18 – Excavate & Weld Repair (EWR) for SCC Mitigation

Annual NRC/Industry Technical Exchange Meeting

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Reference:
Excavate and Weld Repair (EWR)
  o Background and Overview
  o Code Case N-847 and N-770
EWR Partial Arc Mockups
  o Scope and Purpose
  o Design and Fabrication
Residual Stress Predictions by FEA
  o 2-D and 3-D Finite Element Model
  o FEA and CGR Results
Residual Stress Measurements (preliminary results)
  o Contour and Slitting Plan
  o Comparison to FEA Model
Future Work to Implement EWR Option
Excavate and Weld Repair (EWR)

- **Excavate & Weld Repair (EWR) method to mitigate SCC** (ASME Code Case N-847 Record # 10-1845)
  - Removes outer portion of SCC susceptible weld metal and replaces with resistant weld metal
  - Mitigation option for welds with limited access
  - May reduce flaw to acceptable size
  - Full 360° or partial arc EWR
  - Permits consideration of stress reversal

![Schematic of EWR for 82/182 PWSCC Mitigation](image)
Partial Arc EWR for Emergent SCC Mitigation

- Partial arc EWR
  - Permits reduction of flaw to an acceptable size
  - Provides option for case where emergent ISI examination reveals rejetable SCC indication
Overview of N-847 EWR Code Case

• Key elements of N-847
  – EWR can be used for SCC mitigation of cracked or un-cracked welds in PWR or BWR environments
  – Two types of EWR defined
    o **Type 1**: Meets specified residual stress criterion (≤ 10ksi at NOP & NOT on wetted surface of SCC susceptible material)
    o **Type 2**: Does not meet residual stress criterion or residual stress analysis was not performed
  – Weld acceptance standards & NDE specifics are in EWR case
  – ISI & PSI requirements
    o PWRs: per ASME Code Case N-770-5
    o BWRs: Table 1 in N-847 specifies application of Owner’s GL 88-01 or BWRVIP-075 program
PSI and ISI Examination Categories

• N-770-5 examination categories for PWSCC in PWRs
  – **Category M-1**, “Uncracked butt weld mitigated with full 360° **Type 1** EWR”
  – **Category M-2**, “Uncracked butt weld mitigated with full 360° **Type 2** EWR”
  – **Category N-1**, “Cracked butt weld mitigated with full 360° **Type 1** EWR”
  – **Category N-2**, “Cracked butt weld mitigated with full 360° **Type 2** EWR”
  – **Category O**, “Cracked butt weld mitigated with partial arc EWR”

• Extent and frequency of required examination progressively increases from Category M-1 to O

• Similar examination categories in N-847 for SCC in BWRs
  – Appropriate provisions in BWR Owner’s GL 88-01 or BWRVIP-075A program are invoked by Table 1.
Status of N-847 & N-770-5 in Section XI

• Status of N-847
  – Approved by following ASME committees:
    • SG-NDE 12-0-1
    • SG-WCS 16-0-0
    • SG-RRA 11-0-1
  – SG-ES out for comment

• Status of N-770-5
  – Out for 2nd letter ballot at TG-HSNAI (May 2015)
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Residual Stress Predictions by FEA
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Future Work to Implement EWR Option
EWR Partial Arc Mockups
Project Scope and Purpose

• Mock up partial arc EWR
  – Build mockups (WRTC & WSI)
  – Build residual stress model (SIA)
  – Measure stress (Hill Engineering)
• Demonstrate dissimilar metal welding with 52M and temper bead welding in partial arc configuration (EPRI)
• Use modeling results and stress measurements to support EWR Code Case
• All results, data, and documentation intended to support NRC relief request and field implementation
  – Topical report (white paper) for relief request and to support ASME Code Case N-847 (WRTC, SIA & Hill)
EWR Partial Arc Mockup Sketch
(not to scale, dimensions approximated)
Partial Arc Mockup Fabrication

- Designed to simulate typical DMW configuration
- Mockups shown with PWHT’d 182 butter on SA-508 side and with completed 82/182 J-groove weld
Partial Arc Mockup Fabrication

- Mockups with machined partial arc excavation (left)
- EWR 52M deposit complete (right)
Presentation Outline

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Residual Stress Prediction by FEA Model

- Finite element analysis using ANSYS
- 2-D model to evaluate different EWR concepts
- 2-D model to investigate PWHT and strong back sensitivity
- 3-D model to analyze initial DMW and EWR
- Stress intensity factor and crack growth rate study
Von Mises Residual Stress Results

As-welded DMW

Excavation

Strongback Removed

As-welded on Strongback

 ksi

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Stress Contour Cut Planes

Welding Direction

L2
B1
L1
T1
[T1] Axial Residual Stresses

- T1 is cut plane along weld centerline
- Transverse (axial) residual stress comparison
- Slight differences between before and after EWR
  - Increase in tensile RS near ID surface (44 ksi vs. 26 ksi)
  - Increase in compressive RS near in mid-thickness (-44 ksi vs. -26 ksi)
[B1] FEA Hoop Residual Stresses

- B1 is cut plane across EWR mid-length
- Longitudinal (hoop) residual stress comparison
- Some stress reversal in thru-wall RS below EWR

**After DMW, on Strongback**

**After EWR, on Strongback**

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[L1 & L2] FEA Hoop Residual Stresses

- L1 & L2 are cut plane across the EWR start and stop ends
- Longitudinal (hoop) residual stresses
- Similar results between bead start, midpoint, and stop locations

[L1] Bead Stop, on Strongback

[L2] Bead Start, on Strongback
Through-Wall DMW & EWR Hoop Stress Profiles
Preliminary PWSCC CGR for 1:2 Axial Crack

\[
\dot{a} = \exp\left[-\frac{Q_g}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right] \alpha(K)^\beta
\]

- \(\dot{a}\) = Crack growth rate at temp. \(T\) in in/hr
- \(Q_g\) = Thermal activation energy for crack growth
  = 31 kcal/mole
- \(R\) = Universal gas constant
  = 1.103 \times 10^{-3} \text{kcal/mole-} \ ^\circ\text{R}
- \(T\) = Abs. operating temp. at location of crack
  = 650 °F (1081.57 °R)
- \(T_{ref}\) = Abs. reference temp. used to normalize data
  = 617 °F (1076.67 °R)
- \(\alpha\) = Power-law constant
  = 2.47 \times 10^{-7} at 617 °F
- \(K\) = Crack tip stress intensity factor, ksi-in^{0.5}
- \(\beta\) = 1.6

[CGR Reference: MRP-115]
Preliminary Stress Intensity Factor Calculation

1:2 Axial Crack

- EWR results in reduction of thru-wall stress intensity factor, K
Preliminary Crack Growth Rate Results

1:2 Axial Crack

- EWR doubles the PWSCC CG time thru A82/182 DMW
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Residual Stress Measurement Overview

**Contour Method**

- The contour method is a destructive residual stress measurement technique
  - Involves cutting material along a given plane
    - Gives stress component normal to cut plane
    - Provides 2D map of stress over the plane
  - The contour measurements at Plane 1 & 2 measure $\sigma_{zz}$
  - The contour measurement at Plane 3 measures $\sigma_{xx}$
Residual Stress Measurement Plan

EWR Mockup #1

- Measurement steps for EWR mockup #1
  - Apply strain gages
  - Remove strong back
  - Determine stress release from removal
  - Contour measurement longitudinal stress at end of EWR (Plane 1)
  - Contour measurement of the longitudinal stress at the center (Plane 2)
  - Slitting measurements of the transverse stress at the center (Plane 2)
  - Contour measurement of the transverse stress (Plane 3)
• Strain gage layout plan
  – “Bottom” face gages installed prior to EWR
  – “Top” face gages installed after EWR
Residual Stress Results

*Plane 1 (σ_{zz})*

Contour

SS316

SA508

Strong back removal

= Total

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Residual Stress Results

Plane 2 ($\sigma_{zz}$)

Contour

+ Strong back removal

Effect of P1 contour cut

= Total

[Graph showing residual stress results for SS316 and SA508 materials, with contour lines and stress values indicated.]
Residual Stress Results

*Plane 3 (σ_xx)*

Contour +

Strong back removal +

Effect of P1 contour cut +

Effect of P2 contour cut =

Total

[Stress contour diagram with labels and axes]
Slitting Measurements

Adjacent to Plane 2 ($\sigma_{xx}$)

- Perform slitting measurements on slices removed near Plane 2
  - Determine $\sigma_{xx}$ at Plane 2
- Slitting measurements at
  - $X = 3.06$ (C2&D1)
  - $X = 3.56$ (A1&B1)
  - $X = 4.06$ (C1&D2)
Residual Stress Results

Plane 2 ($\sigma_{xx}$) Line Plots
Comparison to FEA Model

*Plane 1 ($\sigma_{zz}$)*

- Good agreement in shape of stress field
- Weld metal measured stress is lower magnitude
Comparison to FEA Model

*Plane 2 ($\sigma_{zz}$)*

- Good agreement in shape of stress field
- Weld metal measured stress is lower magnitude
Comparison to FEA Model

*Plane 2 (σ_{xx})*

- Good agreement in magnitude and shape of stress field
- Measured stress is somewhat lower at the top of the plate
Comparison to FEA Model

*Plane 3 (σ_{xx})*

- Good agreement in magnitude and shape of stress field
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Future WRTC Work to Implement EWR Option

- EWR Partial Arc Mockup
  - Complete CGR and K simulations
  - Complete stress measurements on EWR mockup #2
- ASME Section XI Approval
  - EWR Code Case N-847
  - N-770-5 with EWR option
- Consider pilot plants for future implementation of new EWR case
- Develop generic relief request for EWR implementation
- Work for adoption of N-847 methodology from NRC via relief request
Questions or Comments?

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