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Engineering structural integrity

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Structural Integrity Associates, Inc.®

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

Annual NRC/Industry Technical Exchange Meeting

NRC Three White Flint North, Rockville MD
Wednesday June 3, 2015

Steve McCracken & Jon Tatman
EPRI Welding & Repair Technology Center

Excavate and Weld Repair (EWR) Project

Key Contributors

Steve McCracken, Jon Tatman, Jack Spanner
EPRI

Pete Riccardella, Richard Smith, Francis Ku
Structural Integrity Associates

Michael Hill, Mitchel Olson & Adrian Dewald
Hill Engineering

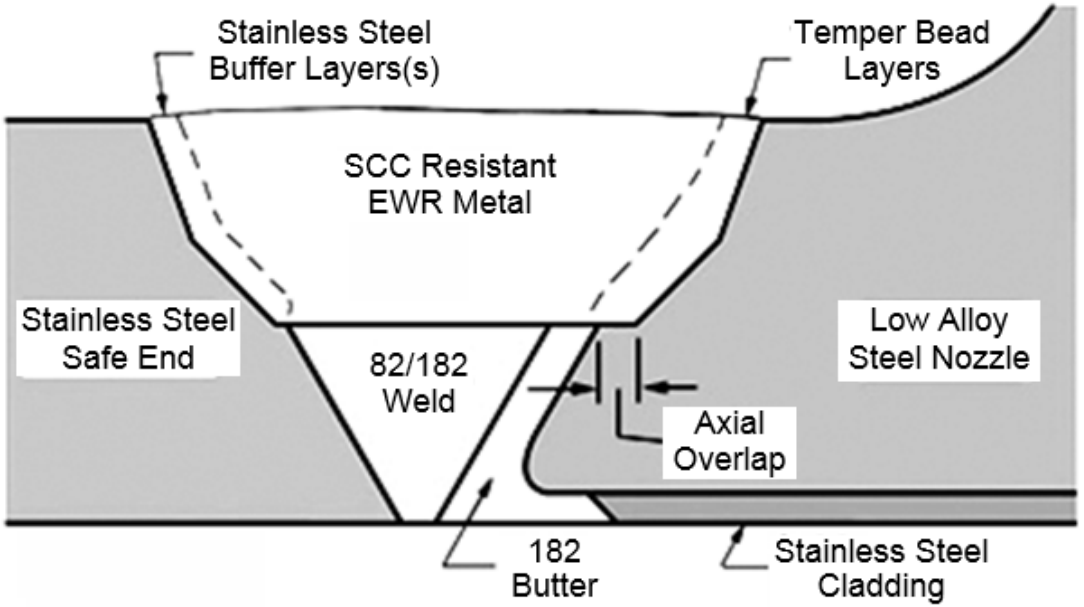
Reference:
Topical Report: Application of the Excavate and Weld Repair Process for Repair and Mitigation of Alloy 182 and 82 in PWRs. EPRI, Palo Alto, CA: 2010. 1021012.

Presentation Outline

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

Excavate and Weld Repair (EWR)

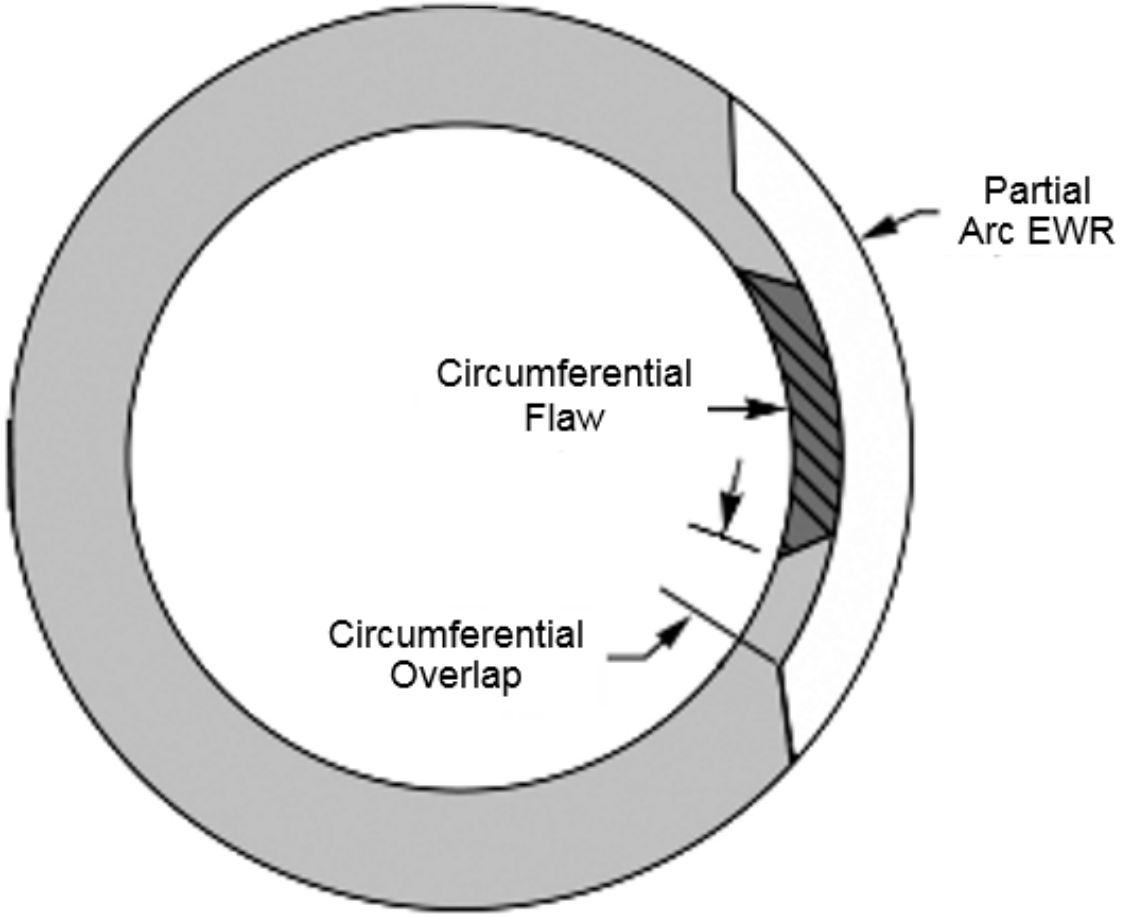
- **Excavate & Weld Repair (EWR) method to mitigate SCC**
  (ASME Code Case N-847 Record # 10-1845)
  - Removes outer portion of SCC susceptible weld metal and replaces with resistant weld metal
  - Mitigation option for welds with limited access
  - May reduce flaw to acceptable size
  - Full 360° or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



Schematic of EWR for 82/182 PWSCC Mitigation

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 rejectable SCC indication



Schematic of Partial Arc EWR

Overview of N-847 EWR Code Case

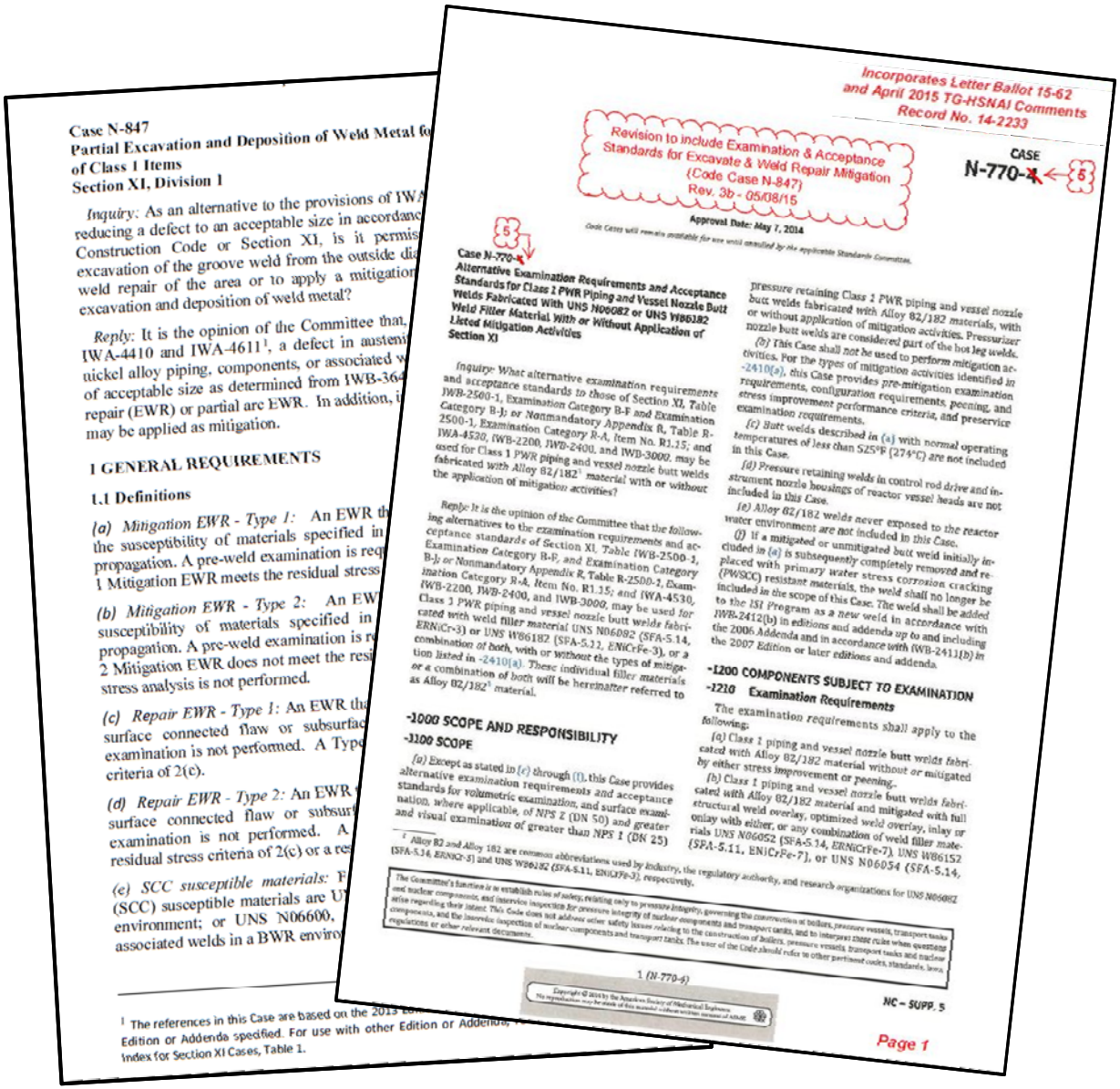
- Key elements of N-847
  - EWR can be used for SCC mitigation of cracked or un-cracked welds in PWR or BWR environments
  - Two types of EWR defined
    - **Type 1**: Meets specified residual stress criterion (≤ 10ksi at NOP & NOT on wetted surface of SCC susceptible material)
    - **Type 2**: Does not meet residual stress criterion or residual stress analysis was not performed
  - Weld acceptance standards & NDE specifics are in EWR case
  - ISI & PSI requirements
    - PWRs: per ASME Code Case N-770-5
    - 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)



Case N-847
Partial Excavation and Deposition of Weld Metal fo
of Class 1 Items
Section XI, Division 1

Inquiry: As an alternative to the provisions of IW
reducing a defect to an acceptable size in accordanc
Construction Code or Section XI, is it permis
excavation of the groove weld from the outside di
weld repair of the area or to apply a mitigation
excavation and deposition of weld metal?

Reply: It is the opinion of the Committee that,
IWA-4410 and IWA-4611[1], a defect in austeni
nickel alloy piping, components, or associated w
of acceptable size as determined from IWB-364
repair (EWR) or partial arc EWR. In addition, i
may be applied as mitigation.

1 GENERAL REQUIREMENTS

1.1 Definitions

(a) Mitigation EWR - Type 1: An EWR th
the susceptibility of materials specified in
propagation. A pre-weld examination is req
1 Mitigation EWR meets the residual stress

(b) Mitigation EWR - Type 2: An EW
susceptibility of materials specified in
propagation. A pre-weld examination is r
2 Mitigation EWR does not meet the resi
stress analysis is not performed.

(c) Repair EWR - Type 1: An EWR th
surface connected flaw or subsurfac
examination is not performed. A Type
criteria of 2(c).

(d) Repair EWR - Type 2: An EWR
surface connected flaw or subsur
examination is not performed. A
residual stress criteria of 2(c) or a re

(e) SCC susceptible materials: F
(SCC) susceptible materials are U
environment; or UNS N06600,
associated welds in a BWR enviro

[1] The references in this Case are based on the 2013 E
Edition or Addenda specified. For use with other Edition or Addend
Index for Section XI Cases, Table 1.

Incorporates Letter Ballot 15-62
and April 2015 TG-HSNAI Comments
Record No. 14-2233

Revision to include Examination & Acceptance
Standards for Excavate & Weld Repair Mitigation
(Code Case N-847)
Rev. 3b - 05/08/15

CASE
N-770-4 ← 5

Approval Date: May 7, 2014

Code Cases will remain available for use until annulled by the applicable Standards Committee.

5

Case N-770-4
Alternative Examination Requirements and Acceptance Standards for Class 1 PWR Piping and Vessel Nozzle Butt Welds Fabricated With UNS N06082 or UNS W86182 Weld Filler Material With or Without Application of Listed Mitigation Activities
Section XI

Inquiry: What alternative examination requirements and acceptance standards to those of Section XI, Table IWB-2500-1, Examination Category B-F and Examination Category B-J; or Nonmandatory Appendix R, Table R-2500-1, Examination Category R-A, Item No. R1.15; and IWA-4520, IWB-2200, IWB-2400, and IWB-3000, may be used for Class 1 PWR piping and vessel nozzle butt welds fabricated with Alloy 82/182[1] material with or without the application of mitigation activities?

Reply: It is the opinion of the Committee that the following alternatives to the examination requirements and acceptance standards of Section XI, Table IWB-2500-1, Examination Category B-F, and Examination Category B-J; or Nonmandatory Appendix R, Table R-2500-1, Examination Category R-A, Item No. R1.15; and IWA-4530, IWB-2200, IWB-2400, and IWB-3000, may be used for Class 1 PWR piping and vessel nozzle butt welds fabricated with weld filler material UNS N06082 (SFA-5.14, ERNiCr-3) or UNS W86182 (SFA-5.11, ENiCrFe-3), or a combination of both, with or without the types of mitigation listed in -2410(a). These individual filler materials or a combination of both will be hereinafter referred to as Alloy 82/182[1] material.

-1000 SCOPE AND RESPONSIBILITY

-1100 SCOPE

(a) Except as stated in *(c)* through *(f)*, this Case provides alternative examination requirements and acceptance standards for volumetric examination, and surface examination, where applicable, of NPS 2 (DN 50) and greater and visual examination of greater than NPS 1 (DN 25)

[1] Alloy 82 and Alloy 182 are common abbreviations used by industry, the regulatory authority, and research organizations for UNS N06082 (SFA-5.14, ERNiCr-3) and UNS W86182 (SFA-5.11, ENiCrFe-3), respectively.

pressure retaining Class 1 PWR piping and vessel nozzle butt welds fabricated with Alloy 82/182 materials, with or without application of mitigation activities. Pressurizer nozzle butt welds are considered part of the hot leg welds.

(b) This Case shall not be used to perform mitigation activities. For the types of mitigation activities identified in -2410(a), this Case provides pre-mitigation examination requirements, configuration requirements, peening, and stress improvement performance criteria, and preservice examination requirements.

(c) Butt welds described in *(a)* with normal operating temperatures of less than 525°F (274°C) are not included in this Case.

(d) Pressure retaining welds in control rod drive and instrument nozzle housings of reactor vessel heads are not included in this Case.

(e) Alloy 82/182 welds never exposed to the reactor water environment are not included in this Case.

(f) If a mitigated or unmitigated butt weld initially included in *(a)* is subsequently completely removed and replaced with primary water stress corrosion cracking (PWSCC) resistant materials, the weld shall no longer be included in the scope of this Case. The weld shall be added to the ISI Program as a new weld in accordance with IWB-2412(b) in editions and addenda up to and including the 2006 Addenda and in accordance with IWB-2411(b) in the 2007 Edition or later editions and addenda.

-1200 COMPONENTS SUBJECT TO EXAMINATION

-1210 Examination Requirements

The examination requirements shall apply to the following:

(a) Class 1 piping and vessel nozzle butt welds fabricated with Alloy 82/182 material without or mitigated by either stress improvement or peening.

(b) Class 1 piping and vessel nozzle butt welds fabricated with Alloy 82/182 material and mitigated with full structural weld overlay, optimized weld overlay, inlay or onlay with either, or any combination of weld filler materials UNS N06052 (SFA-5.14, ERNiCrFe-7), UNS W86152 (SFA-5.11, ENiCrFe-7), or UNS N06054 (SFA-5.14,

The Committee's function is to establish rules of safety, relating only to pressure integrity, governing the construction of boilers, pressure vessels, transport tanks and nuclear components, and inservice inspection for pressure integrity of nuclear components and transport tanks, and to interpret these rules when questions arise regarding their intent. This Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks and nuclear components, and the inservice inspection of nuclear components and transport tanks. The user of the Code should refer to other pertinent codes, standards, laws, regulations or other relevant documents.

1 (N-770-4)

NC – SUPP. 5

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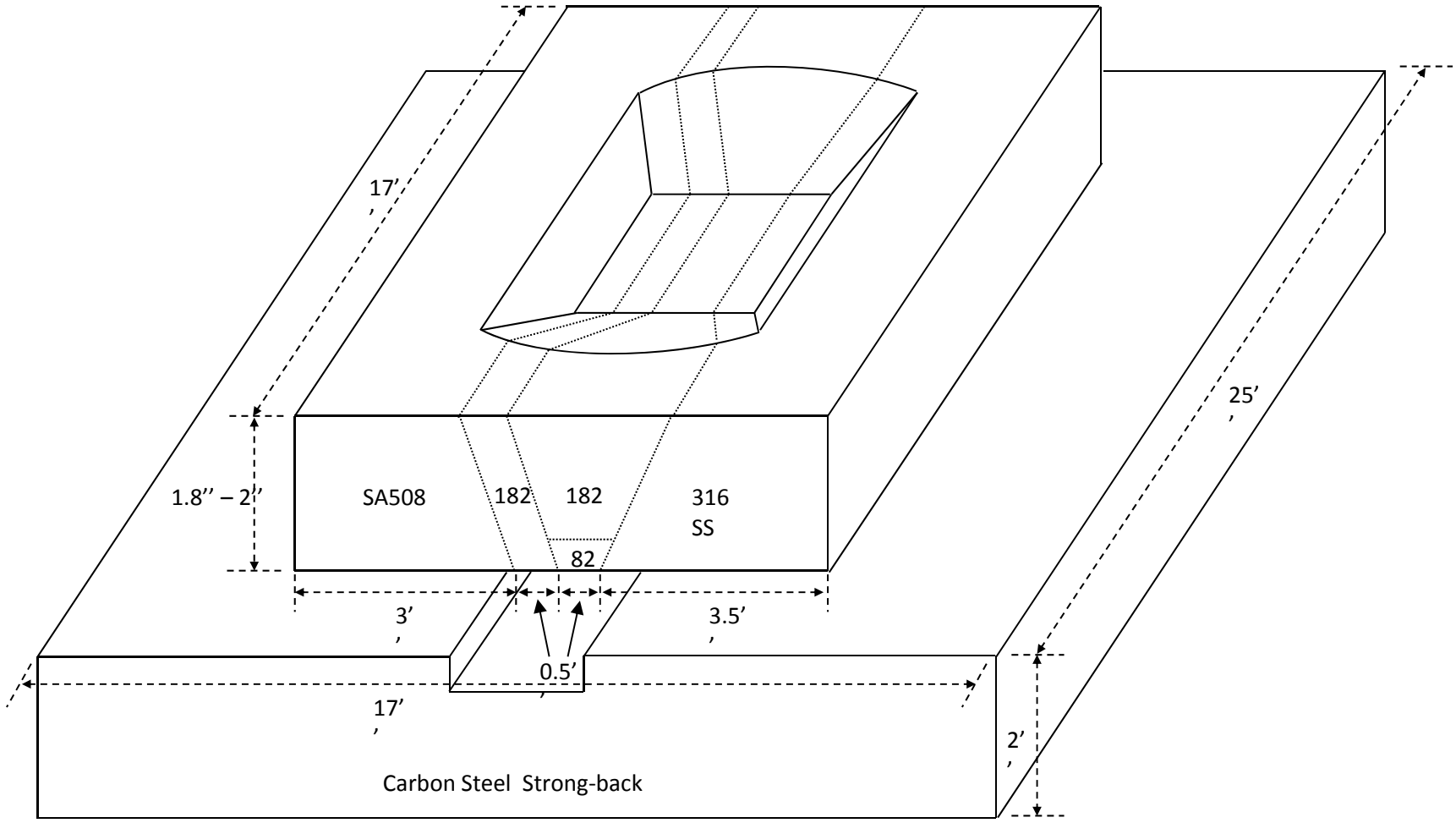
EWR Partial Arc Mockups

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)

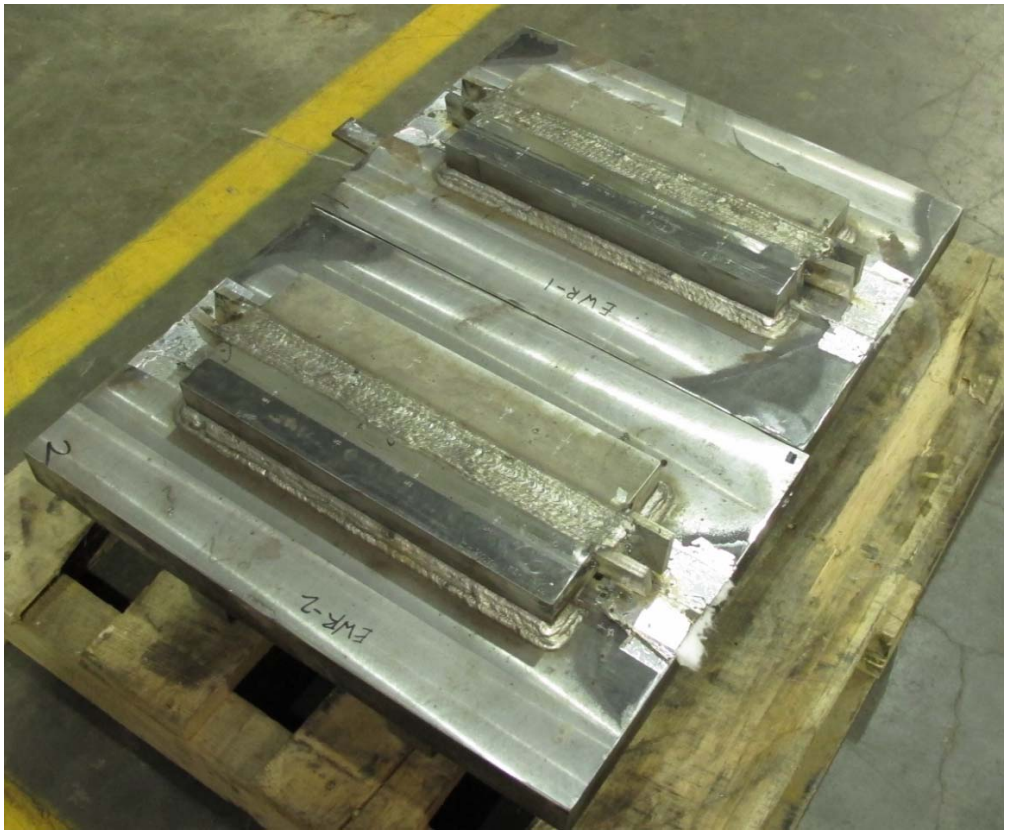
EWR Partial Arc Mockup Sketch

(not to scale, dimensions approximated)



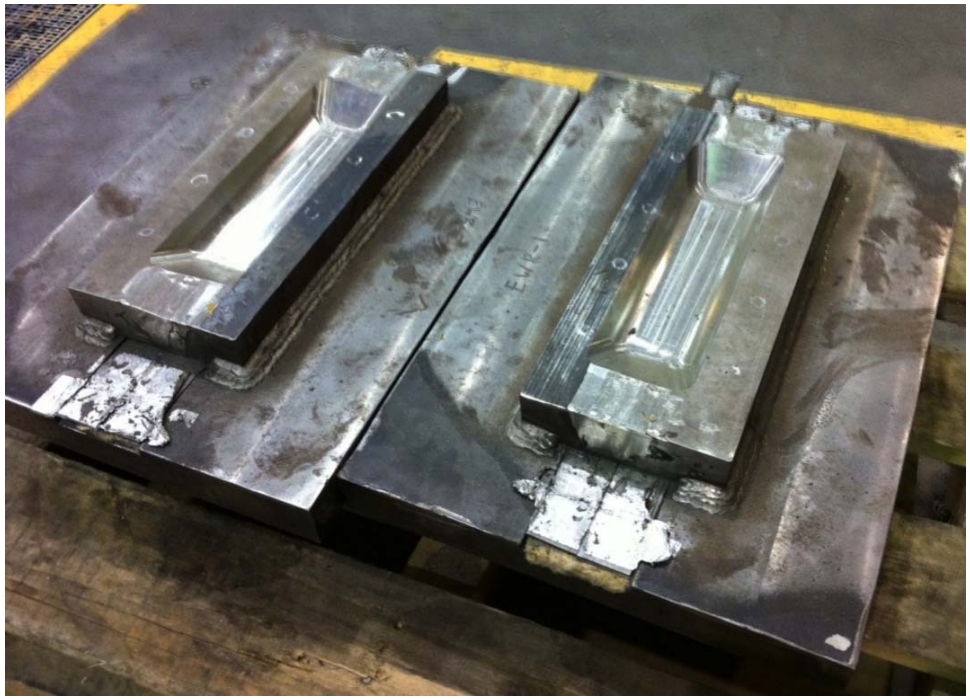
Partial Arc Mockup Fabrication

- 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)



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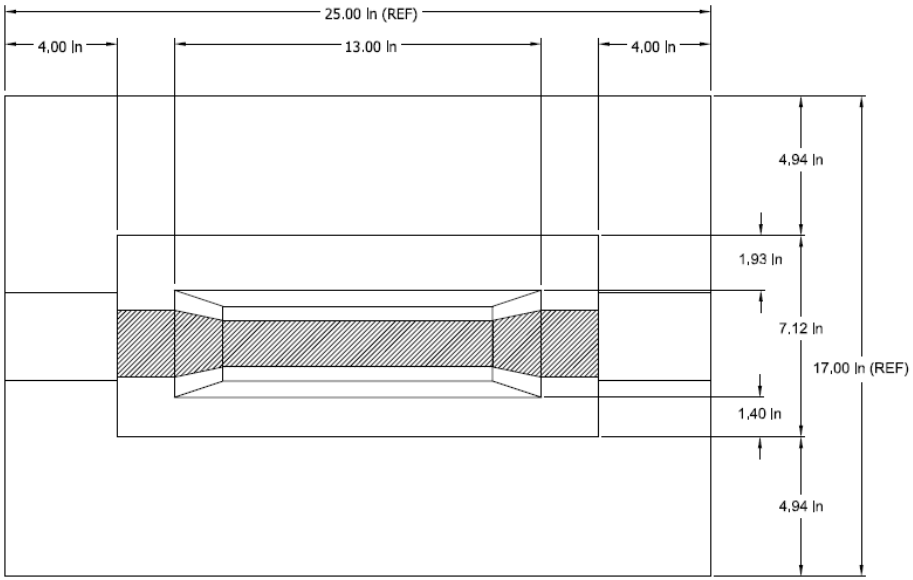
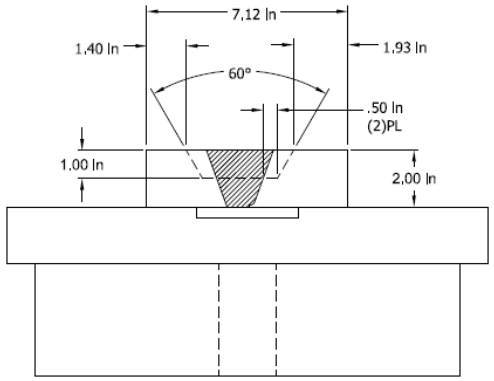
Residual Stress Prediction by FEA Model

- 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





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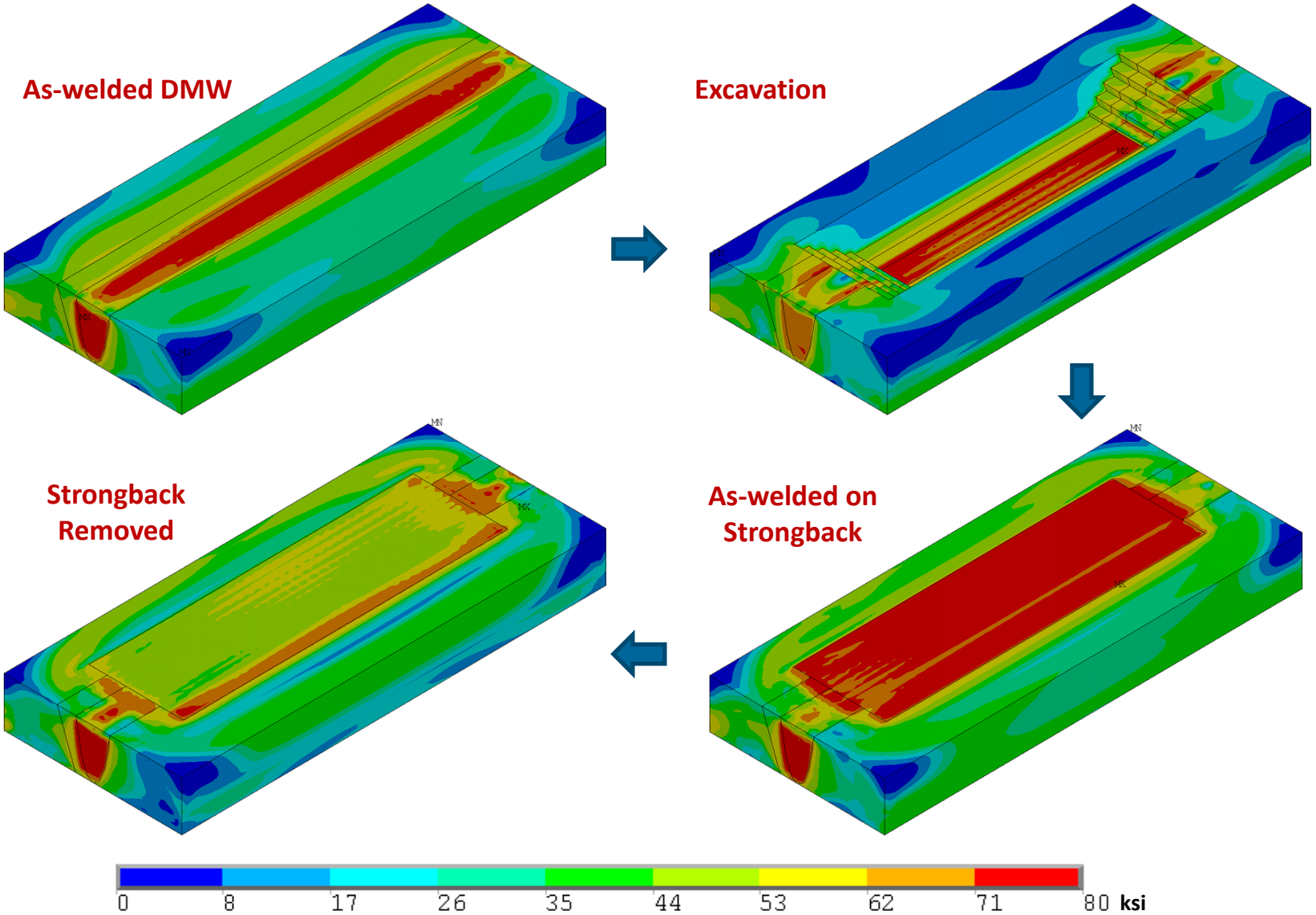
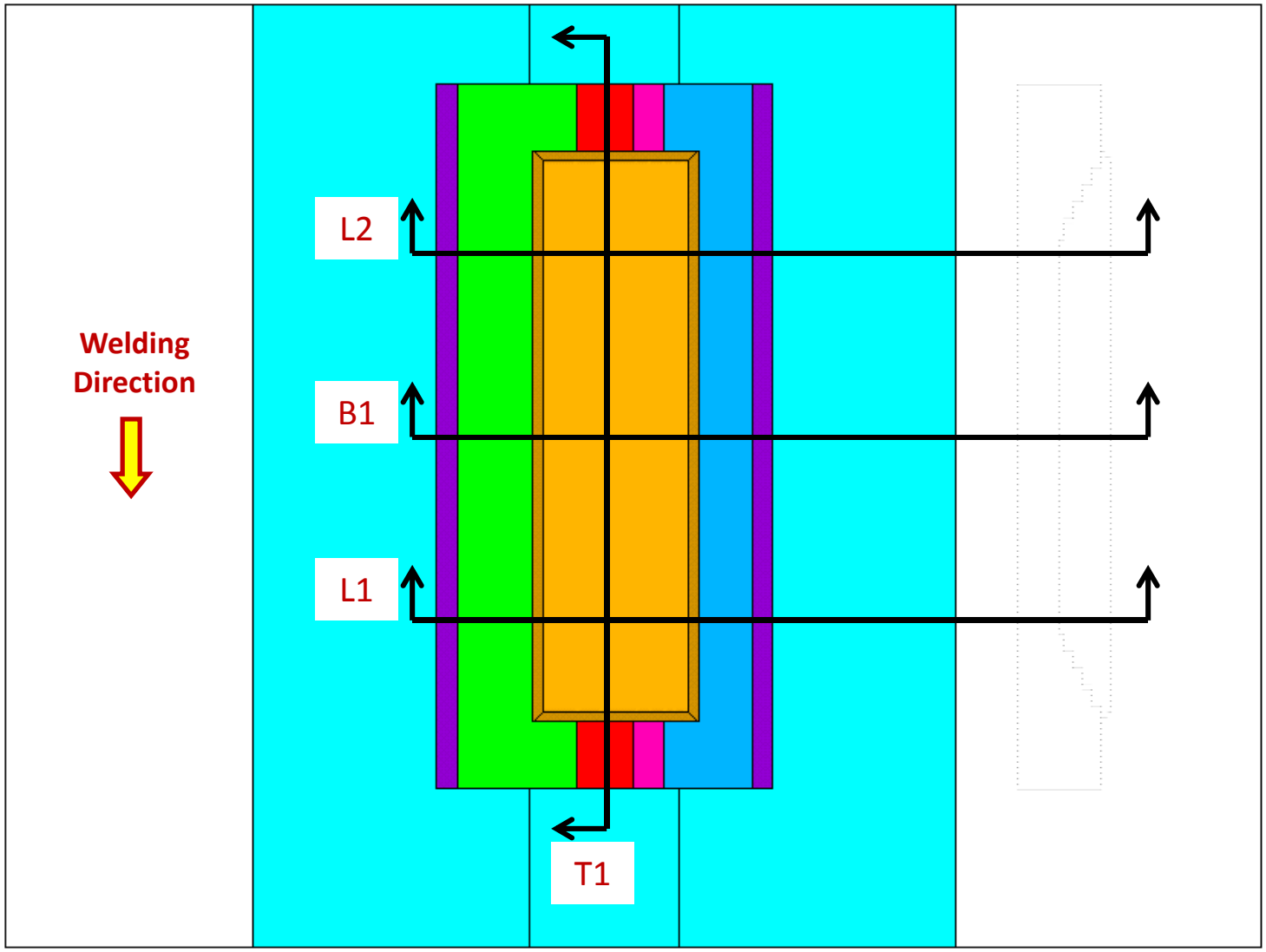
Von Mises Residual Stress Results



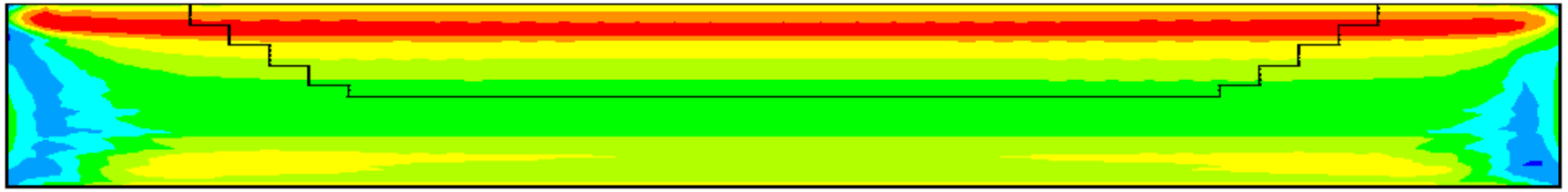
Stress Contour Cut Planes



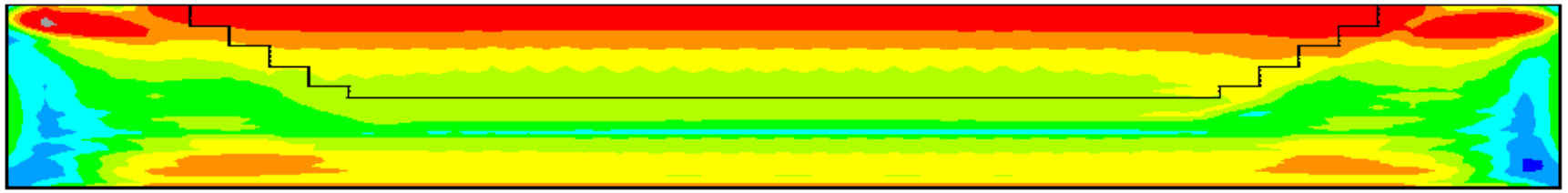
[T1] Axial Residual Stresses

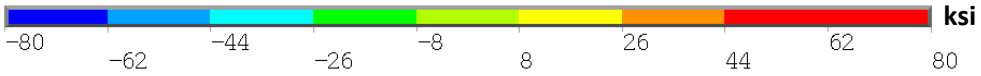
- T1 is cut plane along weld centerline
- Transverse (axial) residual stress comparison
- Slight differences between before and after EWR
  - Increase in tensile RS near ID surface (44 ksi vs. 26 ksi)
  - Increase in compressive RS near in mid-thickness (-44 ksi vs. -26 ksi)

After DMW, on Strongback



After EWR, on Strongback





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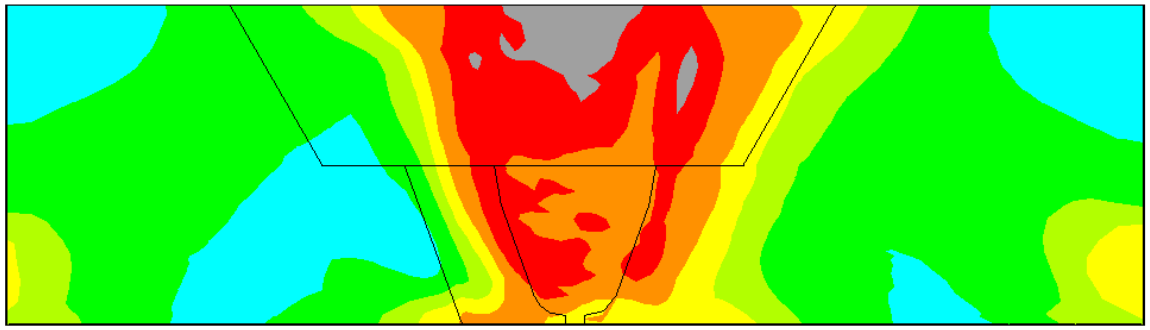
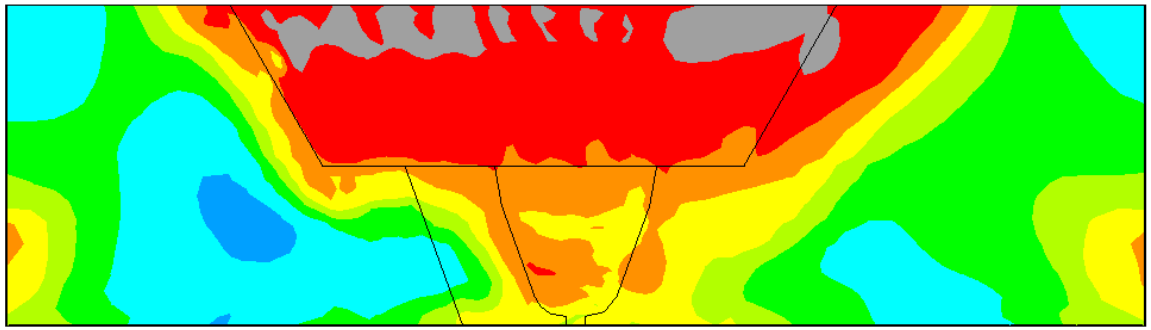
[B1] FEA Hoop Residual Stresses

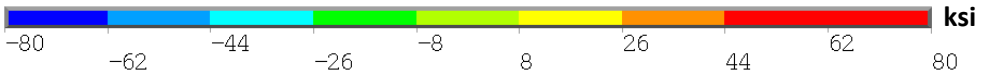
- B1 is cut plane across EWR mid-length
- Longitudinal (hoop) residual stress comparison
- Some stress reversal in thru-wall RS below EWR

After DMW, on Strongback



After EWR, on Strongback





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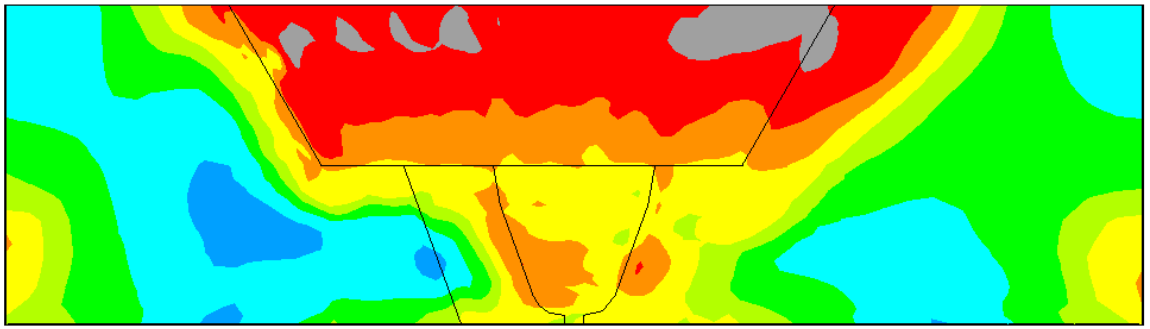
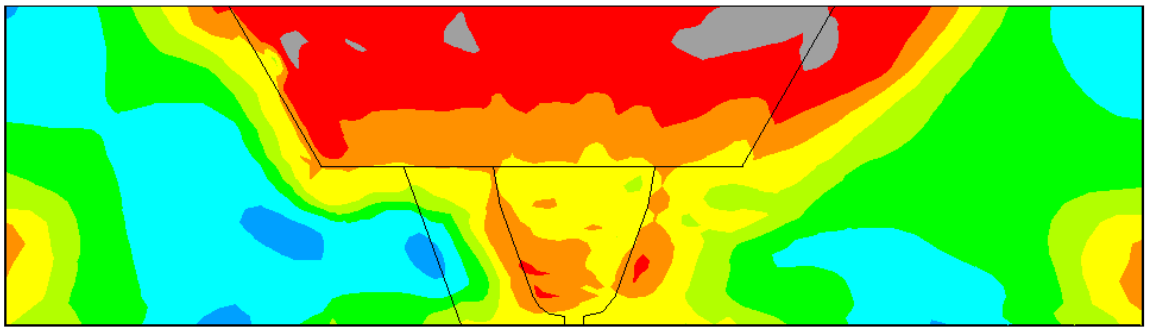
[L1 & L2] FEA Hoop Residual Stresses

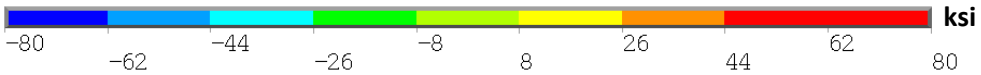
- L1 & L2 are cut plane across the EWR start and stop ends
- Longitudinal (hoop) residual stresses
- Similar results between bead start, midpoint, and stop locations

[L1] Bead Stop, on Strongback



[L2] Bead Start, on Strongback





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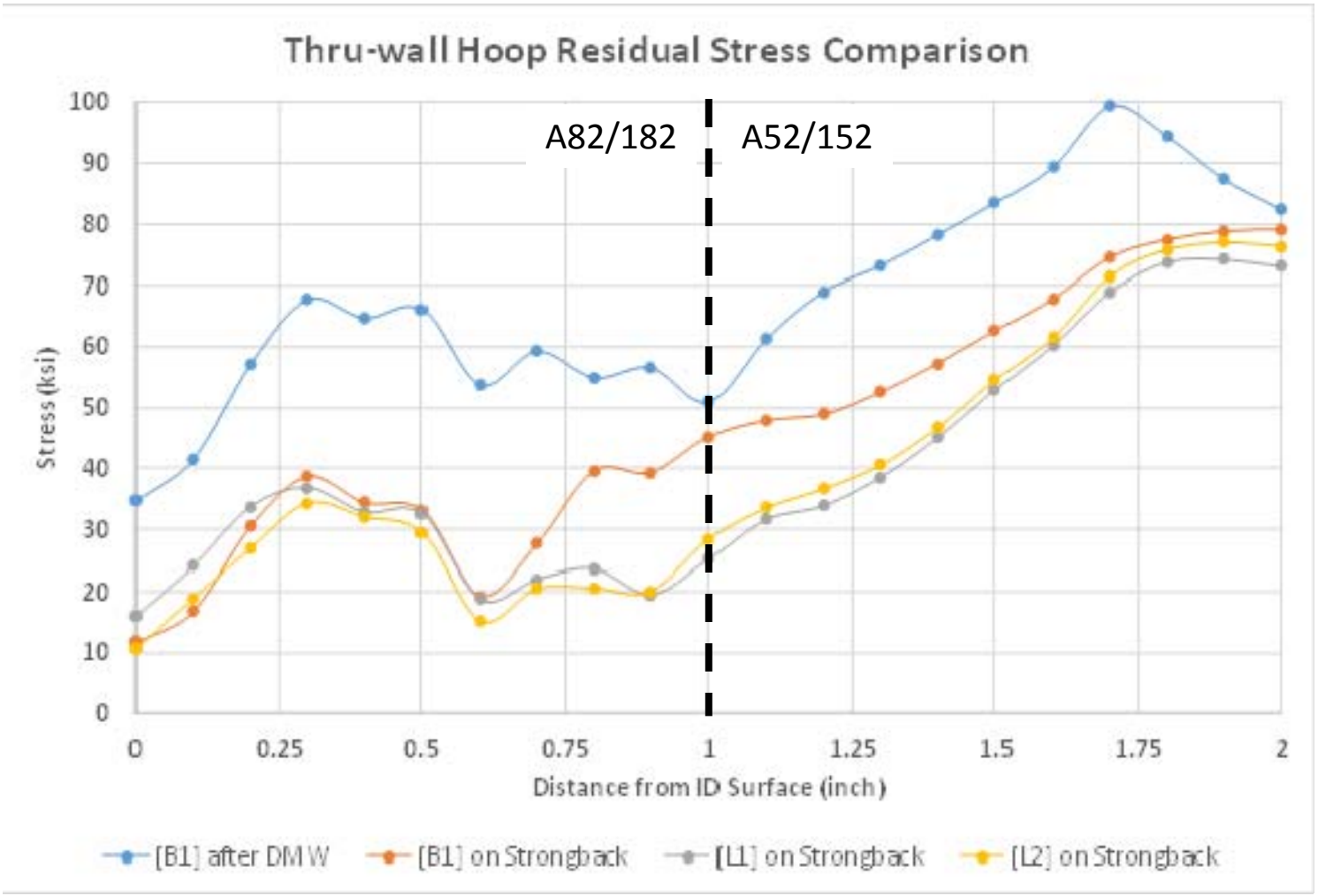
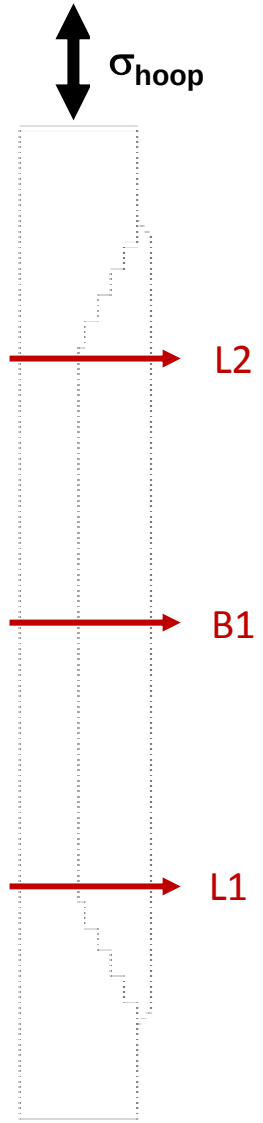
Through-Wall DMW & EWR Hoop Stress Profiles





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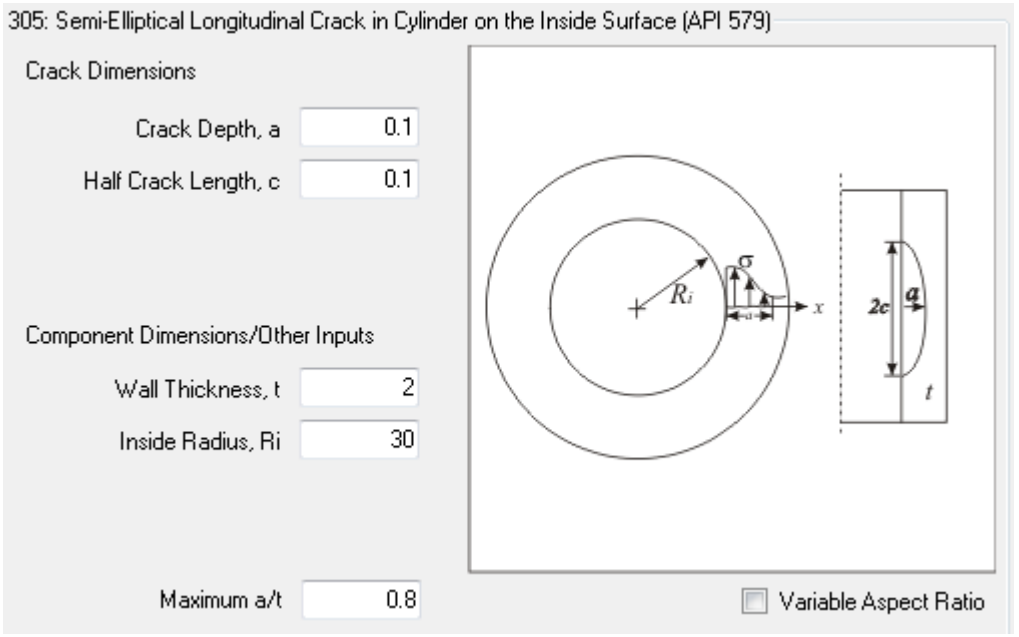
Preliminary PWSCC CGR for 1:2 Axial Crack

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

$\dot{a}$ = Crack growth rate at temp. T in in/hr
Q_g = Thermal activation energy for crack growth
= 31 kcal/mole
R = Universal gas constant
= 1.103×10^{-3}kcal/mole- °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)
α = Power-law constant
= 2.47×10^{-7} at 617 °F
K = Crack tip stress intensity factor, ksi-in$^{0.5}$
β = 1.6

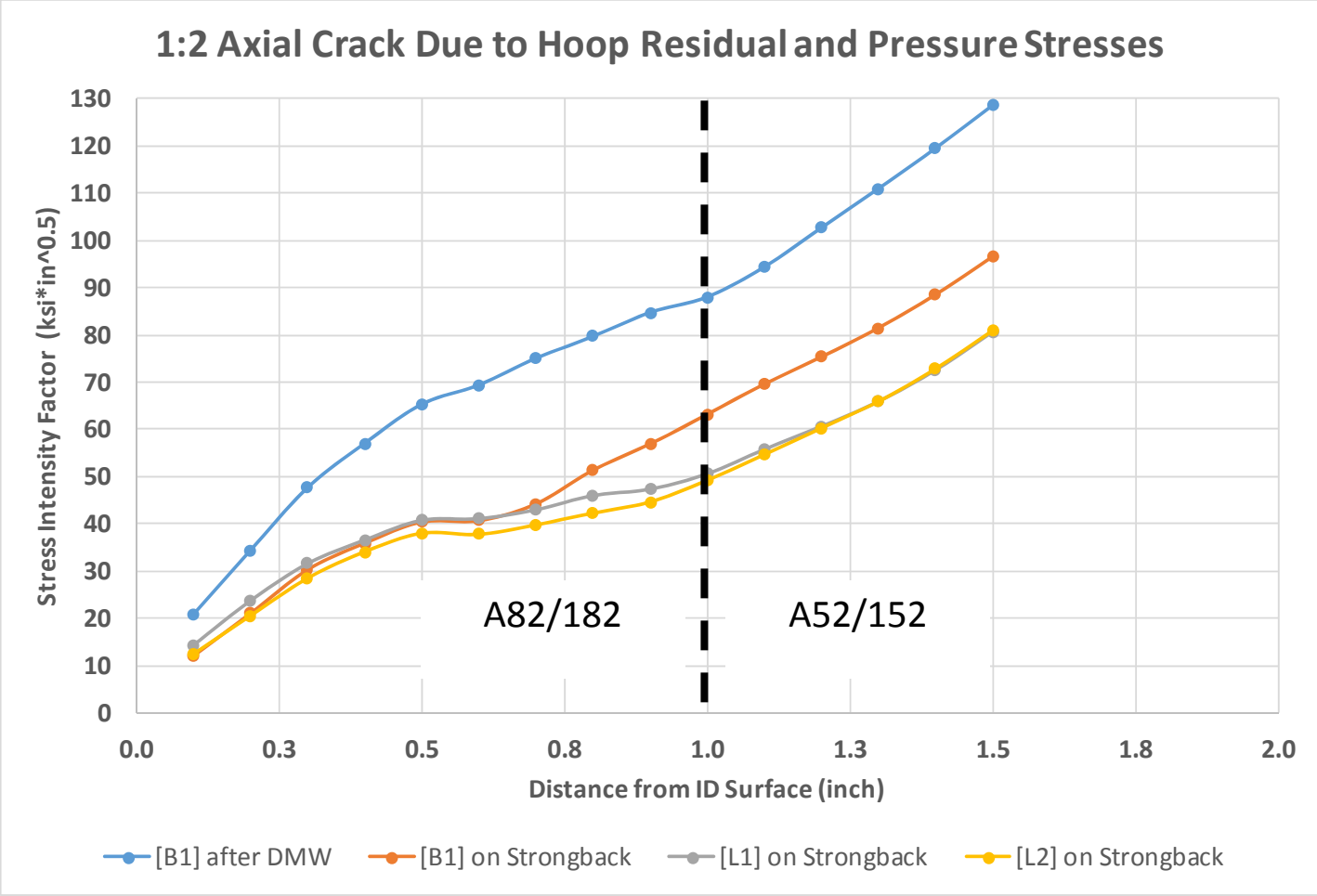
[CGR Reference: MRP-115]



Preliminary Stress Intensity Factor Calculation

1:2 Axial Crack

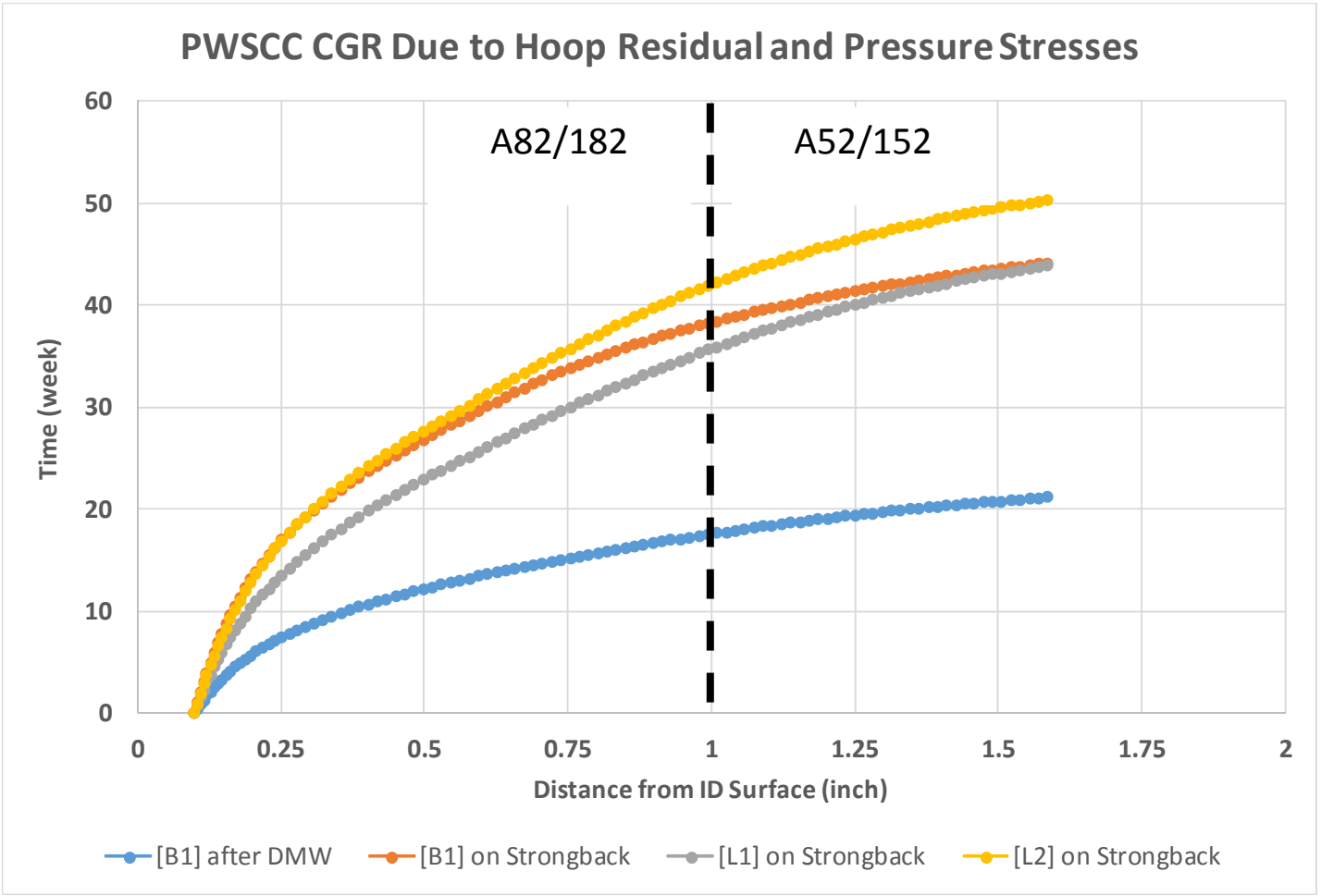
- EWR results in reduction of thru-wall stress intensity factor, K



Preliminary Crack Growth Rate Results

1:2 Axial Crack

- EWR doubles the PWSCC CG time thru A82/182 DMW



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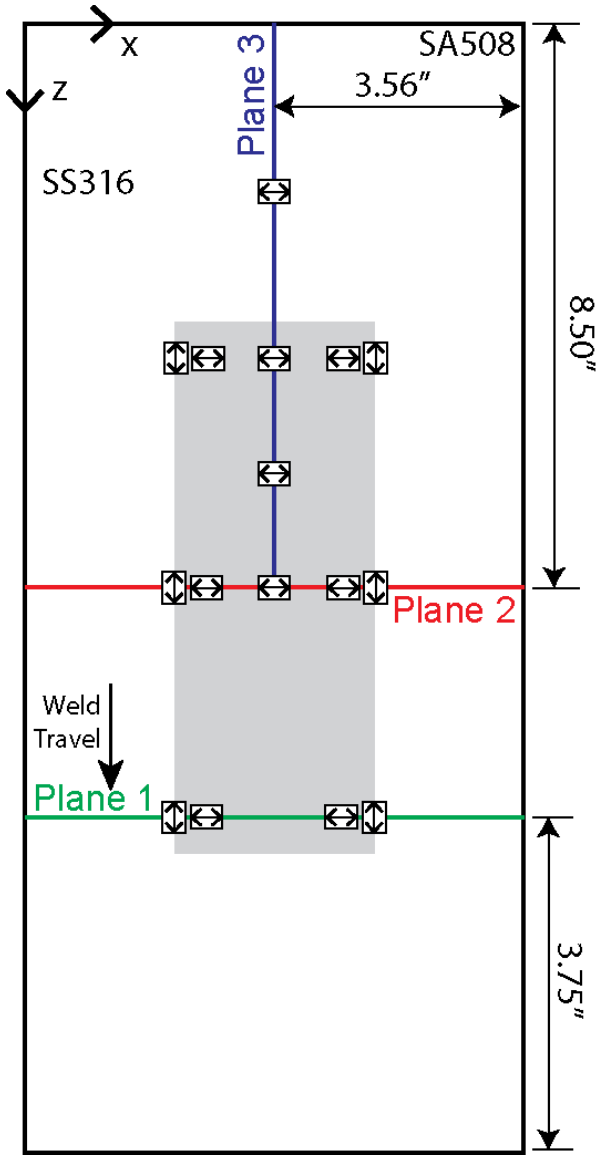
Residual Stress Measurement Overview

Contour Method

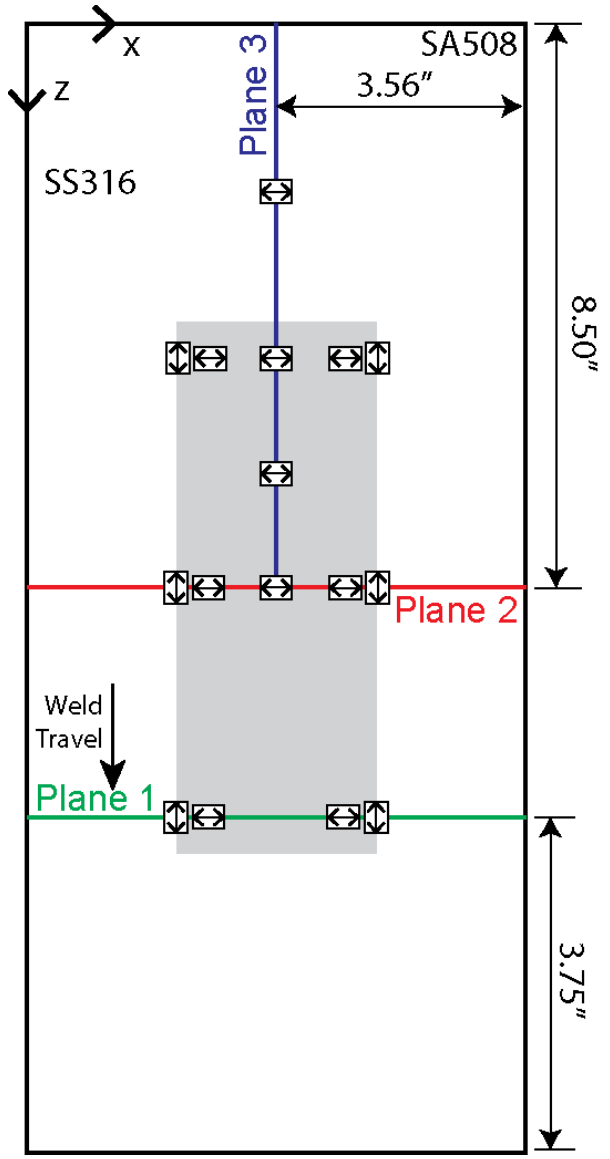
- The contour method is a destructive residual stress measurement technique
  - Involves cutting material along a given plane
    - Gives stress component normal to cut plane
    - Provides 2D *map* of stress over the plane
  - The contour measurements at Plane 1 & 2 measure σ_{zz}
  - The contour measurement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



Residual Stress Measurement Plan

EWR Mockup #1

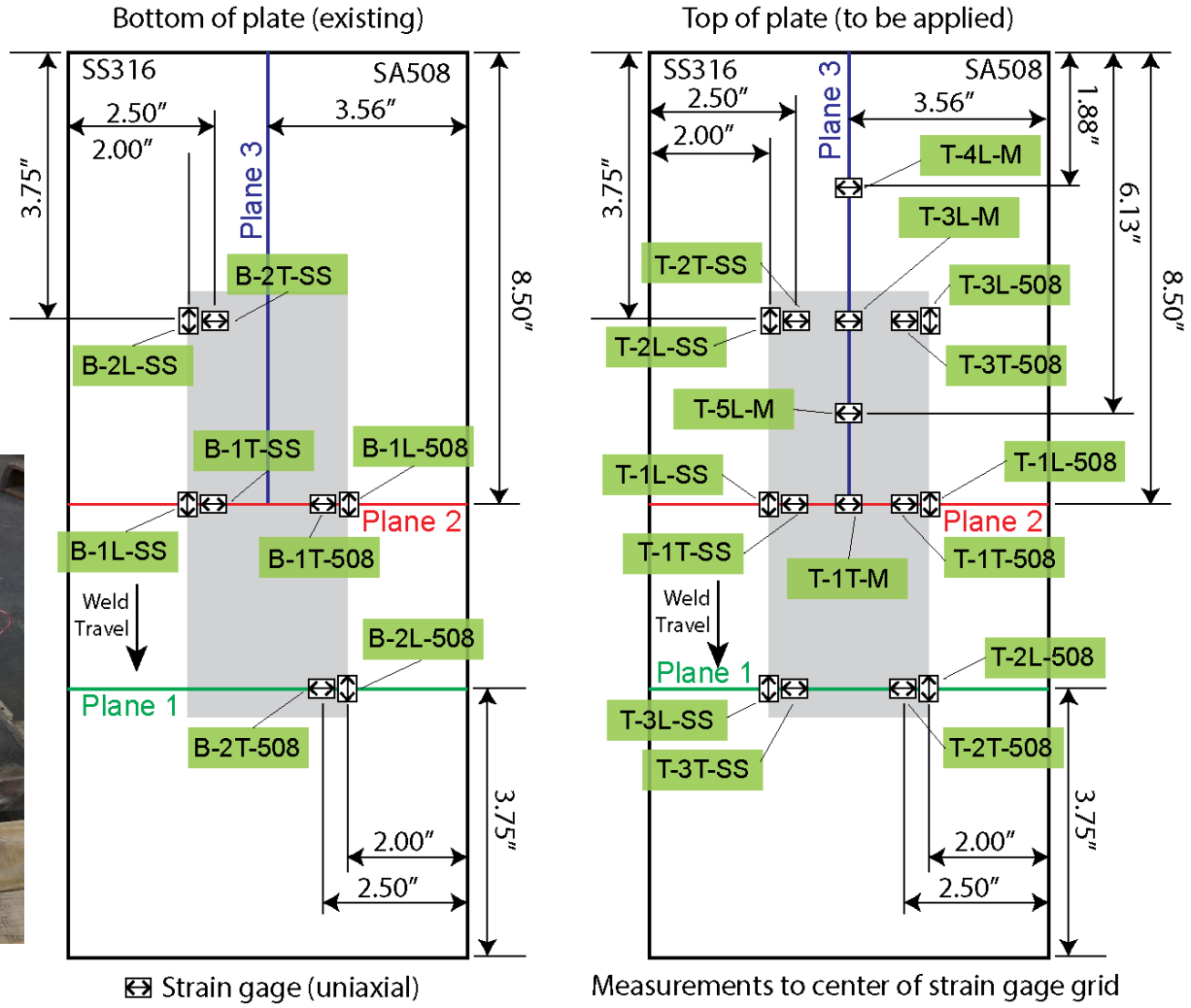
- Measurement steps for EWR mockup #1
  - Apply strain gages
  - Remove strong back
  - Determine stress release from removal
  - Contour measurement longitudinal stress at end of EWR (Plane 1)
  - Contour measurement of the longitudinal stress at the center (Plane 2)
  - Slitting measurements of the transverse stress at the center (Plane 2)
  - Contour measurement of the transverse stress (Plane 3)



Strain Gaging for Strong Back Removal

EWR Mockup #1

- Strain gage layout plan
  - "Bottom" face gages installed prior to EWR
  - "Top" face gages installed after EWR



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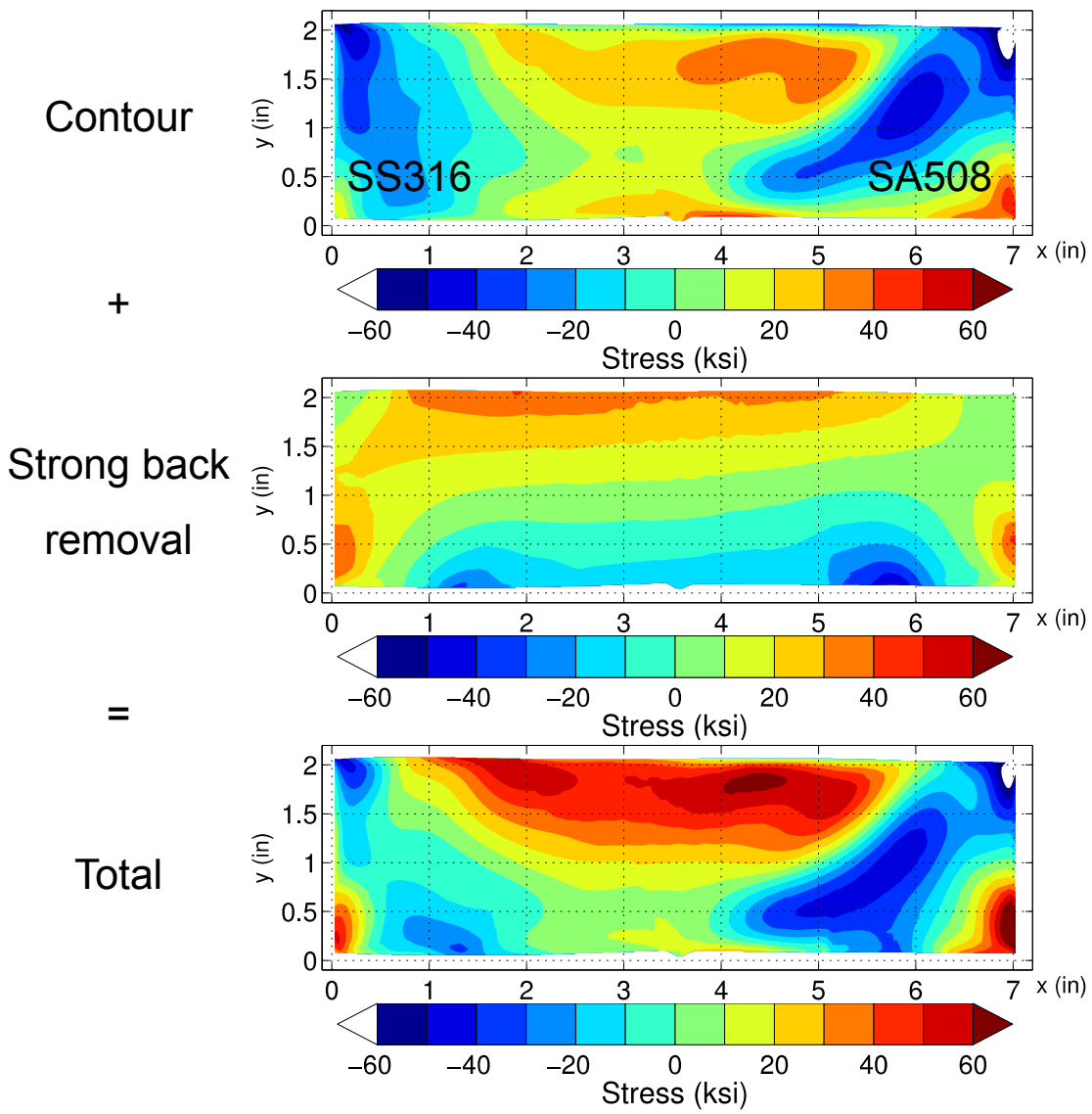
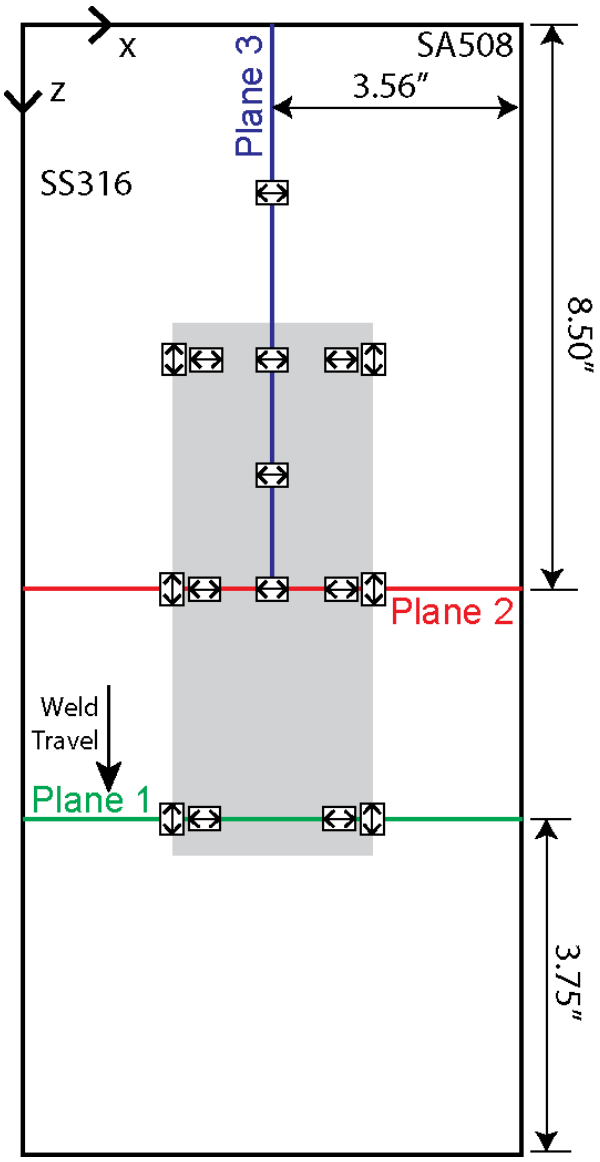
Residual Stress Results

Plane 1 (σ_{zz})





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Residual Stress Results

Plane 2 (σ_{zz})

Contour

+

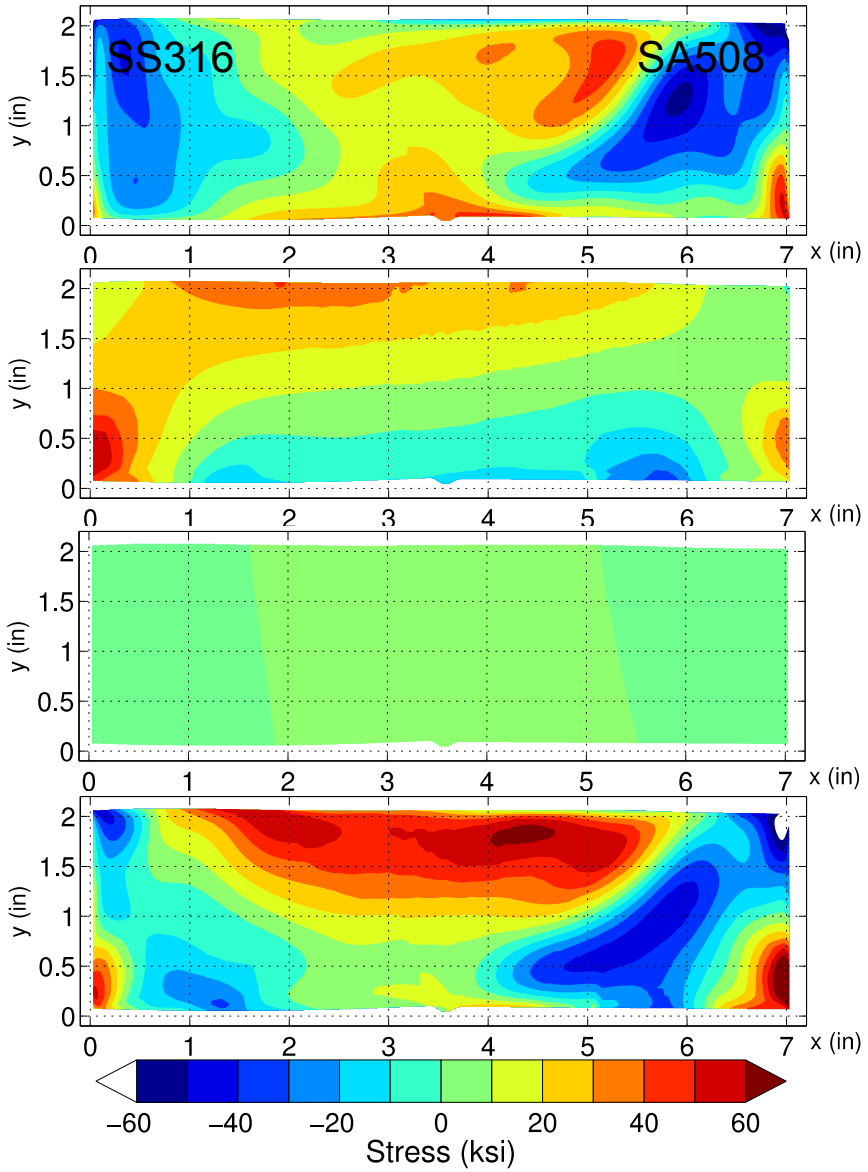
Strong back removal

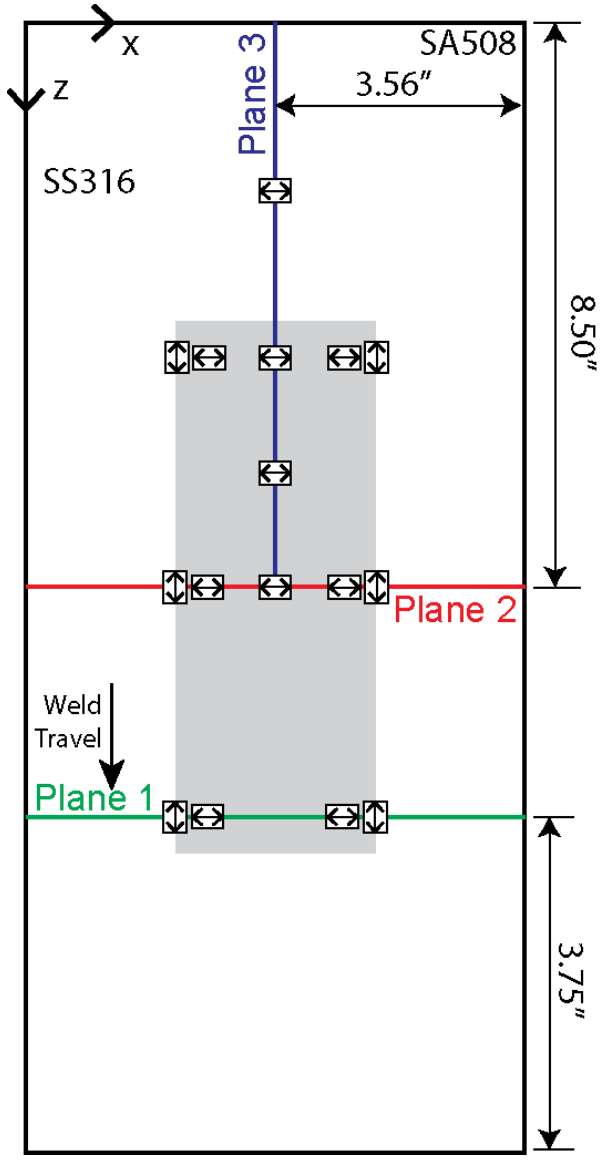
+

Effect of P1 contour cut

=

Total





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Residual Stress Results

Plane 3 (σ_{xx})

Contour

+

Strong back removal

+

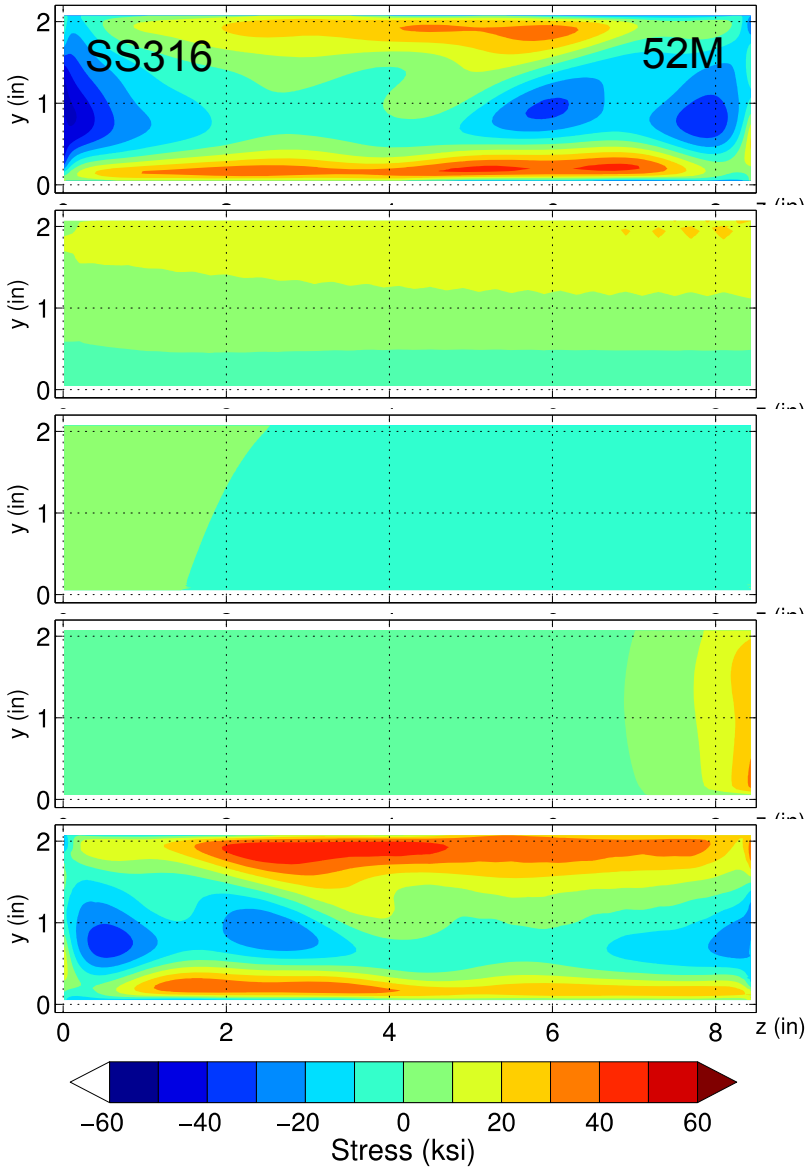
Effect of P1 contour cut

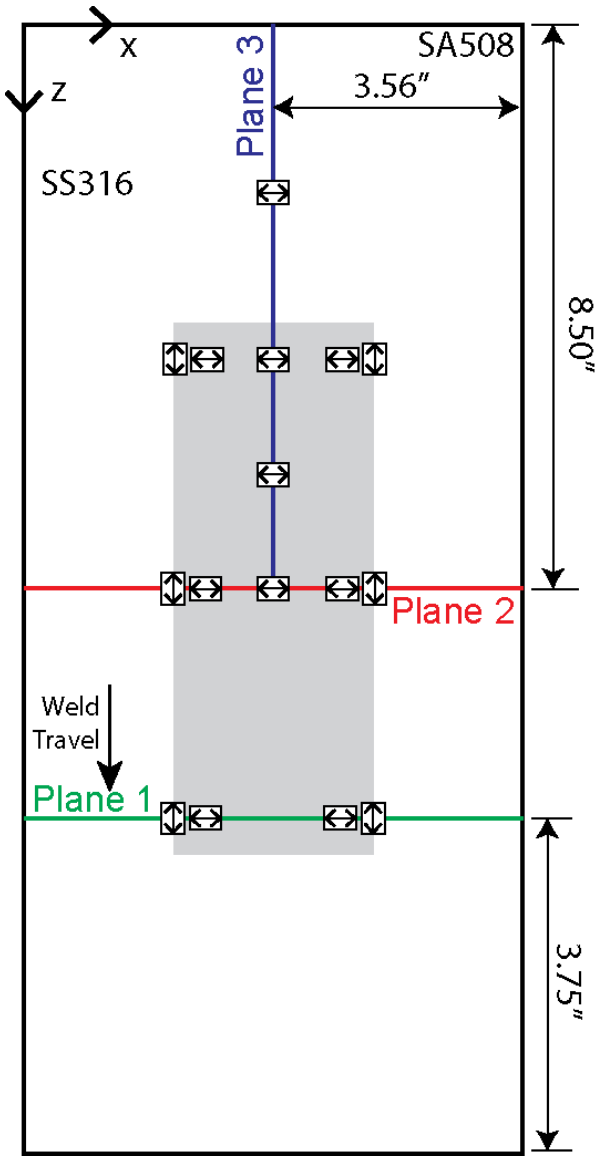
+

Effect of P2 contour cut

=

Total





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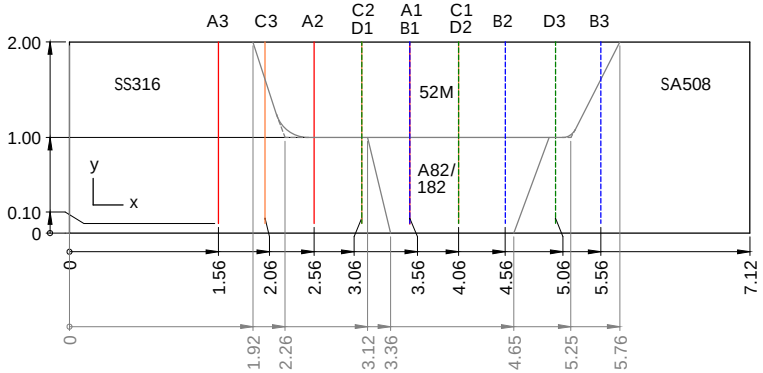
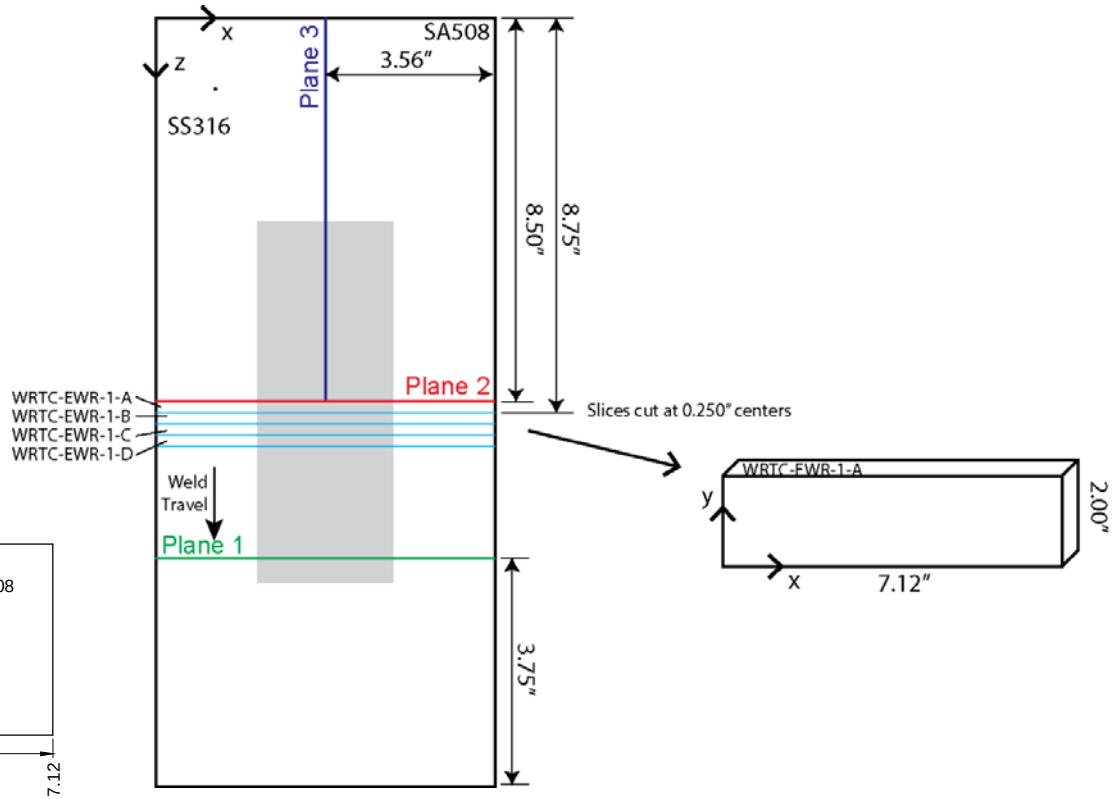
Slitting Measurements

Adjacent to Plane 2 (σ_{xx})

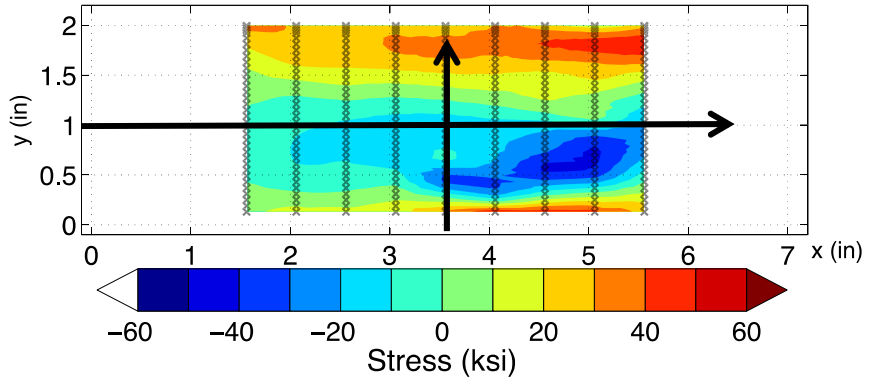
- Perform slitting measurements on slices removed near Plane 2
  - Determine σ_{xx} at Plane 2
- Slitting measurements at
  - X = 3.06 (C2&D1)
  - X = 3.56 (A1&B1)
  - X = 4.06 (C1&D2)

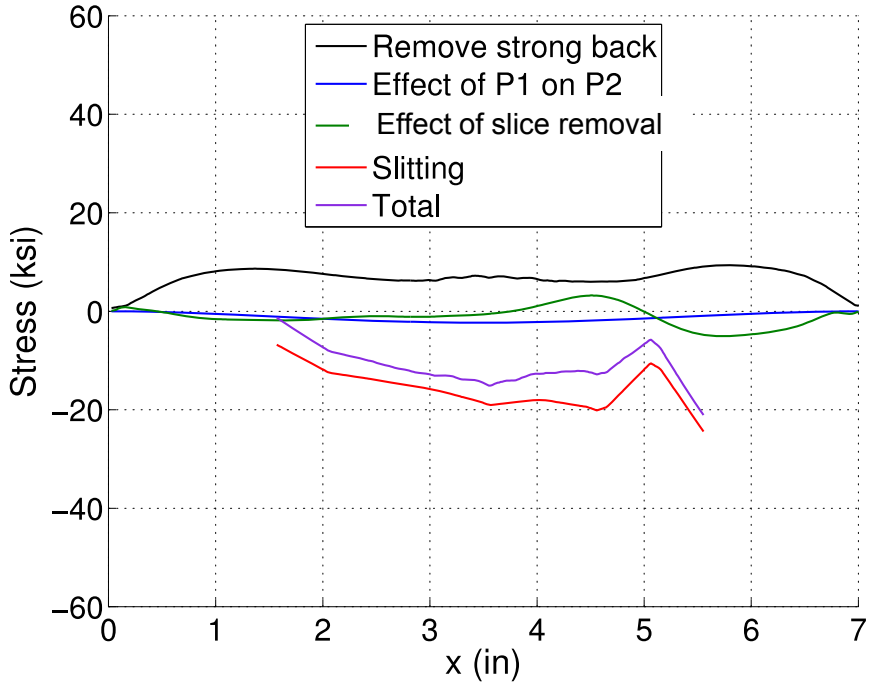


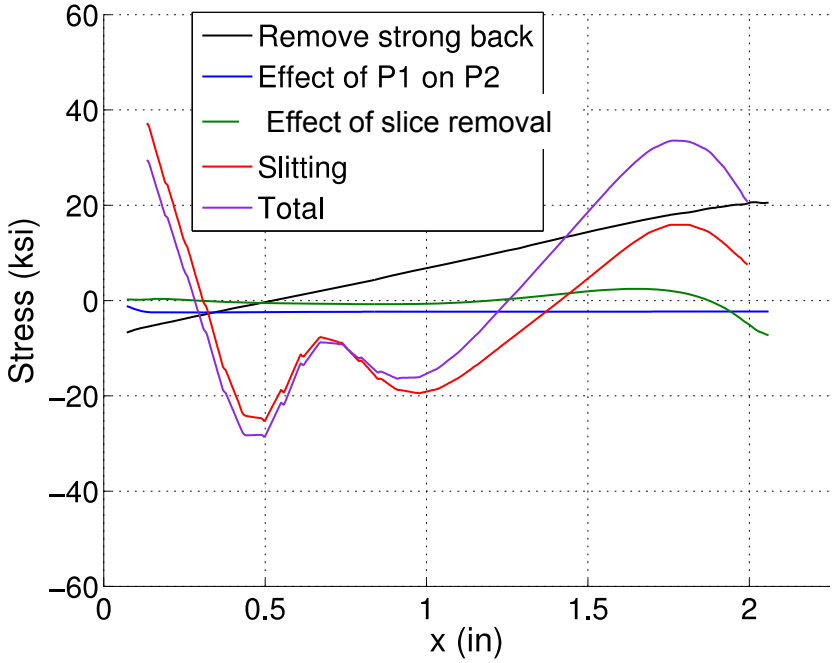


Residual Stress Results

Plane 2 (σ_{xx}) Line Plots



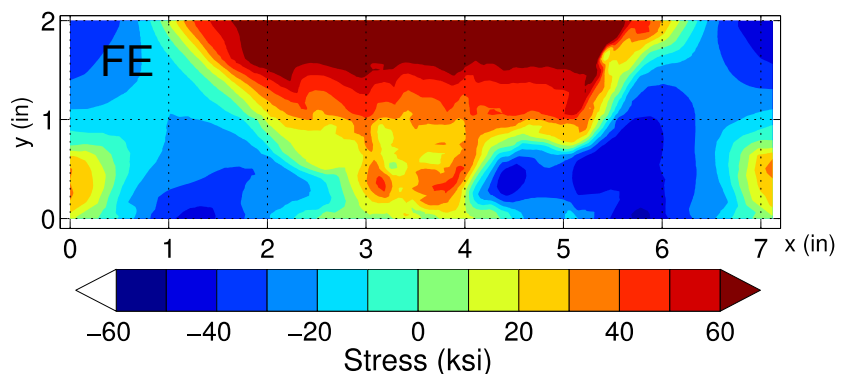


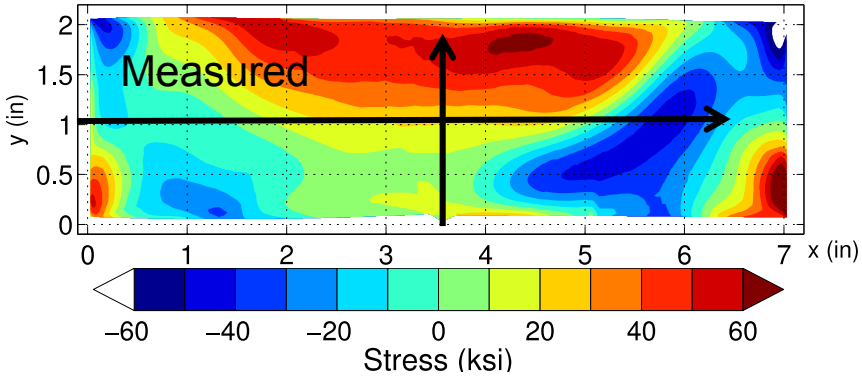


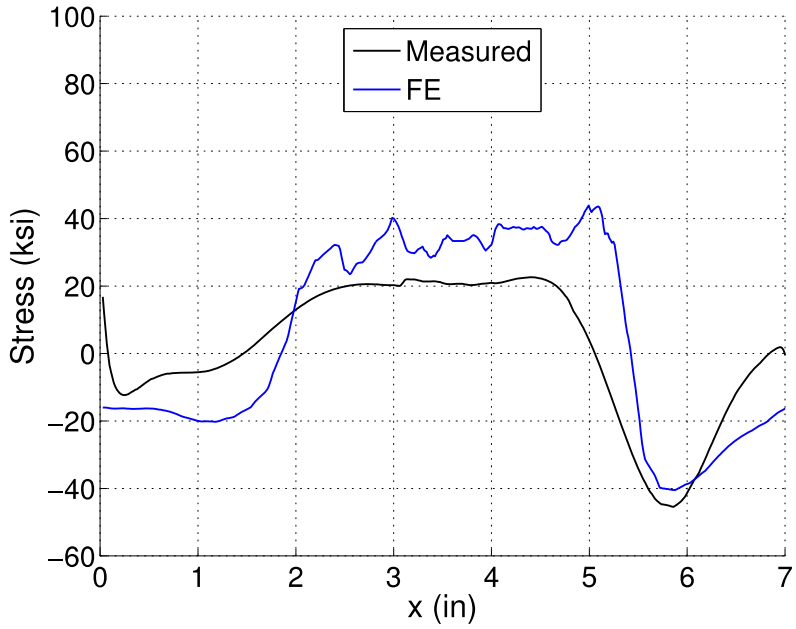
Comparison to FEA Model

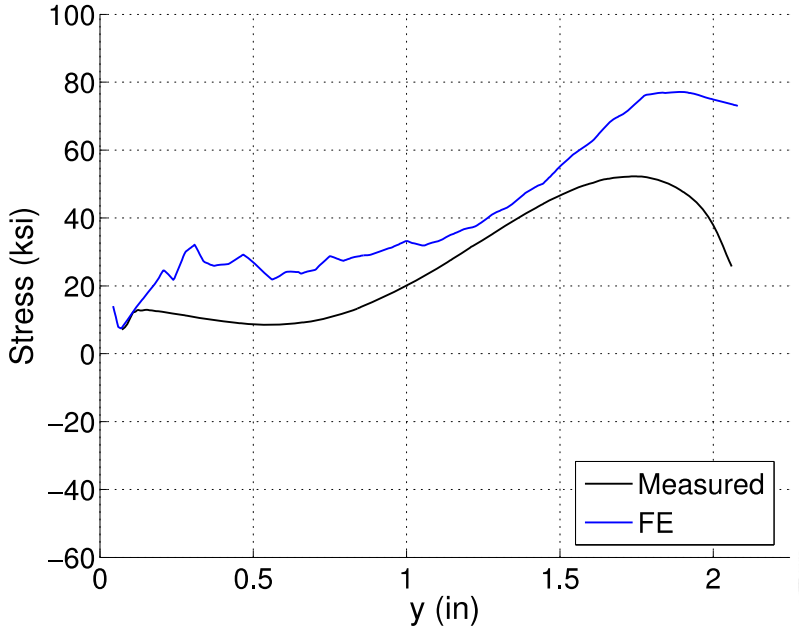
Plane 1 (σ_{zz})

- Good agreement in shape of stress field
- Weld metal measured stress is lower magnitude





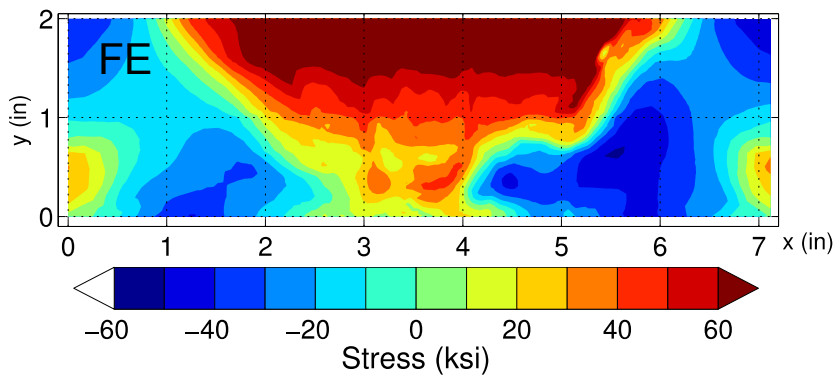


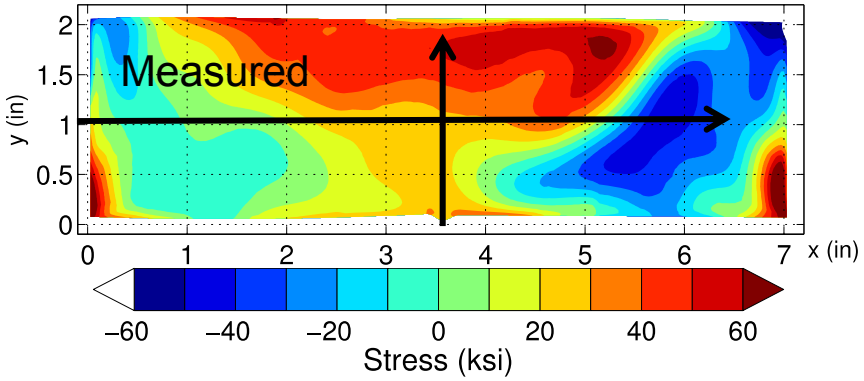


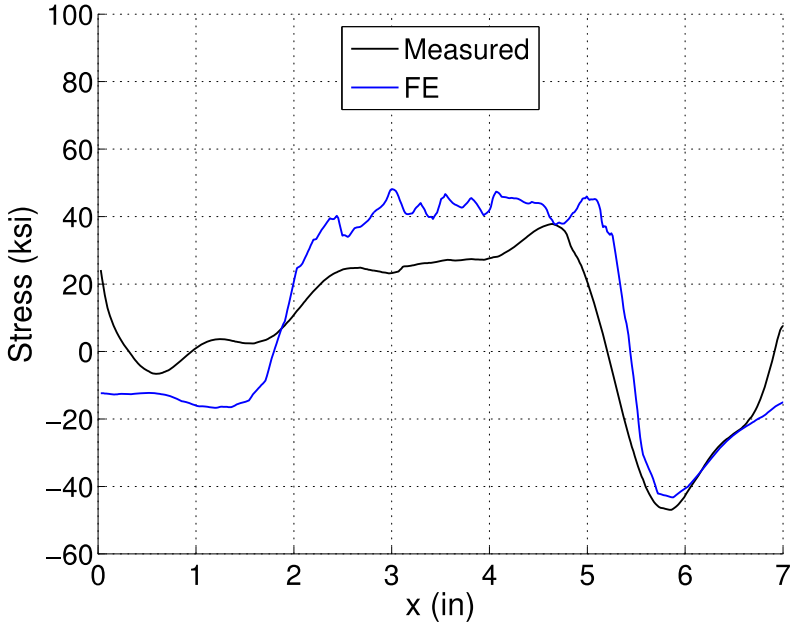
Comparison to FEA Model

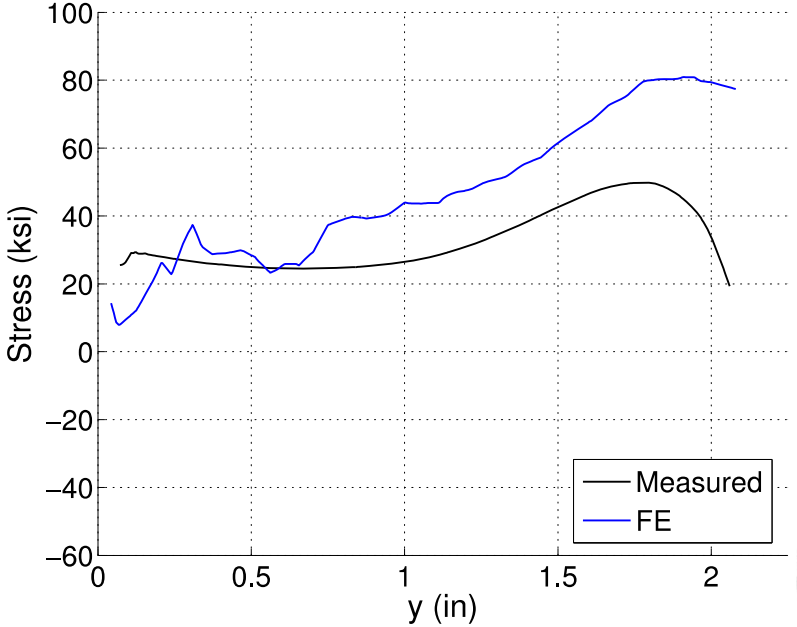
Plane 2 (σ_{zz})

- Good agreement in shape of stress field
- Weld metal measured stress is lower magnitude





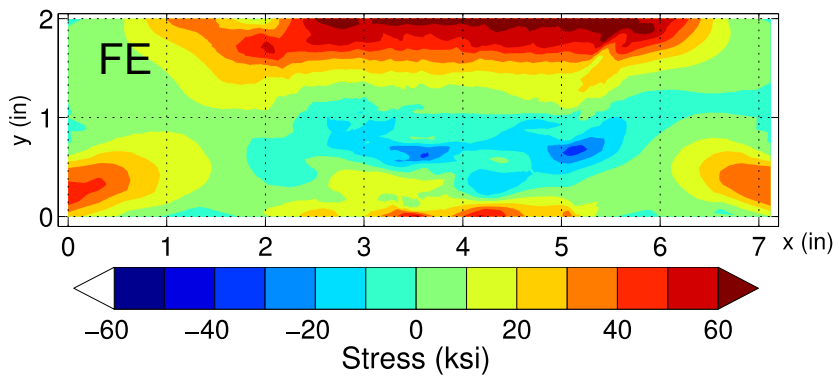


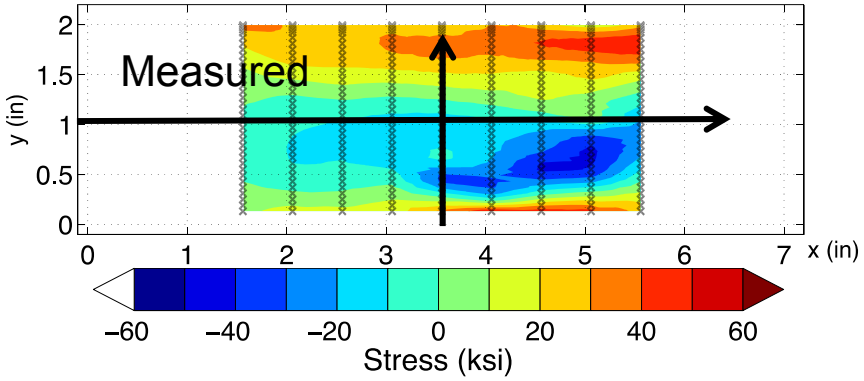


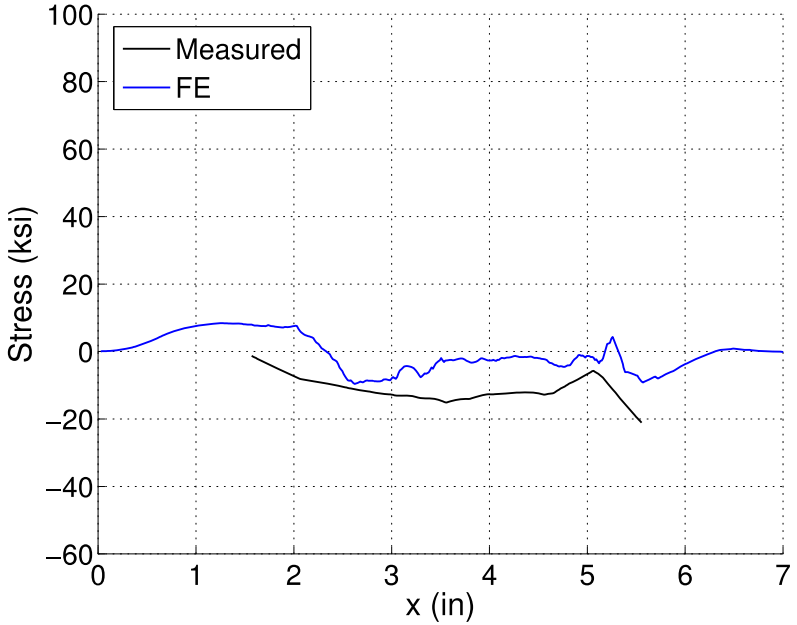
Comparison to FEA Model

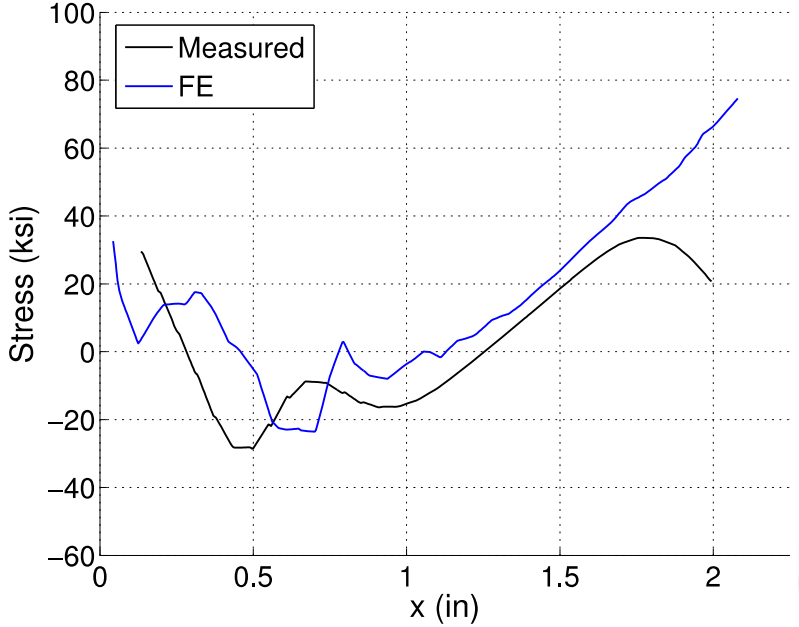
Plane 2 (σ_{xx})

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





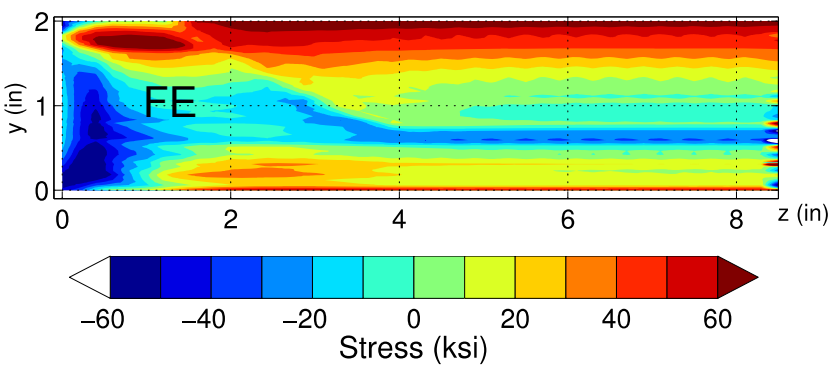


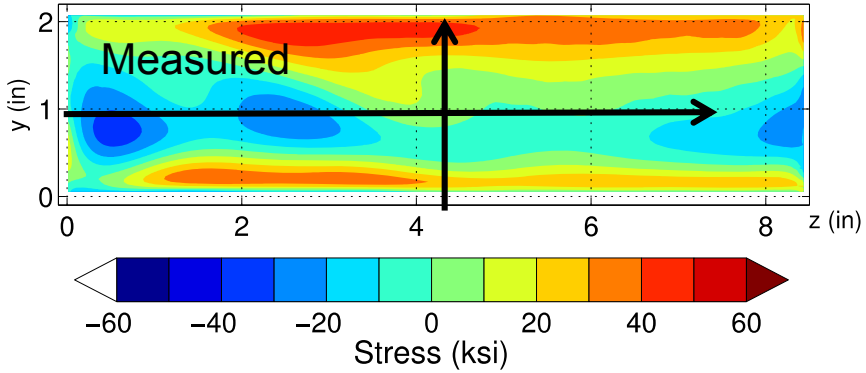


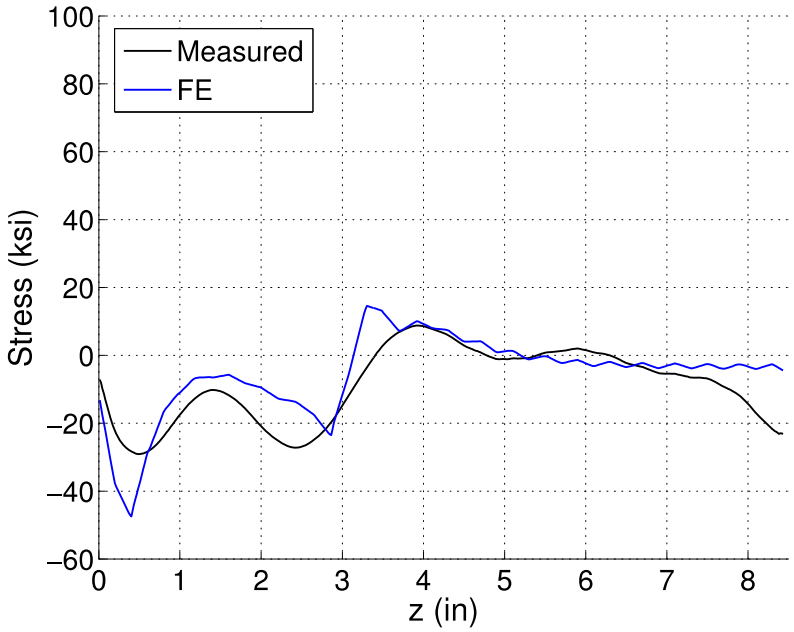
Comparison to FEA Model

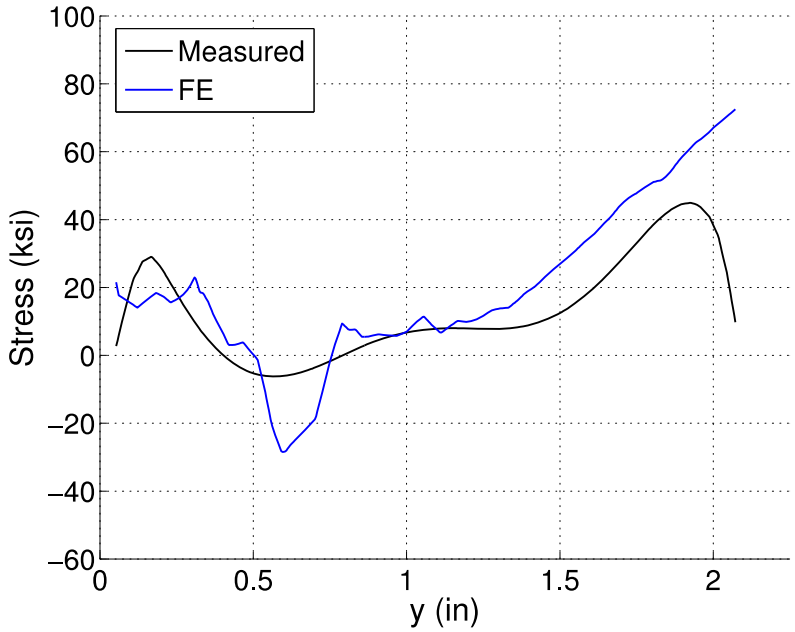
Plane 3 (σ_{xx})

- Good agreement in magnitude and shape of stress field







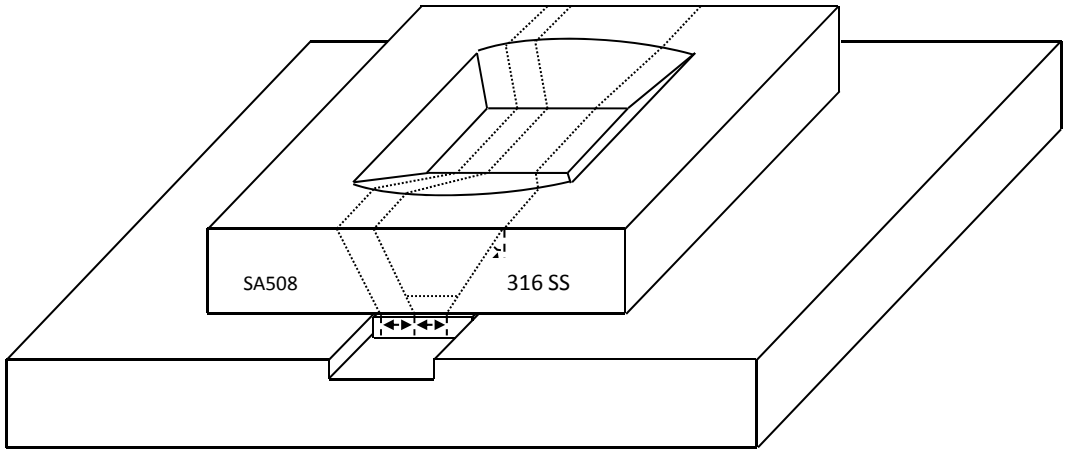


Presentation Outline

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

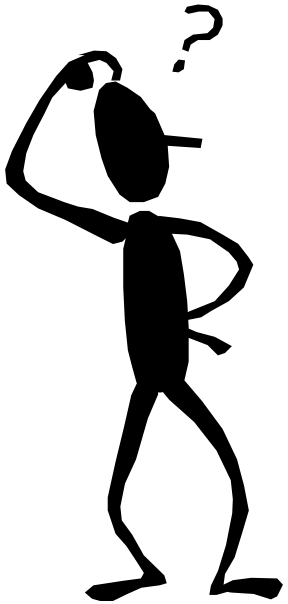
Future WRTC Work to Implement EWR Option

- 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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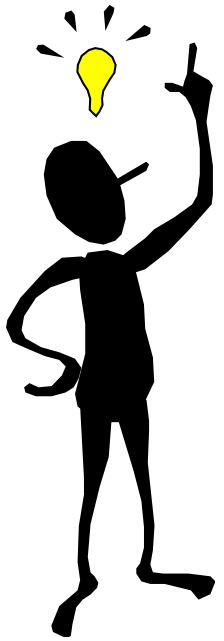
Welding and Repair Technology Center



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