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Repair and Replacement Applications Center: Topical Report Supporting Expedited NRC Review of Code Cases for Dissimilar Metal Weld Overlay Repairs

1014351

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Technical Update, December 2006

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Electric Power Research Institute (EPRI)

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This document describes research sponsored by EPRI.

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

Repair and Replacement Applications Center: Topical Report Supporting Expedited NRC Review of Code Cases for Dissimilar Metal Weld Overlay Repairs. EPRI, Palo Alto, CA: 2006. 1014351.

PRODUCT DESCRIPTION

ASME frequently develops new Code Cases that offer additional repair options for nuclear facilities. However, to implement this emerging technology requires approval from the NRC in many cases. The purpose of this project is to establish a method for developing generic relief requests on behalf of the RRAC members. This would significantly reduce the time and cost of individual plant sites developing and pursuing a request, as well as speeding up the review process by reducing the number of submittals for common needs. During the first portion of this project the RRAC developed an initial approach with support from a former NRC staff member and utility licensing experts. The second phase presented this approach to the NRC with support from NEI. The second phase included a presentation by the Principle Investigator at the 2004 Licensing Forum. The concept was well received. EPRI, NEI and NRC have met in Spring 2005 to discuss the proposed Topical Report prior to its submittal. The final phase of the effort was to test the approach with a trial submittal for a key repair technique. This report is the topical report providing the methodology from ASME Code Case N-740 needed for addressing overlay repairs of PWSCC.

Results and Findings

This topical report is the result of the development of a process to provide a vehicle that is mutually beneficial to the industry and the regulator in reviewing ASME Code Cases for repairs that have generic applicability. In particular the topical report addresses ASME Code Cases well along in the ASME review process but not yet reviewed for acceptability by the NRC in accordance with.10CFR 50.55a. The particular Code Case is N-740. Code Case N-740 has been approved by all ASME Committees. The topical report when approved by the NRC would provide the technical basis for acceptable alternatives for plant specific repairs until the Code Case is incorporated for use in Regulatory Guide 1.147.

Challenges and Objectives

This report is of value to technical and management personnel tasked with finding solutions and evaluating costs for repairing and mitigating components susceptible to PWSCC. The topical report provides an acceptable generic technical basis suitable for reference for plant specific plant alternatives, thus resulting in reduced cost to the industry and NRC and shorter times for NRC approval of plant specific requests.

Applications, Values, and Use

The topical report provides an acceptable generic technical basis suitable for reference for plant specific plant alternatives pursuant to 10CFR50.55a. This allows cost savings on the part of the industry and NRC and reduces the time needed for NRC approval of plant specific requests.

EPRI Perspective

The report contains technical information for EPRI members that would not be available to the general public given its proprietary nature from an economic perspective.

Approach

The goals of the report were to provide an expedited process for obtaining NRC approval of alternatives and requests for relief for PWR applications for repairing PWSCC until the specific Code Case needed is approved for use by the NRC and incorporated in Regulatory Guide 1.147. Those goals were met by the results and information included in the report.

Keywords

Request for relief
Request for alternatives
IGSCC
PWSCC
Weld overlay
Ambient temperature temper bead welding

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1
INTRODUCTION

Background

The cost of NRC reviews for alternatives to the ASME Code and approved Code Cases have increased significantly. Historically the time for NRC review and approval of new Code Cases has been several years. In order to promote efficiency, maintain safety and reduce burden on Owners and the regulator, an improved process is needed to support alternatives to the existing process for unapproved ASME Code Cases for generic repair activities. This topical report is the result of the development of a process to provide a vehicle that is mutually beneficial to the industry and the regulator in reviewing ASME Code Cases for repairs that have generic applicability. In particular the topical report addresses ASME Code Cases that are well along in the ASME review and approval process, but that have not yet been reviewed for acceptability by the NRC in accordance with.10CFR 50.55a. The particular Code Case for dissimilar metal weld overlay repairs is N-740. ASME Sub-Committee XI unanimously approved Code Case N-740. Main Committee of ASME has approved Code Case N-740 with no negative votes at the May 2006 meeting. The BNCS procedural approval has been received. An appendix in the Code Case for ambient temperature temper bead welding uses the methodology form Code Cases N-638-2 and N-638-3. Code Case N-638-2 has been approved but not published by ASME. ASME Sub-Committee XI unanimously approved Code Case N-638-3. This case passed Main Committee at the February2006 meeting and has been approved by BNCS.

Austenitic stainless steel weld overlays have been used extensively on BWR welds. There is a need to extend this technology to nickel alloy welds joining dissimilar austenitic and ferritic base materials. An existing Code Case (N-504-2), which has been reviewed and accepted by the NRC in accordance with.10CFR 50.55a, does not address the requirements of applying weld overlays on Inconel or ferritic base or filler materials and components, i.e. safe-ends, valves, or component nozzles. Code Case N-740 provides requirements for applying dissimilar metal weld overlays on ferritic, austenitic stainless steel and nickel base alloy materials and components. The Code Case is written to be as consistent as possible with Non-Mandatory Appendix Q which incorporated the requirements of Code Case N-504-2 in ASME XI. ASME Code Case N-740 provides specific rules for the design, fabrication, examination and inspection of weld overlay repairs of the piping and components. Further this case is consistent with the alternatives of the methodology of Code Case N-504-2 approved by the NRC via relief requests for the application of overlay repairs of PWSCC at three PWR plants.

The particular provisions of Code Case N-638-2, providing several methods of determining interpass temperatures, as well as Code Case N-638-3 which changes the surface area limitation of 100 square inches to 500 square inches and clarifies the surface area is over the ferritic material are also needed to support the repair activities. Many of the provisions of these Code Cases have been incorporated in plant specific relief requests related to repairs performed for replacing nozzles and applying overlays at PWRs. These plant specific relief requests have been reviewed and accepted by the NRC.

Code Case N-740, which provides the necessary rules for dissimilar metal weld overlay repair is the subject of this report. The methodologies of Code Cases N-638-2 and N-638-3, with the exception of the examination requirements, have been incorporated as an appendix of N-740 for applications where ambient temperature temper bead welding is needed, and as such are also included in the requested review. The review and approval of this topical report should provide a basis for future relief requests until the Code Cases are published by ASME and endorsed by NRC in Regulatory Guide 1.147.

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PROVISIONS OF THE CODE CASES

2.1 Code Case N-740

This Code Case, which extends the use of overlays to the repair of dissimilar metal weldments in piping and piping components, is included as Appendix A to this report. This case permits application to some ferritic and austenitic nickel base materials and allows the use of nickel alloy filler materials (such as 52, 52M and 52MS) in addition to stainless steel filler materials. The design provisions included in the Code Case are very similar to those in N-504-2. Postulated crack growth by SCC and fatigue are required to be evaluated for the defect left in place.

The Code Case requires that the axial length and end slope of the weld overlay shall cover the weld and the heat affected zones on each side of the weld, and shall provide for load redistribution from the item into the weld overlay and back into the item without violating applicable stress limits of NB-3200. Any laminar flaws in the weld overlay shall be evaluated in the analysis to ensure that load redistribution complies with the above. These requirements will usually be satisfied if the weld overlay full thickness length extends axially beyond the projected flaw by at least $0.75\sqrt{Rt}$, where R is the outer radius of the item and t is the nominal wall thickness of the item. Section XI factors of safety shall be maintained at the end of the evaluated time period for any defects present in the piping or component. Shrinkage of the weld overlay with regard to crack growth and its effects on the piping system and supports must also be evaluated.

A requirement for the minimum Cr content for the nickel based filler material is specified in the Code Case. The Cr content for the first layer for BWR and PWR applications is specified if the first layer is to be credited in the design rather than discarded. A minimum of 24% for PWR and 20% Cr for BWR applications is required for the first layer to be credited in the design. The use of the first layer in the design requires actual chemical analysis of the layer either in the field application or on a mockup welded under similar conditions to those used in the field. This approach is consistent with the treatment of SS filler material in the Appendix Q and N-504-2, in which minimum ferrite requirements are specified for SCC resistance. A White Paper was posted on the ASME website that provided information to the various reviewers justifying the Cr requirements for the first measured layer, and is included as Appendix B to this report. Several of the referenced papers for the White Paper are also posted on the ASME website and are available to NRC personnel who participate in codes and standards activities.

The Examination and Inspection section of the Code Case specifies, "In lieu of all other examination requirements, the examination requirements of this Case shall be met. Nondestructive examination methods shall be in accordance with IWA-2200, except as specifically addressed herein. Nondestructive examination personnel shall be qualified in accordance with IWA-2300. Ultrasonic examination procedures and personnel shall be qualified in accordance with Appendix VIII." The ultrasonic acceptance criteria in the case are from ASME Section XI, which are more appropriate than the workmanship-based standards from ASME III or the Construction Code, which are related to radiographic examinations.

2.2 Code Case N-638-2 and -3

Code Case N-638-3 includes the provisions that were changed in N-638-2. Code Case N-638-2 has been passed by ASME and is scheduled for publication in Supplement 6 to the ASME 2004 Nuclear Code Cases. The following items were the main changes in N-638-2: (1) the applicable materials were clarified, (2) metrification was added, (3) a change was made to lateral expansion requirements providing an option of weld procedure qualification or the use of an "adjustment temperature" if the HAZ average lateral expansion is less than the unaffected base metal and the procedure qualification meets all other requirements of the case, (4) clarified interpass temperature requirements and deleted the temperature limitation from QW 406.3, (5) defined acceptable methods for control of interpass temperature and (6) revised the Examination requirements. The supporting White Paper provides a discussion of the changes and their bases.

The only change in N-638-3 was to change the surface area limitation form 100 to 500 square inches and clarify the surface area limitation is over the ferritic material. The supporting White Paper for N-638-3 contains the results of analyses for several cases of overlay and butt weld repairs where residual stresses were compared for 100 and greater than 100 square inch cases (up to 500 square inches). The cases were cavity and overlay repairs. The residual stresses were the same or less for the 100 square cases as those for the repairs over 100 square inches. The analyses and results are shown

Code Cases N-638-2, N-638-3 and their respective White Papers are attached as Appendices C, D, E and F. Note: Attached Code Cases and Code-related information are for reference only. ASME should be contacted to request published copies for production activities.

3
CONCLUSIONS

- Code Case N-740 (Appendix A) is an acceptable alternative to the requirements of IWA-4410 and IWA-4611 to reduce a defect in austenitic stainless steel or austenitic nickel alloy piping or component to a flaw of acceptable size in accordance with IWB-3640 by addition of a weld overlay.
- The overlay may be applied by deposition of weld reinforcement (weld overlay) on the outside surface of the piping, component or associated weld including ferritic materials, when necessary, provided the requirements of Code Case N-740 are met.
- The attached White Paper (Appendix B) provides adequate technical justification for the Cr content of the first layer of weld filler deposited (BWR - 20% and PWR - 24%). The respective Cr content of the layer must be determined by chemical analysis of the first layer of the production weld or of a representative coupon.
- Code Case N-638-3 (Appendix E) provides the necessary methodology for ambient temperature temper bead welding in lieu of post weld heat treatment. Code Case N-638-2 (Appendix C) is included for clarity so that the changes incorporated in N-638-3 from the earlier case are available. The change in N-638-3 of increasing the limitation of the allowable surface area from 100 to 500 square inches has been shown not to be detrimental. Therefore N-638-3 is an acceptable methodology for ambient temperature temper bead welding and as such the incorporation of the methodology in Appendix 1 to Code Case N-740 is appropriate and acceptable.
- The White Paper (Appendix D) provides the technical basis for the changes in N-638-2
- The White Paper (Appendix F) provides the technical basis for increasing the surface area limitation from 100 to 500 square inches.
- This topical report provides an acceptable technical basis for referencing in plant specific Safety Evaluation Reports for Code Case N-740 until Code Cases N-740, N-638-2 and N-638-3 are approved for use by the NRC in Regulatory Guide 1.147.

Notification

It should be noted, that the description of Code rules and Code-related information provided in this report is strictly for reference purposes and is intended to inform EPRI members of Code support activities performed on their behalf. This information is often incomplete, or in draft form, and should not be used for production activities. Please contact ASME to request a published and official copy of the Boiler & Pressure Vessel Code.

A

APPENDIX A CASE N-740

Case N-740
Dissimilar Metal Weld Overlay for Repair of Class 1, 2, and 3 Items
Section XI, Division 1

Inquiry: As an alternative to the provisions of IWA-4410 and IWA-4611 for reducing a defect to an acceptable size in accordance with the provisions of the Construction Code or Section XI, is it permissible to reduce a defect to a flaw of acceptable size by increasing the wall thickness by deposition of weld overlay on the outside surface of the piping, component, or associated weld?

Reply: It is the opinion of the Committee that, in lieu of the requirements of IWA-4410 and IWA-4611, a defect in austenitic stainless steel or austenitic nickel alloy piping, components, or associated welds may be reduced to a flaw of acceptable size in accordance with IWB-3640 by addition of a weld overlay. All Section XI references are to the 2004 Edition with the 2005 Addenda. For the use of this Case with other Editions and Addenda, refer to Table 1. The weld overlay shall be applied by deposition of weld reinforcement (weld overlay) on the outside surface of the piping, component, or associated weld, including ferritic materials when necessary, provided the following requirements are met:

1.0 General Requirements

1.1 This Case applies to dissimilar metal austenitic welds between P-No.8 or 43 and P-No.1, 3, 12A, 12B, or 12C[1] materials or between P-No, 1, 3, 12A, 12B, and 12C materials. This Case also applies to dissimilar metal welds between P No.8 to P No.43 material and to welds between P-No.8 to P-No. 8 or P-43 to P-43 materials joined with an austenitic filler material.

1.2 Weld overlay filler metal shall be low carbon (0.035% max.) austenitic stainless steel or an austenitic nickel alloy (28% Cr min.) applied 360 deg. around the circumference of the item, and shall be deposited using a Welding Procedure Specification for groove welding, qualified in accordance with the Construction Code and Owner's Requirements and identified in the Repair/Replacement Plan. As an alternative to the post weld heat treatment requirements of the Construction Code and Owner's requirements, the provisions of Appendix 1 may be used for ambient-temperature temper bead welding.

1.3 Prior to deposition of the weld overlay, the surface to be repaired shall be examined by the liquid penetrant method. Indications larger than 1/16 in. (1.5 mm) shall be removed, reduced in size, or corrected in accordance with the following requirements.

1.3.1 One or more layers of weld metal shall be applied to seal unacceptable indications in the area to be repaired with or without excavation. The thickness of these layers shall not be used in meeting weld reinforcement design thickness requirements. Peening the unacceptable indication prior to welding is permitted.

1.3.2 If correction of indications identified in 1.0(c) is required, the area where the weld overlay is to be deposited, including any local repairs or initial weld overlay layer, shall be examined by the liquid penetrant method. The area shall contain no indications greater than 1/16 in. (1.5 mm) prior to the application of the structural layers of the weld overlay.

1.4 Weld overlay deposits shall meet the following requirements:

1.4.1 The austenitic stainless steel weld reinforcement shall consist of at least two weld layers having as-deposited delta ferrite content of at least 7.5 FN. The first layer of weld metal with delta ferrite content of at least 7.5 FN shall constitute the first layer of the weld reinforcement that may be credited toward the required thickness. Alternatively, first layers of at least 5 FN are acceptable, provided the carbon content of the deposited weld metal is determined by chemical analysis to be less than 0.02%.

1.4.2 The austenitic nickel alloy weld overlay shall consist of at least two weld layers deposited from a filler material with a Cr content of at least 28%. The first layer of weld metal deposited may not be credited toward the required thickness. Alternatively, for PWR applications, a diluted layer may be credited toward the required thickness, provided the portion of the layer over the austenitic base material, austenitic filler material weld and the associated dilution zone from an adjacent ferritic base material contains at least 24% Cr and the Cr content of the deposited weld metal is determined by chemical analysis of the production weld or of a representative coupon taken from a mockup prepared in accordance with the WPS for the production weld. Alternatively, for BWR applications, a diluted layer may be credited toward the required thickness, provided the portion of the layer over the austenitic base material, austenitic filler material weld and the associated dilution zone from an adjacent ferritic base material contains at least 20% Cr and the Cr content of the deposited weld metal is determined by chemical analysis of the production weld or of a representative coupon taken from a mockup prepared in accordance with the WPS for the production weld .

1.5 This Case is only for welding in applications predicted not to have exceeded thermal neutron fluence of 1×10^{17} (E< 0.5 eV) neutrons per cm^2 prior to welding.

2.0 Design

2.1 Flaw characterization and evaluation requirements shall be based on the as-found flaw. However, the size of all flaws shall be projected to the end of the design life of the overlay. Crack growth, including both stress corrosion and fatigue crack growth, shall be evaluated in the materials in accordance with IWB-3640. If the flaw is at or near the boundary of two different materials, evaluation of flaw growth in both materials is required.

2.2 The design of the weld overlay shall satisfy the following, using the assumptions and flaw characterization restrictions in 2.0(a). The following design analysis shall be completed in accordance with IWA-4311.

2.2.1 The axial length and end slope of the weld overlay shall cover the weld and the heat affected zones on each side of the weld, and shall provide for load redistribution from the item into the weld overlay and back into the item without violating applicable stress limits of NB-3200. Any laminar flaws in the weld overlay shall be evaluated in the analysis to ensure that load redistribution complies with the above. These requirements will usually be satisfied if the weld overlay full thickness length extends axially beyond the projected flaw by at least $0.75\sqrt{Rt}$, where *R* is the outer radius of the item and *t* is the nominal wall thickness of the item.

2.2.2 Unless specifically analyzed in accordance with 2.0(b) (1), the end transition slope of the overlay shall not exceed 45 deg. A slope of not more than 1:3 is recommended.

2.2.3 For determining the combined length of circumferentially-oriented flaws, multiple flaws shall be treated as one flaw of length equal to the sum of the lengths of the individual flaws characterized in accordance with IWA-3300.

2.2.4 For circumferentially-oriented flaws, if the combined length is greater than 10% of the circumference of the item, the flaws shall be assumed to be 100% through the original wall thickness of the item for the entire circumference of the item. For circumferentially-oriented flaws, if the combined length does not exceed 10% of the circumference of the item, the flaws shall be assumed to be 100% through the original wall thickness of the item for a circumferential length equal to the combined length of the flaws.

2.2.5 For axial flaws 1.5 in. (38 mm) or longer, or for five or more axial flaws of any length, the flaws shall be assumed to be 100% through the original wall thickness of the item for the entire axial length of the flaw or combined flaws, as applicable.

2.2.6 The overlay design thickness of items meeting 2.0(b)(4) or (5) above shall be based on the measured diameter, using only the weld overlay thickness conforming to the deposit analysis requirements of 1.0(d). The combined wall thickness at the weld overlay, any planar flaws in the weld overlay, and the effects of any discontinuity (e.g., another weld overlay or reinforcement for a branch connection) within a distance of $2.5\sqrt{Rt}$ from the toes of the weld overlay, shall be evaluated and shall meet the requirements of IWB-3640, IWC-3640, or IWD-3640, as applicable.

2.2.7 The effects of any changes in applied loads, as a result of weld shrinkage from the entire overlay, on other items in the piping system (e.g., support loads and clearances, nozzle loads, changes in system flexibility and weight due to the weld overlay) shall be evaluated. Existing flaws previously accepted by analytical evaluation shall be evaluated in accordance with IWB-3640, IWC-3640, or IWD-3640, as applicable.

3.0 Examination and Inspection

In lieu of all other examination requirements, the examination requirements of this Case shall be met. Nondestructive examination methods shall be in accordance with IWA-2200, except as specified herein. Nondestructive examination personnel shall be qualified in accordance with IWA-2300. Ultrasonic examination procedures and personnel shall be qualified in accordance with Appendix VIII , Section XI.

3.1 Acceptance Examination

3.1.1 The weld overlay shall have a surface finish of 250 micro-in. (6.3 micrometers) RMS or better and a flatness sufficient to allow for adequate examination in accordance with procedures qualified per Appendix VIII. The weld overlay shall be examined to verify acceptable configuration.

3.1.2 The weld overlay and the adjacent base material for at least ½ in. (13 mm) from each side of the weld shall be examined using the liquid penetrant method. The weld overlay shall satisfy the surface examination acceptance criteria for welds of the Construction Code or NB-5300. The adjacent base metal shall satisfy the surface examination acceptance criteria for base material of the Construction Code or NB -2500. If ambient temperature temper bead welding is used, the liquid penetrant examination shall be conducted at least 48 hours after the completed overlay has returned to ambient temperature.

3.1.3 The examination volume in Fig.1 shall be ultrasonically examined to assure adequate fusion (i.e., adequate bond) with the base metal and to detect welding flaws, such as interbead lack of fusion, inclusions, or cracks. The interface C-D shown between the overlay and the weld includes the bond and the heat affected zone from the overlay. If ambient temperature temper bead welding is used, the ultrasonic examination shall be conducted at least 48 hours after the completed overlay has returned to ambient temperature. Planar flaws shall meet the preservice examination standards of Table IWB-3514-2. In applying the acceptance standards, wall thickness "t_w" shall be the thickness of the weld overlay. Laminar flaws shall meet the following:

3.1.3.1 Laminar flaws shall meet the acceptance standards of Table IWB-3514-3 with the additional limitation that the total laminar flaw shall not exceed 10% of the weld surface area and that no linear dimension of the laminar flaw area exceeds 3.0 in. (76 mm).

3.1.3.2 The reduction in coverage of the examination volume in Fig. 1 [*Note: Correct Figure should be Figure 2*] due to laminar flaws shall be less than 10%. The dimensions of the uninspectable volume are dependent on the coverage achieved with the angle beam examination of the overlay.

3.1.3.3 Any uninspectable volume in the weld overlay shall be assumed to contain the largest radial planar flaw that could exist within that volume. This assumed flaw shall meet the inservice examination standards of Table IWB-3514-2. Alternately, the assumed flaw shall be evaluated and shall meet the requirements of IWB-3640, IWC-3640, IWD-3640, as applicable. Both axial and circumferential planar flaws shall be assumed.

3.1.4 After completion of all welding activities, affected restraints, supports, and snubbers shall be VT-3 visually examined to verify that design tolerances are met.

3.2 Preservice Inspection

3.2.1 The examination volume in Fig 2 shall be ultrasonically examined. The angle beam shall be directed perpendicular and parallel to the piping axis, with scanning performed in four directions, to locate and size any cracks that might have propagated into the upper 25% of the base material or into the weld overlay.

3.2.2 The preservice examination acceptance standards of Table IWB-3514-2 shall be met for the weld overlay. In applying the acceptance standards, wall thickness, t_w, shall be the thickness of the weld overlay. Cracks in the outer 25% of the base metal shall meet the design analysis requirements of 2.0.

3.3 Inservice Inspection

3.3.1 The weld overlay examination volume in Fig. 2 shall be added to the inspection plan and shall be ultrasonically examined during the first or second refueling outage following application.

3.3.2 The weld overlay examination volume in Fig. 2 shall be ultrasonically examined to determine if any new or existing cracks have propagated into the upper 25% of the base material or into the overlay. The angle beam shall be directed perpendicular and parallel to the piping axis, with scanning performed in four directions.

3.3.3 The inservice examination acceptance standards of Table IWB-3514-2 shall be met for the weld overlay. Alternatively, for Class 1, 2, or 3 piping systems, the acceptance criteria of IWB-3600, IWC-3600, or IWD-3600, as applicable, shall be met for the weld overlay. Cracks in the outer 25% of the base metal shall meet the design analysis requirements of 2.0.

3.3.4 Weld overlay examination volumes that show no indication of crack growth or new cracking shall be placed into a population to be examined on a sample basis. Twenty-five percent of this population shall be examined once every ten years.

3.3.5 If inservice examinations reveal crack growth, or new cracking, meeting the acceptance standards, the weld overlay examination volume shall be reexamined during the first or second refueling outage following discovery of the growth or new cracking.

3.3.6 For weld overlay examination volumes with unacceptable indications as described in 3.0(c)(2) and (3), the weld overlay shall be removed, including the original defective weld, and the item shall be corrected by a repair/replacement activity in accordance with IWA-4000.

3.4 Additional Examinations. If inservice examinations reveal an unacceptable indication, crack growth into the weld overlay design thickness, or axial crack growth beyond the specified examination volume, additional weld overlay examination volumes, equal to the number scheduled for the current inspection period, shall be examined prior to return to service. If additional unacceptable indications are found in the second sample, a total of 50% of the total population of weld overlay examination volumes shall be examined prior to operation. If additional unacceptable indications are found, the entire remaining population of weld overlay examination volumes shall be examined prior to return to service.

4.0 Pressure Testing

A system leakage test shall be performed in accordance with IWA-5000.

5.0 Documentation

Use of this Case shall be documented on Form NIS-2.

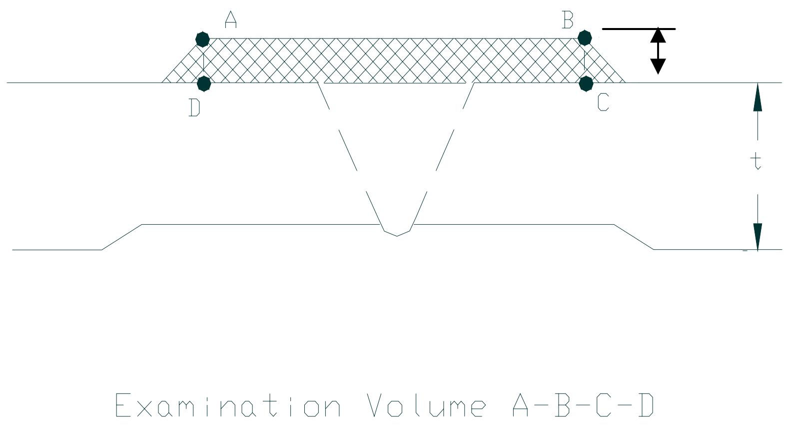
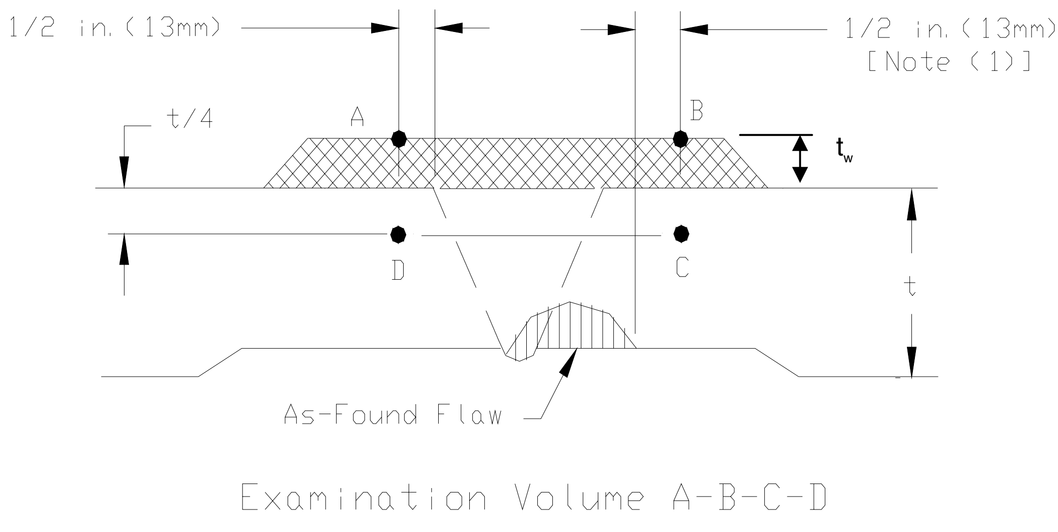


Fig. 1
Acceptance Examination Volume



NOTE:

(1) For axial or circumferential flaws, the axial extent of the examination volume shall extend at least ½ in. (13mm) beyond the as-found flaw and at least ½ in. (13mm) beyond the toes of the original weld, including weld end butter, where applied.

Fig. 2
Preservice and Inservice Examination Volume

Appendix 1

1.0 GENERAL REQUIREMENTS

(a) This appendix applies to dissimilar austenitic filler metal welds between P-Nos. 1, 3, 12A, 12B, and 12C[1] materials and their associated welds and welds joining P-No. 8 or 43 materials to P-No. 1, 3, 12A, 12B, and 12C[1] materials with the following limitation: This Appendix shall not be used to repair SA-302 Grade B material unless the material has been modified to include from 0.4% to 1.0% nickel, quenching and tempering, and application of a fine grain practice.

(b) The maximum area of an individual weld overlay based on the finished surface over the ferritic base material shall be 500 sq. in. (325,000 sq. mm).

(c) Repair/replacement activities on a dissimilar-metal weld in accordance with this Appendix are limited to those along the fusion line of a nonferritic weld to ferritic base material on which 1/8 in. (3 mm), or less of nonferritic weld deposit exists above the original fusion line.

(d) If a defect penetrates into the ferritic base material, repair of the base material, using a nonferritic weld filler material, may be performed in accordance with this Appendix, provided the depth of repair in the base material does not exceed 3/8 in. (10 mm).

(e) Prior to welding the area to be welded and a band around the area of at least 1-1/2 times the component thickness or 5 in. (130 mm), whichever is less, shall be at least 50F (10 C).

(f) Welding materials shall meet the Owner's Requirements and the Construction Code and Cases specified in the Repair/Replacement Plan. Welding materials shall be controlled so that they are identified as acceptable until consumed.

(g) Peening may be used, except on the initial and final layers.

2.0 WELDING QUALIFICATIONS

The welding procedures and the welding operators shall be qualified in accordance with Section IX and the requirements of 2.1 and 2.2.

2.1 Procedure Qualification

(a) The base materials for the welding procedure qualification shall be of the same P-Number and Group Number, as the materials to be welded. The materials shall be postweld heat treated to at least the time and temperature that was applied to the materials being welded.

(b) The root width and included angle of the cavity in the test assembly shall be no greater than the minimum specified for the repair.

(c) The maximum interpass temperature for the first three layers of the test assembly shall be 150F (66C).

(d) The test assembly cavity depth shall be at least 1 in. (25 mm). The test assembly thickness shall be at least twice the test assembly cavity depth. The test assembly shall be large enough to permit removal of the required test specimens. The test assembly dimensions surrounding the cavity shall be at least the test assembly thickness and at least 6 in. (150 mm). The qualification test plate shall be prepared in accordance with Fig. 1-1.

(e) Ferritic base material for the procedure qualification test shall meet the impact test requirements of the Construction Code and Owner's Requirements. If such requirements are not in the Construction Code and Owner's Requirements, the impact properties shall be determined by Charpy V-notch impact tests of the procedure qualification base material at or below the lowest service temperature of the item to be repaired. The location and orientation of the test specimens shall be similar to those required in (f) below, but shall be in the base metal.

(f) Charpy V-notch tests of the ferritic heat-affected zone (HAZ) shall be performed at the same temperature as the base metal test of (e) above. Number, location, and orientation of test specimens shall be as follows:

(1) The specimens shall be removed from a location as near as practical to a depth of one-half the thickness of the deposited weld metal. The coupons for HAZ impact specimens shall be taken transverse to the axis of the weld and etched to define the HAZ. The notch of the

Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much HAZ as possible in the resulting fracture. When the material thickness permits, the axis of a specimen shall be inclined to allow the root of the notch to be aligned parallel to the fusion line.

(2) If the test material is in the form of a plate or a forging, the axis of the weld shall be oriented parallel to the principal direction of rolling or forging.

(3) The Charpy V-notch test shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. The test shall consist of a set of three full-size 10 mm X 10 mm specimens. The lateral expansion, percent shear, absorbed energy, test temperature, orientation and location of all test specimens shall be reported in the Procedure Qualification Record.

(g) The average lateral expansion value of the three HAZ Charpy V-notch specimens shall be equal to or greater than the average lateral expansion value of the three unaffected base metal specimens. However, if the average lateral expansion value of the HAZ Charpy V-notch specimens is less than the average value for the unaffected base metal specimens and the procedure qualification meets all other requirements of this appendix, either of the following shall be performed:

(1) The welding procedure shall be requalified.

(2) An *Adjustment Temperature* for the procedure qualification shall be determined in accordance with the applicable provisions of NB-4335.2 of Section III, 2001 Edition with 2002 Addenda. The RT_{NDT} or lowest service temperature of the materials for which the welding procedure will be used shall be increased by a temperature equivalent to that of the Adjustment Temperature.

2.2 Performance Qualification

Welding operators shall be qualified in accordance with Section IX.

3.0 WELDING PROCEDURE REQUIREMENTS

The welding procedure shall include the following requirements.

(a) The weld metal shall be deposited by the automatic or machine GTAW process.

(b) Dissimilar metal welds shall be made using A-No. 8 weld metal (QW-442) for P-No. 8 to P-No. 1, 3, or 12 (A, B, or C) weld joints or F-No. 43 weld metal (QW-432) for P-No. 8 or 43 to P-No. 1, 3, or 12 (A, B, or C) weld joints.

(c) The area to be welded shall be buttered with a deposit of at least three layers to achieve at least 1/8 in. (3mm) overlay thickness with the heat input for each layer controlled to within ±10% of that used in the procedure qualification test. The heat input of the first three layers shall not exceed 45,000 J/in. (1,800 J/mm) under any conditions. Particular care shall be taken in the placement of the weld layers of the austenitic overlay filler material at the toe of the overlay to ensure that the HAZ and ferritic base metal are tempered. Subsequent layers shall be deposited with a heat input not exceeding that used for layers beyond the third layer in the procedure qualification.

(d) The maximum interpass temperature for field applications shall be 350F (180C) for all weld layers regardless of the interpass temperature used during qualification. The interpass temperature limitation of QW-406.3 need not be applied.

(e) The interpass temperature shall be determined by one of the following methods:

(1) temperature measurement (e.g. pyrometers, temperature indicating crayons, thermocouples) during welding

(2) heat flow calculations using the variables listed below as a minimum:

(i) welding heat input
(ii) initial base material temperature
(iii) configuration, thickness, and mass of the item being welded
(iv) thermal conductivity and diffusivity of the materials being welded
(v) arc time per weld pass and delay time between each pass
(vi) arc time to complete the weld

(3) measurement of the maximum interpass temperature on a test coupon that is equal to or less than the thickness of the item to be welded. The maximum heat input of the welding procedure shall be used in the welding of the test coupon.

(f) Particular care shall be given to ensure that the weld region is free of all potential sources of hydrogen. The surfaces to be welded, filler metal, and shielding gas shall be suitably controlled.

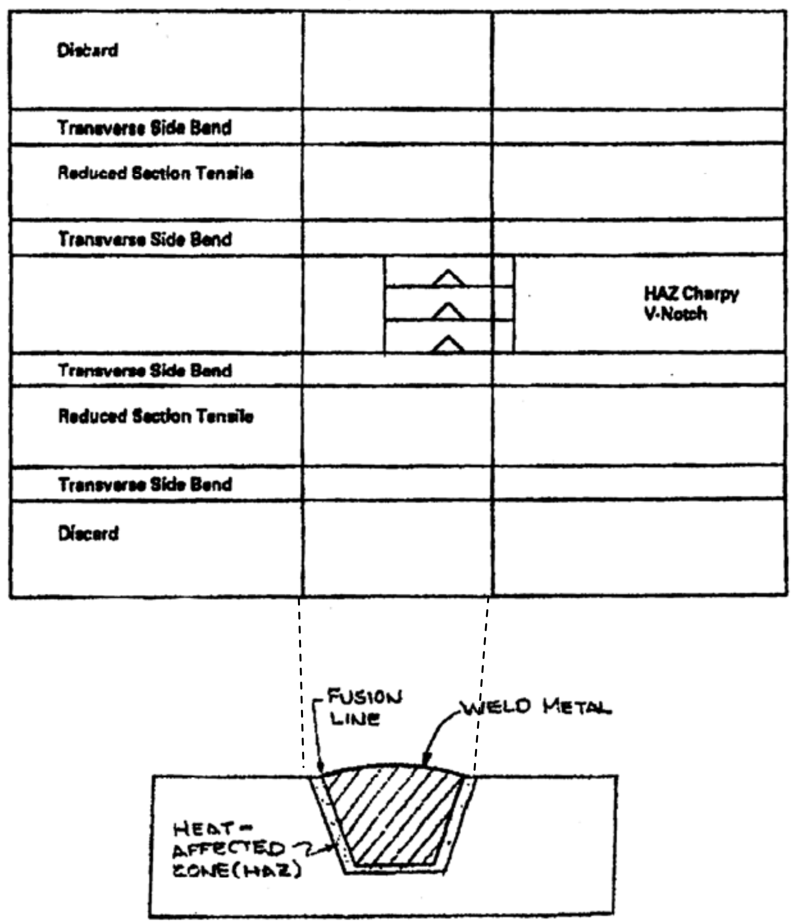


Fig. 1-1 QUALIFICATION TEST PLATE
GENERAL NOTE: Base metal Charpy impact specimens are not shown. This figure illustrates a similar-metal weld.

2001 Edition with 2003 Addenda through 2004 Edition with 2005 Addenda	1995 Edition with 1996 Addenda through 2001 Edition with 2002 Addenda	1995 Edition with 1995 Addenda	1989 Edition with 1991 Addenda through 1995 Edition	1986 Edition with 1988 Addenda through 1989 Edition with 1990 Addenda	1983 Edition with Winter 1983 Addenda through 1986 Edition with 1987 Addenda	1980 Edition with Winter 1981 Addenda through 1983 Edition with Summer 1983 Addenda
IWA-4000 Repair/Replacement Activities	IWA-4000	IWA-4000	IWA-4000	IWA-4000 & IWA-7000	IWA-4000 & IWA-7000	IWA-4000 & IWA-7000
IWA-4221 Construction Code and Owner's Requirements	IWA-4220	IWA-4220	IWA-4170	IWA-4120 & IWA-7210	IWA-4120 & IWA-7210	IWA-4120 & IWA-7210
IWA-4311 Configuration Changes	IWA -4311	IWA -4311	NA	NA	NA	NA
IWA-4410Welding, Brazing, Metal Removal, and Installation – General Requirements	IWA 4410	IWA 4410	IWA 4410	IWA 4410	IWA 4410	IWA-4110 & IWA-4170
IWA-4411 Welding, Brazing, Fabrication, and Installation	IWA-4410, IWA-4421, IWA-4430	IWA-4410, IWA-4421, IWA-4430	IWA-4170(b)	IWA-4120	IWA-4120	IWA-4120
IWA-3300 Flaw Characterization	IWA-3300	IWA-3300	IWA-3300	IWA-3300	IWA-3300	IWA-3300
IWA-4611 Defect Removal	IWA-4611	IWA-4421 & IWA-4424	IWA-4421 & IWA-4424	IWA-4421 & IWA-4424	IWA-4421 & IWA-4424	IWB-4230
IWB-3514 Standards for Category B-F	IWB-3514	IWB-3514	IWB-3514	IWB-3514	IWB-3514	IWB-3514
IWB/C/D-3600 Analytical Evaluation	IWB/C/D-3600	IWB/C/D-3600	IWB/C/D-3600	IWB/C/D-3600	IWB/C/D-3600	IWB/C/D-3600
IWB/C/D-3640 Evaluation Procedures	IWB/C/D-3640 or IWB/C/D-3650	IWB/C/D-3640 or IWB/C/D-3650	IWB/C/D-3640 or IWB/C/D-3650	IWB/C/D-3640 or IWB/C/D-3650	IWB/C/D-3640 or IWB/C/D-3650	IWB/C/D-3640 or IWB/C/D-3650

Table 1 References for Alternative Editions and Addenda of Section XI

Applicability: 1980 Edition with Winter 1981 Addenda through 2004 Edition with 2006 Addenda

B

APPENDIX B – WHITE PAPER-EFFECT OF CHROMIUM CONTENT ON NICKEL-BASE ALLOY SCC RESISTANCE)

Effect of Chromium Content on Nickel-base Alloy SCC Resistance

Introduction

This evaluation provides a technical basis to establish a minimum chromium content for an overlay layer to be considered resistant to Inter Granular Stress Corrosion Cracking (IGSCC) in BWR environment as well as resistant to Primary Water Stress Corrosion Cracking (PWSCC) in the PWR environment. Experimental work was performed in the 1980's to study crack initiation in BWR environments for creviced Alloy 600 and its filler alloys, 82 and 182. In addition, field experience on the use of this family of alloys has been good, absent a crevice, in BWR service. More recently work has been done by the Japanese to develop a stress corrosion resistivity index (SCRI) [8].

The only well established correlation between primary water stress corrosion cracking (PWSCC) propensities and nickel-based alloys and weld metal composition is the chromium content of the alloy [1]. However, there have been very few systematic studies to determine the minimum chromium content for PWSCC mitigation in either wrought materials or weld metals. Most studies have involved a straightforward comparison of Alloy 600 with 14-17% chromium and Alloy 690 with 28-31% chromium with no testing of custom nickel-chromium-iron alloys whose chromium content falls in between these two alloys. This absence creates a chromium composition gap between the susceptible Alloy 600/182/82 and very resistant Alloy 690/152/52.

Table B-1 presents the nominal chemical compositions of nickel-base weld metals plus reference wrought Alloys 690 and 600 for each weld metal, i.e., Alloys 52, 152 and 72 for Alloy 690 and Alloys 82, 182, and 132 for Alloy 600 [2-5]. Based on chromium content, it would be anticipated that weld metals Alloys 52, 152 and 72 would be the most PWSCC resistant and this hypothesis has been verified by experiment. It is noted that Alloy 52M has the same chromium content as Alloy 52 and should be considered equivalent. Alloy 52M is a variant of Alloy 52 having increased Niobium (Nb) to improve weldability.

Discussion

1.1 Investigations of IGSCC in a BWR Environment

The relative susceptibilities of wrought Alloys 600 and 690 and weld metals Alloys 52 (R-127), 152 (R-135), 82 and 182 to IGSCC in pure or simulated resin intrusion BWR environments at 550° F have been investigated [6,7]. CERTs for IGSCC initiation evaluations were conducted in high purity water containing 200 ppb or 8 ppm dissolved oxygen for uncreviced specimens and 16 ppm dissolved oxygen for graphite wool/nickel foil creviced specimens. Uncreviced Alloys 600, 690, 82 and 182 demonstrated resistance to IGSCC in oxygenated environments (no cracking). Creviced Alloys 600 and 182 did suffer IGSCC and Inter Dendritic Stress Corrosion Cracking (IDSCC), respectively, while creviced Alloy 82 suffered Inter Granular Attack (IGA). Creviced Alloy 690 exhibited no susceptibility to IGSCC initiation in this CERT study. Types 316 NG and 308L stainless steel and Alloys 72, 52 (R-127) and 152 (R-135) were also found to resist IGSCC in this investigation.

Similar to the CERT studies described above, twenty constant load specimens of the same materials were tested at 1.25 and 1.5 times the 550 °F yield stress in high purity water containing 200 ppb or 8 ppm dissolved oxygen for uncreviced specimens and 16 ppm dissolved oxygen for graphite wool/nickel foil creviced specimens. Although no IGSCC was detected during the 8200-hour exposure, post-test examination of the specimens revealed "grooving" of machining marks on the specimen's surface. The grooves seemed to be the result of localized attack of machining marks and resembled linear crevices. A number of cracks <1 mil deep were associated with the grooving. Since the cracking was only identified with the grooves and not the smooth surface, it appeared that IGSCC susceptibility was related only to the presence of the crevice. Surface grooves accompanied by small cracks were present on all Alloy 600 or 182 specimens. No IGSCC of Alloy 690 or 82 was identified. Furthermore, neither cracks nor grooves were identified underneath the graphite crevice on the Alloy 690 specimens.

1.2 Stress Corrosion Resistivity Index (SCRI)

The SCRI was developed based on the results of creviced bent beam (CBB) tests where the beneficial effect of chromium content on IGSCC resistance is indeed factored into the materials resistance ranking [8]:

SCRI = %Cr + 5[%Nb] + 10[%Ti] – 116.5[%C]

Cr, Nb, Ti and C are individual weight percentages of these alloying elements.

To assure strong resistance to IGSCC in the BWR environment, a criterion of SCRI $\geq$34 is used.

If one calculates the SCRI for Alloy 82 and Alloy 182, the respective values are 32.85 versus 22.85. This is further evidence of the superior resistance to IGSCC for Alloy 82. Alloy 52 and Alloy 152 produce even higher values. The Alloy 52M variant of Alloy 52 has higher Nb with the same Cr level and thus results in even higher SCRI ranking.

1.3 Chromium Content "Threshold" for PWSCC Resistance

To determine the "threshold" chromium content of a nickel-base weld metal to mitigate PWSCC, it is necessary to review the limited test results obtained in PWR environments and also examine the results from tests on wrought nickel alloys. Note that some information was obtained in oxygenated environments. However, these data are also largely characterized by Alloy 600 versus Alloy 690 investigations.

The PWSCC resistance of nickel-based weld metals with various chromium contents ranging from approximately 15% to 30% chromium has been evaluated [1,9]. Testing was performed on U-bend specimens exposed to impurity doped steam and primary water. Alloy 182, with approximately 14.5% chromium, was the most susceptible to PWSCC while Alloy 82 with 18–

20% chromium took three or four times longer to initiate PWSCC. For example, PWSCC appeared in one of the Alloy 182 specimens at the first test interruption after 500 hours of exposure and the second specimen cracked after 1,500 hours. The first Alloy 82 specimen cracked after 2,000 hours and all were cracked at 6,500 hours. For chromium contents between 21 and 22%, no PWSCC initiation was observed for tests lasting between 18,000 and 27,000 hours. This was also the case for Alloys 52 and 152 that have approximately 30% chromium. These results indicated that weld metals having 30% chromium were very resistant to PWSCC. Thus a "threshold" for PWSCC resistance appears to exist somewhere between 21% and 30% chromium.

The above PWSCC behavior for nickel base alloys is consistent with test results on solution annealed wrought Ni-Cr-Fe base alloys (i.e., higher chromium content provides more PWSCC resistance) [1,10]. Constant load tests were used to evaluate the effect of chromium content on the PWSCC susceptibility of wrought Ni-Cr-Fe alloys in 680°F (360°C) water. The constant load specimens were loaded at an applied stress 2.4 times the 0.2% proof stress. Figure B-1 clearly demonstrates that the PWSCC initiation susceptibility decreased as the chromium content increased from approximately 1% to over 15% [1,10]. Unfortunately, this study did not evaluate higher chromium alloys (e.g., 18-22% Cr).

To possibly identify a chromium content "threshold" for PWSCC mitigation, it is necessary to discuss a more fundamental mechanistic experiment. Alloy 600 obtained from a vessel head penetration containing 16.05% chromium and Alloy 690 obtained from a steam generator tube plug containing 29.14% chromium were tested in simulated PWR primary water (1200 ppm B and 2 ppm Li) at 680 °F (360 °C) under electrochemical conditions corresponding to Ni/NiO equilibrium potential. The Ni/NiO equilibrium potential corresponds to a maximum susceptibility of Alloy 600 to the initiation of PWSCC [11]. The resulting oxidized structures (corrosion scale and underlying metal) were examined by transmission electron microscopy (TEM) using cross section specimens. The oxide on Alloy 600 consisted of small 50 nm $Ni(Cr,Fe)_2O_4$ and large 200 nm $NiFe_2O_4$ crystallite oxides, while the oxide on Alloy 690 consisted of small 30 nm $Ni(Cr,Fe)_2O_4$ and large 100 nm $NiFe_2O_4$ crystallite oxides. Alloy 690's oxide film was 50% thinner than Alloy 600's oxide film, which is characteristic of a more rupture resistant and protective oxide film.

For both alloys energy dispersive X-ray spectroscopy (EDX) analysis revealed a chromium rich oxide layer where the underlying metal was chromium depleted. In both alloys a non-compact external oxide scale was identified, and a thin continuous inner layer rich in chromium was observed. Consequently, a chromium depleted zone just in the underlying alloy was observed. For Alloy 600, the particular importance of the depletion was found to be also associated with the presence of oxygen. Chromium oxide was even found in a triple grain boundary as far as 3 μm from the metal-oxide interface.

These test results tend to support the crack initiation mechanism induced by intergranular oxidation of the chromium depleted zones [12]. Assuming that this mechanism is operative in these exposure conditions, it is then possible to explain, at least in terms of local reactivity, the effect of the carbide precipitation sites (transgranular- intergranular) on the crack initiation resistance of Alloy 600 exposed to PWR experimental conditions. Most importantly for this evaluation, when considering Alloy 690, despite its chromium depletion from 29% to 17% in the underlying alloy, the chromium content remains sufficiently high that an intergranular oxidation mechanism cannot be operative because the chromium content is greater than the 10% chromium needed to mitigate intergranular oxidation [13]. Thus, the excellent resistance of Alloy 690 to PWSCC can be explained. In contrast, Alloy 600 suffers PWSCC because its chromium content is also reduced by approximately 11 to 12% from a starting level of 16%. This reduces the chromium level to 5% - a level that is below the 10% chromium “threshold” for internal oxidation.

The oxide mechanistic study results suggest that a chromium depletion of 11 to 12% occurs in nickel-base wrought alloys exposed to PWR environments under environmental conditions that clearly support and promote PWSCC. Since the internal oxidation “threshold” for these alloys is approximately 10% chromium, then an additional 11 to 12% chromium should be present in the starting material to mitigate PWSCC. This suggests that an initial concentration of 21 to 22% chromium should be sufficient to mitigate PWSCC. This “threshold” value is consistent with the U-bend test results that indicated weld metals having 22 and 30% chromium were very resistant to PWSCC. The results from the above Alloy 82 studies suggest that 18 to 20% chromium is insufficient to mitigate cracking. However, since the required chromium content to mitigate cracking must exceed 22%, and the Alloy 82 specification permits up to 22% chromium [1], then the required chromium required to mitigate cracking must exceed 22%.

Conclusion

BWR Applications

Testing and field service has shown that Alloy 600, Alloy 82 and 182 are all reasonably resistant to IGSCC. In the creviced condition test results and field service have shown that Alloy 600 and Alloy 182 have cracked where Alloy 82 has remained uncracked. The SCRI has shown that Alloy 82 is more resistant than Alloy 182 or Alloy 600. To provide some IGSCC margin, it is recommended that a minimum of 20% chromium be present in the first overlay layer considered resistant to IGSCC.

PWR Applications

Considering the paucity of data and fragmentary nature of the available data on the effects of chromium on PWSCC, the relevant available test data plus a mechanistic analysis has been combined to suggest that the “threshold” chromium content for PWSCC mitigation will be somewhere greater than 22% chromium. Therefore a conservative estimate of the chromium threshold to mitigate PWSCC is 24%. This level of chromium would be considered as a minimum in the first overlay layer to be considered resistant to PWSCC.

Table B-1:
Compositions of Nickel-base Alloys and Weld Metals

Alloying Element	Alloy 690 (Nuclear) [2]	Alloy 52 filler metal [3]	Alloy 152 electrode) [3]	Alloy 72 filler metal (nominal) [4]	Alloy 600 [5]	Alloy 82 filler metal [3}	Alloy 182 electrode [3]	Alloy 132 electrode [1-3]
Ni + Co	58.0 min.	Balance	Balance	55	72.0 min.	67.0 min.	59.0 min.	62.0 min
C	0.04 max.	0.04 max.	0.05 max.	0.05	0.15 max.	0.10 max.	0.10 max.	0.08 max
Mn	0.5 max.	1.0 max.	5.0 max.	0.1	1.00 max.	2.5-3.5	5.0-9.5	3.5 max
Fe	7.0-11.0	7.0-11.0	7.0-12.0	0.2	6.00-11.00	3.0 max.	10.0 max.	11.0 max
S	0.015 max.	0.015 max.	0.015 max.	0.008	0.015 max.	0.015 max.	0.015 max.	0.02 max
Si	0.50 max.	0.50 max.	0.75 max.	0.1	0.50 max.	0.50 max.	1.0 max.	0.75 max
Mo		0.50 max.	0.50 max.					
Cu	0.50 max.	0.30 max.	0.50 max.	0.20	0.50 max.	0.50 max.	0.50 max.	0.50 max
Cr	28.0-31.0	28.0-31.5	28.0-31.5	44.0	14.0-17.0	18.0-22.0	13.0-17.0	13.0-17.0
Ti		1.0 max.	0.50 max.	0.6		0.75 max.	1.0 max.	
Al		1.10 max.	0.50 max.					
P		0.020 max.	0.030 max.			0.030 max.	0.030 max.	0.03 max
Nb + Ta		0.10 max.	1.0-2.5			2.0-3.0	1.0-2.5	1.5-4.0
Al + Ti		1.5 max.						
Others		0.50 max.	0.50 max.			0.50 max.	0.50 max.	0.50 max

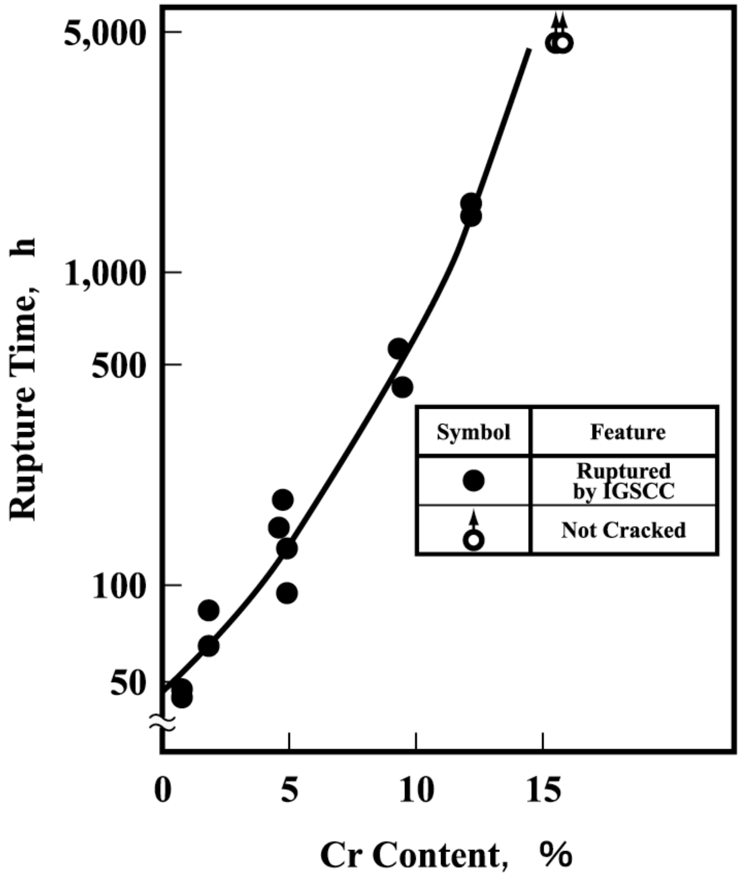


Figure B-1:
Effect of Chromium Content on the Stress Corrosion Cracking Resistance of Solution Annealed Ni-Cr-Fe Alloys [7]

References

1. "Materials Reliability Program: Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking of Alloy 82, 182, and 132 Welds (MRP-115)," EPRI, Palo Alto, CA: 2004. 1006696.
2. Special Metals Corporation, SMC-079, October 3, 2003.
3. Inco Alloy International, IAI-27-3/7M, 1993.
4. S. Kiser fax to B. M. Gordon, "Inconel Filler metal 72," May 2, 2000.
5. Special Metals Corporation, SMC-027, September 2, 2002.
6. R. A. Page and A. McMinn, "Stress Corrosion Cracking Resistance of Alloys 600 and 690 and Compatible Weld Metals in BWRs," EPRI, NP-5882M, Palo Alto, CA, July 1988.
7. R. A. Page and A. McMinn, "Stress Corrosion Cracking Resistance of Alloys 600 and 690 and Compatible Weld Metals in BWRs," EPRI, NP-5882S, Palo Alto, CA, July 1988. M.
8. Akashi, "Effects of Cr and Nb Contents on the Susceptibility of Alloy 600 Type Ni-base Alloys to Stress Corrosion Cracking in a Simulated BWR Environment," paper 407 presented at Corrosion 95, NACE, Orlando, FL, March 1995.
9. D. Buisine, et al., "PWSCC Resistance of Nickel Based Weld Metals with Various Chromium Contents," Proceedings: 1994 EPRI Workshop on PWSCC of Alloy 600 in PWRs, EPRI, Palo Alto, CA: 1995. TR-105406, Paper D5.
10. T. Yonezawa, N. Sasaguri, and K. Onimura, "Effects of Metallurgical Factors on Stress Corrosion Cracking of Ni-base Alloys in High Temperature Water," Proceedings of the 1988 JAIF International Conference on Water Chemistry in Nuclear Power Plants, 1988, pp. 490–495.
11. J. Panter, et al., "Surface Layers on Alloys 600 and 690 in PWR Primary Water: Possible Influence on Stress Corrosion Crack Initiation," paper 02519 presented at Corrosion 2002, Houston, TX, April 7-11, 2002, NACE, Houston, TX.
12. P. M. Scott, "An Overview of Internal Oxidation as a Possible Explanation of Intergranular Stress Corrosion Cracking of Alloy 600 in PWRs," paper presented at the 9th International Symposium on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors, Newport Beach, CA, August 1-5, 1999, published in proceedings of same, TMS, Warrendale, PA, p. 387.
13. C. S. Giggins and F. S. Petit, "Oxidation of Ni-Cr Alloys between 800 and 1200 °C, Transaction of the Metallurgical Society of AIME, 245, 1969.

C
APPENDIX C

Code Case N-638-2

Approval Date: July 1, 2005

The ASME Boiler and Pressure Vessel Standards Committee took action to eliminate Code Case expiration dates effective March 11, 2005. This means that all Code Cases listed in this Supplement and beyond will remain available for use until annulled by the ASME Boiler and Pressure Vessel Standards Committee.

Case N-638-2
Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique
Section XI, Division 1

Inquiry: In lieu of the preheat and PWHT requirements of IWA-4400, may the automatic or machine GTAW temper bead technique be used without use of preheat or postweld heat treatment on Class 1 components?

Reply: It is the opinion of the Committee that, in lieu of the preheat and postweld heat treatment requirements of IWA-4400, the materials and welds specified in 1(a) may be repaired using the automatic or machine GTAW temper bead technique without the specified preheat or postweld heat treatment of the Construction Code, when it is impractical to drain the component or impractical for radiological reasons. All other requirements of IWA-4000[1] shall be met, except as modified in 1 through 5.

1 GENERAL REQUIREMENTS

(a) This Case applies to repair to P-No. 1, 3, 12A, 12B, and 12C[2] materials, and their associated welds and welds joining P-No. 8 or 43 materials to P-No. 1, 3, 12A, 12B, and 12C[2] materials, with the following limitations. This Case shall not be used to repair SA-302, Grade B material, unless the material has been modified to include 0.4% to 1.0% nickel, quenching and tempering, and application of a fine gain practice.

(b) The maximum area of an individual weld based on the finished surface shall be 100 sq. in. (65,000 sq. mm), and the depth of the weld shall not be greater than one-half of the ferritic base metal thickness.

(c) Repair/replacement activities on a dissimilar-metal weld in accordance with this Case are limited to those along the fusion line of a nonferritic weld to ferritic base material on which $\frac{1}{8}$ in. (3 mm), or less of nonferritic weld deposit exists above the original fusion line.

(d) If a defect penetrates into the ferritic base material, repair of the base material, using a nonferritic weld filler material, may be performed in accordance with this Case, provided the depth of repair in the base material does not exceed $\frac{3}{8}$ in. (10 mm).

(e) Prior to welding the area to be welded and a band around the area of at least $1\frac{1}{2}$ times the component thickness or 5 in. (130 mm), whichever is less shall be at least 50°F (10°C).

(f) Welding materials shall meet the Owner's Requirements and the Construction Code and Cases specified in the Repair/Replacement Plan. Welding materials shall be controlled so that they are identified as acceptable until consumed.

(g) Peening may be used, except on the initial and final layers.

2 WELDING QUALIFICATIONS

The welding procedures and the welding operators shall be qualified in accordance with Section IX and the requirements of 2.1 and 2.2.

2.1 Procedure Qualification

(a) The base materials for the welding procedure qualification shall be of the same P-Number and Group Number, as the materials to be welded. The materials shall be postweld heat treated to at least the time and temperature that was applied to the materials being welded.

(b) Consideration shall be given to the effects of welding in a pressurized environment. If they exist, they shall be duplicated in the test assembly.

[1] The references to Section XI in this Case refer to the 2004 Edition. For use of this Case with other Editions and Addenda, refer to Table 1.

[2] P-No. 12A, 12B, and 12C designations refer to specific material classifications originally identified in Section III and reclassified in a later Edition of Section IX.

TABLE 1
REFERENCES FOR ALTERNATIVE EDITIONS AND ADDENDA FOR SECTION XI

1989 Edition with 1991 Addenda through 2004 Edition	1986 Edition with 1988 Addenda through 1989 Edition with 1990 Addenda	1983 Edition with 1983 Winter Addenda through 1986 Edition with 1987 Addenda	1980 Edition with 1981 Winter Addenda through 1983 Edition with 1983 Summer Addenda
IWA-2210 Visual Examinations	IWA-2210	IWA-2210	IWA-2210
IWA-2300 Personnel Qualifications	IWA-2300	IWA-2300	IWA-2300
IWA-4000 Repair/Replacement Activities	IWA-4000 & IWA-7000	IWA-4000 & IWA-7000	IWA-4000 & IWA-7000
IWA-4400 Welding, Brazing, Metal Removal and Installation	IWA-4400	IWA-4300	IWA-4300

(c) Consideration shall be given to the effects of irradiation on the properties of material, including weld material for applications in the core belt line region of the reactor vessel. Special material requirements in the Design Specification shall also apply to the test assembly materials for these applications.

(d) The root width and included angle of the cavity in the test assembly shall be no greater than the minimum specified for the repair.

(e) The maximum interpass temperature for the first three layers of the test assembly shall be 150°F (66°C).

(f) The test assembly cavity depth shall be at least one-half the depth of the weld to be installed during the repair/replacement activity and at least 1 in. (25 mm). The test assembly thickness shall be at least twice the test assembly cavity depth. The test assembly shall be large enough to permit removal of the required test specimens. The test assembly dimensions surrounding the cavity shall be at least the test assembly thickness and at least 6 in. (150 mm). The qualification test plate shall be prepared in accordance with Fig. 1.

(g) Ferritic base material for the procedure qualification test shall meet the impact test requirements of the Construction Code and Owner's Requirements. If such requirements are not in the Construction Code and Owner's Requirements, the impact properties shall be determined by Charpy V-notch impact tests of the procedure qualification base material at or below the lowest service temperature of the item to be repaired. The location and orientation of the test specimens shall be similar to those required in (i) below, but shall be in the base metal.

(h) Charpy V-notch tests of the ferritic weld metal of the procedure qualification shall meet the requirements as determined in (g) above.

(i) Charpy V-notch tests of the ferritic heat-affected zone (HAZ) shall be performed at the same temperature as the base metal test of (g) above. Number, location, and orientation of test specimens shall be as follows:

(1) The specimens shall be removed from a location as near as practical to a depth of one-half the thickness of the deposited weld metal. The coupons for HAZ impact specimens shall be taken transverse to the axis of the weld and etched to define the HAZ. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much HAZ as possible in the resulting fracture. When the material thickness permits, the axis of a specimen shall be inclined to allow the root of the notch to be aligned parallel to the fusion line.

(2) If the test material is in the form of a plate or a forging, the axis of the weld shall be oriented parallel to the principal direction of rolling or forging.

(3) The Charpy V-notch test shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. The test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion, percent shear, absorbed energy, test temperature, orientation and location of all test specimens shall be reported in the Procedure Qualification Record.

(j) The average lateral expansion value of the three HAZ Charpy V-notch specimens shall be no less than the average lateral expansion value of the three unaffected base metal specimens. However, if the average lateral expansion value of the HAZ Charpy V-notch specimens is less than the average value for the unaffected base metal specimens and the procedure qualification meets all other requirements of this Case, either of the following shall be performed:

(1) The welding procedure shall be requalified.

(2) An *Adjustment Temperature* for the procedure qualification shall be determined in accordance with the applicable provisions of NB-4335.2 of Section III, 2001 Edition with the 2002 Addenda. The RT_{NDT} or lowest

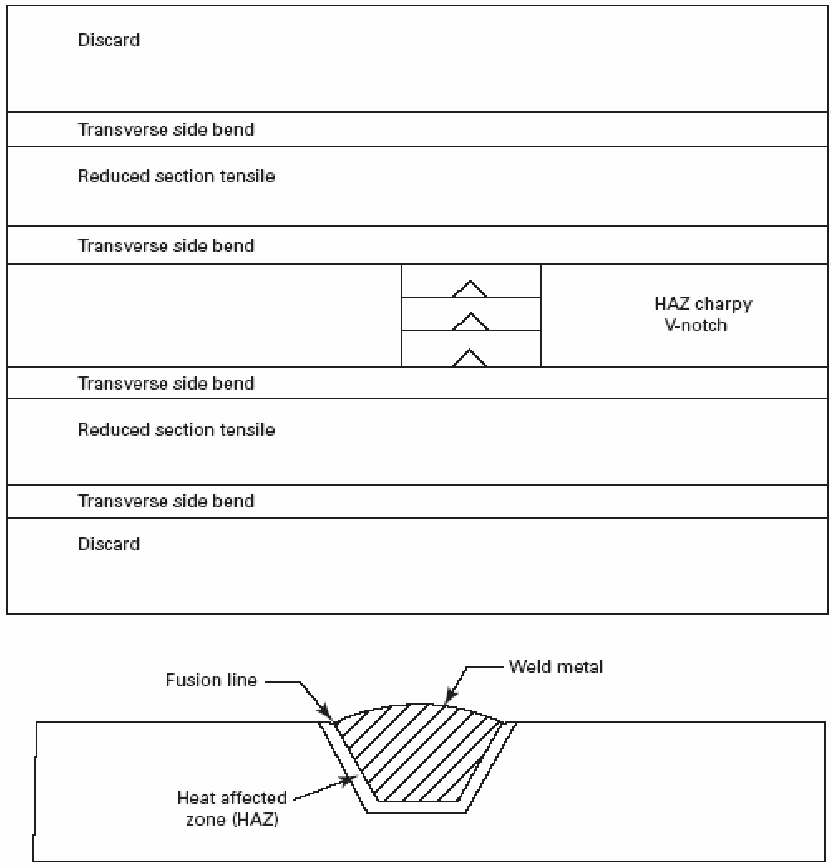


FIG. 1 QUALIFICATION TEST PLATE

service temperature of the materials for which the welding procedure will be used shall be increased by a temperature equivalent to that of the *Adjustment Temperature*.

2.2 Performance Qualification

Welding operators shall be qualified in accordance with Section IX.

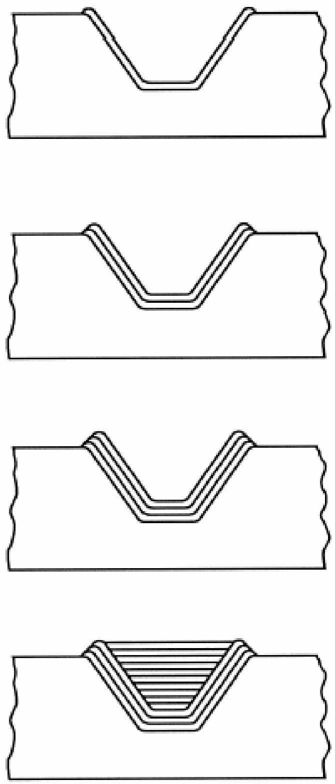
3 WELDING PROCEDURE REQUIREMENTS

The welding procedure shall include the following requirements.

(a) The weld metal shall be deposited by the automatic or machine GTAW process.

(b) Dissimilar metal welds shall be made using A-No. 8 weld metal (QW-442) for P-No. 8 to P-No. 1, 3, or 12 (A, B, or C) weld joints or F-No. 43 weld metal (QW-432) for P-No. 8 or 43 to P-No. 1, 3, or 12 (A, B, or C) weld joints.

(c) The area to be welded shall be buttered with a deposit of at least three layers to achieve at least $\frac{1}{8}$ in. (3 mm), overlay thickness as shown in Fig. 2, Steps 1 through 3, with the heat input for each layer controlled to within ±10% of that used in the procedure qualification test. The heat input of the first three layers shall not exceed 45,000 J/in. under any conditions. Particular care shall be taken in placement of the weld layers at the weld toe area of the ferritic material to ensure that the HAZ and ferritic weld metal are tempered. Subsequent layers shall be deposited with a heat input not exceeding that used for layers beyond the third layer in the procedure qualification. For similar-metal welding, the completed weld shall have at least one layer of weld reinforcement



Step 1: Deposit layer one with first layer weld parameters used in qualification.

Step 2: Deposit layer two with second layer weld parameters used in qualification. NOTE: Particular care shall be taken in application of the second layer at the weld toe to ensure that the weld metal and HAZ of the base metal are tempered.

Step 3: Deposit layer three with third layer weld parameters used in qualification. NOTE: Particular care shall be taken in application of the third layer at the weld toe to ensure that the weld metal and HAZ of the base metal are tempered.

Step 4: Subsequent layers to be deposited as qualified, with heat input less than or equal to that qualified in the test assembly. NOTE: Particular care shall be taken in application of the fill layers to preserve the temper of the weld metal and HAZ.

GENERAL NOTE: The illustration above is for similar-metal welding using a ferritic filler material. For dissimilar-metal welding, only the ferritic base metal is required to be welded using steps 1 through 3 of the temper bead welding technique.

FIG. 2 AUTOMATIC OR MACHINE (GTAW) TEMPER BEAD WELDING

deposited. This reinforcement shall be removed by mechanical means, so that the finished surface is essentially flush with the surface surrounding the weld (Fig. 3).

(d) The maximum interpass temperature for field applications shall be 350°F (180°C) for all weld layers, regardless of the interpass temperature used during qualification. The interpass temperature limitation of QW-406.3 need not be applied.

(e) The interpass temperature shall be determined by one of the following methods:

(1) temperature measurement (e.g., pyrometers, temperature indicating crayons, thermocouples) during welding

(2) heat flow calculations using the variables listed below as a minimum:

(a) welding heat input

(b) initial base material temperature

(c) configuration, thickness, and mass of the item being welded

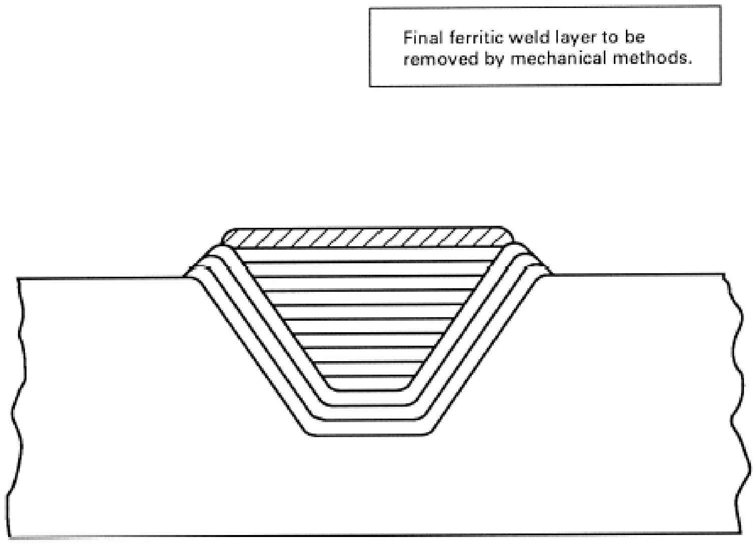
(d) thermal conductivity and diffusivity of the materials being welded

(e) arc time per weld pass and delay time between each pass

(f) arc time to complete the weld

(3) measurement of the maximum interpass temperature on a test coupon that is equal to or less than the thickness of the item to be welded. The maximum heat input of the welding procedure shall be used in the welding of the test coupon.

(f) Particular care shall be given to ensure that the weld region is free of all potential sources of hydrogen. The surfaces to be welded, filler metal, and shielding gas shall be suitably controlled.



GENERAL NOTE: For ferritic filler metals the completed weld shall have at least one layer of weld reinforcement deposited. This reinforcement shall be removed by mechanical means, so that the finished surface of the weld is essentially flush with the surface of the component surrounding the repair.

FIG. 3 FINAL FERRITIC WELD LAYER

4 EXAMINATION

(a) Except as permitted in 4(a)(1), the following examinations shall be performed in accordance with the Construction Code or Section III.

(1) Prior to repair welding, surface examination shall be performed on the area to be welded. When surface examination is impractical, VT-1 visual examination may be performed, provided the requirements of 4(b) are met.

(2) The weld shall be nondestructively examined after the completed weld has been at ambient temperature for at least 48 hr. Examination of the welded region shall include both volumetric and surface examination methods.

(3) Areas from which weld-attached thermocouples have been removed shall be ground and examined using a surface examination method.

(4) Acceptance criteria for surface and volumetric examination shall be in accordance with the Construction Code or Section III.

(b) VT-1 visual examinations performed in accordance with 4(a)(1) shall meet the following:

(1) VT-1 visual examination shall be performed using a procedure that meets the requirements of IWA-2210 and shall be capable of resolving text with lower case characters (e.g., a, c, e, o) not exceeding a height of 0.044 in. (1.1 mm) at the examination distance. The maximum direct VT-1 distance shall not exceed 2 ft (610 mm).

(2) VT-1 visual examination personnel shall be qualified in accordance with IWA-2300 and shall receive additional training in examination of weldments for fabrication conditions, including dimensional requirements and fabrication flaws.

(3) Visual examination acceptance standards shall comply with the following:

(a) Linear indications are indications in which the length is more than three times the width. Rounded indications are circular or elliptical with length equal to or less than three times the width.

(b) Only indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant. The following relevant indications are unacceptable.

(1) any cracks or linear indications

(2) rounded indications with major dimensions greater than 3/16 in. (5 mm)

(3) four or more rounded indications in a line separated by 1/16 in. (1.5 mm) or less edge to edge

(4) ten or more rounded indications in any 6 sq. in. (4 000 sq. mm) of surface with major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the indication being evaluated

5 DOCUMENTATION

Use of this Case shall be documented on Form NIS-2.

D

APPENDIX D – WHITE PAPER – CHANGES TO CODE CASE N-638-1

The following changes have been proposed to Code Case N-638-1 under this item. The changes are summarized as follows:

I. Revise limitation of SA302, Grade B to allow welding of SA302, Grade B modified.

II. Clarify impact testing acceptance criteria and add provisions for an Adjustment Temperature.

III. Change NDE requirements and acceptance criteria to comply with the Construction Code.

IV. Allow performance of visual examinations when surface examinations are impractical.

V. Add requirement to monitor process temperatures during the welding process.

VI. Clarified existing interpass temperature provision of paragraph 3.0(d).

VII. Miscellaneous changes and clarifications were also made to update Code Case.
- Added metric conversions.
- Added Table 1, *References for Alternate Editions and Addenda of Section XI*.
- Editorial corrections to Figure 1.

Discussion on Basis for Changes

I. Revision of limitation on SA302, Grade B to allow welding of SA302, Grade B modified.

A. Code Case 1339 and SA-302, Grade B Modified

As of the 1965 Edition of ASME Section III, pressure vessels could be fabricated from materials conforming to the material specifications listed in Table N-421, *Design Stress Intensity Values, S_m, for Carbon and Low Alloy Steels*. While Table N-421 approved the use of materials conforming to SA-302, Grades A and B, the use of SA-302, Grade B modified or SA-533, Grades A, B, and C were not approved.

In August 1964 ASME Code Case 1339 was issued to allow the use of SA-302, Grade B modified plate materials in the fabrication of nuclear vessels. The Inquiry and Reply of Code Case 1339 are provided below:

Inquiry: *What plate materials not listed in Table N-421 of Section III may be used in construction of nuclear vessels in accordance with Section III and what requirements apply to these materials?*

Reply: *It is the opinion of the Committee that the following plate materials may be used and the following specified special requirements apply in addition to the requirements for plates specified in Section III.*

1. *Plates made of materials conforming to the requirements of SA-302, Grade B except the composition may be modified to include from 0.4 to 1.0 percent nickel and the thickness may exceed 4".*

   (a) *The design stress intensity values shall be the same as listed in Table N-421 for SA302, Grade B plates.*

   (b) *The material shall receive P-Number 3 classification in Table Q11.1 of Section IX and shall be subject the same requirements for preheating (N-531) and for Postweld Heat Treatment (N-532) as SA-302, Grade B plates.*

B. Comparison SA-302, Grade B Modified to SA-533, Grade B Class 1 and Grade C Class 1

The chemical and mechanical properties, heat treatment, and grain refinement practices are compared in the table below. As shown in the table, the SA-302, Grade B Modified materials used in reactor pressure vessels are essentially equivalent to SA-533, Grade B Class 1 and Grade C Class 1 materials used in reactor pressure vessels.

Material Properties	**SA-302, Grade B (1)**	**SA-302, Grade B Modified (2)**		**SA-533, Grade B, Class 1 (1)**	**SA-533, Grade C, Class 1 (1)**
		SA-302, Grade C (1)	**SA-302, Grade D (1)**		
Chemistry					
• Carbon	0.25 max	0.25 max	0.25 max	0.25 max	0.25 max
• Manganese	1.15-1.50	1.15-1.50	1.15-1.50	1.15-1.50	1.15-1.50
• Phosphorus	0.035 max	0.035 max	0.035 max	0.035 max	0.035 max
• Sulfur	0.040 max	0.040 max	0.040 max	0.040 max	0.040 max
• Silicon	0.15-0.30	0.15-0.30	0.15-0.30	0.15-0.30	0.15-0.30
• Molybdenum	0.45-0.60	0.45-0.60	0.45-0.60	0.45-0.60	0.45-0.60
• Nickel	-	0.40-0.70	0.70-1.00	0.40-0.70	0.70-1.00
Mechanical					
• Tensile Strength	80-100 ksi	80-100 ksi	80-100 ksi	80-100 ksi	80-100 ksi
• Yield Strength	50 ksi	50 ksi	50 ksi	50 ksi	50 ksi
• % Elongation	18 (3)	20 (3)	20 (3)	18 (3)	18 (3)
Heat Treatment	• Normalized with/without accelerated cooling • Hot Forming with/without normalizing, stress relief or both			• Quenched and tempered	
Fine Austenitic Grain Practice	Not required.			Not required until the 1986 Edition, 1987 Addenda of Section II.	

Notes:
1. Properties and heat treatment based on the 1971 Edition of Section II. The SA-302 and SA-533 material specifications in the 1971 Edition of Section II are identical to ASTM specifications A-302-69a and A-533-69a.
2. SA-302, Grade B modified was approved under Code Case 1339 in August 1964.

3. For materials over 3-1/2” in thickness, a deduction of 0.5% elongation shall be m-ade for each increase of ½” above 3-1/2” but not to exceed 3%.

The following chronology has been provided to supplement the information provided in the above table and summarizes incorporation of SA-302, Grade B modified, SA-533, and grain refinement practices into the ASME Code.

- Code Case 1339 issued in August 1964 to approve use of SA-302, Grade B modified materials for construction of nuclear vessels.
- **Note**: As of the 1965 Edition of Section III, only SA-302, Grades A and B are approved by Section III for construction of nuclear vessels.
- SA-533, Grade A Class 1, Grade B Class 1, and Grade C Class 1 approved in 1965 Edition, Summer 1967 Addenda of Section III.
- SA-302, Grades C and D approved in 1968 Edition, Summer 1968 Addenda of Section III.
- **Note**: As of the 1968 Edition, Summer 1968 Addenda of Section II, SA-533 did not include “fine austenitic grain refinement” requirements.
- The 1986 Edition, 1987 Addenda of Section II revised SA-533 to add “fine austenitic grain refinement” requirement.
- The 1986 Edition, 1988 Addenda of Section II revised SA-20 to state that when fine grain size is specified, aluminum shall be used (unless other methods specified by purchaser).

As shown above, the chemical composition and the mechanical properties of SA-302, Grade B modified materials are essentially identical to those of the SA-533, Grade B Class 1 and Grade C Class 1. Prior to 1987, the fundamental difference between SA-302, Grade B modified plate materials and SA-533, Grades B Class 1 or C Class 1 was heat treatment. SA-302, Grade B modified plate materials were normalized (accelerated) while SA-533 materials were quenched and tempered. Therefore, the toughness of the quenched and tempered SA-533 materials would be somewhat better than that of the SA-302, Grade B modified materials. However, while this may be a material property issue for SA-302, Grade B modified materials, it would have no impact on Code Case N-638 welding procedures.

One other point should be noted. In an effort to evaluate this issue further, original equipment manufacturers (OEMs) were contacted to discuss their use of SA302, Grade B modified materials to manufacture nuclear pressure vessels. According to the OEMs, purchase orders for SA-302, Grade B modified materials supplemented the Code Case 1339 requirements to require quenching and tempering and the application of a fine grain practice. Random spot checking seemed to confirm this information.

C. Code Case N-638 Temper Bead Welding Process and SA-302, Grade B Modified

Section 2.1 of Code Case N-638 contains welding procedure qualification requirements. Simulating base materials, filler metals, restraint, impact properties, and procedure variables, the qualification requirements of Section 2.1 provide assurance that the impact properties in the heat affected zone of repair welds will be equivalent or superior to those of the surrounding base material. Although the Code Case is being revised to accept some degradation in the heat affected zone due to the welding process, this degradation will be accounted for by the addition of an “Adjustment Temperature”. “Adjustment Temperatures” have been utilized in Section III procedure qualifications since the Winter 1974 Addenda, and Section III does not impose any restrictions on welding SA-302, Grade B modified materials.

The Code Case N-638 ambient temperature temper bead welding process utilizes the tempering action of the welding procedure to produce tough and ductile microstructures. Because precision bead placement and heat input control is characteristic of the machine GTAW process, effective tempering of weld heat affected zones is possible without the application of preheat. According to Section 2-1 of EPRI Report GC-111050, "*the temper bead process is carefully designed and controlled such that successive weld beads supply the appropriate quantity of heat to the untempered heat affected zone such that the desired degree of carbide precipitation (tempering) is achieved. The resulting microstructure is very tough and ductile*." EPRI Report GC-111050 also concluded the following in Section 6.0: "*Repair of RPV components utilizing machine GTAW temper bead welding at ambient temperature produces mechanical properties that are commonly superior to those of the service-exposed substrate. The risk of hydrogen delayed cracking is minimal using the GTAW process. Cold stress cracking is resisted by the excellent toughness and ductility developed in the weld HAZ (heat affected zone). Process design and qualification plate geometry largely control restraint considerations, and these factors are demonstrated during weld procedure qualification*." Laboratory tests, analysis, successful procedure qualifications, and successful repairs have all demonstrated the effectiveness of this process.

It should also be noted that ASME Section XI does not impose any restrictions on welding SA-302, Grade B modified materials in IWA-4600. Likewise, Code Case N-606-1, *Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique for BWR CRD Housing/Stub Tube Repairs*, allows ambient temperature temper bead weld repairs on SA-302, Grade B modified materials without any restrictions.

D. Reactor Vessels Manufactured from SA-302, Grade B Modified

- Browns Ferry 1
- Browns Ferry 2
- Browns Ferry 3
- Dresden 2
- Dresden 3
- Indian Point 2
- Indian Point 3
- Nine Mile Point 1
- Oconnee-1
- Palisades
- Peach Bottom 2
- Peach Bottom 3
- Quads Cities 1
- Quads Cities 2

Note: Above information is based on NRC – Reactor Vessel Integrity Database (RVID).

II. Clarification of impact testing acceptance criteria and add provisions for an Adjustment Temperature

A. Clarification of Acceptance Criteria

The current text in paragraph 2.1(j) of Code Case N-638-1 states: "*The average of the three HAZ impact tests shall be equal to or greater than the average values of the three unaffected base metal tests.*" The current Charpy V-notch test acceptance criteria in Code Case N-638-1 is misleading and inconsistent with the specified acceptance criteria in Section XI applicable to other Class 1 components, since it implies that all three parameters - lateral expansion, absorbed energy, and percent shear fracture - have to be equal or exceed the base material values. This was never the intent of this requirement.

Under the proposed change, the Charpy V-notch acceptance criteria will be revised to read as follows: *"The average of the three HAZ Charpy V-notch lateral expansion values shall be equal to or greater than the average value of the three unaffected base metal lateral expansion values…"* This change clarifies the intent of the Code Case and aligns its Charpy V-notch acceptance criteria with that of Sections III and XI as demonstrated in the code references provided below.

- Section XI - IWA-4620, Temper Bead Welding of Similar Materials
- Section XI - IWA-4630, Temper Bead Welding of Dissimilar Materials
- Section III – NB-4330, Impact Test Requirements

B. Charpy V-notch Adjustment Temperatures

NB-4335 of Section III establishes impact testing requirements for welding procedure qualifications that include provisions to determine and apply an "Adjustment Temperature". Although not specifically defined in Section III, the "Adjustment Temperature" of a welding procedure is the temperature added to the RT_{NDT} or Lowest Service Temperature of materials to compensate for degradation of base material impact properties due to the welding process. Provisions to utilize an "Adjustment Temperature" have existed in Section III, NB-4335 since the Winter 1974 Addenda of the 1974 Edition.

Where impact testing is required, the acceptability of a welding procedure qualification is based in part on Charpy V-notch testing of the weld heat affected zone. The welding procedure qualification is acceptable if the average lateral expansion value of the heat affected zone specimens is equal to or greater than the average lateral expansion value of the unaffected base material specimens. However, if the heat affected zone average lateral expansion value is less than that of the unaffected base material, an "Adjustment Temperature" must be determined. Alternatively, the welding procedure may be requalified.

According to the 2001 Edition, 2002 Addenda of NB-4335.2(c)(5), (6), or (7) of Section III, the Adjustment Temperature for the welding procedure may be determined using any of the three methods described below. It should be noted that the Adjustment Temperature determination method described in NB-4335.2(c)(5) has been in the code since the Winter 1974 Addenda; whereas, the NB-4335.2(c)(6) and (7) methods were added to the code by the 2002 Addenda.

- NB-4335.2(c)(5): "Additional Charpy V-notch tests shall be performed either on the heat affected zone or the unaffected base material, or both, at temperatures where the lateral expansion value of all three specimens tested is not less than 35 mils. The average lateral expansion value for each test meeting this requirement shall be plotted on a lateral expansion verses temperature graph. The difference in temperature T_{HAZ} and T_{UBM} where the heat affected zone and the unaffected base material average lateral expansion values are the same and not less than 35 mils shall be used to determine the Adjustment Temperature T_{ADJ} where: $T_{ADJ} = T_{HAZ} – T_{UBM}$. If $T_{ADJ} \leq 0$, then $T_{ADJ} = 0$.

- NB-4335.2(c)(6): "As an alternative to NB-4335(c)(5), if the average lateral expansion value of the heat affected zone is no less than 35 mils and the average of the heat affected zone specimens is not less than 5 mils below the average lateral expansion value of the unaffected base material specimens, T_{ADJ} may be taken as 15°F."

- NB-4335.2(c)(7): "As a second alternative to NB-4335(c)(5), if the average lateral expansion value of the heat affected zone specimens is no less than 35 mils, the difference between the average lateral expansion value of the heat affected zone and the unaffected base material specimens shall be calculated as described in NB-4335.2(e)(3)."

Once determined, the "Adjustment Temperature" must be applied to compensate for the degradation of heat affected zone toughness due to the welding procedure. According to NB-4335.2(e) of the 2001 Edition, 2002 Addenda of Section III, any of the following three methods may be used.

- NB-4335.2(e)(1): "The RT_{NDT} temperature established in NB-2331 or NB-2332(b) or the lowest service temperature specified in the Design Specification [NB-2332(a)] for all of the material to be welded in production welding procedure specifications (WPSs) supported by this PQR shall be increased by the adjustment temperature T_{ADJ}."

- NB-4335.2(e)(2): "The specified testing temperature for the production material may be reduced by the adjustment temperature T_{ADJ}."

- NB-4335.2(e)(3): "The materials to be welded may be welded using the WPS provided they exhibit Charpy V-notch values that are no less than the minimum required lateral expansion value required by NB-2300 plus the difference in average lateral expansion values established in NB-4335.2(c)(7) or NB-4335.2(d)(5)."

<u>Addition of Adjustment Temperature Provisions Into Code Case N-638</u>

Code Case N-638-1 does not presently address utilization of an Adjustment Temperature. The proposed change will add provisions for determining and applying an Adjustment Temperature that will be consistent with Section III. This change should also eliminate questions that could result in unwarranted procedure requalifications that are costly and time consuming. The proposed change would revise paragraph 2.1(j) as follows:

"The average lateral expansion value of the three HAZ Charpy V-notch specimens shall be equal to or greater than the average lateral expansion value of the three unaffected base metal specimens. However, if the average lateral expansion value of the HAZ Charpy V-notch specimens is less than the average value for the unaffected base metal specimens and the procedure qualification meets all other requirements of this Case, either of the following shall be performed:

(1) The welding procedure shall be requalified.

(2) An *Adjustment Temperature* for the procedure qualification shall be determined in accordance with the applicable provisions of NB-4335.2 of Section III, 2001 Edition with 2002 Addenda. The RT_{NDT} or lowest service temperature of the materials for which the welding procedure will be used shall be increased by a temperature equivalent to that of the Adjustment Temperature."

III. Change of NDE Requirements and Acceptance Criteria to Compliance With Construction Code

Section 4.0 of Code Case N-638 establishes examination requirements for repair welds. According to paragraph 4.0(b), the ultrasonic examination is performed in accordance with Appendix I. Paragraph 4.0 is silent with regard to surface examinations. Except where specifically stated in Section XI, examination of repair welds is performed in accordance with the Construction Code or Section III. This is true for temper bead and non-temper bead weld repairs. The proposed change to the Code Cases revises the NDE requirements to require compliance with the Construction Code or Section III. This change simply aligns the Code Case with Section XI repair/replacement examination philosophy.

IV. Change to Allow Performance of Visual Examinations When Surface Examinations Are Impractical.

Code Case N-638-1 presently requires the performance of a surface examination of a repair cavity prior to repair welding. This surface examination requirement is specified to ensure freedom from cracks and other unacceptable defects. However, the repair cavity surfaces should also exhibit a high state of cleanliness prior to welding. According to NB-4412 of Section III, "The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The surfaces for welding shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces."

With respect to surface examinations, unremoved or entrapped surface examination materials could be "deleterious material" to the welding process. Accordingly, a surface examination of a repair cavity would not be advisable in weld joint geometries where this condition could exist. This particular problem is most likely to occur in repair cavities of partial penetration welds or when performing repair welding over crevices. Under either of these conditions, surface examination materials (liquid penetrant or magnetic particle) could become trapped in the root of the joint or crevice. Trapped examination materials could be consumed during the welding process and have a deleterious effect on the repair weld.

Section XI recognizes the potentially deleterious effects of examination materials on a weld. According to IWA-4611.2(a), "After final processing, the affected surfaces including surfaces of cavities prepared for welding shall be examined by the magnetic particle or liquid penetrant method to ensure that the indication has been reduced to an acceptable size in accordance with… No examination of the defect removal area is required when defect elimination removes the full thickness of the weld and the backside of the weld joint <u>is not accessible for removal of examination materials</u>." This exemption also exists in NB-4453.1 of Section III: "Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with NB-5110, and meet the acceptance standards of NB-5340 or NB-5350. This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is <u>not accessible for removal of examination materials</u>."

The proposed change to Code Case N-638-1 establishes provisions for performing a VT-1 visual examination of repair cavities when a surface examination is not practical. The VT-1 visual examination procedure must meet the requirements of IWA-2210. VT-1 personnel must be qualified in accordance with IWA-2300. The specified acceptance criteria is appropriate for identifying cracks, linear imperfections, and other unacceptable imperfections in a repair of cavity. The proposed visual examination procedure and personnel qualification requirements are consistent with requirements in IWA-4660 for Underwater Welding and new Code Case N-666, *Reinforcement of Class 1, 2, and 3 Socket Weld Connections*.

V. Add Requirement to Monitor Process Temperatures During the Welding Process

The present revision of Code Case N-638 does not clearly address the monitoring of process temperatures during the production welding operation. The proposed change adds the following requirement in new paragraph 3.0(e):

"The interpass temperature shall be controlled by one of the following methods:

(1) Temperature measurement (e.g. pyrometers, temperature indicating crayons, thermocouples) during welding;
(2) Heat flow calculations using the maximum heat input permitted by the welding procedure;
(3) Mock-up testing using the maximum heat input permitted by the welding procedure."

The proposed change will allow the use of any temperature monitoring or analytical method that ensures that process temperatures are controlled within the interpass temperature limitations of the welding procedure. Because this Code Case is generally used to perform repair welding on Reactor Coolant System (RCS) components where radiological exposure is a significant concern, temperature monitoring has been generally performed remotely using devices such as infrared thermometers. While thermocouples[1] are certainly allowed under the proposed change, the radiological exposure associated with their installation and removal (which includes NDE) make them a less attractive option. As an alternative to temperature monitoring methods, analytical evaluations that provide assurance that process temperatures will remain within welding procedure variables can be performed.

① Although the use of thermocouples and recording instruments are critical when using traditional temper bead welding procedures that are based on elevated preheat and postweld bake temperatures, their use is not critical to ambient temperature temper bead procedures.

VI. Clarified existing interpass temperature provision of paragraph 3.0(d)

ASME IX, QW-256 specifies that the interpass temperature used during production welding shall not be more than 100°F above the interpass temperature used in the procedure qualification. This interpass temperature limitation is a Section IX supplementary essential variable. Code Case N-638 takes exception to this Section IX supplemental essential variable requirement. Paragraph 2.1(e) of the Code Case specifies that the maximum interpass temperature for the first three layers of the procedure qualification shall not exceed 150°F; paragraph 3.0(d) specifies that the maximum interpass temperature of the welding procedure shall be 350°F regardless of the interpass temperature during qualification.

Paragraph 2.1(e) of the Code Case limits the interpass temperature to 150°F (maximum) during the procedure qualification. This limitation on interpass temperature was included in the Code Case to ensure that cooling rates obtained during the procedure qualification were more severe than those to be experienced in production welding. In other words, the 150°F (maximum) interpass temperature requirement of paragraph 2.1(e) ensures that cooling rates obtained during the procedure qualification are <u>not</u> slower than those achievable during production welding. Additionally, the 350°F maximum interpass temperature requirement of paragraph 3.0(d) "for field applications" allows for slower (i.e. less severe) cooling rates which are helpful in producing more ductile transformation products in the heat affected zone.

The proposed change to paragraph 3.0(d) was made to clarify the intent of this requirement. It does not amend or change the original intent of this requirement.

VII. Miscellaneous changes and clarifications were also made to update Code Case.

- Added metric conversions.
- Added Table 1, *References for Alternate Editions and Addenda of Section XI.*

VII. Miscellaneous changes and clarifications were also made to update Code Case.

- Added metric conversions.
- Added Table 1, *References for Alternate Editions and Addenda of Section XI*.
- Editorial correction to Figure 1.

E

APPENDIX E CHANGE TO CODE CASE N-638-2 (N-638-3)

RRA 00-04, BC 04-1000, Revise Code Case N-638-2 to Address Limitations on Size of Repairs

2

Case N-638-1
Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique
Section XI, Division 1

1.0 GENERAL REQUIREMENTS

500 sq. in. (325,000 sq. mm)

(b) The maximum area of an individual weld based on the finished surface shall be and the depth of the weld shall not be greater than one-half of the ferritic base metal thickness.

over the ferritic material

F

APPENDIX F WHITE PAPER- CODE CASE N-638-3

1) Background

The purpose of this action is to relax an arbitrary limitation that was included in Code Case N-638 to restrict the use of the ambient temperature temper bead welding to a surface area of less then 100 square inches and a depth of less then 50% through wall. Code Case N-432-1, which requires a preheat temperature of 300° F and a post weld soak in the 450 – 550° F for 2 hours does not require that the temper bead repair be limited to the 100 square inch surface area limit. The same rules for temper bead welding by GTAW in ASME Section XI, IWA – 4630 require the same preheat and post weld soak requirement for temperature as required by Case N-638, but a 2 hour hold is required for P-1 materials and a 4 hour hold for P-3 materials except restrictions on size and depth similar to those in N-638 are required.

It is not clear what the restriction on surface area for ambient temperature temper bead process was intended to address. The welding in N-638 is done using bare filler wire and dry shielding gases. The process is by its nature a low hydrogen process. Further diffusion of hydrogen is very rapid for low alloy steels. Nonetheless the post weld soaks in the Code and Code Case are intended as post hydrogen bake outs permitting NDE after the repair has returned to ambient temperature. N-638, since it does not impose the post bake, requires that a 48 - hour hold time prior to NDE be imposed to verify that the unlikely event of hydrogen induced cold cracking has not occurred. Further it should be pointed out that the post weld soak temperatures are too low to either temper the heat affected zone (HAZ) in the ferritic material or be an effective stress relief.

Dissimilar metal overlays have been performed at some BWR units for about 20 years. The initial dissimilar metal weld overlay repair was applied at Vermont Yankee at the core spray nozzle to safe end weld during the 1985-1986 outage, and is still in service without incident. Several BWR units recently applied weld overlays to nozzle/safe-end locations and one PWR unit, Three Mile Island Unit 1 applied an overlay on a hot leg-to-surge line nozzle using temper bead welding procedures.

Ambient temperature machine GTAW temperbead procedures were used to perform the repairs with the RPVs filled with water to avoid excessive radiation exposure to repair personnel. These BWR plants include Perry, Duane Arnold, Hope Creek, Nine Mile Point Unit 2 (NMP-2), Pilgrim, Susquehanna and two at Hope Creek. The Perry and Nine Mile Point Unit 2 overlays were applied to feedwater nozzles. Duane Arnold applied overlays to two recirculation inlet nozzles, and Hope Creek applied an overlay to a core spray nozzle and a recirculation inlet nozzle. All of these repairs were performed at ambient preheat temperatures except for the Hope Creek core spray nozzle overlay. Several utilities have planned contingent repairs for nozzle welds that have Alloy 182 butter and Alloy182 filler.

The code requirement limiting the application of temperbead procedures to 100 in^2 has significantly influenced the design of some of the weld overlays. Further relief from the surface area limitation has been requested and approved by the NRC on a case basis for several of these repairs. Service history with these overlays at dissimilar metal weldments has been excellent, with no subsequent incidences reported. Inspection methods that are qualified in accordance with PDI are available and have been used to conduct the examinations.

2) Technical Discussion

The temper bead weld process for excavated cavity and overlay repairs of ferritic and dissimilar metal welds using the automatic GTAW process have been performed at operating nuclear power plants for approximately the past 20 years. They have been performed by both welding at ambient temperature and with a pre-heat and post weld soak as discussed above. In no instance has hydrogen induced cracking occurred. Further vendor qualification tests have demonstrated that fracture toughness of the heat affected zones are as high or higher than repairs using conventional welding and post weld stress relief heat treatments in according to ASME code rules.

Older Qualification Programs

EPRI conducted a program to evaluate weld overlay repairs of 12" BWR N-2 inlet nozzle to safe end weld joints (1) that was published in January 1991. As a feature of the program a mockup of a nozzle to safe end weld was fabricated and destructively tested. The destructive testing included mechanical, hardness and Metallographic testing. The metallography and hardness demonstrated that the temper bead welding resulted in adequate tempering of the P-3 nozzle in the HAZ at the toe of the weld overlay and reduced hardness in the HAZ to about 300 to 350 Knoop (about R_c 34 - 37) after three layers of weld had been deposited. In addition FEA analysis was performed to demonstrate that the residual stresses after the overlay were compressive on the ID in the region of the weld with the material susceptible to IGSCC. An overlay following the EPRI program was implemented at Vermont Yankee. Results of the qualification program and inspections are included in the report as well. The overlay has been in-service since the 1986, and has been inspected several times with no evidence of degradation reported.

EPRI conducted a program to provide a justification for extended overlay design life for austenitic stainless steel weld overlays (2). While most of the program was intended to address overlay repairs for susceptible SS welds, the results of several test programs are included that show experimental results for ID residual stresses before and after application of a weld overlay. Further these programs were conducted on large diameter piping where the overlays would be far in excess of the 100 square inch limitation.

In one test (GPC/SI/WSI) two sections of 28" diameter pipe were welded together in a manner similar to that for the BWR main reactor coolant piping. A baffle was welded axially to divide the pipe segment into 2 halves. Axial and circumferential notches were ground in to the pipe near the girth weld. One half of the pipe ID was exposed to boiling $MgCl_2$ prior to applying the weld overlay. Extensive cracking was seen at the tip of each notch showing the presence of high residual tensile stresses at the notch tip. After weld overlay the other half of the pipe was exposed to boiling $MgCl_2$. No cracking occurred at the similar notch locations in the second half of the pipe showing the residual tensile stress at the notch tips changed from tensile to compressive following application of the overlay. This test confirmed the efficacy of the FEA in evaluating weld overlay repairs of austenitic materials.

In a second test (EPRI/J.A. Jones 24" mockup) a weld overlay was applied to the pipe and the residual stresses were determined experimentally and by FEA. The results of this residual stress and measurement project have shown that both axial and circumferential residual stresses are compressive at the pipe ID surface following a weld overlay of the thickness applied to the pipe. This also represents an experimental verification of FEA results for a large diameter reasonably thick wall pipe where the overlay would well exceed 100 square inches.

It should be noted that much of the weld shrinkage numerical methods as well the experimental verifications and failure analysis have been performed at government and not-for- profit laboratories (ANL, PNL and Battelle Columbus). Further details on the specific programs are found in the reference sections in (1) and (2).

More Recent Qualification Programs

During the development of the Code Case to relax the limitation on the surface area for ambient temperature temper bead welding, the Working Group on Welding, after receiving comments from other Code Committees and the NRC, requested that supporting analyses be performed to determine if any significant changes in residual stresses occur if the repair exceeded 100 square inches. It was assumed that the focus on residual stresses was made because past programs have demonstrated that temper bead welding using automatic GTAW provides adequate tempering of the HAZ in P-1 and P-3 materials and does not degrade strength or fracture toughness. Further associated inspections have shown that hydrogen induced cracking has not been a problem with repairs produced by the automatic GTAW temper bead process. The metallurgical aspects discussed appear to be independent of the surface area of the repair but related to input qualified for the welding.

EPRI sponsored analytical work (3) to evaluate the effects from increases in surface area beyond 100 square inches for both cavity and weld overlay repairs. Three cases were evaluated as a part of the program: a 100 square inch overlay on a nozzle was increased modestly and analyzed, a 500 square inch cavity repair was analyzed and three adjacent 100 square inch cavity repairs were analyzed.

In the first case a weld overlay that was applied to one of the 12 in. diameter Feedwater Nozzles of an operating BWR. The weld overlay was applied in order to restore the structural integrity of the flawed location assuming no credit for any remaining uncracked material in the original safe end. Due to the availability of the information from the utility and a finite element model, this geometry was selected for this initial phase of this work. These residual stress predictions were performed using the ANSYS Rev. 5.3 finite element program. The analysis consists of two parts: a thermal analysis and a stress analysis, to model the welding process in both thermal and mechanical respects. Two axisymmetric finite element models were created, one with a weld overlay of 100 in^2 (Figure 1), the other with the weld overlay extended on the nozzle side until it blends into the nozzle taper surface (Figure 2) (approximately 126 in^2). Figure 3 shows the residual stress on the pipe inside surface. These two figures show that the residual hoop stress is very similar, and in fact the hoop stress for the extended case is even more compressive. The axial stress is less compressive for the extended model, but still with significant compressive stress. This figure also shows that the main area of concern, near the weld, is not significantly affected by the extended overlay. In summary results of this evaluation indicate that the combination of the extended overlay and geometric discontinuity of caused by the increased nozzle diameter on the outside surface modify the residual stress. This modified behavior is local to the end where the extension of the overlay was made and the presence of the geometric discontinuity. All other stresses remain essentially the same and the effectiveness of the overlay to provide structural reinforcement at the nozzle-to-safe end weld remains assured. Results of this evaluation indicate that the alternate extended overlay would have been an acceptable overlay from a structural integrity perspective.

In the second case the weld repair configuration selected for evaluation is a cavity of rectangular trough shape, along the longitudinal axis of the reactor vessel, with a depth equal to half of the vessel wall thickness. Two repair sizes, 100 in^2 and 500 in^2 are used. These are the projected areas on the inside surface of the vessel. The actual surface areas in the cavity are much larger, at 328 in^2 and 1894 in^2.

Comparison was made on different paths for the residual stress distribution between the two repair sizes. The stress contours for the two repairs are shown in Figures 4-9. In general, the residual stress distributions in the axial and hoop directions are very similar to each other for the two repair sizes. Within the weld repair area, the axial surface residual stress (S_z) for the smaller repair area is lower than the larger repair area. The hoop surface residual stress (S_y) for the smaller repair area is higher than the larger repair cavity. Outside the weld repair cavity, the residual stress for the larger repair area has lower residual stresses on the selected paths, both on the inside surface and through the wall of the reactor vessel.

It is shown that a larger weld repair area does not have a significant adverse effect on the weld residual stress. In some cases, the larger repair area is much more beneficial because of the lower tensile residual stress or higher compressive residual stress. Especially for the case of axial weld repair where an axial crack could exist, the hoop stress is more compressive or less tensile within the weld repair area and outside the repair area. The larger repair area could be less susceptible to the crack growth, due to either stress corrosion or fatigue.

The third case addresses the implementation of a 300 in^2 weld repair on a Reactor Pressure Vessel (RPV) vertical shell weld. The repair is implemented in 3 separate 100 in^2 repair, i.e., a 100 in^2 repair is simulated, then another 100 in^2 repair is simulated immediately adjacent to the first repair, followed by a third 100 in^2 repair immediately adjacent to the second repair. This case was selected to evaluate to ascertain the ramifications of repairs being performed sequentially to stay within the 100 in^2 limitations.

The final weld repair configuration selected for evaluation is a rectangular trough shape, with a depth equal to half of the vessel wall thickness. The final weld repair consists of three temperbead layers, and a weld out of the remaining cavity. Due to the complexity in the modeling, the temperbead layers are present only on the final weld repair volume outside surfaces, or boundaries, that are in contact with the base metal. The temperbead was not modeled in between the two adjacent weld repairs. Also, a half model of the weld repair is used in order to account for the effect of sequence in the weld repairs.

Due to the large volume of the repair cavity and the large number of bead passes, simplifying assumptions, as identified earlier, were used in the weld residual stress analyses. These assumptions should not have a significant impact on the conclusion since the evaluation is made on the comparison of residual stresses among the three individual weld repair areas using similar assumptions and parameters.

The stress contours for the single and three sequential repairs are shown in Figures 10 and 11. Comparison was made for the residual stress distribution on different paths after the completion of each 100 in^2 repair area. In general, each weld repair area induces a similar residual stress distribution within its repair area. In addition, the residual stress in the previously repair area is reduced due to the subsequent adjacent repairs. This is due to the excavation of base metal in the subsequent weld repair volume that has a relaxation effect of residual stress in the previously repaired area. Also, the welding in the subsequent repair area has an effect similar to PWHT on the previously repair area.

Based on the comparison of the residual stress distributions for the sequential weld repairs, it can be concluded that a subsequent adjacent repair has an overall effect on reducing the residual stress distribution in the previously repair areas. Also, the residual stress in the last repaired area has a very similar residual stress magnitudes compared to an individual repair of 100 in^2.

The current evaluation uses three 100 in^2 repair areas. But the discussions on these results and the conclusions could be applied to any number of weld repair areas in each with an area of 100 in^2.

As a part of a program to evaluate weld overlays as a measure to mitigate PWSCC (4), SI conducted an analysis to determine the residual stress profiles of a 33 in. OD PWR reactor coolant nozzle to a stainless steel pipe. A summary of the dimensions for the finite element mode is shown in Figure 12. The reduced thickness overlay modeled is 0.48 in.thick which is about ½ the thickness of a full structural overlay. The surface area of the overlay on the low alloy steel nozzle was 332 square in. The stress contours before and after the overlaying is shown in Figures 13 and 14. Again it quite apparent that tensile residual stresses at the ID in the weld location before overlaying become compressive after the overlay is applied. The inside surface axial and hoop stresses are shown in Figure 15. Note that the condition for the pre-WOL at 120 F shown in black curve with diamonds shows the high residual tensile stresses and the post-WOL leakage test curve at 120 F shown in the blue curve with diamonds show that all residual stresses in the weld are compressive where there is any PWSCC susceptible material. Other conditions for residual stresses for the hoop and axial directions are also shown. This evaluation as well as those shown above again demonstrates that acceptable residual stresses to mitigate PWSCC are induced by the shrinkage of the weld overlay. Also it demonstrates that these residual stresses are independent of the surface area of the repair and related to other parameters. The overlay could well have been extended an additional 2 in. up the nozzle to increase the surface area over 500 square in. with similar results for the 332 square in. case analyzed.

3) Conclusions

The restriction on surface area for temper bead welding appears to have been arbitrary, is overly restrictive, and leads to increased cost and dose for repairs and does not contribute to safety.

There is no direct correlation of amount of surface area repaired when comparing residual stresses either for cavity or overlay repairs done using temper bead welding. Cases have been analyzed up to 500 square in. that verify that residual stresses for cavity repairs are at an acceptable level and that residual stresses associated with weld overlay repairs remain compressive in the weld region for larger area repairs as well a for smaller area repairs. The implementing ASME Code and Code Case requirements assure that code stress limits and safety factors are maintained for overlay repairs regardless of size. Metallurgical, mechanical, and hardness testing results show that adequate tempering is achieved and that adequate fracture toughness and strength is maintained in the weld and heat affected zone, and that the results are not dependent upon the repair area. It is the recommendation of this paper that the restriction on surface area of repairs should be increased to 500 square in. based on the results of analyses and testing performed to date. The Code should provide an option to allow users to justify repairs beyond 500 square in. by additional analysis and evaluation.

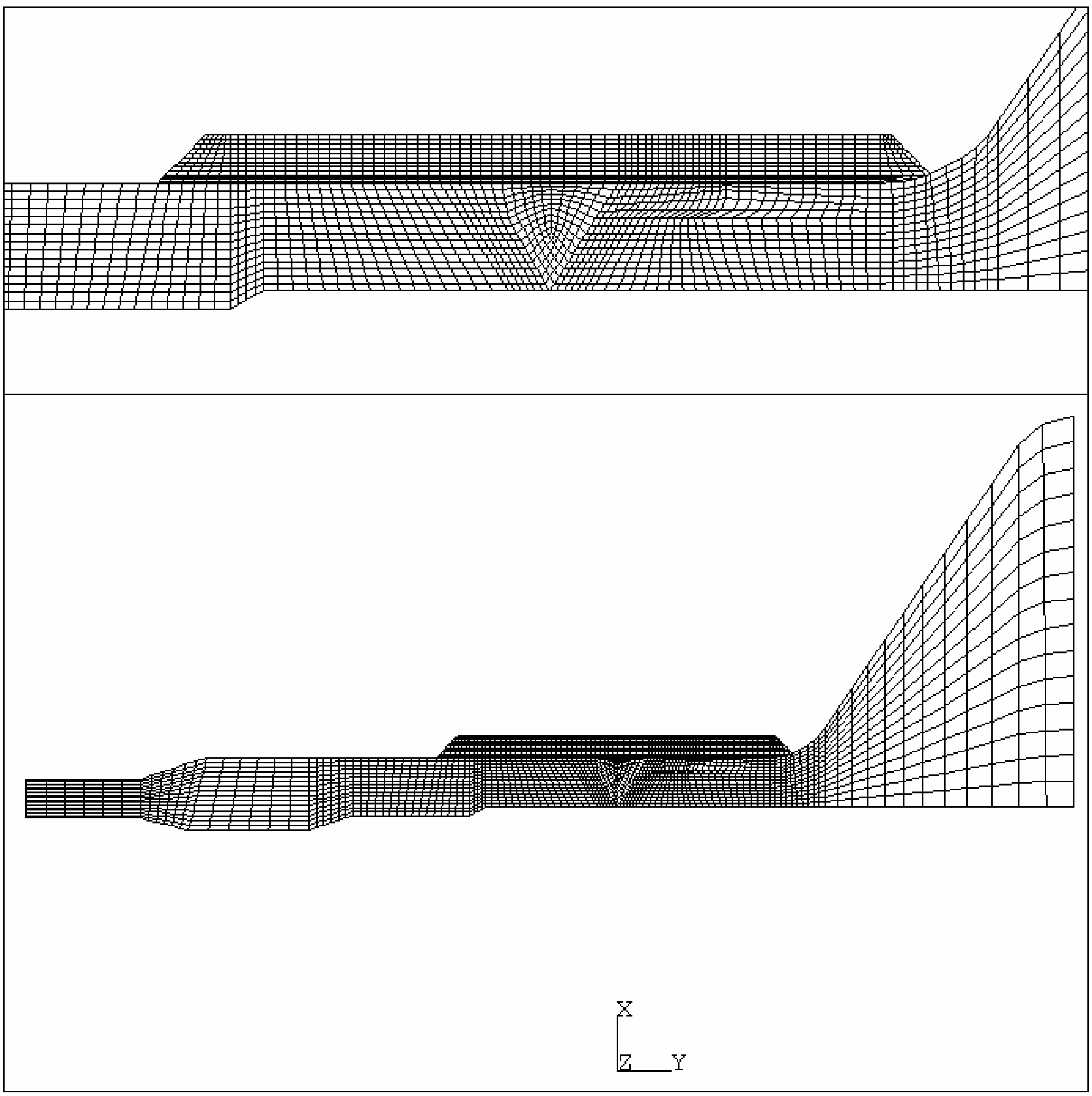


Figure F-1

:100 in^2 Finite Element Model

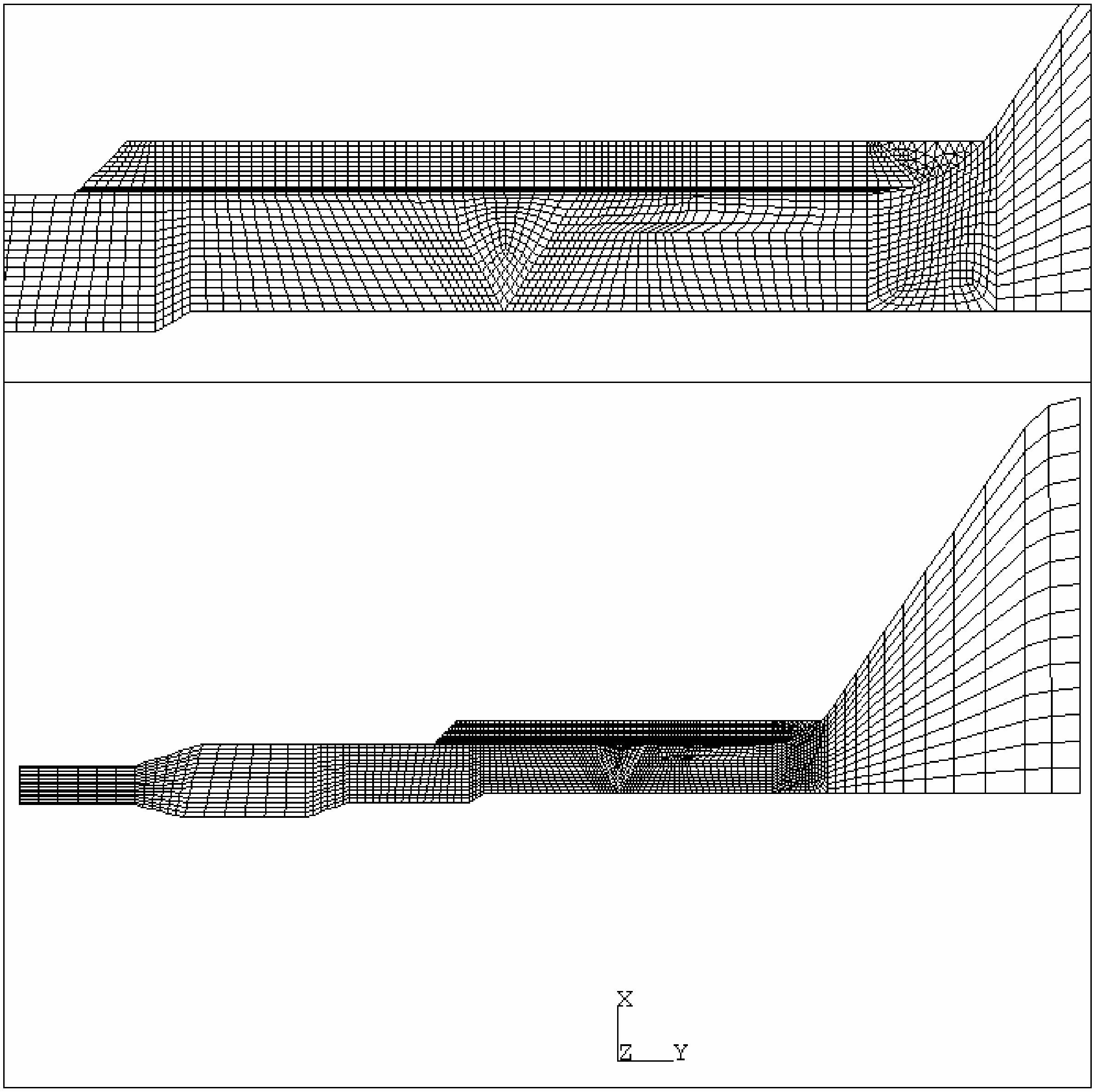
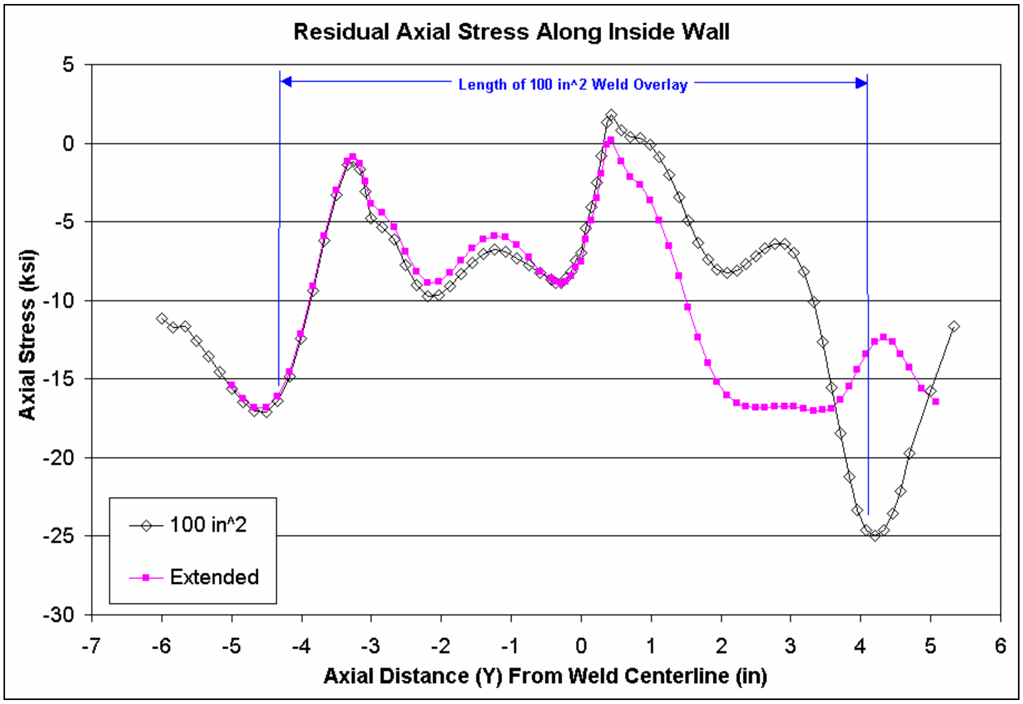


Figure F-2:
Extended (126 in^2) Overlay Finite Element Model



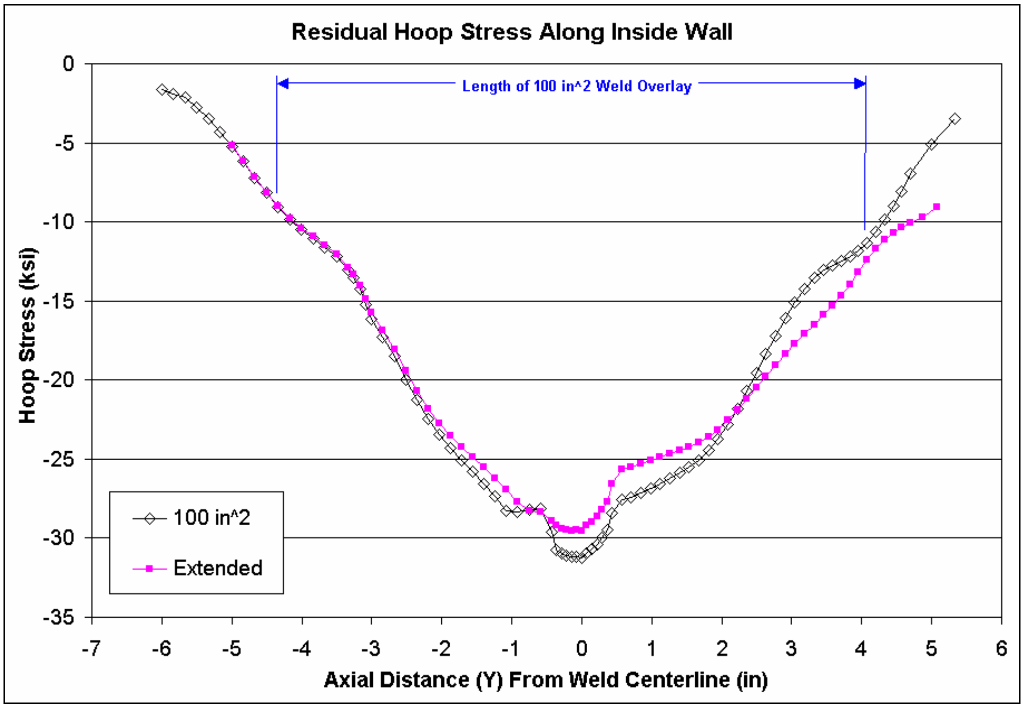


Figure F-3:
Residual Stresses Along Inside Wall of Pipe

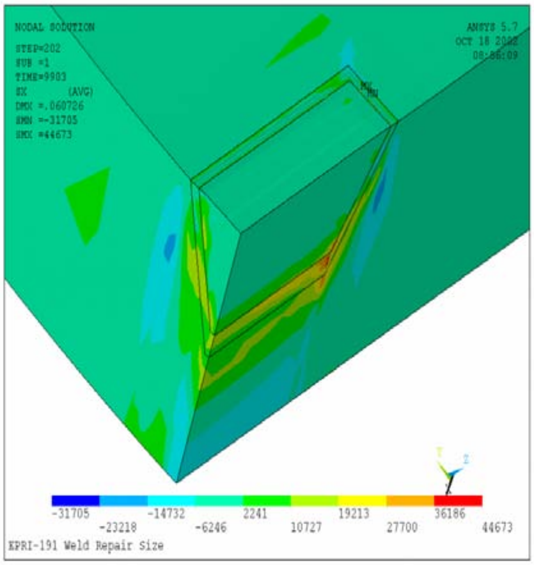


Figure F-4:
Stress Contour, Sx, at 50° F After 100 in² Repair

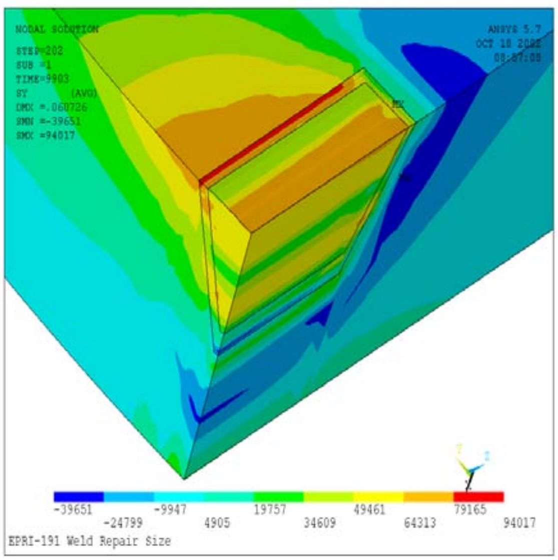


Figure F-5:
Stress Contour, Sy, at 50 °F After 100 in² Repair

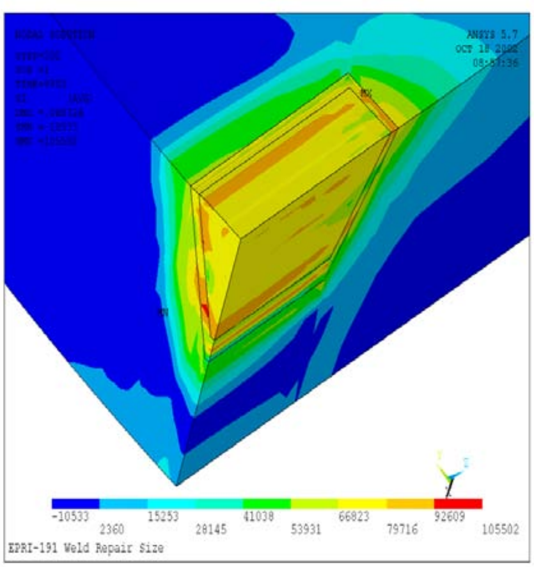


Figure F-6:
Stress Contour, Sz, at 50 °F After 100 in² Repair

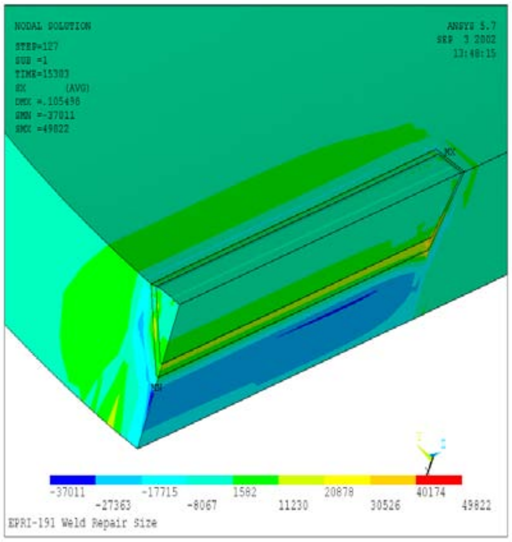


Figure F-7:
Stress Contour, Sx, at 50 °F After 500 in² Repair

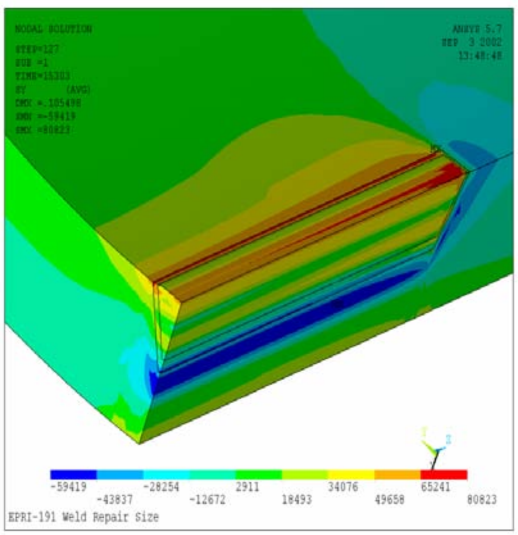


Figure F-8:
Stress Contour, Sy, at 50 °F After 500 in² Repair

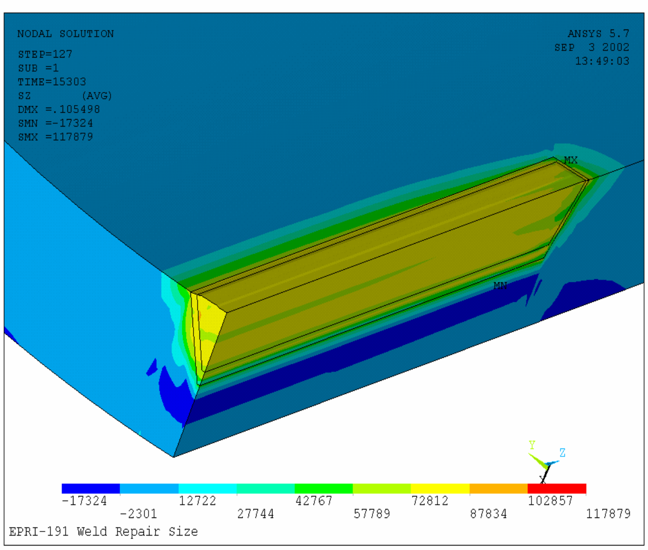
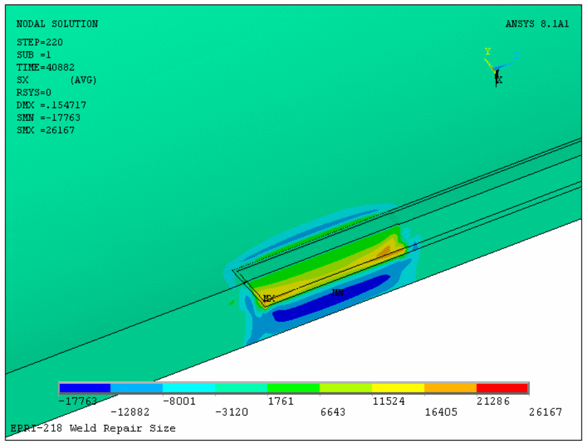
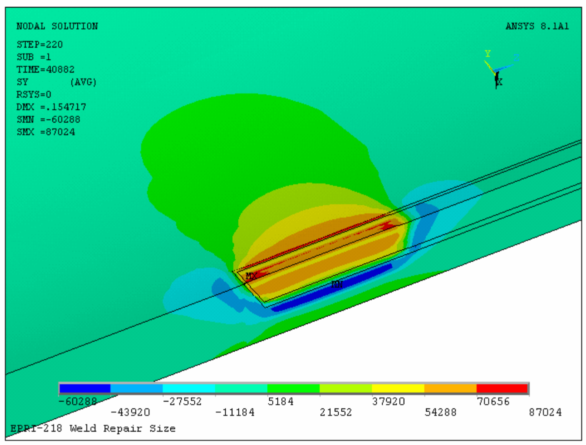


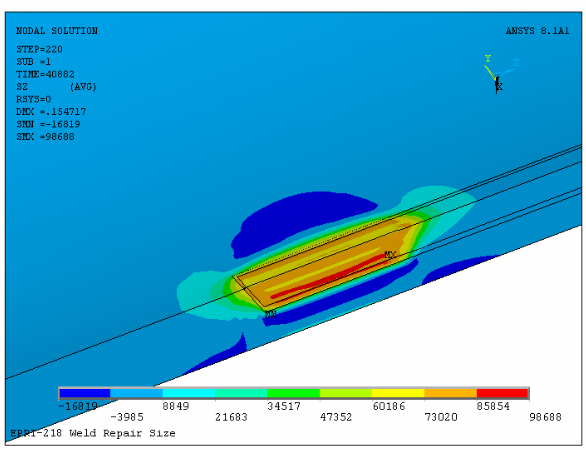
Figure F-9:
Stress Contour, Sz, at 50 °F After 500 in² Repair



a. Radial Stress (S_x)

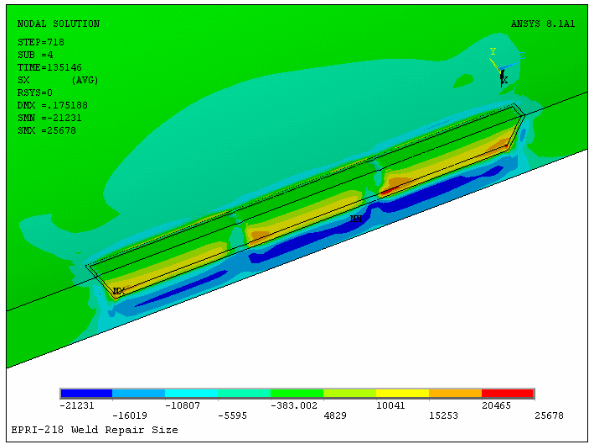


b. Hoop Stress (S_y)

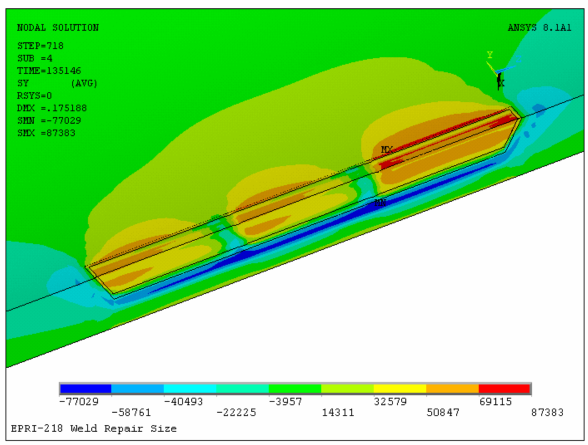


c. Axial Stress (S_z)

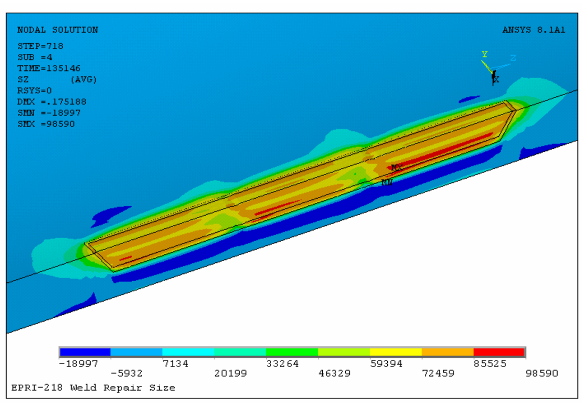
Figure F-10:
Stress Contour, at 70°F After 1st 100 in2 Repair



a. Radial Stress (S_x)



b. Hoop Stress (S_y)



c. Axial Stress (S_z)

Figure F-11:
Stress Contour, at 70 °F After 3rd 100 in2 Repair

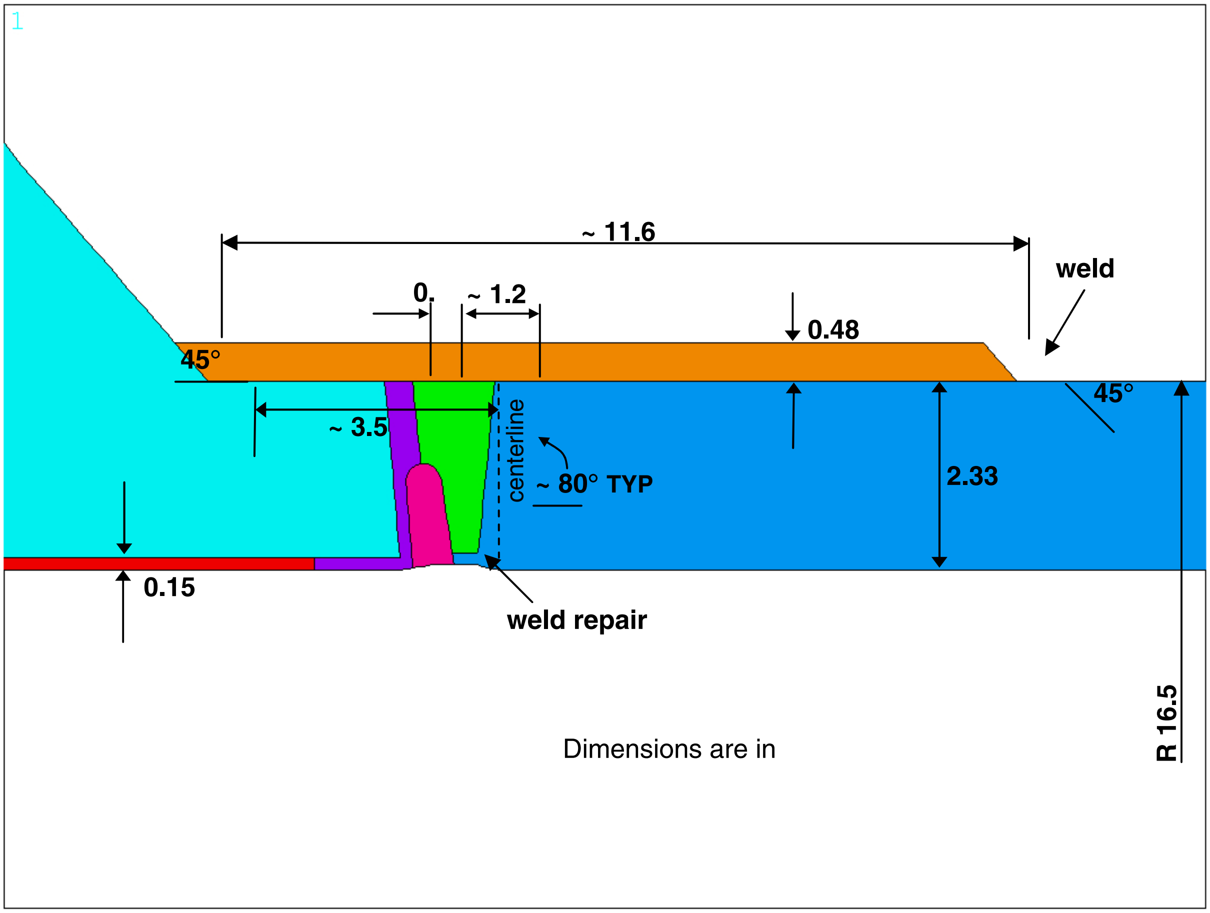
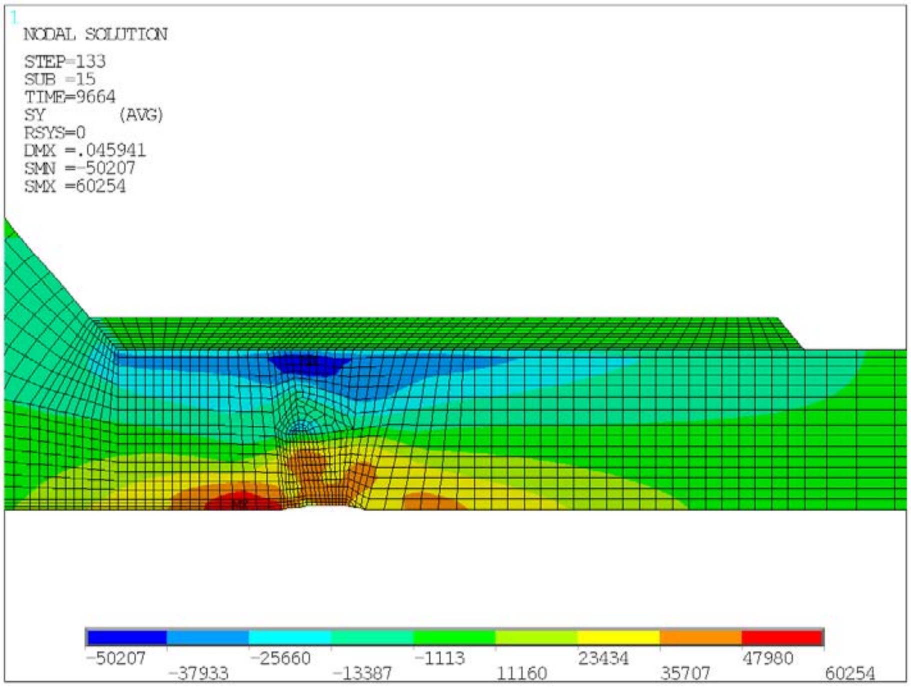
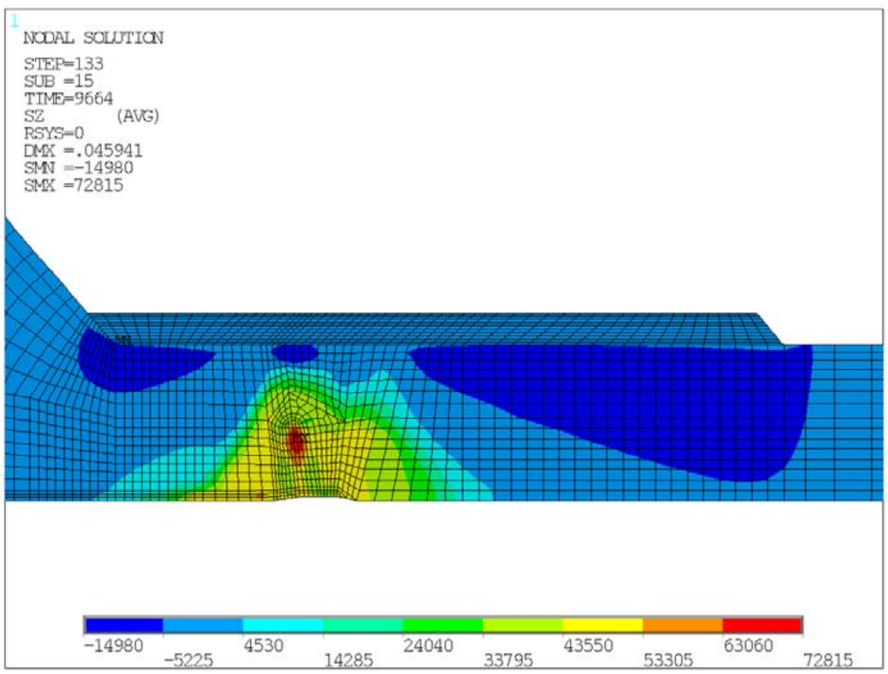


Figure F-12:
Summary of Dimensions for the Weld Overlay Finite Element Model

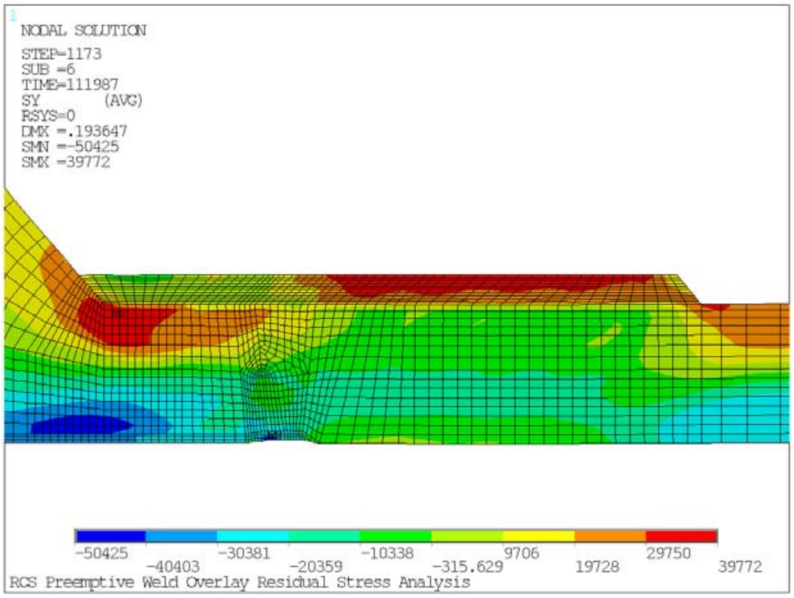


a. Axial

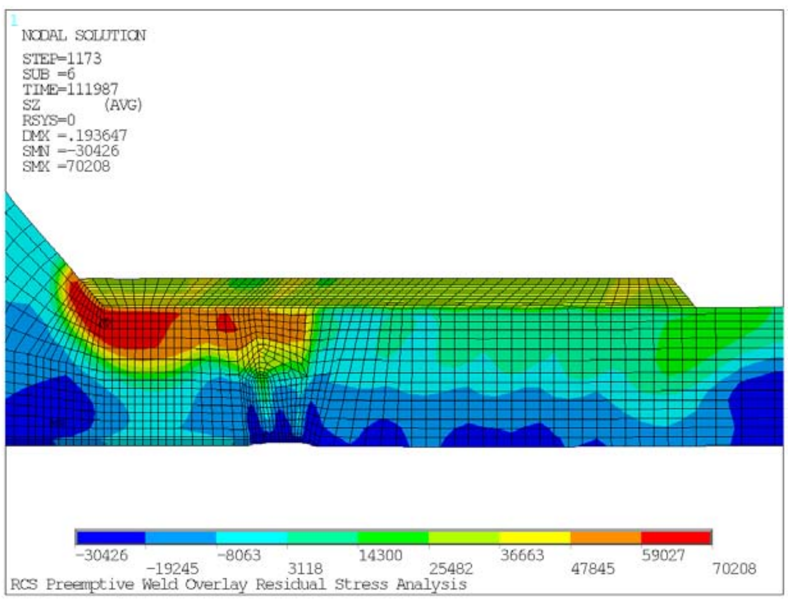


b. Hoop

Figure F-13:
Pre-WOL Stress Contours, 70°

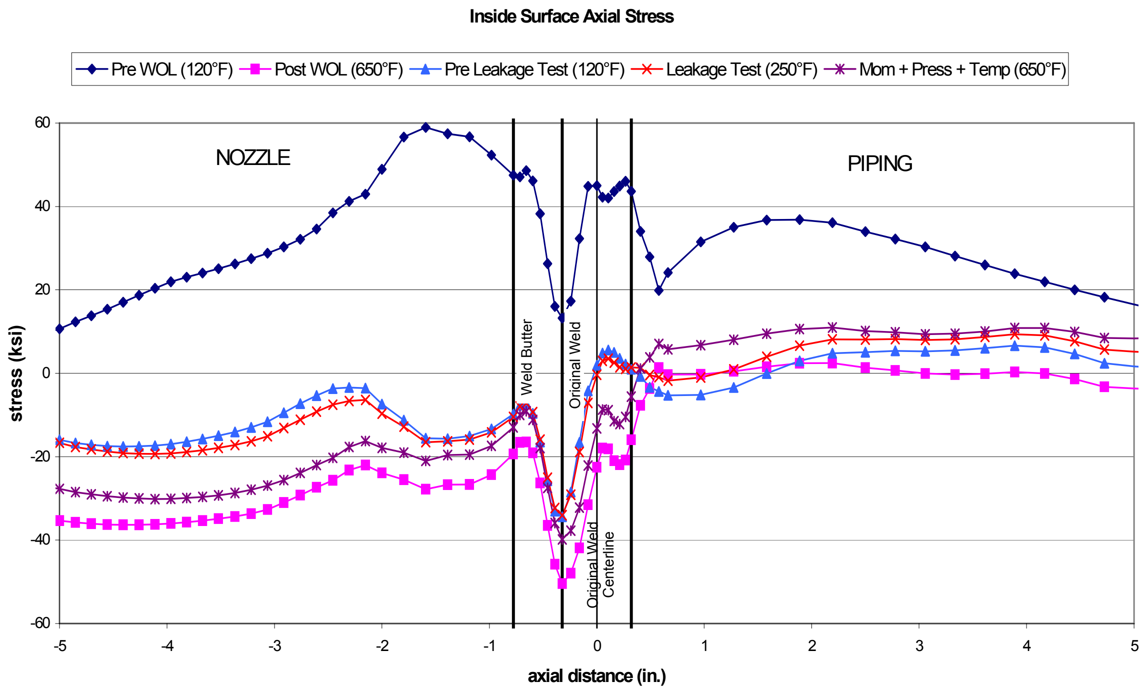


a. Axial



b. Hoop

Figure F-14:
Post WOL Hoop Stress Contour, 650 F°



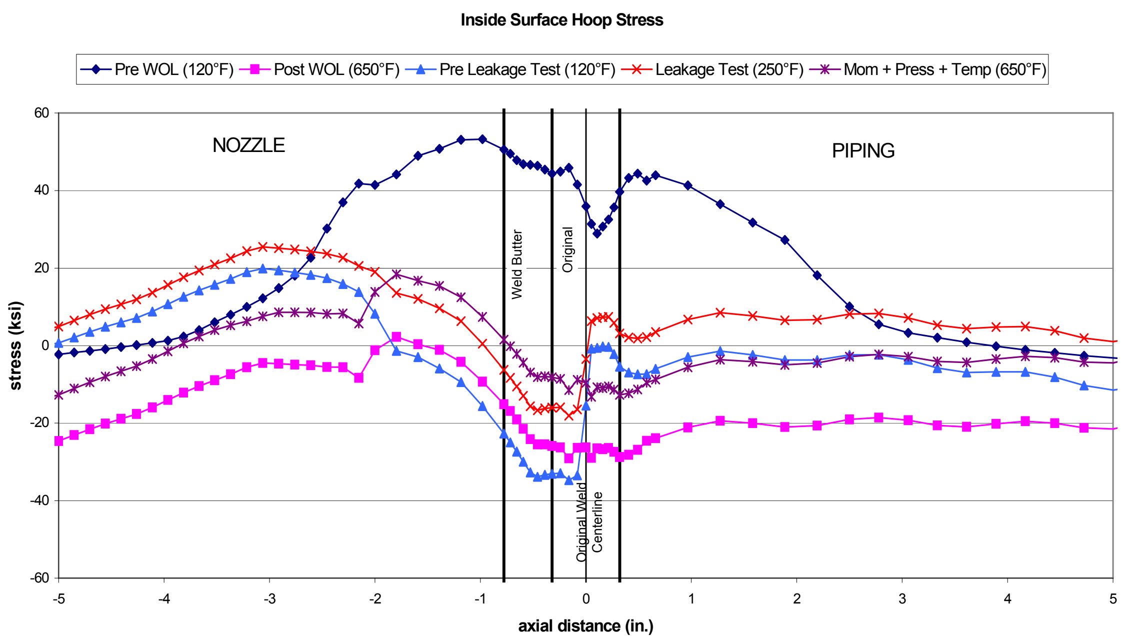


Figure F-15:
Inside Surface Stresses at Different Conditions, 5 Layers, Long Overlay, Water Inside Pipe

References

1. "Inconel Weld-Overlay Repair for Low-Alloy Steel Nozzle to Safe-End Joint", EPRI NP—7085-D, January 1991.
2. "Justification for Extended Weld-Overlay Design Life", EPRI-NP-7103-D, January 1991.
3. "Justification for the Removal of the 100 Square Inch Limitation for Ambient Temperature Temper Bead Welding on P-3 Material", EPRI-NP-XXXX, February 2005.
4. "Calculation Package, Preemptive Weld Overlay Residual Stress Analysis", DEV-03-3xx, Structural Integrity Associates, Inc., San Jose, CA, January 2005.

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