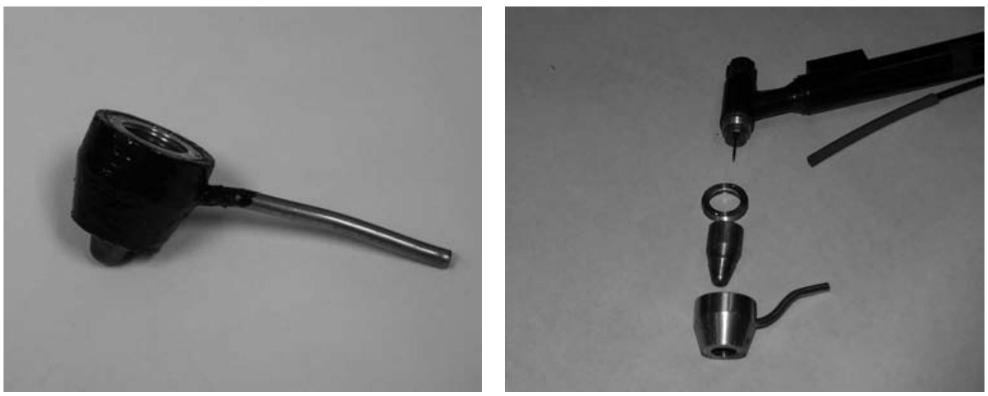


Figure 2-4. Porous copper gas diffuser/shielding nozzle

As seen in Figure 2-1, the powder is carried between the powder nozzle and the constricting nozzle and is directed into the plasma column. The tungsten electrode is protected from the powder contamination by the constricting nozzle and the gas flow through the constricting nozzle. The configuration of the powder and constricting nozzle, orifice diameter and the gas flow rate all contribute to the powder distribution pattern. Ceramic materials (nonconductive) were evaluated as alternative material for the powder nozzle to eliminate arcing of the powder nozzle to work piece during manual operation. The ceramic material was also evaluated for applications using AC welding current. The reverse polarity portion of the AC waveform causes additional wear of the nozzle orifice, not seen with the DC straight polarity typically used with PTAW. Without a special powder nozzle, plasma welding with AC is typically limited to a lower range of amperage.

The ceramic nozzles as seen in Figure 2-2, were fabricated from Reaction Bonded Silicon Nitride (RBSN) and alumina silicate machineable ceramic materials. The alumina silicate material, which could be freely machined and fired at 2000°F while the RBSN, was molded and fired at 3600°F. Both materials were rated in excess of 3000°F operating temperature. A number of ceramic nozzles were manufactured at various diameters to allow optimal orifice diameters to be determined through weld trials. The ceramic nozzles failed to withstand the heat of the plasma arc, which caused the orifice to deteriorate after only a few weld trials. Variations in the orifice size in the ceramic nozzle were evaluated with similar results (Figure 2-5). Larger orifice diameters were not evaluated due to the resulting powder distribution pattern. The original copper powder feed nozzle was used for the remainder of the torch evaluations.

Figure 2-5 Ceramic Nozzle

2.2 PTAW Equipment Evaluation

A number of welding systems were collected to evaluate out-of-position PTAW powder welding and the prototype manual PTAW torches. The PTAW welding systems evaluated included:

- Miller Aerowave power supply with Eutectic powder feeder
- Dimetric-MicroPaw with Eutectic powder feeder
- Stellite-MicroStar complete system.

Miller Aerowave

The Miller Aerowave system (Figure 2-6) was evaluated as a power supply for PTAW because of its unique AC waveform capabilities. The Aerowave can be adjusted from 10-90% DC electrode positive (reverse polarity) with the corresponding DC electrode negative (straight polarity), allowing control of penetration, heat input and cleaning action of the reverse polarity. The Aerowave is also equipped with pulsing capabilities not utilized in this evaluation. The Aerowave power supply is not a complete PTAW system and required an independent plasma console and powder feed system. A Hobart Plasma Console (HPW-400), Eutectic (5300 LF) powder feeder and powder fed torch (Figure 2-7) were coupled to the Aerowave for welding evaluations.

Prototype welding torches described in Section 2.1 and a Process Welding System's MP 5-13 powder fed torch were evaluated for manual welding applications. The MP 5-13 torch was originally developed for autogenous welding applications but was modified by Process Welding

Systems for powder feed capabilities. Successful weld demonstrations were completed with each of the plasma torch configurations. The standard torch set up allowed as low as 2 amps reverse polarity, and 30 to 38 amp straight polarity with a switching frequency of 150 Hz. An AC waveform with greater than 10% reverse polarity, caused the electrode to over heat degrading the tungsten geometry.

Optimal welding parameters and waveform for the Aerowave system with the MP 5-13 torch was, 90% straight polarity (38 amps), 10 % reverse polarity (2-35 amps), AC frequency of 150 Hz, and 93% Argon 7% Hydrogen shield gas and 100 % Argon plasma gas. For thick section weldments the full 45 amp (maximum amperage setting for this torch) and a 93% Argon 7% hydrogen would be necessary. For thin section components (tip or edge welding) a stable arc could be maintained at 2 amps with an AC frequency between 40 to 400 Hz.

Welding with this system was limited by the powder feed capabilities and the plasma control console. The 5300 LF powder feeder produce erratic powder feed when altering the welding position or during torch manipulation. The powder feed system could be set up to weld in various positions but could not be manipulated while feeding powder, necessary for manual welding. The system is ideal for automatic welding applications where the torch remained stationery and the component was manipulated or rotated.

The Hobart plasma control console was originally designed for a larger automatic weld torch, which could handle high current range. The current required to maintain the non-transferred arc (pilot arc) is greater than 12 amps. The smaller manual torches would overheat when the system was idle, causing shielding and handling problems.

Figure 2-6. Miller Aerowave Power Supply

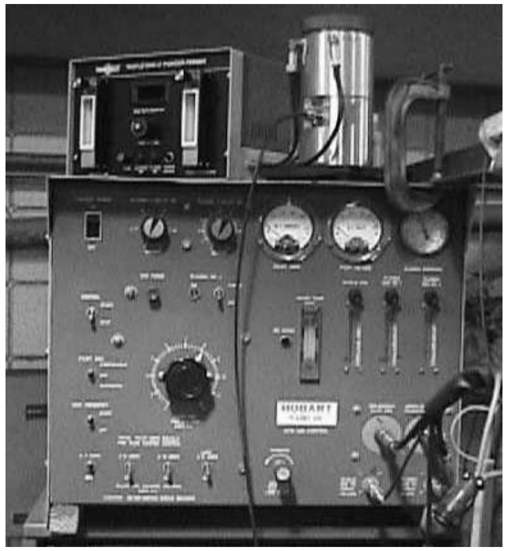


Figure 2-7 Hobart Plasma Console and Eutectic Powder Feeder

Dimetrics MicroPaw

Dimetrics-MicroPaw 100 plasma system was originally designed for autogenous welding applications. The MicroPaw system was coupled with the Eutectic 5300 LF powder feeder and the powder fed torch similar to the Miller Aerowave system (Figure 2-8). The MicroPaw 100 offered a current range appropriate for powder welding applications (0-100 amps), but did not have AC capabilities. The current requirements for the non-transferred arc were less than the Hobart plasma console, allowing the torch to remain relatively cool while idle.

The 5300 LF powder feeder as discussed in the Miller Aerowave Section limited the system.

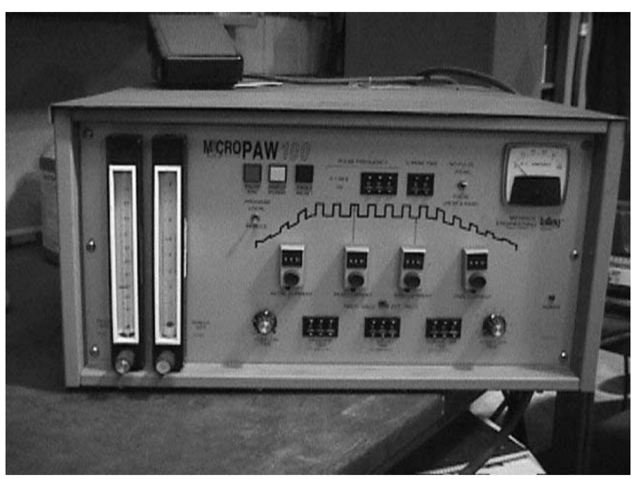


Figure 2-8. Dimetrics Micropaw System

Stellite MicroStar

The Stellite MicroStar system is a complete PTAW welding system with powder feed (Figure 2-9). The Microstar system has two working ranges 0-40 amps and 40-100 amps and two manual powder fed torch designs (HPH80 and HPH150). The HPH80 has a working range up to 80 amps and the HPH150 up to 120 amps.

The advantage of this system is that the powder feed was consistent through a range of motion typical of manual operation. Due to the out-of position capabilities, the Stellite system was used for all procedure qualifications for Stellite 21 and Norem-02A, described in Section 3.

Figure 2-9 Stellite MicroStar System

3 PROCEDURE QUALIFICATION

Manual all-position welding with powder alloys was qualified in accordance with 1998 ASME Section IX, QW-453, Procedure/Performance Qualification Thickness Limits and Test Specimens for Hard-Facing (Wear Resistant) and Corrosion-Resistant Overlays. Test requirements and acceptance criteria per QW-453 are listed in Table 3-1. The Stellite Microstar plasma welding system with the HPH150 plasma torch was used for the qualification welds due to the out-of position welding capabilities of the system. Both Stellite 21 and Norem-02A filler materials were demonstrated with the PTAW process.

Two procedure qualifications were written for manual PTAW with Stellite 21 to verify oscillation limits (oscillation < and > 0.25-in.), and one procedure qualification was written for manual PTAW with Norem-02A. The Procedure Qualifications are attached in Appendix A for both alloys. Overlays were applied manually in the 6-G position on 4-inch, Schedule 80 stainless steel pipe (Figure 3-1). All welds were welded double up (vertical up) and were two layers by approximately 1.5-in. wide.

Section 3 is divided into four sections corresponding to the test requirements in QW-453; 3.1 Liquid Penetrant Tests, 3.2 Hardness Readings, 3.3 Visual Examination and 3.4 Chemical Analyses.

Table 3-1. Test requirements per QW-453 Procedure/Performance Qualifications

Test	Location	Acceptance Criteria
Liquid Penetrant Testing	Entire surface (360 degree continuous for pipe), surface conditioning acceptable	QW-195.2 or as specified in WPS
Hardness Readings	Locations specified in QW-462.5(b) or QW-462.5(e)	At minimum thickness specified in WPS
Visual Examination (x5 magnification)	Locations specified in QW-462.5(b) or QW-462.5(e)	Crack and defect free base metal or HAZ and meet requirements in WPS
Chemical analyses	Locations specified in QW-462.5(b) or QW-462.5(e)	In accordance with QW-462.5(a) and range specifies in WPS

Figure 3-1. Manual 6G welding setup

3.1 Liquid Penetrant Testing (PT)

Liquid Penetrant (PT) testing was conducted on the weld overlay specimens (Stellite 21 and Norem-02A) and evaluated per ASME QW 195.2 (Table 3-2). The Stellite 21 was welded on one side of the pipe using a wide weave pattern (>0.25-in torch oscillation) and opposite side using a narrower weave pattern (<0.25-in. torch oscillation). Both oscillation techniques provided acceptable PT, as seen in Figure 3-2 and 3-3. The narrow oscillation produced a more consistent weld profile and is recommended for multi-layer overlays. The Norem-02A overlay utilized the narrow oscillation technique, which also provided acceptable PT results (Figure 3-4). No relevant indications were documented for Norem-02A or the Stellite 21 weld overlays per QW195.2.

Table 3-2. PT Acceptance Criteria per QW 195.2

Indications	Terminology	Acceptance Criteria
Relevant Indications	Indication with major dimension greater than 1/16-in. (1.6-m)	
Linear Indication	Indication having a length greater than three times the width	Any relevant linear indications
Rounded Indication	Indication of circular or elliptical shape with the length equal to or less than three times the width	Four or more relevant rounded indications in a line separated by 1/16-in (1.6-mm) or less (edge-to-edge). Relevant rounded indications greater than 3/16-in. (4.8-mm).

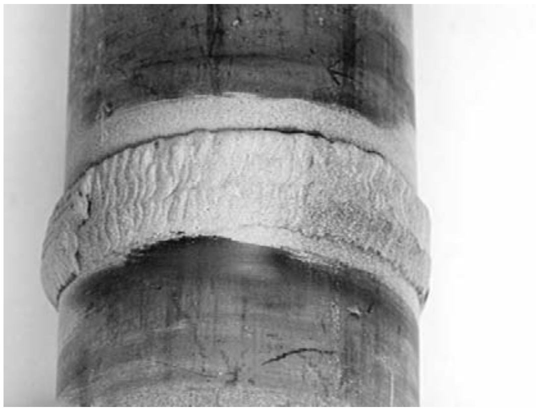


Figure 3-2. Liquid Penetrant Test - Stellite 21/Type 304 SS 4-in. schedule 80 (wide oscillation, >0.25-in.)

Figure 3-3. Liquid Penetrant Test - Stellite 21/Type 304 SS 4-in. schedule 80 (narrow oscillation, <0.25-in.)

Figure 3-4. Liquid Penetrant Test – NOREM-02A/Type 304 SS 4-in. schedule 80

3.2 Hardness Values

Hardness measurements are required per ASME Section IX, QW-453 for procedure qualification. The hardness measurements were taken on the top surface of the overlay specimens at locations specified in ASME QW-462.5 (b) for the 6G position. The welds were sectioned and surfaced to provide a smooth flat surface for hardness testing (Figure 3-5). Hardness values were measured with a Brinnel hardness tester, on the Rockwell C scale. Hardness values and overlay thicknesses are documented in Table 3-3 and 3-4, for Stellite 21 and Norem-02A. Suggested hardness values for each alloy is also listed for reference.

The desired deposited chemistry and overlay thickness are typically in an acceptable range when the minimum hardness values are met. To verify the actual buildup thickness required to achieve an acceptable hardness and chemistry, hardness reading were taken through the thickness of the Norem-02A overlay specimen. This was accomplished by incrementally removing layers of the weld buildup and measuring the hardness corresponding to the remaining thickness. Hardness values remained relatively constant from the full thickness (0.080-in.) to approximately 0.021-in. buildup as seen in Table 3-4 and Figure 3-6, indicating a single layer would have been sufficient to achieve material properties.

Figure 3-5. Typical surface preparation and location for Hardness measurements per QW-462.5 (b).

Table 3-3. Hardness Values for Stellite 21 Overlay

	Stellite 21 Overlay			Stellite 21
	Top (0)	Vertical (90)	Bottom (180)	Suggested
Hardness (Rockwell C)	33.5	32.3	33.2	30.8
Overlay Thickness	0.180-in.	0.200-in.	0.160-in.	

Table 3-4. Hardness Values for Norem-02A Overlay

	NOREM-02A Overlay			NOREM-02A
	Top (0)	Vertical (90)	Bottom (180)	Suggested
Hardness (Rockwell C)	39.8	40.2	38.2	38
Overlay Thickness	.096-in.	.080-in.	.145-in	

Table 3-5. Hardness measurements of Norem-02A overlay at various thickness.

Buildup Thickness (in.)	Average Hardness (Rockwell C)
0.080 (full thickness)	38.5
0.066	39.4
0.044	38.6
0.032	37.6
0.021	35.1
0.009	24.5

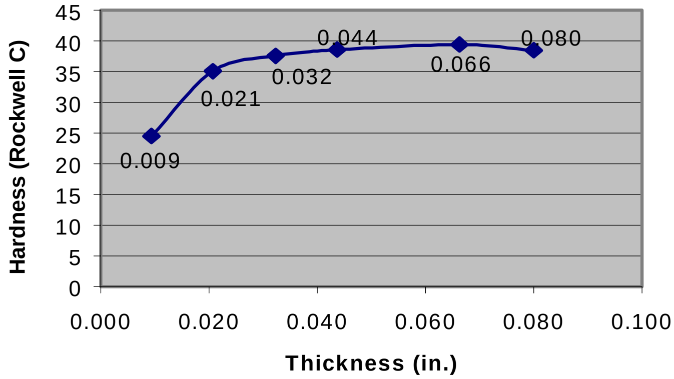


Figure 3-6. Plot of hardness values vs. overlay thickness

3.3 Visual Examination

A 5X visual examination of the overlay specimens was conducted by cross sectioning the pipe at three locations per ASME QW-462.5. Each cross section was examined for defects on both sides of the cross section. Both the Stellite 21 and the Norem-02A overlays were free of cracks and porosity. Figure 3-7 through 3-9 are cross sections of the Stellite 21 overlay with a narrow oscillation (<0.25-in.) and Figure 3-10 through 3-12 are cross sections of the Norem-02A overlay at specified locations.

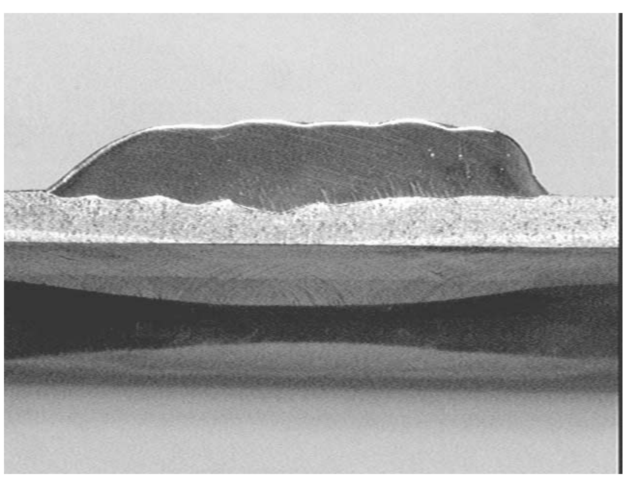


Figure 3-7. 5x examination at 180 degrees location (top) - Stellite 21

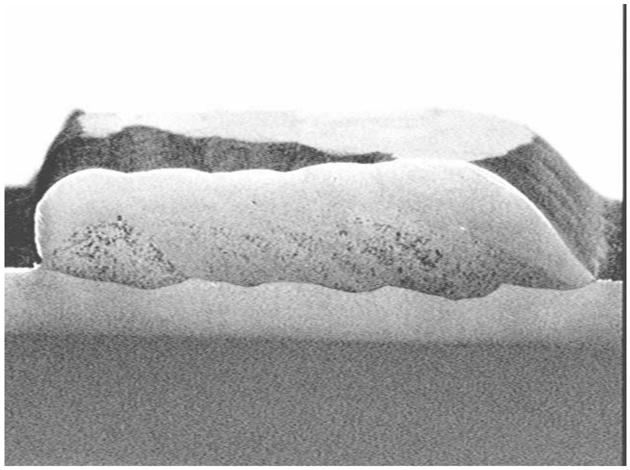


Figure 3-8. 5x examination at 90 degree location (side) - Stellite 21

Figure 3-9. 5x examination at 0 degrees location (bottom) - Stellite 21

Figure 3-10. 5x examination at 180 degrees location (top) – Norem-02A

Figure 3-11. 5x examination at 90 degree location (side) – Norem-02A

Figure 3-12. 5x examination at 0 degrees location (bottom) – Norem-02A

3.4 Chemistry Requirements

Chemistry of the weld overlay specimens was taken at three locations per ASME QW-462.5. The same cross sections removed for hardness measurements were used chemistry analyses. The cross sections were surface ground deposited chemistry was measured on the top surface of each specimen as seen in Figure 3-13. Results of the chemistry analyses for the Stellite 21 and the Norem-02A are listed in Table 3-4 and 3-5. Chemistry and hardness values corresponded to an acceptable range for both alloys.

Figure 3-13. Typical surface preparation and location of chemistry analyses.

Table 3-6. Chemistry Analysis - Stellite 21/Type 304 SS 4-in. schedule 80

Chemical Analysis (WT%)	Stellite 21 Overlay			Stellite 21
	Sample 1	Sample 2A	Sample 2B	Actual (CMTR)
Carbon	0.22	0.24	0.25	0.222
Sulfur	0.012	0.010	0.009	NR
Manganese	0.63	0.64	0.63	0.497
Cobalt	BAL	BAL	BAL	BAL
Chromium	27.05	27.23	27.31	26.807
Iron	1.74	2.11	1.43	1.253
Molybdenum	5.48	5.46	5.48	5.749
Nickel	2.73	2.78	2.72	3.415
Boron	NR	NR	NR	0.009
Silicon	1.67	1.67	1.68	1.863

Table 3-7. Chemistry Analysis – NOREM-02A/Type 304 SS 4-in. schedule 80

Chemical Analysis (WT%)	NOREM-02A Overlay			NOREM 02A
	Bottom	Side	Top	Actual (CMTR)
Carbon	1.03	1.02	1.04	1.10-1.35
Sulfur	0.006	0.006	0.006	.010 max.
Manganese	3.78	3.82	3.79	4.0-5.0
Cobalt	0.053	0.053	0.054	.05 max.
Chromium	24.2	24.2	24.3	23.0-26.0
Iron	BAL	BAL	BAL	BAL
Molybdenum	1.96	1.95	1.95	1.8-2.2
Nickel	3.83	3.84	3.85	3.7-4.5
Boron	NR	NR	NR	.002 max.
Phosphorous	0.024	0.024	0.024	.020 max.
Silicon	3.04	3.06	3.03	3.1-3.5

4
CONCLUSIONS AND RECOMMENDATIONS

The goal of the program was to evaluate powder PTAW systems for manual repair applications and to verify the powder fed process could be qualified. Varies PTAW power supplies, control consoles, powder feeders and welding torches were evaluated, developed and modified for manual operation. After the initial welding evaluation, the powder feed capabilities of the systems was found to be the limiting factor for out-of-position welding applications, with the exception of the Stellite MicroStar system. The results of the program are divided into three sections, Equipment Evaluation, PQR Test Results, and Recommendations.

4.1 Equipment Evaluation

- *Miller Aerowave power source*
  - Not a complete PTAW system, requires an independent plasma control console, powder feed system and welding torch
  - Versatile power supply with unique AC waveform capabilities
    - Asymmetric AC wave function capabilities
    - Adjusted from 10-90% DC reverse polarity/straight polarity
    - Controlled penetration, heat input and cleaning action
- *Process Welding System, MP 5-13 PTAW torch*
  - Lightweight
  - Limited to 45 amps max. with DC straight polarity
  - Capable of handling limited AC welding current
  - Can accommodate limited accessibility areas with modifications
- *Hobart Plasma Console (HPW-400)*
  - Designed for large automatic plasma torches
  - Requires 12-15 amps to maintain non-transferred arc (pilot arc)
  - Limited use with manual, lightweight torch designs (overheat potential)
- *Eutectic 5300 LF Powder Feeder*
  - Limited use for out-of-position welding application
  - Adaptable to any weld torch assembly
- *Stellite MicroStar system*
  - Complete system, various torch sizes for manual and automatic welding
  - Out-of-position powder feed capabilities
  - Limited to DC straight polarity

- Light weight torch assembly
- High and low current range settings, corresponding to torch size and application

4.2 PQR Test Results

Once the equipment evaluation was completed the Stellite Microstar system was selected to qualify the PTAW process. Manual all-position welding with powder alloys was qualified in accordance with 1998 ASME Section IX, QW-453, *Procedure/Performance Qualification Thickness Limits and Test Specimens for Hard-Facing (Wear Resistant) and Corrosion-Resistant Overlays*. Stellite 21 and Norem-02A were successfully demonstrated with the powder PTAW process. The qualification welds consisted of 360-degree overlays applied manually in the 6-G position on 4-inch, Schedule 80 stainless steel pipe. All welds were welded double up (vertical up) and were two layers by approximately 1.5-in. wide. The Procedure Qualifications are attached in Appendix A for Stellite 21 and Norem-02A. Test results are summarized in Table 4-1

Table 4-1. Test Results for Hardfacing PQR per ASME QW-453 Procedure/Performance Qualifications

Test	Results
Liquid Penetrant Testing	Stellite 21 - Entire surface was crack free Norem 02A - Entire surface was crack free
Hardness Readings	Average hardness 33 Rc was recorded for the Stellite 21 (Rc=31) Average hardness 39 Rc was recorded for the Norem-02A (Rc=38)
Visual Examination (5X magnification)	Norem-02A and Stellite 21 – No visible cracks in base metal, HAZ or weld metal
Chemical analyses	Chemistry met acceptance criteria for critical elements.

4.3 Recommendations (Phase 2)

Repair practices for hardfacing alloys using Gas Tungsten Arc Welding (GTAW), Shielded Metal Arc Welding (SMAW) have been evaluated in a past on hardfacing applied with various automated welding processes. Further evaluation is recommended to validate the use of manual Plasma Transfer Arc Welding (PTAW) process using powder alloys to repair hardfacing alloys originally applied with automated PTAW process. A matrix of test coupons should be fabricated to establish guidelines for repair welding with the powder welding process.

Test coupons should consist of carbon steel and stainless steel pipe (6-in., Schedule 80) overlaid on the OD surface (Figure 4-1), with Norem-02A and Stellite 21 (Table 4-2). The overlays should be applied with automatic PTAW process in any welding position. Overlays should be 1.5-in. wide or greater and have a minimum of 2 layers (>0.200-in. buildup). Overlays should be left in the as-welded condition.

Table 4-2. PTAW Repair Matrix

Test Configuration	Quantity	Test Specimen	Repair Sequence
Pipe Overlay	2	Norem-02A on Carbon Steel Pipe	Transverse repair approach Parallel repair approach
Pipe Overlay	2	Norem-02A on Stainless Steel Pipe	Transverse repair approach Parallel repair approach
Pipe Overlay	2	Stellite 21 on Carbon Steel Pipe	Transverse repair approach Parallel repair approach
Pipe Overlay	2	Stellite 21 on Stainless Steel Pipe	Transverse repair approach Parallel repair approach

Repair welds will be should be conducted with manual PTAW process in the 6G position (Figure 4-2). The repair geometry will be consistent with the groove geometry recommended for Norem and Stellite 21 in EPRI report TR-108130, "Localize Hardfacing Repair Techniques", for multi-bead, multi-layer repair approaches (Figure 4-3). Hardfacing repairs will be conducted with like materials and Type 309L for substrate buildup (where required).

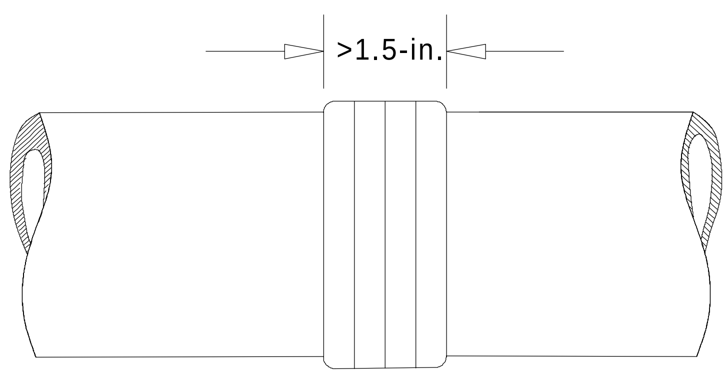


Figure 4-1. Test Configuration

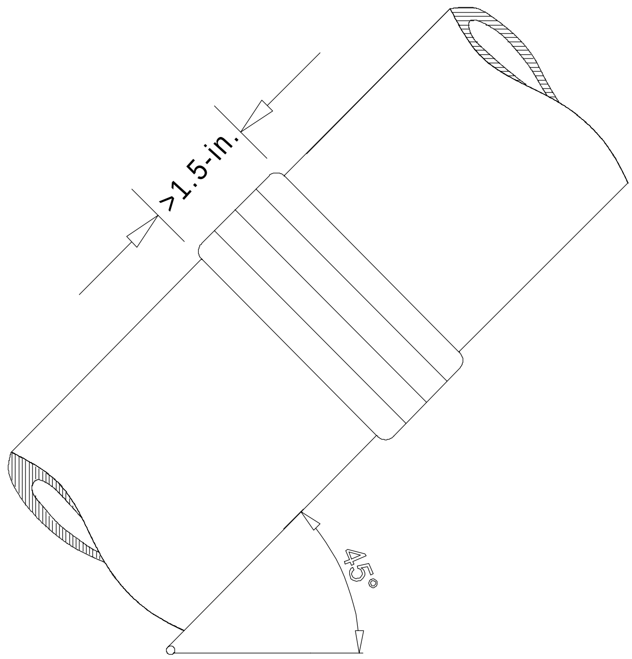


Figure 4-2. Repair Configuration

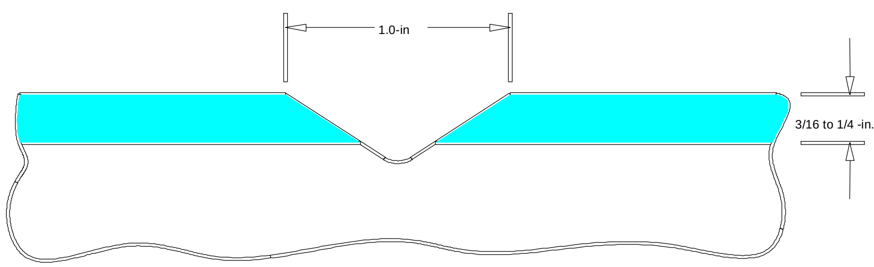


Figure 4-3. Groove Profile for Multi-Bead, Multi-Layer Repair App

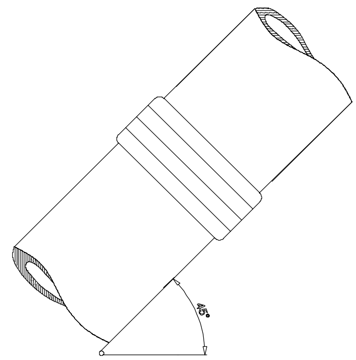
APPENDIX A: PROCEDURE QUALIFICATIONS

DRAFT 11-27-00 NOREM-02, Schedule 80 Type 304L Stainless Steel Pipe	Form PQR-1 **WELDING PROCEDURE QUALIFICATION**	PQR No.003 REV. Page 1 of 2 WPS No(s).

WELDING PROCESS(ES)

1. PTAW-Powder — TYPE: Manual
2. — TYPE

JOINTS (QW-402)



BASE METALS (QW-404)
P No. 8 Gr. No. ____ to P No. ___-Gr. No. ____
Type 304L
Thickness: Schedule 80 (.337-in.)
Pipe Diameter: 4-inch
Maximum Pass Thickness:

POSTWELD HEAT TREATMENT (QW-407)
Type: N/A
Temperature:
Time Range:

FILLER METALS (QW-404)
1. 2,
F No.:
A No.:
SFA Spec. No.: Norem-02
AWS Class: FeCrMn-02
Size of Electrode: N/A
Size of Filler: -100/+325 mesh
Supplemental Filler: N/A
Supplemental Powder: N/A
Electrode-Flux Class: N/A
Consumable Insert: N/A
Deposited Thickness: ~.1-in. per pass
Other:
Powder Feed Rate: 2.75 setting

GAS (QW-408)

	Gas(es)	Percent Composition Mixture	Flow Rate, CFH
Shielding:	Argon	Weld Grade	25cfh
Trailing:	N/A		
Backing:	N/A		
Powder:	Argon	Weld Grade	10cfh
Plasma:	Argon	Weld Grade	10cfh

ELECTRICAL CHARACTERISTICS (QW-409)
1. 2.
Current: DCSP
Amp Range: 50-70 amps (~57)
Volt Range: 23-25 (24V)
Transfer Mode: N/A
Tungsten Electrode Size/Type: 3/32-in. 2% Thoriated

POSITION (QW-405)
Welding Position(s): 6G
Welding Progression: uphill

PREHEAT (QW-406)
Preheat Temp. 70^{0}F (min.)
Interpass Temp. 400^{0}F (max.)
Preheat Maintenance

JOINT DESIGN (QW-407)
Groove Design: Overlay
Joint Type: OB ______ CI ______ BS
Backing Material Type:
Retainers:

TECHNIQUE (QW-410)
1. 2.
Stringer or Weave Bead: Weave
Bead Width (max.): ½-in.
Orifice of Gas Cup Size: 5/8-in.
Oscillation (max.): ¼-in. max.
Travel Speed (ipm): ~2.5 ipm
Contact Tube to Work (in.): 3/8 to ½-in.
Multiple or Single Layer/Side: Multiple
Multiple or Single Electrodes: Single
Initial and interpass cleaning: Welding surfaces shall be wire brushed or ground as required to remove slag, scale or other contaminants.
Method of Backgouging: N/A
Peening: N/A

PQR No.003

Rev.

Tensile Tests (QW-150)

Specimen No.	Width, in.	Thickness, in.	Area, in^2	Ultimate Total Load, lbs.	Ultimate Unit Stress, psi	Type of *Failure/**Location

***(D=Ductile, B=Brittle) **(BM=BaseMetal, WM=Weld Metal)**

Guided Bend Tests (QW-160)

Type	Figure No.	Result

Toughness Tests (QW-170)

Specimen No.	Notch Location	Notch Type	Test Temp.	Impact Value	Lateral Expansion		Drop Weight	
					% Shear	Mils	Break	No Break

Fillet Weld Test (QW-180)

Result – Satisfactory	*Yes*	*No*	Penetration into Base Metal	Yes	No	Macro – Results Satisfactory	Yes	No

Other Tests

Type of Test	Penetetrant Test QW-195, Hardness (Rc), Visual Examination (5X)
Deposit Analysis	See Table 3-5
Other	

Welder/Operator: **Stamp No.:**

Test Conducted By: **Laboratory Test No.:**

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

By: ________________________________

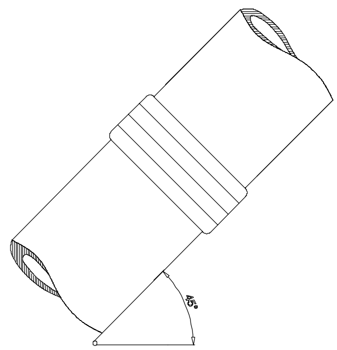
Date: ____________________

Form PQR-2

DRAFT 10-10-00 **Stellite 21, Schedule 80 Type 304L Stainless Steel Pipe**	Form PQR-1 **WELDING PROCEDURE QUALIFICATION**	**PQR No.001** **REV.** **Page 1 of 2** **WPS No(s).**

WELDING PROCESS(ES)
1. PTAW-Powder **TYPE: Manual**
2. **TYPE**

JOINTS (QW-402)



BASE METALS (QW-404)
P No. 8 Gr. No. _____ to P No. ___-Gr. No. _____
Type 304L
Thickness: Schedule 80 (.337-in.)
Pipe Diameter: 4-inch
Maximum Pass Thickness:

POSTWELD HEAT TREATMENT (QW-407)
Type: N/A
Temperature:
Time Range:

FILLER METALS (QW-404)
1. **2,**
F No.:
A No.:
SFA Spec. No.: Stellite 21- Plasma Weld-W
AWS Class: Lot 3000553-1
Size of Electrode: N/A
Size of Filler: -100/+325 mesh
Supplemental Filler: N/A
Supplemental Powder: N/A
Electrode-Flux Class: N/A
Consumable Insert: N/A
Deposited Thickness: .1 to .12-in. per layer
Other:
Powder Feed Rate: 4.0 setting

GAS (QW-408)

	Gas(es)	Percent Composition Mixture	Flow Rate, CFH
Shielding:	Argon	Weld Grade	25cfh
Trailing:	N/A		
Backing:	N/A		
Powder:	Argon	Weld Grade	10cfh
Plasma:	Argon	Weld Grade	15cfh

ELECTRICAL CHARACTERISTICS (QW-409)
1. **2.**
Current: DCSP
Amp Range: 50-70 amps (~70)
Volt Range: 23-25 (23V)
Transfer Mode: N/A
Tungsten Electrode Size/Type: 3/32-in. 2% Thoriated

POSITION (QW-405)
Welding Position(s): 6G
Welding Progression: uphill

PREHEAT (QW-406)
Preheat Temp. (min.) 70^0F
Interpass Temp. (max.) 400^0F
Preheat Maintenance

JOINT DESIGN (QW-407)
Groove Design: Overlay
Joint Type: OB _______ CI _______ BS
Backing Material Type:
Retainers:

TECHNIQUE (QW-410)
1. **2.**
Stringer or Weave Bead: Weave
Bead Width (max.): ¾-in. max.
Orifice of Gas Cup Size: 5/8-in.
Oscillation (max.): ¼ to 5/16-in. max.
Travel Speed (ipm): ~2.0 ipm
Contact Tube to Work (in.): 3/8 to ½-in.
Multiple or Single Layer/Side: Multiple
Multiple or Single Electrodes: Single
Initial and interpass cleaning: Welding surfaces shall be wire brushed or ground as required to remove slag, scale or other contaminants.
Method of Backgouging: N/A
Peening: N/A

PQR No.001

Rev.

Tensile Tests (QW-150)

Specimen No.	Width, in.	Thickness, in.	Area, in^2	Ultimate Total Load, lbs.	Ultimate Unit Stress, psi	Type of *Failure/**Location

***(D=Ductile, B=Brittle) **(BM=BaseMetal, WM=Weld Metal)**

Guided Bend Tests (QW-160)

Type	Figure No.	Result

Toughness Tests (QW-170)

Specimen No.	Notch Location	Notch Type	Test Temp.	Impact Value	Lateral Expansion		Drop Weight	
					% Shear	Mils	Break	No Break

Fillet Weld Test (QW-180)

Result – Satisfactory	*Yes*	*No*	Penetration into Base Metal	Yes	No	Macro – Results Satisfactory	Yes	No

Other Tests

Type of Test	Penetetrant Test QW-195, Hardness (Rc), Visual Examination (5X)
Deposit Analysis	See Table 3-4
Other	

Welder/Operator: **Stamp No.:**

Test Conducted By: **Laboratory Test No.:**

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

By: ________________________________

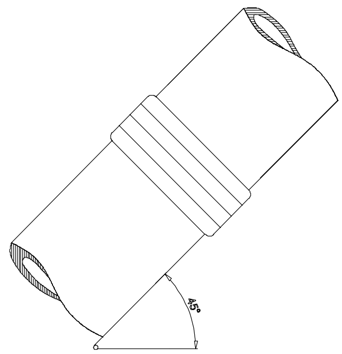
Date: ____________________

Form PQR-2

DRAFT 10-10-00 Stellite 21, Schedule 80 Type 304L Stainless Steel Pipe	Form PQR-1 **WELDING PROCEDURE QUALIFICATION**	PQR No.002 REV. Page 1 of 2 WPS No(s).

WELDING PROCESS(ES)
1. PTAW-Powder — TYPE: Manual
2. — TYPE

JOINTS (QW-402)



BASE METALS (QW-404)	POSTWELD HEAT TREATMENT (QW-407)
P No. 8 Gr. No. ____ to P No. ____-Gr. No. ____ Type 304L Thickness: Schedule 80 (.337-in.) Pipe Diameter: 4-inch Maximum Pass Thickness:	Type: N/A Temperature: Time Range:

FILLER METALS (QW-404)

	1.	2,
F No.:		
A No.:		

SFA Spec. No.: Stellite 21- Plasma Weld-W
AWS Class: Lot 3000553-1
Size of Electrode: N/A
Size of Filler: -100/+325 mesh
Supplemental Filler: N/A
Supplemental Powder: N/A
Electrode-Flux Class: N/A
Consumable Insert: N/A
Deposited Thickness: .16 to .18-in. per layer
Other:
Powder Feed Rate: 4.0 setting

GAS (QW-408)

	Gas(es)	Percent Composition Mixture	Flow Rate, CFH
Shielding:	Argon	Weld Grade	25cfh
Trailing:	N/A		
Backing:	N/A		
Powder:	Argon	Weld Grade	10cfh
Plasma:	Argon	Weld Grade	15cfh

ELECTRICAL CHARACTERISTICS (QW-409)

	1.	2.
Current:	DCSP	

Amp Range: 50-70 amps (~70)
Volt Range: 23-25 (23V)
Transfer Mode: N/A
Tungsten Electrode Size/Type: 3/32-in. 2% Thoriated

POSITION (QW-405)
Welding Position(s): 6G
Welding Progression: uphill

PREHEAT (QW-406)
Preheat Temp. 70^0F (min.)
Interpass Temp. 400^0F (max.)
Preheat Maintenance

JOINT DESIGN (QW-407)
Groove Design: Overlay
Joint Type: OB ______ CI ______ BS
Backing Material Type:
Retainers:

TECHNIQUE (QW-410)

	1.	2.

Stringer or Weave Bead: Weave
Bead Width (max.): 1/2-in. max.
Orifice of Gas Cup Size: 5/8-in.
Oscillation (max.): 3/16 to 1/4-in. max.
Travel Speed (ipm): ~2.5 ipm (manual)
Contact Tube to Work (in.): 3/8 to ½-in.
Multiple or Single Layer/Side: Multiple
Multiple or Single Electrodes: Single
Initial and interpass cleaning: Welding surfaces shall be wire brushed or ground as required to remove slag, scale or other contaminants.
Method of Backgouging: N/A
Peening: N/A

PQR No.002

Rev.

Tensile Tests (QW-150)

Specimen No.	Width, in.	Thickness, in.	Area, in^2	Ultimate Total Load, lbs.	Ultimate Unit Stress, psi	Type of *Failure/**Location

***(D=Ductile, B=Brittle) **(BM=BaseMetal, WM=Weld Metal)**

Guided Bend Tests (QW-160)

Type	Figure No.	Result

Toughness Tests (QW-170)

Specimen No.	Notch Location	Notch Type	Test Temp.	Impact Value	Lateral Expansion		Drop Weight	
					% Shear	Mils	Break	No Break

Fillet Weld Test (QW-180)

Result – Satisfactory	*Yes*	*No*	Penetration into Base Metal	Yes	No	Macro – Results Satisfactory	Yes	No

Other Tests

Type of Test	Penetetrant Test QW-195, Hardness (Rc), Visual Examination (5X)
Deposit Analysis	See Table 3-4
Other	

Welder/Operator: **Stamp No.:**

Test Conducted By: **Laboratory Test No.:**

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

By: ________________________________

Date: ____________________

Form PQR-2

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