The Use of Weld Overlays to Extend the Life of Seam Welded High Energy Piping in Fossil Power Plants

Common PQR and Thinner Piping Evaluation

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ABSTRACT

Replacement of longitudinally welded reheat and main steam lines is very expensive and can result in extended outages. Inspection and re-inspection of such systems every few years is also expensive and time consuming. An alternative to continued inspection or system replacement is weld overlay. Weld overlay of longitudinal seamed clamshell elbows was investigated in EPRI report "The Use of Weld Overlays to Extend the Useful Life of Seam Welded High Energy Piping in Fossil Power Plants" 1001270, February 2001. The development of other piping system components, straight pipe, builds upon the technology developed by that program and is detailed in this report.

Background

A number of failures in longitudinally welded reheat and main steam lines during the mid-to-late 1980s resulted in a focused utility effort to improve both inspection and assessment programs for continued operation. EPRI developed a set of guidelines in 1987 to address this issue and later updated the guidelines in 1995. Periodic inspections of long seam welds have been embraced by the industry and are now very common. Based on these inspections and damage found, many utilities have made the decision to replace entire piping systems. The present effort is aimed at providing an alternative to extended outages and entire piping system replacement if long seam creep damage is located.

Objectives

- Develop an alternative to reducing temperature (and load) if creep damage is found associated with longitudinal weld seams in main steam or hot reheat steam lines.
- Evaluate and demonstrate the use of weld overlays to extend the life of a long seam welded, high-energy components.
- Develop a method that will allow utilities to keep piping containing creep damage in service while planning replacement.

Approach

For weld overlay of long seamed piping components to be economically advantageous, the overlay must be applied in a non-postweld heat-treated condition with reasonably high deposition rates. In Phase 1[1] of this program, the EPRI Fossil Repair Applications Center established a temperbead welding approach to deposit the weld overlay using the flux-cored arc welding (FCAW) process. In parallel, finite element analysis (FEA) was performed to establish the stress levels generated via weld overlay buildup on a double-vee clamshell elbow weldment. A weld overlay design was established with the FEA and was used in conjunction with the temperbead welding parameters to develop a full scale, clam shell elbow weld mockup. Upon completion of welding, blindhole residual stress measurements were completed to determine the stresses imposed by the weld overlay. Phase 2[2] included metallurgical and crack growth modeling of the demonstration overlay as well as the development of a position paper to support the use of the

weld overlay technology by utilities. All tests required by ASME for procedure qualification were performed satisfactorily.

Research documented in this report details welding trials on a straight 23-inch diameter, 1-1/4 thick longitudinally seamed pipe. Welding was performed by a contractor with several utilities present. This was performed so utilities would have a qualified procedure that could be utilized in the event that damage was located in a longitudinal seamed pipe during a scheduled inspection.

Current research also evaluated the effects of temperbead weld overlay on thinner piping. Phase 1 work was performed on a thick (2-1/4") pipe and demonstrated residual stresses that were unexpected. Residual stresses were in tension at the ID surface. The development work documented in this report was performed on a geometry that is closer to what would be encountered in most installations of seam-welded piping. The effect of preheat temperature on the toughness of temperbead welds was also evaluated.

Results

A temperbead welding approach using flux cored arc welding (FCAW) has been developed which will allow for rapid deposition of the weld overlay and provides excellent heat affected zone and weld properties. Residual stresses for the weld overlay have been measured using blindhole residual stress measurement techniques.

The overlay technique when applied to a straight piece of longitudinal seamed piping with a thickness of about one inch was able to develop compressive stresses throughout the original longitudinal seam weld. One contractor and five utilities participated in a procedure qualification of the FCAW temperbead welding process. The welding procedure was qualified according to ASME Section IX procedure qualification requirements. An alternative to lowering the operating temperature or pressure (and load) has been developed.

EPRI Perspective

During the 1980s, the nuclear industry developed a weld overlay approach for austenitic piping girth welds which is now recognized by the US Nuclear Regulatory Commission as a "permanent" long-term repair. The repair technology has literally saved the nuclear industry millions of dollars while allowing plants to remain operational for several additional years. In this project, a similar repair approach for weld overlay of long seam welds in main steam and hot reheat piping was developed under the sponsorship of member utilities of the EPRI Fossil Repair Applications Center (FRAC). The weld overlay technology will provide utilities with a methodology to address specific plant conditions including:

1. After an inspection is conducted and "no recordable defects" are found, the seam weld overlay could be used to extend the re-inspection interval by a factor of 10X-20X.
2. If "minor" damage is located in a seam weld, the weld overlay could be used to extend the re-inspection interval.
3. If "major" damage is found, the weld overlay could be used to justify continued operation until replacement piping can be procured and installed.

CONTENTS

1 INTRODUCTION

In the mid 1980's, the utility industry experienced a couple failures of longitudinal welded seams in hot reheat piping. These failures caused major damage to utility equipment, injuries, and fatalities. They demonstrated the potential for damage from such occurrences and raised the level of awareness in utilities across the country. Since that time several approaches have been utilized by utilities to manage potential risks associated with longitudinal seam welded piping.

Utilities have generally taken two approaches to managing long seamed piping assets. Although there are generally large capital costs associated with replacement of piping, many utilities have replaced their seam welded piping with seamless piping. This has minimized the risk associated with high energy piping, but many of these units still have seamed welded headers in the boiler attics. The potential for catastrophic failure of these headers is generally less than seamed piping because of the extra wall thickness included for ligament reinforcement, however, the risk of failure to these longitudinal seams is reduced but not eliminated.

Alternatively, utilities have chosen to manage their seam-welded assets through a risk assessment and inspection plan. This strategy often utilizes inspection of the seam welds on a periodic basis with either manual or automatic ultrasonic inspection techniques. Complete inspections of all longitudinal seams are generally performed on a periodic basis although to further reduce costs, prioritization of inspection areas have been performed through stress analysis.

Several advanced inspection techniques have been developed in recent years that allow for earlier detection of damage while increasing the speed data can be acquired. What has been lacking is the technology to manage piping that has had damage detected by one of the various inspection techniques. Utilities have three options when damage is detected:

1. Replace the damaged piping
2. Continue to operate at reduced piping stress
3. Repair the damaged areas of the piping

Historically, utilities do not have spare pipe on hand for immediate replacement when damage is detected. Lead times for replacement piping frequently runs 9 to 12 months. Manpower and equipment generally need to be coordinated to perform the piping replacement. The time requirement for piping replacement necessitates that outages be scheduled during times of low demand. To allow for continued operation during this planning time, the approach generally utilized involves reducing the operating temperature and/or pressure to lower the stress on the piping and provide sufficient life to enable scheduling piping replacement. Either of these options, reducing temperature or pressure, impacts the profitability of the unit and affects the utility bottom line.

Normal repair procedures require extended outages to complete. ASME Code requires post weld heat treatment (PWHT) of low alloy steel at a temperature of up to 1300F. The strength of the piping at these elevated temperatures requires temporary support of the piping during the repair process. Additionally, the amount of welding filler material needing to be deposited to provide adequate reinforcement makes manual welding techniques impractical. This makes repair of the piping by traditional methods labor intensive and expensive.

With the power shortages during peak demand periods and the high cost associated with replacement power, an alternative is required. This alternative should allow the for continued operation of the unit at full load and designed heat rate until labor, materials, and equipment can be coordinated with system demand loads and an outage of sufficient duration for the piping replacement can be scheduled.

EPRI Fossil Repair Applications Center (FRAC) has developed a temperbead repair procedure that utilizes the flux-cored arc welding (FCAW) process which has been demonstrated to be an effective repair option for this type of damage. The welding development, stress analysis, and remaining life calculations resulting from this development can be reviewed in EPRI publication 1001270.[2] There are two key issues involved in this technology:

1. High deposition automatic FCAW process
2. Temperbead welding technique

The high deposition FCAW process allows the weld overlay to be applied in a timely manner. The welding process was developed on a 20” diameter by 1” thick piece of pipe. Stringer and weave bead welding techniques were evaluated. The weave bead technique developed higher toughness in the HAZ in the base metal. The weld metal also demonstrated good toughness in the as welded condition.

The FCAW temperbead welding technique was then demonstrated on a 38” diameter 2-1/2” thick 2-1/4Cr 1Mo clamshell elbow that was removed from service. The weld was sectioned and evaluated metallurgically and all tests were performed to qualify the welding procedure.

A finite element stress analysis was performed to determine the residual stress induced in the original pipe weld from the addition of the welding overlay. Compressive stress were developed from the outside surface of the pipe approximately ¾ of the way through to the inside surface. The stresses on inside surface of the elbow were mildly tensile. These stresses were confirmed after welding trials using the blind hole drilling technique. Although these stresses were shown to be tensile on the inside surface, they were shown to relax out in a short time at the operating temperature of the pipe.

The welding took a little over one shift to perform and was performed with preheat that was substantially lower than the operating temperature of the pipe. Due to the low temperature, no additional piping support was required. Through the utilization of the temperbead welding process, desired material properties were developed during the welding process that eliminated the need for a PWHT. This substantially reduces the duration of the repair process.

Although good results were demonstrated in the earlier work, some additional development work was required. The elbow used in the earlier development was thicker than most typical applications. The residual effects of the welding on thinner piping needed to be determined.

Additionally, for this technology to be utilized by utilities, welding procedures needed to be qualified.

This report details the development of these two phases of this project. The first was welding development and qualification of a common procedure qualification. Evaluation of the effects of the weld overlay on residual stresses in a smaller thinner piece of pipe that more closely matches the pipe in most older plants was the second major part of the research. Additionally, the effect of preheat on the impact strength of the weld metal was evaluated.

2
WELDING DEVELOPMENT

The goal of this program was to develop an alternative to reducing temperature or pressure if creep damage is found associated with longitudinal weld seams in main steam and hot reheat steam lines. It was demonstrated in Phase 1 that reducing the stress on the longitudinal seam weld could result in substantial life improvement. Stress on the weld was shown to be governed by the equation.

$$\sigma = \frac{pD}{2t}$$

Where: σ = Stress
p = internal pressure
t = thickness of the cylinder
D= internal diameter

This equation suggests that to reduce stress, one needs to reduce the internal pressure, reduce the internal diameter, or increase the thickness. While it is not feasible to reduce the internal diameter of existing piping (which would have a negative effect on steam flow and load) and one of the goals of the program was to eliminate the need to reduce pressure, increasing the thickness of the pipe is possible. The best way to accomplish the increase in thickness is through welding.

The increase in thickness can best be achieved using a temperbead repair procedure for the repair of longitudinal seamed piping. Temperbead welding process was selected to eliminate requirements for costly and time-consuming post weld heat treatment (PWHT). An added benefit of temperbead welding is that it eliminates the need for temporary bracing of the piping which can save significant time during the repair process. Normal PWHT temperature for piping made from 2 ¼ Cr – 1 Mo material is 1300 to 1375F. The strength of the piping material at this temperature requires temporary support to keep the piping from deforming under its own weight.

Before a welding procedure can be utilized during the manufacture or repair of a pressure vessel, the procedure must be qualified. The American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code govern this type of work. This Code requires welding procedures to be demonstrated and mechanical properties of the completed weldment tested. For repairs to boiler headers, these procedures cannot be shared between utilities.

Most of the high energy piping in fossil power plants is governed under ASME B31.1, Power Piping Code. Under this code, paragraph 127.5.3 allows for sharing of welding procedures. Any utility can use the welding procedure qualified by this project for piping covered by B31.1 but the utility must still qualify the welders performing the welding.

In addition to the large expenditure required to weld and test coupons for procedure qualification, several weeks may be required to complete all the steps required to fully qualify a procedure. For a utility to timely utilize the overlay technology, while maintaining the current short outage schedules, in the event that damage is found during an inspection of longitudinal seamed piping, the utility must already have a welding procedure specification (WPS) qualified. To help utilities prepare for this possibility, the members of the FRAC voted to perform a common procedure qualification using the temperbead FCAW process for repair of longitudinal seamed piping. Although the welding was performed on a longitudinal seamed pipe, the procedure is qualified for all applications of the same type of material and hence may find other uses in the power plant besides long seamed piping repair. This procedure can be used for build-up of wasted areas in heater shells, pressure vessels, turbine shells, or other plant equipment where high deposition welding is desired while eliminating required post weld heat treatment (PWHT).

Welding

A common procedure qualification was performed with five utilities in attendance. Each of these utilities now has a qualified procedure to perform this type of repair. Additionally one welding contractor was qualified during the welding procedure qualification. Five utilities attended the welding procedure qualification. Those in attendance included:

–Hawaiian Electric Company, Inc.
–City Public Service –San Antonio
–Kansas City Power & Light
–Constellation Energy Group, Inc.
–Duke Energy Corporation

As a result of the development, each of these utilities has a qualified welding procedure that can be utilized for this type of repair. A sample copy of a Procedure Qualification Record (PQR) is included in the appendix.

To facilitate the welding development, FRAC members were canvassed to find a suitable piece of long seamed reheat piping that more closely demonstrated the size and thickness found in long seamed utility applications (original development of the technology was performed on a 38 inch diameter, 2 1/8" thick pipe). A service-aged pipe was desired to demonstrate that the HAZ could be improved via the temperbead welding process. Duke Energy Corporation donated the pipe utilized for the test which had seen 232,621 hours of service at 1000F. Pipe material specification was A155 CL D (2 ¼ Cr 1 Mo). Outside diameter of the pipe was 23" and thickness was specified as 1" minimum. Actual wall thickness was about 1 ¼".

After baseline stress measurements were complete, a stand was fabricated to place the pipe in the vertical (3G) position. The pipe welding was to be demonstrated in the vertical position with uphill progression.

The FCAW temperbead procedure may be used with the manual or semi-automatic process. The area requiring overlay for a typical longitudinal seam repair would probably require the semi-automatic process because of the need for a high production rate and good control of welding variables. While the utilities participating in the common procedure qualification would have a qualified procedure, it was realized that most might not have the necessary equipment to perform this type of repair.

Wachs Energy Services volunteered to assist with the welding part of the procedure qualification. Through their participation in the welding procedure, they now have a qualified procedure and the capability to assist utilities in this type of repair. The pipe mockup was shipped to the Wachs Facility in Charlotte, North Carolina. Thermal Solutions of Columbus Ohio volunteered to provide equipment for preheat and post weld bake out. Figure 2-1 below was taken during the welding process. The track for the Pipeliner semi-automatic welding head is located on the right of the picture. Welding is progressing uphill in the center of the overlay.

Figure 2-1. Procedure Qualification Welding Operation

A 450F preheat was applied to the pipe before welding operations were started and maintained until welding was completed. Preheat was applied with strips of resistance heating pads located on either side of the original weld. The pads were located about 4” from the center of the original weld. This would allow for clearance between the completed 5” wide weld and the heating pads. The same pads were utilized for the temperbead post weld bake.

Three welding layers were applied to the pipe which resulted in an overlay of about ½” thickness. The overlay was about 5” wide and 57” long. The welding process took 11 hours actual arc time and the entire weld required 35 lbs of filler material. The filler metal utilized was supplied by Metrode and conformed to ER 81T1-B2M. As can be seen from the low amount of total weight added to the piping, there should not be a requirement to readjust hangers for this type of repair. Actual parameters utilized in the welding process can be seen in Table 2-1.

Table 2-1. Welding Parameters

FCAW Temperbead Welding Parameters	
Amperage	190-200 A
Voltage	23.0-26.6 V
Wire Feed Speed (ipm)	285-290
Travel Speed (ipm)	6
Power Ratio (KW/in2)	63.6
Oscillation (inch)	0.250 max
Preheat/Interpass Temp.	450F/600F
Shielding Gas	75Ar/25CO2
FCAW Wire Type	81T1-B2M
Wire Diameter (inch)	0.045
Wire Stick-out (inch)	0.75
Total 3 layer height (inch)	0.55
No. of Beads/Layer	13-15
Total Deposit Weight (lbs.)	35

After welding was finished, the weld was covered with insulation and the temperature was raised to 500F. This was performed to remove hydrogen that might have been trapped in the weld metal during the welding process. The pipe was held at the postbake temperature for two hours, covered with insulation and allowed to cool slowly.

Metallurgical Testing

Upon completion of residual stress work discussed later in Chapter 3, the pipe was sectioned and coupons were removed for bend tests, impact tests, and metallurgical evaluation to qualify the welding procedure. A sample cross section of the weld is shown in Figure 2-2. The original weld can clearly be seen in this figure as well as the new weld overlay.

Figure 2-2. Cross section of Weld Overlay

Bend Tests

Four side bend tests were performed for qualification of the welding procedure. The samples for the side bend tests were 3/8” thick and about 10 inches long. They were bent around a 1 ½” mandrel per ASME Section IX, QW-466. All bend tests passed with no visible flaws. A sample bend tests is shown in Figures 2-3 and 2-4.

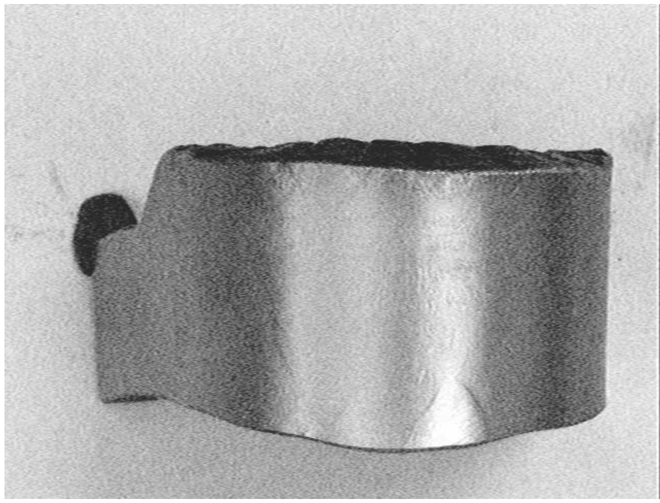


Figure 2-3. Side Bend (view of bend)

Figure 2-4. Side Bend (top view)

Tensile Tests

Tensile tests were performed on all weld metal coupons from the weld overlay to verify the weld metal is stronger than the required ASME minimums. The ASME requires base metal for Class 155 piping to have a minimum of 60 ksi tensile and 30 ksi yield strength or 75 ksi tensile and 45 yield strength depending on the grade ordered. The results of the all weld metal tests are shown in Table 2-2. As demonstrated, both samples are clearly above the ASME required minimums for either strength of Class 155 piping.

Table 2-2. Results of tensile tests.

Long Seam Weld Overlay Tensile Tests				
Sample #	Yield 0.02% (ksi)	Tensile (ksi)	Elongation (%)	Reduction In Area (in/in)
1	97.3	105.0	22.3	58.6
2	95.4	102.7	21.9	63.0

Hardness

Hardness traverses were performed across the base metal, HAZ, and weld metal. Results are shown in Figure 2-5. A maximum hardness of 320 Hv was measured in the peak of a weld bead in the HAZ.

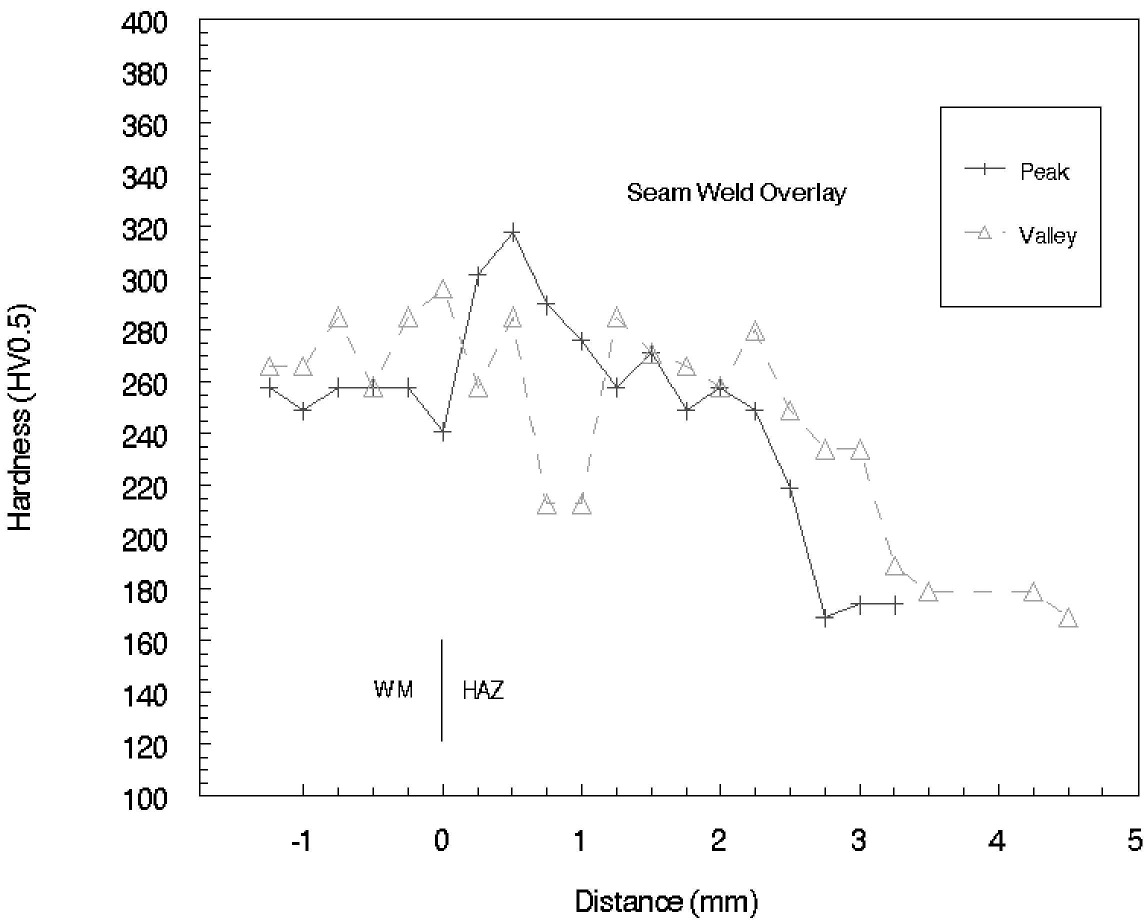


Figure 2-5. Hardness of weld.

Impact Strength

Toughness properties for the weld overlay were also evaluated. Samples were machined from all weld metal and base metal for comparison. The samples were tested in the longitudinal and transverse directions. The toughness measured from both directions was higher than the base metal. The transverse direction was measured perpendicular to the welding direction. The longitudinal direction was measured parallel to the welding direction. Additionally, the HAZ in the base metal was improved by almost four ft-lbs over the untempered base metal by the temperbead welding process. All toughness values are shown in Table 2-3.

Table 2-3. Impact Strength

Toughness (72F test temperature)			
Location	Ft/Lb	% Shear	Lat. Exp.
Base Metal	14.7	10	10
HAZ	19.2	20	23.3
Weld Metal (Transverse)	16.2	40	16.3
Weld Metal (Longitudinal)	39.3	40	31.7

Discussion

Metallographically, the weld overlay was a sound weldment. Figure 2-3 above clearly shows the original weld and the weld overlay. No weld discontinuities were detected. A good bond was achieved with no lack of fusion or other welding defect. All tests required by ASME for qualification of a welding procedure were performed according to ASME Section IX, QW-450. Bend, tensile, hardness and impact strength were all acceptable. Tensile strength was above ASME minimums. Toughness, while not outstanding, was higher than the base metal. It also must be pointed out that toughness is only a problem at low temperatures. The fracture appearance transition temperature (FATT), the temperature above which failures occur in a ductile manner instead of a brittle manner, is well below the operating temperature for these materials. All tests indicated that the FCAW temperbead welding procedure is an excellent choice for this type of repair.

3 RESIDUAL STRESS MEASUREMENTS

Early development of the temperbead weld overlay for seam weld repair was performed on a 2-1/8" elbow with thickness over 2". Stress analysis and blind hole stress measurements indicated that the temperbead weld overlay developed compressive hoop stresses from the outside surface of the elbow to within 25% of the ID surface. Although, analysis showed that residual stresses from the welding process would relax in a short amount of time, a compressive stress was desired where damage was located in the pipe. If tensile stresses were developed in the pipe in damaged areas, damage growth could result.

It was believed that the tensile stresses resulted from bending stresses in the elbow due to the thickness of the elbow. Most longitudinal seamed piping in older fossil power plants would be substantially smaller (16"to 24" vs 38" diameter of original elbow) in diameter with a corresponding reduced thickness than the elbow previously tested. An assumption was made that compressive stresses could be developed through wall of thinner piping. To investigate the effect on smaller, thinner piping, utilities were canvassed to find some service removed piping. Duke Energy Services donated a pipe for the development. Details about the pipe are listed in Chapter 2.

There are two methods to evaluate residual stress from the welding process. The first is to perform a finite element analysis of the piping and weld. Alternatively, welds could be completed and the resulting stresses could be measured using the blind hole analysis technique. If the dimensions of the pipe used during the welding trials allowed access to the inside surface, information about the stress state of the original weld could be determined and the costs associated with finite stress analysis could be avoided. Because welding development was already ongoing, the second method was chosen, as this would be the most economical.

Baseline Residual Stress Testing

To determine the residual stress in the piping before welding, the blind hole drilling technique outlined in ASTM E 837 "Determining Residual Stresses by the Hole-Drilling Strain-Gage Method" was used. Baseline stresses were measured to allow for determining the change in stress due to the weld overlay. Stresses were measured in the centerline and 2 ½" on either side of the original weld on the inside and outside surface of the pipe. Tram points were also added on either side of the original weld to allow for measurements to determine if deformation of the pipe occurred during the welding process.

Residual Stress Measurements

After the welding was complete, the pipe was returned to the EPRI Charlotte Facility for final residual stress measurements. Blind hole measurements were again performed in the same locations as before welding except the center hole on the outside surface was centered in the new weld metal. Figure 3-1 shows the locations of the blind hole measurements. Table 3-1 lists the stresses on the ID and OD surfaces of the pipe after the weld overlay was performed. The figure also shows the location of tram points. After welding the tram points measured 0.020" smaller than prior to welding.

Figure 3-1. Locations of blind hole measurements

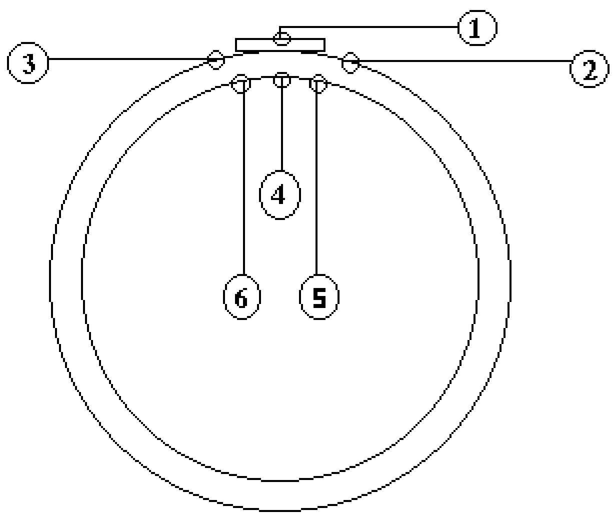


Table 3-1. Residual Stresses after weld overlay

		Stress(ksi)	
Position		Axial	Hoop
1	OD	26.7	29.0
2	OD	36.6	46.8
3	OD	23.1	14.8
4	ID	30.6	-7.7
5	ID	24.9	-10.3
6	ID	63.8	6.9

- is compression

This clearly demonstrates of the compressive stresses developed in the original seam weld by addition of the weld overlay. Welding progression was from right to left. As can be seen, where the passes were first placed on each layer had a large effect on the residual stresses. Additional research may show that stresses in the original weld can be tailored by bead placement in the overlay. The highest compressive residual stress occurred on the inside surface where the first pass of each welding layer was placed. We may be able to develop higher compressive stresses in the original weld by starting the welding in the center of the original weld and then alternating passes on either side of the centerline until the entire layer is complete.

The measurement that is of the most interest in Table 3-1 above is measurement location 5, which clearly shows that the original weld is put into compression by addition of the welding overlay. This information combined with the stress analysis from Task 1 show that the entire original weld is placed in compression via the application of the overlay weld. Any active creep growth damage accumulation will be substantially reduced by application of the weld overlay. However due to the relaxation of the residual stress from the weld overlay at temperature and pressure stresses not included in the above, the creep damage will continue to accumulate.

4
EFFECT OF PREHEAT ON WELD METAL PROPERTIES

The goal for the welding development performed in the first two phases of this project was to develop a welding repair procedure that could be utilized without a PWHT and to develop toughness in the HAZ and weld metal greater than that in the base metal.

The original temperbead welding development was performed on a 20 inch diameter piece of service removed pipe and demonstrated an average HAZ toughness of 17.8 ft-lbs using stringer beads and 32.0 ft-lbs using a weave bead. These compare with a 7.5 ft-lb toughness of the base metal. The weave bead technique satisfied all the goals for the program. The stringer bead developed properties in the HAZ better than the base metal but were not as good as the weave bead. The weave bead approach was selected for additional development because it developed better toughness, allowed for faster weld metal deposition, and was more easily applied out-of-position.

Additional testing with filler metal from Hobart was performed using the weave bead technique and average weld metal impact strength of 27.3 ft-lbs was measured. This met the goal of toughness better than the base metal. The Hobart filler metal was a Tri-Mark TM811B2 and was also used in the welding trials on the elbow in Phase 1 employing identical welding parameters as those used in the procedure development. Samples were removed from the elbow during Phase 2 and tested. All of the tensiles, bends, etc indicated good results but the impact strength of the weld metal left a little to be desired. The average impact strength of the base metal (elbow) was 13 ft-lbs. The HAZ demonstrated improvement via the temperbead welding process and had toughness of 15 ft-lbs. The disappointing area was the weld metal. The weld metal only developed average toughness of 12.3 ft-lbs. This was substantially lower than the procedure development impact strength of 27.3 ft-lb.

Filler metal vendors were contacted to discuss what could have caused the decrease in weld metal toughness. One vendor suggested that cooling rate of the weld metal could have an effect on the toughness. This vendor offered to supply some filler metal to evaluate the cooling rate effect on toughness. The filler metal was formulated to be used either in the as deposited or PWHT condition. The wire was from Metrode and was classified as an E81T1-B2M wire meeting the requirements of AWS A5.29-98 requirements. All of the filler metals used in this project met the AWS Specification for FCAW A5.29, 81T1-B2. The nominal composition of the filler metal was 1-1/4 Cr- ½ Mo. This filler metal was intentionally chosen as an under matching filler metal than the 2¼ Cr1 Mo base metal to match the strength of the aged piping.

To investigate the cooling rate of the weld metal on toughness, two different preheats were utilized in welding trials. The Metrode filler metal was utilized in the testing. Two weld coupons was prepared using identical parameters to those used in the elbow welding except one used a 450F preheat and the other used no preheat and was allowed to cool back to below 100F between welding passes. The results of the Metrode filler metal impact tests are shown in Table 4-1. The tests were performed at room temperature.

Table 4-1. Effect of Preheat on Toughness

Charpy Impact Strength @ 72F (Ft-lbs)		
Preheat	100F	450F
Transverse	8.2 (ave)	32.5 (ave)
Longitudinal	15.7 (ave)	56.2 (ave)

As can be seen, the preheat temperature, and resulting cooling rate had a dramatic effect on the toughness of the weld metal.

Although these tests show a relationship between cooling rate and toughness of the weld metal, there is no way to definitely determine what happened in the welding trials on the elbow during phase 1. The procedure called for a 450F preheat. Preheat was applied using resistance heating mats. The temperature was controlled using thermocouples mounted under the mats. These thermocouples were insulated from the mats. Perhaps the base material directly under the mats close to the thermocouples was hotter than the exposed area of the pipe where welding was being performed. No temperature measurements were taking on the weld metal during the welding process.

To eliminate this possibility in Phase 3, the test on the straight piece of pipe, thermocouples were placed next to the heating pads close to the area to be welded. Temperature measurements of the weld metal were taken with an infrared temperature-indicating instrument and with contact pyrometers. Interpass temperatures were also closely measured. Although a preheat of 450F was specified, the pipe stabilized at 500F because of the heat input from welding. The impact values for the welding trials on the straight piece of pipe are shown in Table 2-3. As reported in this table, impact strength in the weld metal was higher than the base metal. Furthermore, toughness along the longitudinal direction approach 40 ft-lbs, while lower values (16 ft-lbs) were reported in the transverse direction. .

5 CONCLUSIONS

- A repair method for creep damaged longitudinal seamed piping has been developed. This repair method can be utilized in three different scenarios:

  1. After an inspection is conducted and "no recordable defects" are found, the seam weld overlay could be used to extend the re-inspection interval by a factor of 10X-20X.
  2. If "minor" damage is located in a seam weld, the weld overlay could be used to extend the re-inspection interval.
  3. If "major" damage is found, the weld overlay could be used to justify continued operation until replacement piping could be procured and installed.

- Temperbead welding procedures have been developed and qualified to allow for repair of piping without costly and time-consuming PWHT. All required tests were successful. Impact strength of the weld metal was better than the base metal. Tensile strength was above the required ASME minimums. All bend tests passed.
- Five utilities and one welding vendor have qualified welding procedures to utilize this technology.
- Compressive residual stresses were developed throughout the original longitudinal seam weld.
- Preheat temperature maintenance during the welding operation can have significant effect on the properties of the weld metal.
- An option has been developed that would allow utilities to return creep damaged piping to service at full pressure and temperature while allowing the utility to schedule manpower and equipment and procure replacement piping.

6
REFERENCES

1. K. Coleman, D. Gandy and T. Sherlock, *The Use of Weld Overlays to Extend the Useful Life of Seam Welded High Energy Piping in Fossil Power Plants*, EPRI, Charlotte, NC: 1999. TE-114212.

2. K. Coleman, D. Gandy and T. Sherlock, *The Use of Weld Overlays to Extend the Useful Life of Seam Welded High Energy Piping in Fossil Power Plants*, EPRI, Charlotte, NC: 2001. 100270.

A
APPENDIX

On the next two pages is a sample procedure qualification record developed during the common procedure qualification at Wachs Energy.

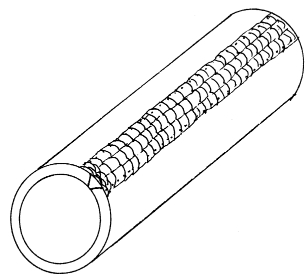
EPRI FRAC WELDING PROCEDURE SPECIFICATIONS (WPS)

Welding Procedure Specification No. LONGSEAM1 Supporting PQR No.(s) ____________
Revision No. 0 Date 06/01/01
Welding Process(es) FCAW Type(s) Machine
(Automatic, Manual, Machine, or Semi-Auto.)
Prepared by: Kent Coleman

JOINTS (QW-402) Details

Joint Design Temperbead Overlay
Backing (Yes/No) Yes
Backing Material (Type) Base metal
Open Root Allowed (Yes/No) No

Other: ____________



BASE METALS (QW-403)

P-No. 5a Group No. 1 to P-No. 5a Group No. 1
OR
Specification type and grade ____________
to Specification type and grade ____________
OR
Chem. Analysis and Mech. Prop. ____________
to Chem. Analysis and Mech. Prop. ____________
Thickness Range:
Base Metal: Groove 3/16" – 2 ½" Fillet ____________
Pipe Dia. Range: Groove All Fillet ____________
Other ____________

FILLER METALS (QW-404)

Spec. No. (SFA) ____________
AWS No. (Class) A5.29 E81T1-B2M
F-No. 6
A-No. 3
Size of Filler Metals 0.045" diameter
Weld Metal Thickness 1.100"
Electrode-Flux (Class) ____________
Flux Trade Name N/A
Consumable Insert N/A
Other ____________

* Each base metal-filler metal combination should be recorded individually.

WPS No. LONGSEAM1 Rev. 1

POSITIONS (QW-405)
Position(s) of Groove All (3G)
Welding Progression: Up X Down ____
Position(s) of Fillet ____

PREHEAT (QW-406)
Preheat Temp. Min. 450°F
Interpass Temp. Max. 600°F
Preheat Maintenance Post Weld Bake at 500 °F +/- 50 °F for 2 hours

POSTWELD HEAT TREATMENT (QW-407)
Temperature Range None (temperbead)
Time Range None

GAS (QW-408)

	Gas(es)	Percent Composition (Mixture)	Flow Rate
Shielding	75Ar/25CO_2	weld grade	35-45 CFH
Trailing	N/A		
Backing	N/A		

ELECTRICAL CHARACTERISTICS (QW-409)

Current AC or DC DC Polarity EP

Amps (Range) 170-210 Volts (Range) 22-27

(Amps and volts range should be recorded for each electrode size, position, and thickness, etc. This information may be listed in a tab-ular form silmilar to that shown below.)

Tungsten Electrode Size and Type NA

(Pure Tungsten, 2% Thoriated, etc.)

Mode of Metal Transfer for GMAW NA

(Spray arc, short circuiting arc, etc.)

Electrode Wire feed speed range 265-310

TECHNIQUE (QW-410)

String or Weave Bead Weave (minimal)

Orifice or Gas Cup Size

Initial and Interpass Cleaning (Brushing, Grinding, etc.) Prior to welding, the base metal shall be ground bright and solvent cleaned. Interpass cleaning by grinding brushing, sanding, or filing.

Method of Back Gouging N/A

Oscillation 0.250 (max.)

Contact Tube to Work Distance approximately .750

Multiple or Single Pass (per side) Multiple

Multiple or Single Electrodes Single

Travel Speed (Range) approximately 6 ipm

Peening N/A

Other Subsequent beads should overlap prior beads approximately 50%.

		Filler Metal		Current				
Weld Layer(s)	Process	Class	Dia.	Type Polar.	Amp. Range	Volt Range	Travel Speed Range	Other (e.g., Remarks, Comments, Hot Wire Addition, Technique, Torch Angle, Etc.)
All	FCAW		.045	DC-EP	170-210	22-27	6”/min	

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