Welding Residual Stress Analysis of Narrow-Gap Weld

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Outline

• Introduction
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• Analysis Summary
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Introduction

Primary Water Stress Corrosion Cracking (PWSCC)

- 3 necessary conditions must exist simultaneously:
  - Susceptible Material
  - Corrosive Environment
  - Tensile Stress

- Welding residual stress can be the primary mechanical driving force for PWSCC

- PWSCC is a time dependent degradation mechanism
Introduction (continued)
RES WRS Analysis Support to NRC Offices

• NRR – Addressing PWSCC Issues
  – Multiple WRS and flaw evaluation calculations performed
    • Examples: North Anna, Wolf Creek, etc.
  – ASME Code actions, Code Cases
    • Examples: N-754, N-740, WRS Guidance Appendix
  – PWSCC mitigation reviews
    • Examples: MSIP, Inlay, Overlay, EWR
  – Safety evaluation input for EPRI MRP-169 review
  – WRS Validation Program

• NMSS – Addressing Chloride Induced SCC Issues
  – Dry storage container WRS analysis performed
Introduction (continued)

• RV nozzle fabrication flaw indications were identified and repaired from the ID

• NRO requested RES to perform weld residual stress analysis of nozzle-to-safe-end weld with repair
Pipe and Weld Geometry

Narrow Gap Weld Analysis

- Axi-symmetric model used in analysis
  - Revolved model shown here for illustration

Carbon Steel Nozzle
SS Cladding
Alloy 52 Butter
Alloy 52 Weld
SS Safe End
Alloy 52 Repair
Analysis Summary
Narrow Gap Weld Analysis

• Model simulates pass by pass weld deposition process
  – Butter heat treatment results in low stresses, so the butter weld is not analyzed

• Sequentially coupled thermal / structural analysis

• Axi-symmetric geometry

• Temperature-dependent material properties
  – Isotropic/kinematic mixed strain hardening
Analysis Summary (cont’d)

Narrow Gap Weld Analysis

- Weld parameters extracted from actual case
- Weld current applied is average of Base and Peak Current
- Welding heat addition
- Stress values reported are at room temperature
Stress Results
Narrow Gap Weld Analysis

- Axial stresses before and after repair weld
Stress Results
Narrow Gap Weld Analysis

- Axial stresses along butter to weld fusion line
Stress Results
Narrow Gap Weld Analysis

• Hoop stresses before and after repair weld
Stress Results
Narrow Gap Weld Analysis

- Hoop stresses along butter to weld fusion line

Path for stress distributions

![Graph showing stress distributions before and after repair](image)
Discussion

Narrow Gap Weld Analysis

• FE analysis shows significant stress increase near inner diameter due to repair

• Consistent with previous analysis and measurements
  – Weld Residual Stress Validation Program
    • Cooperative with nuclear industry under Memorandum of Understanding Addendum
  – Pressure Vessels and Piping Conference publications
  – Journal of Pressure Vessel Technology publications

• Reasonable assurance in the calculated residual stress shift due to weld repair
Conclusions

Narrow Gap Weld Analysis

• Repair significantly alters through-wall weld residual stresses

• Hoop and axial stresses are greatly increased at ID and inner half of through-wall thickness

• Mixed hardening assumption leads to reasonable stress magnitudes