NEW YORK POWER AUTHORITY

JAMES A. FITZPATRICK NUCLEAR POWER PLANT

DEVELOPMENT OF INCONEL WELD OVERLAY REPAIR FOR CARBON STEEL TO STAINLESS STEEL WELD JOINTS

Prepared By: Joseph Lafferty 4-10-90
Joseph Lafferty

Reviewed By: 4/10/90
Robert Penny

Approved By: 4/10/90
Richard Lauman

NEW YORK POWER AUTHORITY
JAMES A. FITZPATRICK NUCLEAR POWER PLANT
DOCKET NO. 50-333

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLES

TABLE OF CONTENTS (Cont'd)

FIGURES

EXECUTIVE SUMMARY

The weld overlay repair for austenitic stainless steel butt welded joints has gained widespread acceptance as one of the piping repair options of choice since it was first applied to boiling water weld joints in 1982. Since that time, industry attention has expanded to those pressure boundary joints which do not fall within this family of acceptable joints for weld overly repair (i.e., low alloy and carbon steel material).

Specific guidance is not available for qualifying structural weld overlays on dissimilar metal weld joints. The general practice has been to qualify this weld procedure by performing a groove weld per ASME Section IX and by taking guidance from Code Case N-432 with regard to preheat, welding, and post weld heat treatment requirements.

At the James A. FitzPatrick Nuclear Power Plant, there are six bimetallic weld joints consisting of stainless steel to carbon steel material. These joints are located between the Residual Heat Removal (RHR) system piping and the main recirculation system.

As it is not feasible to isolate these welds from the recirculation system, a modified "Temper Bead" approach was developed to qualify a weld overlay repair without dewatering the recirculation system. The noteworthy advantages of not dewatering the recirculation system during an overlay repair are the reduced man rem exposure and the savings of approximately two weeks of critical path time during a normal refuel outage.

The test results from the qualification of the "Temper Bead" weld overlay repair approach demonstrate that sound metallurgical bonding and the special issues of preserving base metal toughness is achievable. Carbon steel test weldments demonstrated the same degree of tempering and grain refinement with lower preheat and no post heat treatment as those weldments receiving the Code Case N-432 prescribed heat treatments.

The procedure development and testing was based on the modeling and qualification work developed by Structural Integrity and Georgia Power Company for EPRI. The following report describes the weld repair development and qualification, the ASME Code considerations addressed, and the microhardness and Section IX mechanical property results from this qualification. This qualification work is the technical basis for weld overlay repairs on low alloy steel material with reduced preheat and no post heat treatments.

SECTION 1.0 - INTRODUCTION

The Residual Heat Removal (RHR) inlet piping system at the James A. FitzPatrick Nuclear Power Plant (JAFNPP) is basically a carbon steel system, and as such is not considered susceptible to intergranular stress corrosion cracking (IGSCC). It consists of two lines (24W20-902-14A and 24W20-902-14B) of 24 inch nominal pipe size (NPS) carbon steel piping. There are, however, three bimetallic welds in each line near the point where the RHR piping joins the main recirculation system. These welds are potentially susceptible to IGSCC.

As illustrated in Figure 1-1, there are a total of six such bimetallic welds in the RHR System. They include two carbon steel pipe elbow to stainless steel check valve welds (weld numbers 24-10-132 in loop A and 24-10-144 in loop B), two stainless steel check valve to carbon steel valve welds (weld numbers 24-10-131 in loop A and 24-10-143 in loop B), and two carbon steel valve to main recirculation pipe tee welds (weld numbers 24-10-130 in loop A and 24-10-142 in loop B). Valve and weld identification numbers are also shown in Figure 1-1.

The general configuration of these six welds is similar and is illustrated in Figure 1-2. The carbon steel sides of the weld joints were buttered with Inconel 182 and then an inconel butt weld was made between the stainless steel component and the inconel buttered carbon steel component using an Inconel 82 root pass and Inconel 182 filler material. Inconel 182 has been identified as an IGSCC susceptible material by the Nuclear Regulatory Commission (NRC) and has in fact exhibited such cracking in a number of operating BWRs, e.g., Pilgrim, Brunswick, Vermont Yankee, and Chinshan (Taiwan). At some of these plants the weld overlay repair technique has been used to reestablish the original design code safety margins of cracked weldments

Since the geometry of the weld joints involve carbon steel components of nominal thicknesses greater than 3/4 inches, the original construction code for the piping, Reference 2, requires Post Weld Heat Treatment (PWHT) following application of the weld overlay. The geometry of the six weld joints is illustrated in Figure 1-2. Calibration block drawings are included in Appendix 2 to illustrate joint geometry based on ultrasonic inspections.

As a conservative approach, the New York Power Authority (NYPA) chose to qualify a weld repair procedure in accordance with current industry practices using NRC accepted Temper Bead Repair Welding techniques. The results of NYPA's procedural qualification demonstrates that carbon steel is adequately tempered with good grain refinement when performing weld overlays using temper bead welding techniques with low and no post weld heat treatments.

The alternative to PWHT, as presented in Code Case N-432 (Reference 6), is called "temper bead welding" which has been applied successfully to similar weld overlay repairs of inconel buttered low alloy steel reactor vessel nozzle to safe-end welds (See References 3 and 7). An adaptation of the temper bead weld overlay approach for carbon steel components was selected for this development program. Code Case N-432 was developed for the repair of a cavity created by excavation of a defect found in a carbon or low-alloy steel pressure boundary material. The weld procedure specifications developed for these applications will provide tempering of the heat affected zones through control of the welding parameters used to deposit the first few layers of the weld overlay. Specific guidance is not available in the code on the requirements for qualifying structural weld overlays on hardenable nozzle to safe-end or other dissimilar metal welds. The general practice has been to qualify these weld procedures by performing a groove weld per ASME Section IX and by taking guidance from Code Case N-432 with regards to welding, preheat, and PWHT requirements.

Performing the preheat and post heat treatment of Code Case N-432 may require that the component be drained of water since a water-backed condition makes it difficult and in some cases impossible to reach the temperatures specified using resistance heater elements. An additional consideration in developing these procedures was the radiation exposure to personnel working around a drained nozzle, pipe, or valve. Two of the six bimetallic RHR weld joints can not be readily isolated from the reactor recirculation system. Five pairs of jet pump plugs would need to be installed and the recirculation system drained to perform the prescribed pre/post heat treatments on the carbon steel valve bodies. It is estimated an additional two weeks of critical path time would be required to perform this work. Given these considerations, it is extremely desirable to be able to perform these weld overlay repairs under a water-backed condition with reduced pre/post heat requirements.

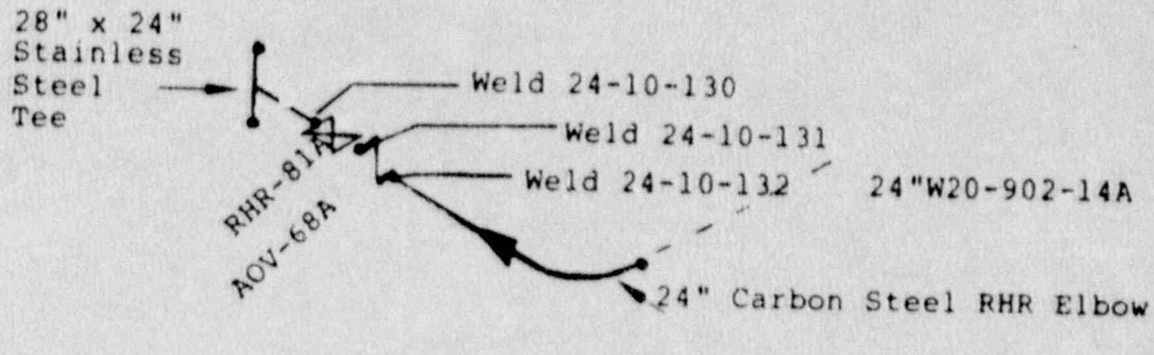
On four of the six bimetallic RHR weld joints, cast carbon steel A216 WCB makes up the hardenable component of the weldment. Therefore, cast carbon steel material of the same specification, type, and grade as found in the field installed valves was selected to perform the modified heat treatment qualification. Two of the six bimetallic welds are forgings qualified under the same Section IX "P" number grouping but are not of the exact specification, type, and grade as prescribed by Code Case N-432. The qualifications are acceptable for field use on those weld joints where the hardenable components are forged carbon steel material A234 WPB. Both materials A234 WPB and A216 WCB are listed as weldability Group P-1 under ASME Section XI. Both materials are compatible from the standpoint of metallurgical properties (i.e., chemical, and microstructure), heat treatment, design and mechanical properties.

The post heat requirements of Code Case N-432 is a low temperature bake-out to drive any potential hydrogen away from the weld. However, since this welding utilizes the gas tungsten arc welding (GTAW) technique, the possibility of significant hydrogen entering the base material from the welding process is low. In addition, the austenitic alloy used for weld deposit is hydrogen soluble which prevents the hydrogen from entering the base material. The Section XI special working committee on welding has been formally approached with the unanimous support of the Electric Power Research Institute (EPRI) advisory committee on temper bead welding to eliminate the 500 ± 50 °F post heat "Bake-Out" period when utilizing GTAW during temper bead repair welding. Elimination of the post heat treatment and relying on the weld procedure specification developed for these applications will provide the tempering of the heat affected zones through control of the welding parameters used to deposit the first few layers of the weld overlay.

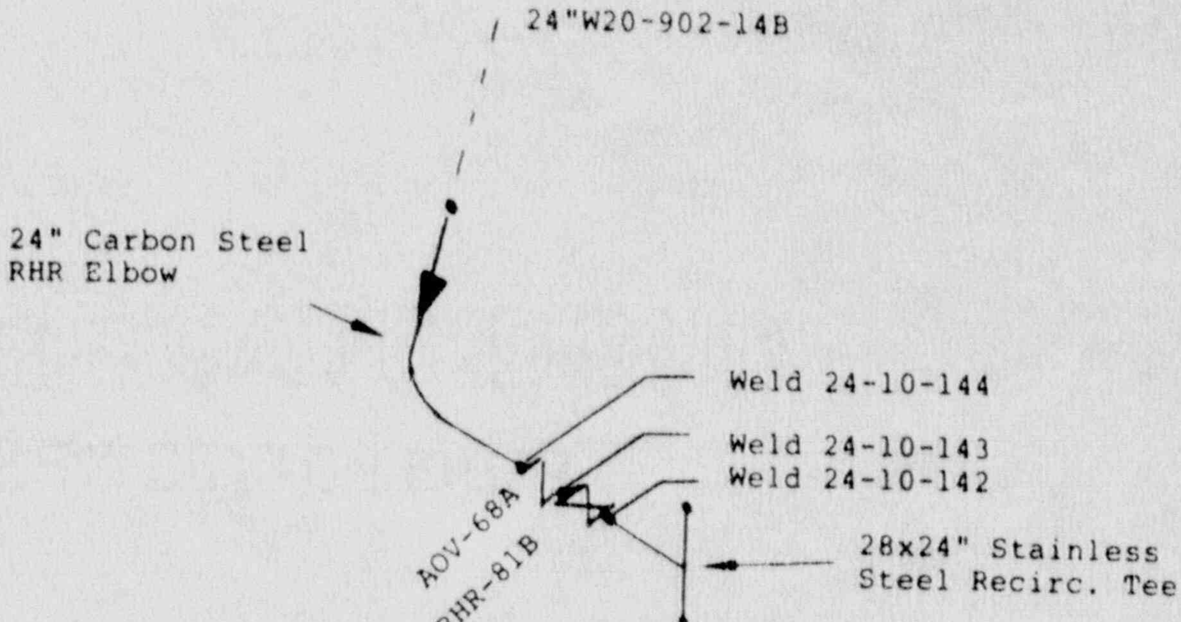
Section 2.0 of this report provides background information on the development and implementation of the temper bead weld overlay repair procedure approach. Section 3.0 of this report is a summary of extensive mechanical testing on various weld coupon sections. Testing was performed consistent with previous developmental qualification work, see References 3 and 7.

FIGURE 1-1

Isometric Sketches of Relevant Portions of RHR Inlet Piping Showing Bimetallic Welds



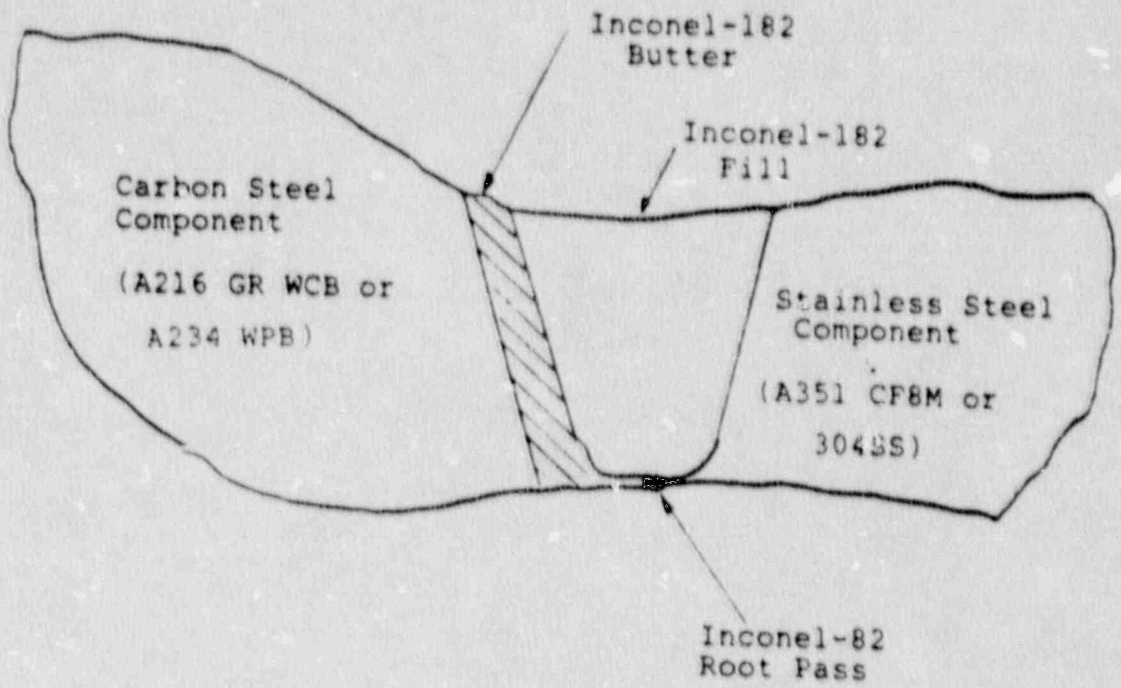
Loop A



Loop B

FIGURE 1-2

General Configuration of Bimetallic Welds



Pipe Component	Weld No	Pipe Component
Elbow	24-10-132 24-10-144	Check Valve
Valve	24-10-131 24-10-143	Check Valve
Valve	24-10-130 24-10-142	Tee

SECTION 2.0 - INCONEL TEMPER BEAD WELD OVERLAY REPAIR

2.1 INTRODUCTION

The inconel weld overlay procedure proposed for the JAFNPP RHR weld joints follows the procedural and technical approach for inconel weld overlays developed in Reference 3. This section of the report presents a summary and overview of the procedure development and significant test results from that program, which is the basis for the currently proposed contingency repairs at JAFNPP. This section is the basis for comparison of important welding variables between accepted practice and NYPA developed parameters.

2.2 BACKGROUND

The ASME Boiler and Pressure Vessel Code, Reference 4, and associated Codes, Reference 2, contain criteria and requirements for heat treatments associated with the welding of carbon and low alloy steel (P-1 and P-3) materials. In particular, for pressure boundary components such as piping, vessels and valves, criteria for preheat and post weld heat treatment for these materials are specified when the nominal thicknesses of these materials are above certain minimum values. Section XI of the Code also provides heat treatment criteria and controls for repair welding to pressure boundary materials. The criteria applied by Section XI allow for, in addition to the standard approach, the use of "half bead" repairs using the shielded metal arc welding technique. When applied according to the criteria of Article IWB-4000 of Section XI, this "half bead" approach requires no post weld heat treatment of the component. Specifically, subarticle IWB-4340 provides the criteria for welding dissimilar materials to P-1 and P-3 materials using the half bead welding technique. This approach involves welding according to IWB-4340 and removal of approximately one-half of the first layer by grinding. The second layer, when deposited according to IWB-4340, provides grain refinement and tempering of the underlying P-1 or P-3 material heat affected zone when deposited over the half bead remaining from the first layer of weld deposition. Thus, when using the half bead weld repair approach on carbon or low alloy steel components, no post weld heat treatment is required.

One restriction of the repair approach described in IWB-4340 is that only the shielded metal arc welding technique is allowed. To address this limitation, a program was initiated in 1978 by the EPRI and Babcock & Wilcox (B&W). During that study, the welding processes evaluated included the Shielded Metal Arc Welding process, the Gas Metal Arc Welding process, the Gas Tungsten Arc Welding process, and the somewhat non-conventional explosive welding and electron beam welding processes. The principal objective of the EPRI/B&W program was to develop an alternative to the half bead technique which was amenable to automation, allowing for greater ease of use in a radiation environment. The other objective of the program was to develop a process which was readily reproducible and which deposited a high quality weld, one in which the fracture toughness of the weld deposit would not be significantly undermined.

The EPRI/B&W program was successfully completed in 1983. The program demonstrated that the machine gas tungsten arc process could be qualified for repair of a pressure vessel cavity using specific welding controls. The results of this program, reported in Reference 7, provided the basis for a second welding development program, Reference 3, which qualified an inconel weld overlay for the repair of cylindrical bimetallic pipe weld such as the subject RHR welds at JAFNPP.

2.3 INCONEL WELD OVERLAY PROCEDURE DEVELOPMENT

Fundamental to the weld overlay development approach taken in Reference 3, was that the essential weld variables of Reference 7 would be maintained, as closely as possible, while developing the orbital weld repair approach needed for weld overlay repair. In doing so, it was anticipated the heat input required to provide the necessary grain refinement and tempering of the P-1 and P-3 material would be preserved. A further expectation was that an ASME Section XI Code Case on the topic, which at the time of the study was under consideration, could be referenced to form the basis of a licensing submittal to the NRC in the event that an inconel weld overlay repair was required at a domestic light water reactor nozzle to safe end joint. The Code Case, N-432, was approved in February, 1986.

The best of the temper bead procedures identified in the EPRI/B&W program was selected as the weld procedure to follow in development of the weld overlay temper bead approach for the low alloy steel side of the overlay. This procedure had produced the most favorable low alloy steel properties following weld repair in that program. The important welding variable and welding information from that procedure are reproduced in Table 2-1 of this report.

The approach used in Reference 3 for overlay welding of the stainless steel side of the joint was established to follow the standard for overlay repairs performed on numerous BWR pipe welds in the United States and Europe. In this approach, waterbacking is provided and stringer beads are deposited to obtain a favorable post-repair residual stress pattern while minimizing axial and radial shrinkage beneath the overlay. Consequently, a composite inconel weld overlay was designed as a temper bead overlay for the carbon or low-alloy steel material, followed by a "structural" weld overlay on the stainless steel side and covering over the inconel temper bead layers. The final overlay length and thickness were selected using conventional weld overlay design considerations for stainless steel pipe weld overlays. Specifics on these design characteristics (i.e., thickness and length) are not part of this submittal.

2.4 FABRICATION OF QUALIFICATION WELDMENTS

The approach taken in this development program was to follow as closely as practical the EPRI/B&W welding repair procedure as well as to comply with the intent of Section XI subsection IWB-4340 and Code Case N-432 requirements as applicable in qualifying the inconel weld overlay repair. Consequently, provisions were made in the mock-up program for the Code required tensile, bend and Charpy specimens as well as for metallurgical samples which would be used for hardness evaluations.

The actual mock-up utilized for PQR-396A was a 13-1/2 inch OD x 1-1/8 inch thick forged carbon steel SA-105 Grade B ring. The certified material test report is included in Appendix 1 of this report. The ring was prepped and buttered with Inconel 182 and heat treated at 1140°F for 10 hours. This conservatively simulates, under Section IX "P" number groups, a valve or pipe condition as installed prior to being prepped for the dissimilar metal girth weld to Type 347 stainless steel ring forging. Reviewing the carbon steel installation records revealed the valve material to have been buttered and heat treated in the shop and then repaired in the field. Shop records were not available to show actual times at temperature for heat treatment in the shop so a conservative approach of 10 hours to bound the actual time at temperature of the valve material was selected. The stainless steel ring which was welded to the aforementioned carbon steel ring consisted of a 13-1/2 inch OD x 1-1/8 inch thick forging. The girth weld which formed the basis of the mock-up inconel overlay was welded with a GTAW Inconel 82 root and welded out with SMAW Inconel 182 electrodes.

The dissimilar metal weld overlay mock-up was "temper bead" welded on the carbon steel side of the joint first using the layer 1, layer 2 and layer 3 parameters provided in Table 2-2. Preheat of 300°F held for one half hour was applied for slower cooling and lower residual stress. Following the completion of the "temper bead" layers, the mock-up received a post heat treatment of 450°F to 550°F for two hours followed by a slow cool consistent with the requirements of IWB-4340. An Inconel 82 overlay was then deposited on the stainless steel side of the joint using layer 4 parameters with preheat and interpass temperatures of 70°F and 350°F, respectively. When three Inconel 82 weld overlay layers were completed across the entire joint, the layer 4 parameters were used for the remainder of the overlay. A total of 6 layers were deposited to fabricate the overlay. The double down welding technique was utilized in the overlay welding. Results from work previously performed by Structural Integrity, Reference 3, establish that the tempering and grain refinement on P-1 material appears to be nearly complete following the third "temper bead" layer. Any further heat input which affects the carbon steel material can only assist in further tempering.

To provide the mechanical test specimens required for procedure qualifications, groove welds (PQR 399 and 401) were made using the weld parameters of Table 2-2. PQR 399 and 401 used a 24 inch OD cast SA 216 WCB pipe, with a 2 inch wall thickness. A copy of the certified material test report is included in Appendix 1. This material was used for the code case base groove weld for the following two reasons. First it was available, procurement of large diameter and heavy wall pipe in small orders is very hard to attain. Secondly, the carbon steel valve material, which can not be isolated from the RHR system, would have the largest impact to critical path if high preheat and post heat requirements were employed. Having data on various pre and post heated SA 216 specimens would address the hardenability issue of welding on carbon steel material for 4 of the 6 dissimilar weld joints in the RHR system based on using Code Case N-432 prescribed material specification type and grade.

A 1 inch deep groove was machined in the middle of the specimen and welded with the same weld parameter for layers 1, 2, and 3 of PQR 396A. The only exception was a 200°F preheat with no post heat treatment. Subsequent fill layers were deposited using Table 2-2 layer 4 parameters. The 200°F preheat is in accordance with the 1986 Edition of the original construction code, ANSI B31.1.

To establish a basis for comparison, a second PQR 401 using the same base material, SA 216 WCB cast carbon steel, was developed . The same 1 inch groove, as in PQR 399, was machined in the ring. Weld metal was deposited in accordance with the parameters of Table 2-2 as was PQR-399. In this case, a 300°F preheat was used in compliance with Section XI and upon completion of the first three layers a 500°F post heat treatment was applied for two hours with a slow cool consistent with the requirements of IWB-4340 of the Code. Subsequent fill layers were deposited using Table 2-2, layer 4 parameters. PQR 401 gave us a code accepted benchmark which we could use to compare the material test results of identical material using a lower preheat and no PWHT during qualification.

2.5 QUALIFICATION OF INCONEL OVERLAY PROCEDURES

As described in Section 2.3 of this report, the approach used in the development and qualification of the inconel weld overlay process for the carbon steel to stainless steel RHR dissimilar metal welds was based upon the EPRI/B&W development program which led to an approved ASME code case in February, 1986. Furthermore, the requirements of this code case are under review by the EPRI advisory committee on temper bead welding, for eliminating the post heat treatment requirements, as the need to drive hydrogen away from the weld is not necessary for the GTAW welding process. Code Case N-432 allows that an automatic GTAW technique can be used for repair welding of low-alloy or carbon steel component without the requirements of a PWHT, provided that the procedures of the Code Case are followed. The welding parameters used for the inconel weld overlay process development followed the EPRI/B&W parameters to the extent practical in conjunction with the requirements of IWB-4340 on weld overlay repairs.

The Charpy and Tensile property data for PQR 399, which received a 200°F preheat and no post heating, are presented in Table 2-3. The two Tensile test runs both failed in the carbon steel base material at stresses of 74.5 and 75.0 KSI, respectively. These results compare very favorably with the Tensile test results presented on the certified material test reports for this heat of material (Appendix 1). The Charpy V notch results taken at 40°F show that the heat affected zone and base metal have essentially the same absorbed energy, percentage of shear fracture, and mils lateral expansion. The bend tests all showed satisfactory results with no rejectable defects.

The Charpy and Tensile property data for PQR 401, which received a preheat and post heat treatment of 300°F and 500°F, are presented in Table 2-4. These results compare very favorably with the Tensile results presented on the certified material test reports for this heat of material (Appendix 1). The Charpy V notch results for the heat affected zone and base metal have essentially the same absorbed energy, percentage of shear fracture, and lateral expansion. The bend test all showed satisfactory results with no rejectable defects. Comparing the Charpy and Tensile results between PQR 399 and 401 shows only marginal improvement in toughness and strength for the SA 216 WCB carbon steel when following the code prescribed pre and post weld heat treatments.

In addition to the mechanical property test, microhardness determinations were performed on both groove specimens and the dissimilar metal mock-up (PQR 399, 401, and 396A). The results of these metallurgical examinations are presented in Section 3.0 of this report.

TABLE 2-1

**Welding Parameters Used in Procedure "F"
Weld in Reference [7]**

	Layer 1	Layer 2	Layer 3
Current (A)	180	200	220
Voltage (V)	11	11	11
Wire Feed (ipm)	39	59	65
Travel (ipm)	8.5	7	6
Bead Overlap (%)	50	50	50
Preheat (°F)	300	300	300
Max. Interpass (°F)	500	500	500

Wire Diameter – 0.035 Inch

Shielding Gas – AR 18 CFH

Electrode
- 2% Thoria Tungsten; 5/32 - Inch Diameter;
- 2-1/2 - Inch Total Stick-out (with Long Gas Cup)
- Tip: 22.5° Included Angle

TABLE 2-2

Temper Bead Weld Overlay Parameter Information

Layer 1 Parameters

- Current: 120 Amps: 1/3 of time
  210 Amps: 2/3 of time
- Voltage: 9.8 volts
- No oscillation
- Wire Size 0.035 inch diameter ARCOS ERNiCR-3 wire
- Torch Angle 90°
- Shield Gas: Welding Grade Argon @ 30 ft^3/hour
- Wire Feed:
  - 30 inches/minute - 1/3 of the time
  - 43 inches/minute - 2/3 of the time
- Travel Speed: 8.5 inches/minute
- Bead overlap was 50%
- Preheat and interpass of 300 to 450°F during entire layer
- Double down welding
- Heat input of 12,451 J/inch

Layer 2 Parameters

- Current: 140 Amps: 1/3 of time
  230 Amp: 2/3 of time
- Voltage: 9.8 Volts
- No oscillation
- Wire Size: 0.035 inch diameter
- Torch Angle - 90°
- Shield Gas: Argon @ 30 ft^3/hour
- Wire Feed:
  - 51 inches/minute: [illegible]/3 of time
  - 63 inches/minute: 2/3 of time
- Travel Speed: 7 inches/minute
- Preheat and interpass temperature 300 to 450°F
- Heat input: 16,800 J/inch
- Double down welding
- Bead overlap was 50%

TABLE 2-2 (cont'd)

Temper Bead Weld Overlay Parameter Information

Layer 3 Parameters

- o Current: 140 Amps: 1/3 of time
  240 Amps: 2/3 of time
- o Voltage: 9.8 Volts
- o Oscillation: none
- o Wire Size: 0.035 inch diameter
- o Torch Angle: as layer 1
- o Shield Gas: as layer 1
- o Wire Feed:
  - 56 inches/minute: 1/3 of time
  - 69 inches/minute: 2/3 of time
- o Bead overlap: 50%
- o Heat input: 20,247 J/inch
- o Preheat and interpass temperature 300 to 450°F
- o Travel speed: 6 inches/minutes

Following Third Layer (For PQR´s 396A and 401 Only)

- o Hold preheat until post-heat
  - Post-Heat - 450 - 550°F
  - Hold two hours and slow cool

Layer 4 and Balance Layers

- o Current: 120 to 140 Amps: 1/3 of time
  210 to 240 Amps: 2/3 of time
- o Voltage: 9.8 Volts
- o Oscillation: none
- o Wire Size: 0.035 inch diameter
- o Torch Angle: as layer 1
- o Shield Gas: as layer 1
- o Wire Feed:
  - 56 inches/minute: 1/3 of time
  - 69 inches/minute: 2/3 of time
- o Bead overlap: 50%
- o Preheat and interpass temperature 70 to 350°F
- o Travel speed: 6 inches/minutes

TABLE 2-3

Mechanical Property Results on Specimens Removed from Groove Weld (Figure 3-1) 200°F Preheat / No Post Heating

Charpy Impact Properties @ 40°F

Location	PQR	Absorbed Energy (Ft-Lbs)	Fracture Appearance (% Shear)	Lateral Expansion (inches)
HAZ	399	32	15	.030
		33	15	.030
		34	15	.032
BM	399	31	20	.034
		34	20	.035
		39	20	.039
Re-Test				
HAZ	399	31	20	.031
		32	20	.034
		33	20	.032
BM	399	35	20	.040
		30	20	.032
		26	20	.033

AVERAGE HAZ = 32.5
AVERAGE BM = 32.5

TENSILE TEST RESULTS

PQR 399

Specimen No.	Ultimate Tensile Strength (KSI)	Failure Location	Fracture Appearance
1	74.5	BM	Ductile/Shear
2	75.0	BM	Ductile/Shear

ALL WELD METAL TENSION TEST

Specimen No.	Ultimate Tensile Strength (PSI)	Failure Location
1	101	WM

TABLE 2-4

Mechanical Property Results on Specimens Removed from Groove Weld (Figure 3-1) 300°F Preheat and 500°F Post Heat Treatment

Charpy Impact Properties @ 40°F

Location	PQR	Absorbed Energy (Ft-Lbs)	Fracture Appearance (% Shear)	Lateral Expansion (inches)
HAZ	401	41	20	.030
		43	25	.036
		46	25	.041
BM	401	34	25	.035
		43	30	.042
		45	35	.045
Re-Test				
HAZ	401	36	20	.034
		22	10	.024
		33	20	.031
BM	401	30	20	.034
		38	20	.039
		36	20	.038

AVERAGE HAZ = 34.8
AVERAGE BM = 37.6

TENSILE TEST RESULTS

PQR 401

Specimen No.	Ultimate Tensile Strength (PSI)	Failure Location	Fracture Appearance
1	76,000	BM	Ductile/Shear
2	75,700	BM	Ductile/Shear

ALL WELD METAL TENSION TEST

Specimen No.	Ultimate Tensile Strength (PSI)	Failure Location
1	105,100	WM

TABLE 2-5

Mochanical Property Results on Dissimilar Metal Weld Overlay Mock-Up (Figure 3-2)

Charpy Impact Properties @ 40°F

Location	PQR	Absorbed Energy (Ft-Lbs)	Fracture Appearance (% Shear)	Lateral Expansion (inches)
HAZ	396A	77	70	.058
		82	75	.061
		84	60	.062
BM	396A	15	15	.017
		22	15	.021
		24	15	.023

TENSILE TEST RESULTS

Specimen No.	Ultimate Tensile Strength (KSI)	Failure Location	Fracture Appearance
1 Overlay	101	WM	Ductile/Shear
2 Overlay	101.7	WM	Ductile/Shear
3 Groove	88.9	BM	Ductile/Shear
4 Groove	102	WM	Ductile/Shear

SECTION 3.0 - MICROHARDNESS STUDIES

3.1 INTRODUCTION

The mechanical property results reported in Section 2.0 verified that the Inconel 82 weld overlay repair did not degrade the strength or toughness of the carbon steel weld heat affected zone. Further, the bend test results indicated that the weldment provided a sound metallurgical bond between the two different specifications of carbon steel and the inconel overlay. In this section, the results of microhardness measurements performed on the test pieces are reported.

The microhardness traverses performed in this study include two traverses for the 2 temper bead trials performed on SA 216 carbon steel pipe per Figure 3-1 and the traverse per Figure 3-2 for the dissimilar metal weld overlay mock-up. Hardness results were compared to the EPRI/B&W results. Noting that the material differences of low alloy versus carbon steel will give different hardnesses values, the trend established for tempering and peak hardness values could be evaluated. A comparison of the microhardness values between the different heat treated cast carbon steel material is presented in this section.

3.2 RESULTS OF MICROHARDNESS INVESTIGATIONS

Extensive microhardness measurements were performed on the P-1 side of the Inconel Weld Overlay Mock-up. Microhardness measurements were performed beneath the overlay to provide representative values (Table 3-1) of the tempering action on the base material. In addition, measurements were performed at the extremity of the overlay in the P-1 material to evaluate the effect of incomplete tempering (Tables 3-2 and 3-3) at the overlay edge. Microhardness measurements were also performed on the heat affected zone of the P-1 material, which received a post weld heat treatment following the butter application (Table 3-4).

Microhardness measurements were performed at the base of the weldment on both groove weldments. This location also corresponds to the location where the Charpy and bend specimens were taken. The results of these microhardness measurements are presented in Table 3-5 for PQR 399 and Table 3-6 for PQR 401. Peak hardness values for PQR's 399 and 401 are 262 KHN and 237 KHN, respectively. The trend of having higher hardness values at a distance between 100 to 900 microns from the weld fusion line compares very favorably to hardness trends established in the testing results presented in Reference 3. Additionally, the rise in hardness values in the 100 to 900 micron range is substantially smaller than the change in hardness found in Reference 3. This confirms, in both PQR's, that carbon steel is a more forgiving material and less hardenable than low alloy steel. The microhardness results of both PQR 399 and PQR 401 approximated the base material hardness values at 200 and 190 KHN, respectively.

The issue of untempered P-1 material at the extremity of the inconel overlay (overlay edge) was also examined in this study. Tables 3-2 and 3-3 presents two individual microhardness traverses at the overlay edge in the P-1 material. The radial microhardness traverses extended from the edge of the overlay into the P-1 material and radially through the P-1 heat affected zone to the base metal. Note that a maximum hardness of 244 KHN occurred on the traverse a distance of approximately 100 microns radially into the P-1 heat affected zone. A tangential microhardness traverse was also made at a depth of approximately 300 microns into the P-1 heat affected zone to determine the extent of this hardened end effect.

Microhardness results greater than 250 KHN were noted at a distance of approximately 900 microns beyond the edge of the overlay. The microhardness fell below 200 KHN beyond approximately 1500 microns from the overlay edge.

A fourth set of microhardness measurements were performed on the P-1 material representative of an inconel buttered, post weld heat treated heat effected zone. Table 3-4 presents the results of these measurements. A microhardness value of 199 KHN was obtained in the post weld heat treated heat affected zone at a distance of approximately 300 microns from the butter fusion line.

TABLE 3-1

Microhardness Measurements in the P-1 Heat Affected Zone of the Inconel Weld Overlay Taken as Illustrated in the Sketch Below

PQR-396A

Distance From Fusion Line (Microns)	Knoop Hardness Values (500 Gram Load)
50	219
100	257
300	232
500	215
700	215
900	213
1100	215
1300	216
1500	206
1700	199
1900	191
2100	200
2300	203
2700	189

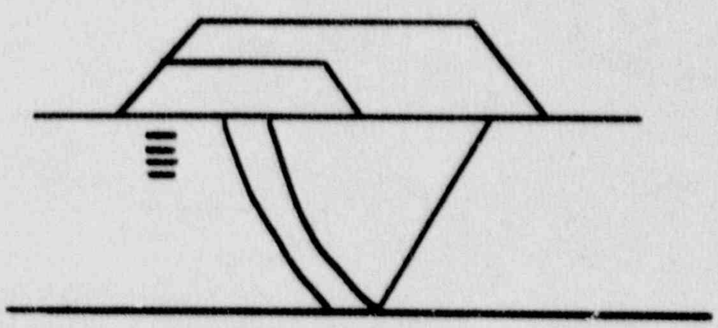


TABLE 3-2

Microhardness Measurements in the P-1 Heat Affected Zone of the Inconel Weld Overlay Taken at the Edge of the Overlay as Illustrated in the Sketch Below

PQR-396A

Distance from Fusion Line (Microns)	Knoop Hardness Values (500 Gram Load)
50	226
100	244
300	220
500	217
700	206
900	225
1100	204
1300	213
1500	215
1700	203
1900	206
2100	210
2300	182
2700	190

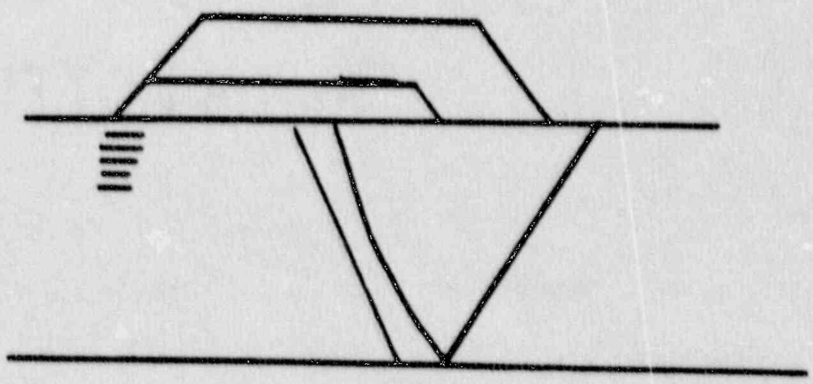


TABLE 3-3

Microhardness Measurements in the P-1 Heat Affected Zone of the Inconel Weld Overlay Taken at the Edge of the Overlay as Illustrated in the Sketch Below

PQR-396A

Distance from Fusion Line (Microns)	Knoop Hardness Valves (500 Gram Load)
50	232
100	242
300	228
500	224
700	232
900	257
1100	245
1300	238
1500	210
1700	217
1900	215
2100	194
2300	192
2700	199

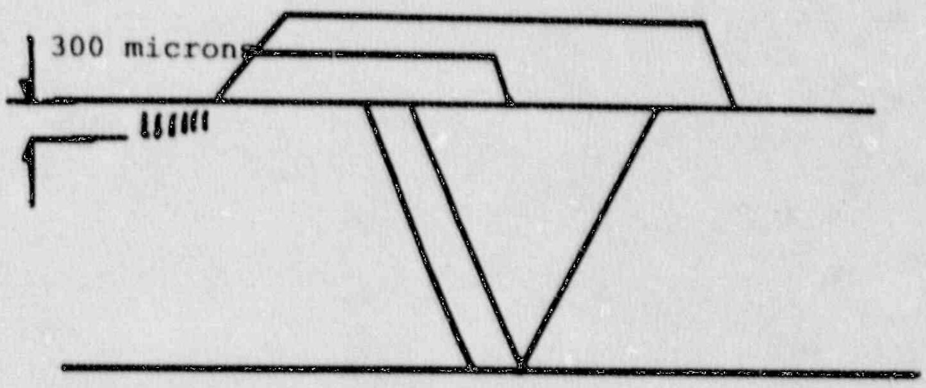


TABLE 3-4

Microhardness Measurements in the P-1 Heat
Affected Zone of the Inconel Weld Overlay
Taken as Illustrated in the Sketch Below

PQR-396A

Distance from Fusion Line (Microns)	Knoop Hardness Values (500 Gram Load)
50	175
100	191
300	199
500	180
700	177
900	191
1100	182
1300	191
1500	205
1700	186
1900	183
2100	191
2300	185
2700	172

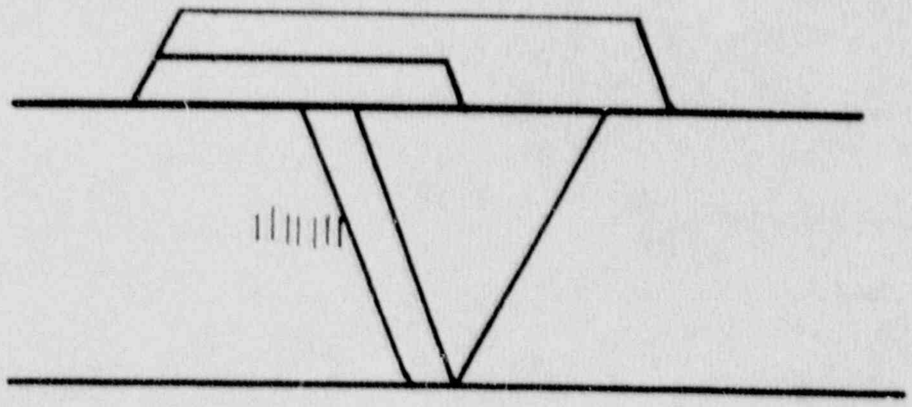


TABLE 3-5

Microhardness Measurements in the P-1 Heat Affected Zone of the Groove Weld Taken as Illustrated in the Sketch Below
200°F Preheat, No Post Heating

PQR-399

Distance from Fusion Line (Microns)	Knoop Hardness Values (500 Gram Load) (Peak)	(Valley)
50	213	223
100	225	230
300	237	237
500	213	262
700	215	237
900	225	185
1100	197	191
1300	229	192
1500	216	183
1700	213	193
1900	210	183
2300	205	211
2700	207	186

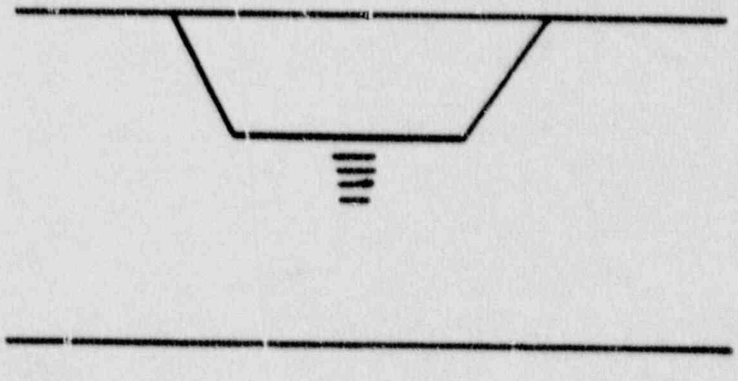


TABLE 3-6

Microhardness Measurements in the P-1 Heat
Affected Zone of the Groove Weld Taken as
Illustrated in the Sketch Below
300°F Preheat and 500°F Post Bake

PQR-401

Distance from Fusion Line (Microns)	Knoop Hardness Values (500 Gram Load)	
	(Peak)	(Valley)
50	216	206
100	237	223
300	229	222
500	214	216
700	209	206
900	208	198
1100	193	200
1300	198	193
1500	226	203
1700	195	192
1900	221	190
2300	207	177
2700	198	196

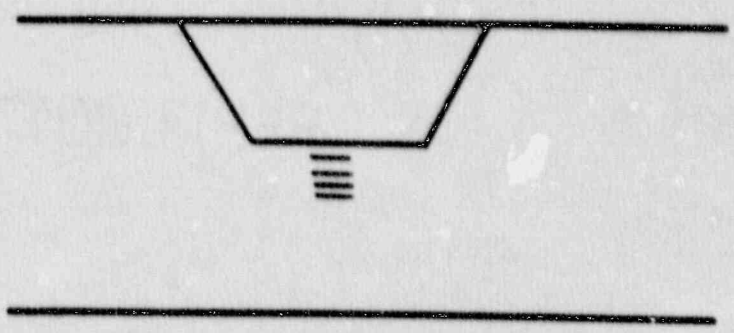


FIGURE 3-1

Groove Weld
SA 216 WCB Carbon Steel Material

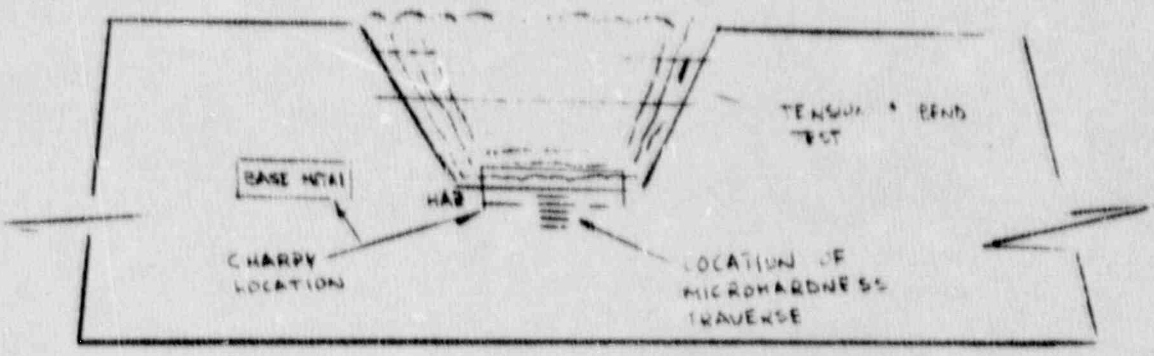
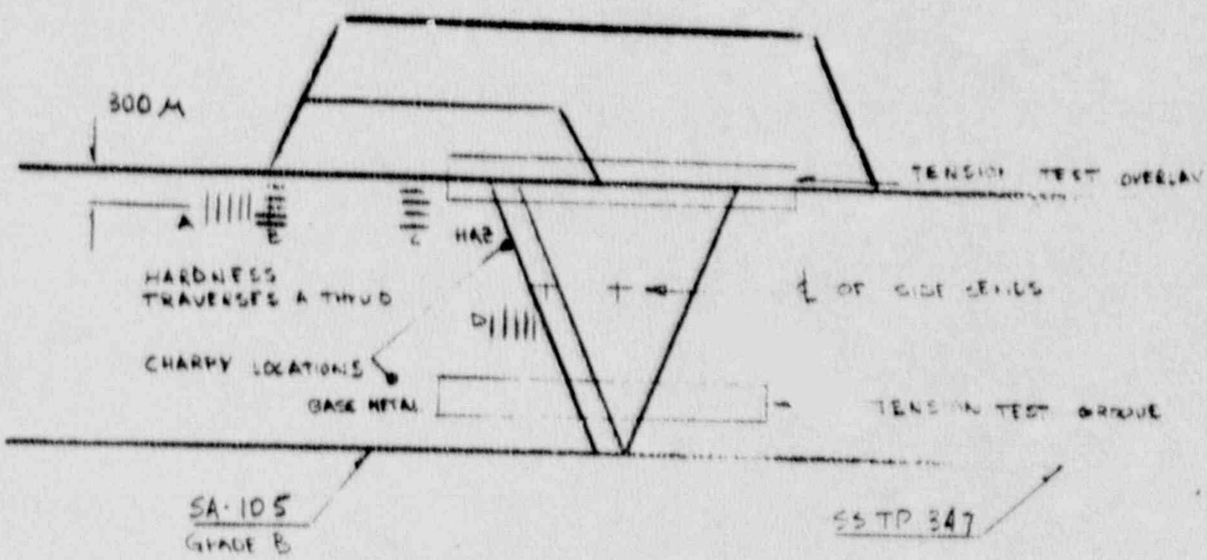


FIGURE 3-2

Dissimilar Metal Weld Overlay Mock Up



SECTION 4.0 - RESULTS

The successful implementation of a weld overlay repair depends on many factors. This includes weld metal bond and metallurgical soundness, resistance of the weld metal to IGSCC crack propagation, and the state of residual stress produced in the weld overlay and underlying base metal. In the case of carbon steel and low alloy valves, fittings, and nozzles, an additional issue must be addressed. Since low alloy and heavy wall carbon steel requires a post weld heat treatment following welding to temper and stress relieve the weld, the application of a weld overlay repair for these materials without preheat and postheating must produce a microstructure which is acceptable for service. In general a post weld heat treatment is performed to satisfy two objectives. First, the heat treatment reduces any weld related residual stresses which may have resulted from buttering, cladding, or welding operation on the material. Secondly, the microstructure produced by the welding process may be less ductile and the effect of post weld heat treating would slightly reduce the tensile strength with an increase in fracture toughness and ductility of the material.

In this study, some of the traditional weld overlay issues of weld metal and weld bond soundness, and the special carbon steel issues involving untempered material have been addressed. This study specifically does not address the IGSCC crack growth resistance and weld residual stress effects of performing an inconel weld overlay repair on various carbon steel components in the RHR system. These particular issues are covered in Reference 1, Revision 2, which is the technical report, issued by Structural Integrity Associates, for implementation of an inconel weld overlay repair of the subject RHR dissimilar metal weld joints.

As previously discussed, weld overlay repair parameters have been developed for carbon to stainless steel dissimilar metal welds which are consistent with Section XI requirements of the ASME code and with the requirements of Code Case N-432, where practical.

This criteria is invoked by NYPA's Section XI repair program. In accordance with code requirements, tensile, bend, and toughness tests were performed on a mock-up simulation of the overlay repair. Welding parameters were demonstrated to conform to meet the intent of Code Case N-432 as applicable. In addition, a comparison of the microhardness readings were made with a post weld heat treated region of the carbon steel material. Similar comparisons were made with the results published in the EPRI/Georgia Power Company qualification test and with the low alloy steel plate utilized in the EPRI/B&W program. The results of these tests show that the parameters used in producing a full structural inconel weld overlay on a carbon steel valve or fitting produces hardness values virtually indifferent between specimens undergoing various stress relief heat treatments, as permitted by the different governing codes.

SECTION 5.0 - REFERENCES

1. Structural Integrity Associates - "Contingency Plan For Implementation of Inconel Weld Overlay Repairs on the Residual Heat Removal System at the James A. FitzPatrick Plant," SIR-87-008, dated December 1989.

2. USA Standard Code for Power Piping, USAS B31.1, 1967 edition with Addenda through 1969.

3. Electric Power Research Institute - "Development of Inconel Weld Overlay Repair for Low Alloy Steel Nozzle to Safe-End Joint," RPT303-1, dated June 1988.

4. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III and XI, 1986 Edition.

5. American Society of Mechanical Engineers , Boiler and Pressure Vessel Code, Section XI, 1980 with 81 Addenda.

6. ASME B & PV Code, Code Case N-432, "Repair Welding Using Automatic or Machine Gas Tungsten Arc Welding (GTAW) Temperatures Technique," Section XI, Division 1, dated February 20, 1986.

7. Repair Welding of Heavy Section Steel Components in LWR's, Volumes 1 and 2, EPRI Report NP-3614, dated July 1984.

APPENDIX 1

CERTIFIED MATERIAL TEST REPORT

MILL TEST REPORT

PSI

Piping Supplies, Inc.
18 E. Black Horse Pike
Folsom, NJ 08094
(609) 561-9323

Fax 1-609-561-9276
Out-of-State 1-800-445-8611

SOLD TO: Consolidated Power Supply
P.O. Box 2472
Birmingham, AL 35201

Date 2-26-88

Customer's Order No. D66-0358

TAG: 87-5842

ITEM	QUANTITY	DESCRIPTION	MATERIAL	HEAT NO.	CODE
3	4	13-1/2 X 11-5/16 X 12 Per Fig. 2 NO WELD REPAIR Materials were manufactured to PSI Quality Program System Manual dated 9/86 Rev. 1 meeting the requirements of ASME Sec. III NCA-3800 which was audited and approved by Consolidated Power on 6/16/87 10CFR21 and 10CFR50-B Apply	ASME SA105-1 Sec. III, Part A latest Edition and Addenda Material normalized at 1700° F for 2 hours and air cooled	22Y3BB CPS QA REVIEW Approved M.G. Date 2/26/88	

CHEMICAL ANALYSIS

ITEM	HEAT NO./CODE	MILL	C	Mn	P	S	Si	Cr	Ni	Mo	Cu		
1	22Y3BB	SHARON	.27	.92	.009	.006	.20						
2													
3													
4													

MECHANICAL PROPERTIES

ITEM	TENSILE LB PER SQ IN	YIELD LB PER SQ IN	ELONGATION IN 2 IN	REDUCTION IN AREA %	TYPE TEST	CHARPY IMPACT TEST: TYPE SAMPLE	°F	IMPACT TEST VALUES FT. LBS				
1	78000	63000	28.0	48.5								
2												
3												
4												

WELDING SERVICES INC
3276 MARJAN DRIVE
ATLANTA, GA.
30340

ATTN. PURCHASING DEPT

Job No.: 05108
P.O. No.: 204501
Part No.: 25.37 X 21.57 X 23

Spec: ASME SA 216 WCB
Quantity: 1
Shipping Date: 5/25/88

Wisconsin Centrifugal In..
906 E. ST PAUL AVE. • WAUKESHA, WI 53188-3896 • USA
414-544-7820

CHEMICAL ANALYSIS

Heat No.	No Pcs.	C	MN	SI	CR*	NI*	S	P	MO*	CU*	V*	TOTAL OF*
P4779	1	.23	.82	.42	.00	.00	.010	.009	.00	.01	.00	.01

MECHANICAL PROPERTIES

Heat No	UTS (PSI)	YS(PSI)	E(%)	RA(%)	TEMP(F)
P4779	70,560	46,340	29	54	

NORMALIZED.

We hereby certify that the material represented by this document has been tested and is in conformance with the Purchase Order, Drawing and Specifications requirements.

Robert Stanley 5/17/88

Kathy Sapinski FEBRUARY 11,1990

APPENDIX 2

CALIBRATION BLOCK DRAWINGS