Residual Stress Process Simulation Subcommittee Progress Report

Engineered Residual Stress Implementation Workshop 2018

Layton, Utah, USA

September 13, 2018

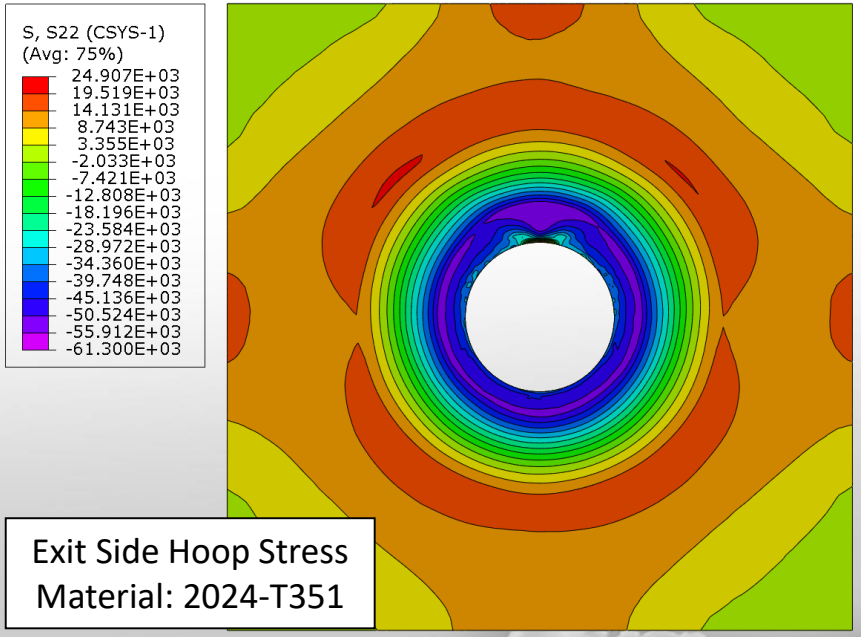
ERSI

FATIGUE TECHNOLOGY

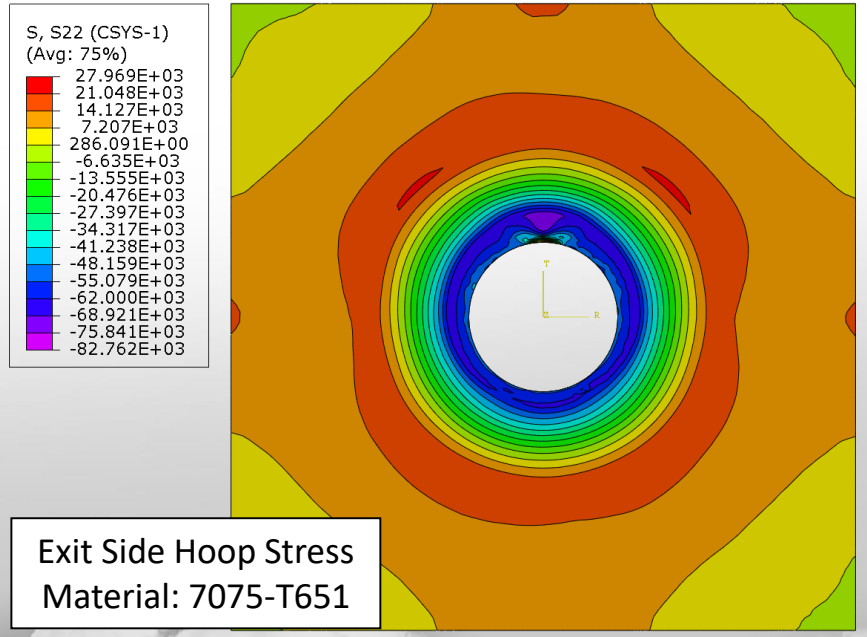
DM#808860

Outline

- Subcommittee Activity
- Material Testing and FEA Model Validation
- 2” x 2” Coupons: Further preliminary correlations



Exit Side Hoop Stress
Material: 2024-T351



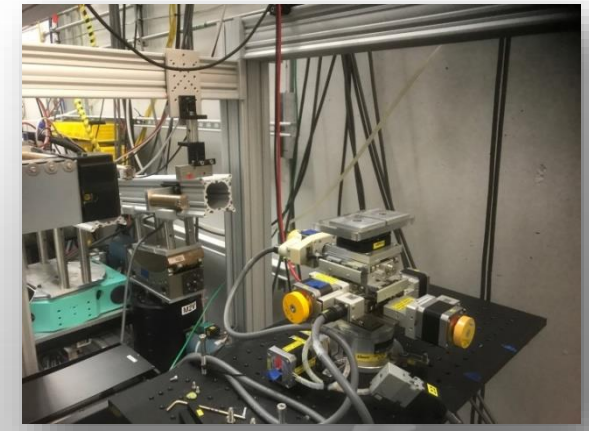
Exit Side Hoop Stress
Material: 7075-T651

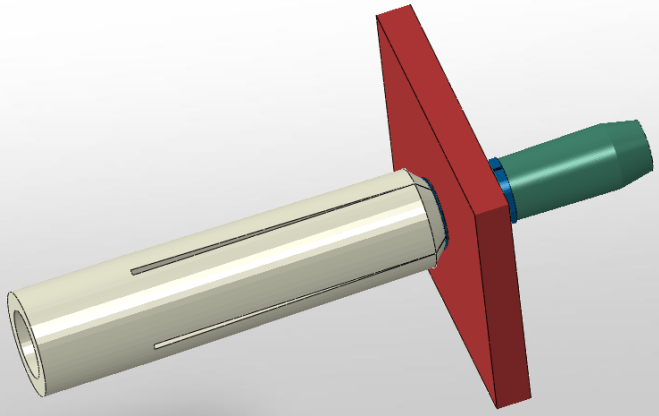
ERSI

FTI FATIGUE TECHNOLOGY

Subcommittee Activity

- Three teleconferences
  - March - June
- Material model coupon fabrication and testing
- 2” x 2” Coupon Correlation Study
  - Measurements (i.e., XRD)
  - Presentations (i.e., ASTM)



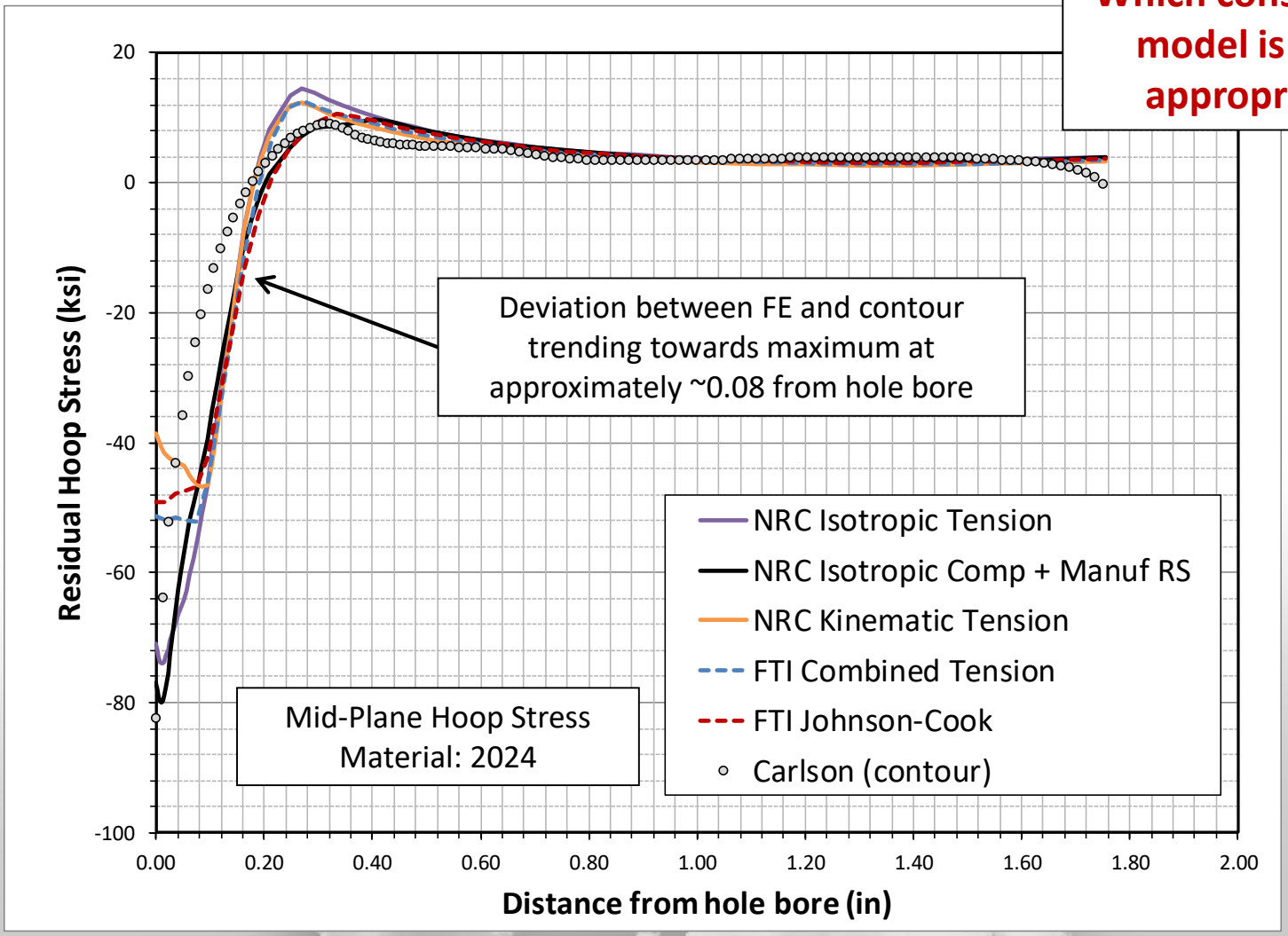


ERSI

FATIGUE TECHNOLOGY

Material Model Testing
Purpose of Program

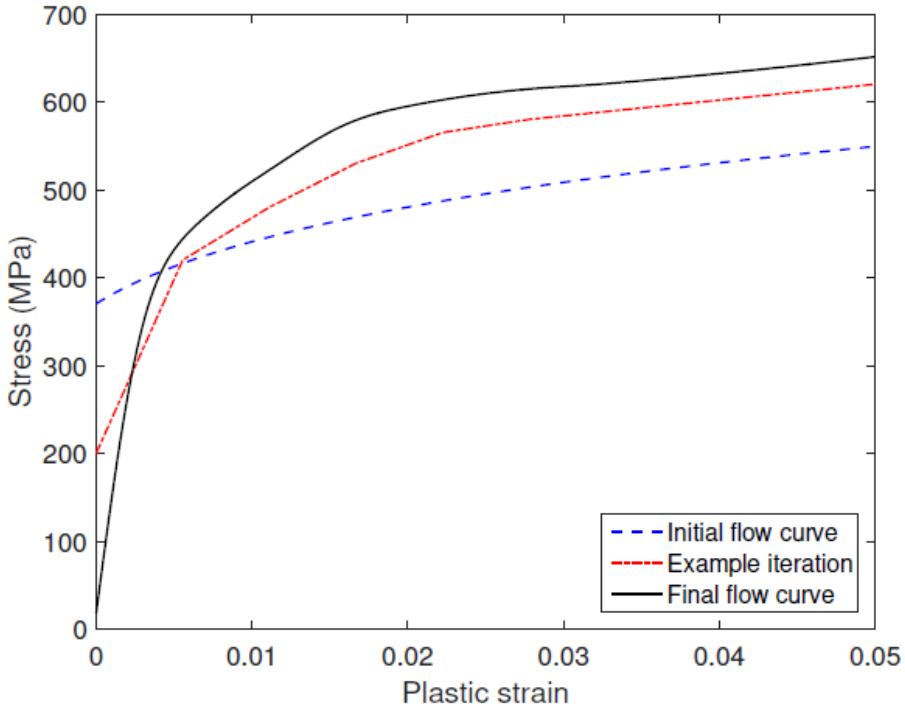
Which constitutive model is most appropriate?



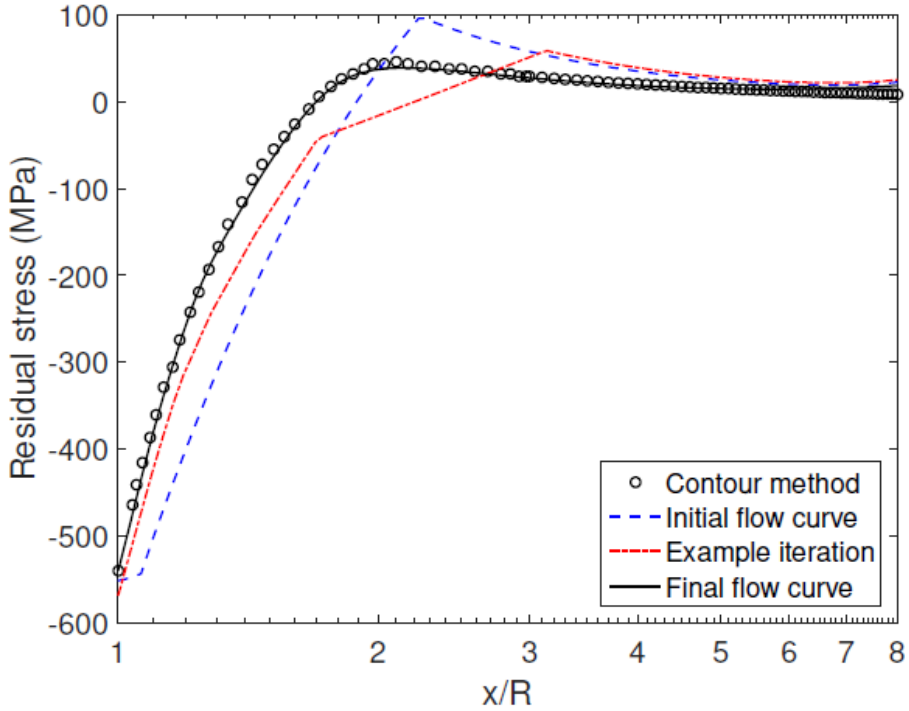
ERSI

FATIGUE TECHNOLOGY

Material Model Testing
Purpose of Program



(a)



(b)

Figure 7 – (a) Flow curves tested, (b) resulting hoop residual stress ($\sigma_{\theta\theta}$); note log scale on x/R

Ribeiro, Renan L., and Michael R. Hill. "Residual Stress From Cold Expansion of Fastener Holes: Measurement, Eigenstrain, and Process Finite Element Modeling." Journal of Engineering Materials and Technology 139.4 (2017): 041012. https://doi.org/10.1115/1.4037021

Material Model Testing
General Plan

- Based upon E606 LCF, up to ±4% in./in., reduced to ±1.5%
- Isolating current investigation to orthotropy
- Non-stabilized cyclic loading capturing reverse-yield behavior (2024 currently, 7075 to follow)
- **Testing was to be complete Fall 2017, actually completed late Spring 2018.**

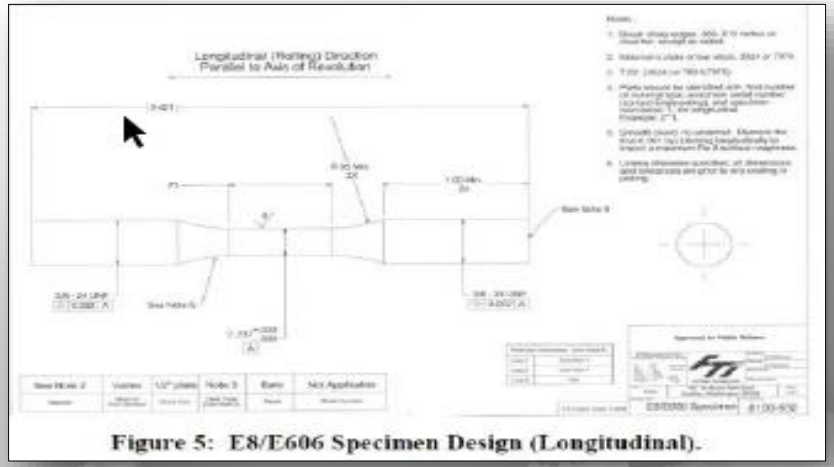


Figure 5: E8/E606 Specimen Design (Longitudinal).

ERSI

FATIGUE TECHNOLOGY

Material Model Testing

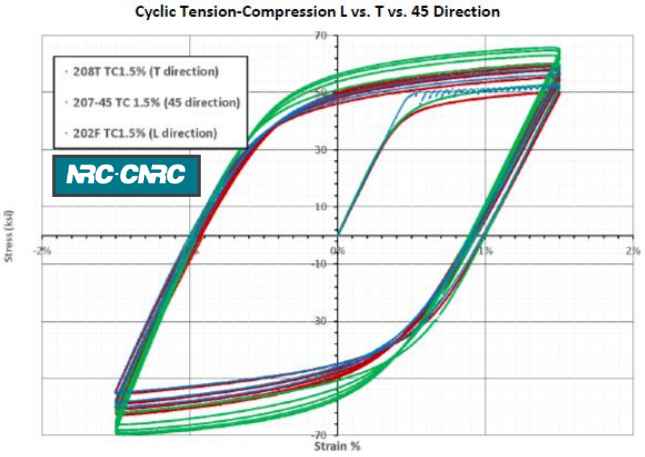
Test Results

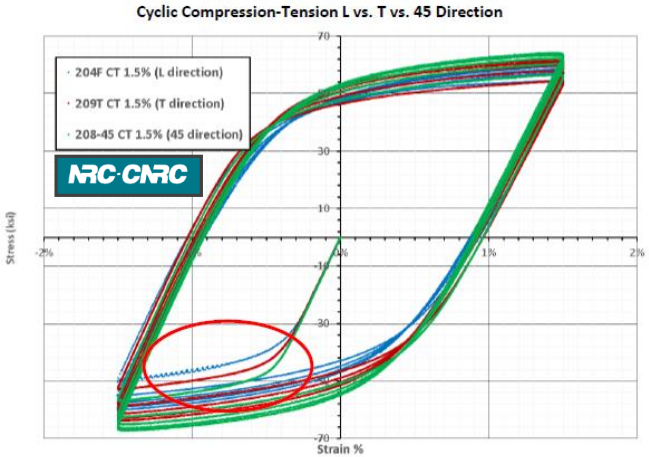
- FTI fabricated 10 each T, L and 45° specimens from plate provided (same lot as 2” x 2” coupons).
  - Issue: Poor transition on one side of specimen
  - Issue: specimen design (grip, gauge length) not conducive to high (~4% strains).
- NRC worked through issues to provide an excellent body of data.

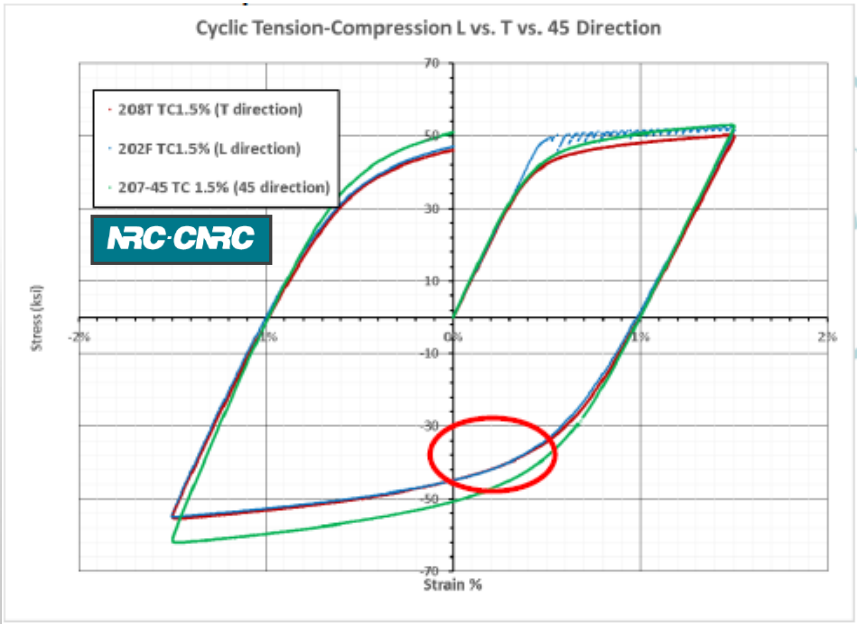
ERSI FTI FATIGUE TECHNOLOGY

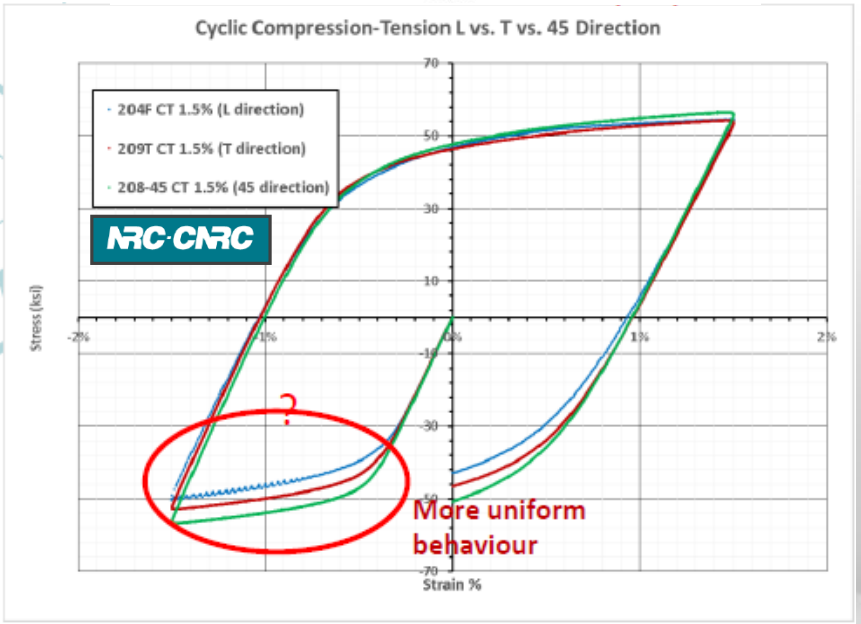
Material Model Testing

Test Results







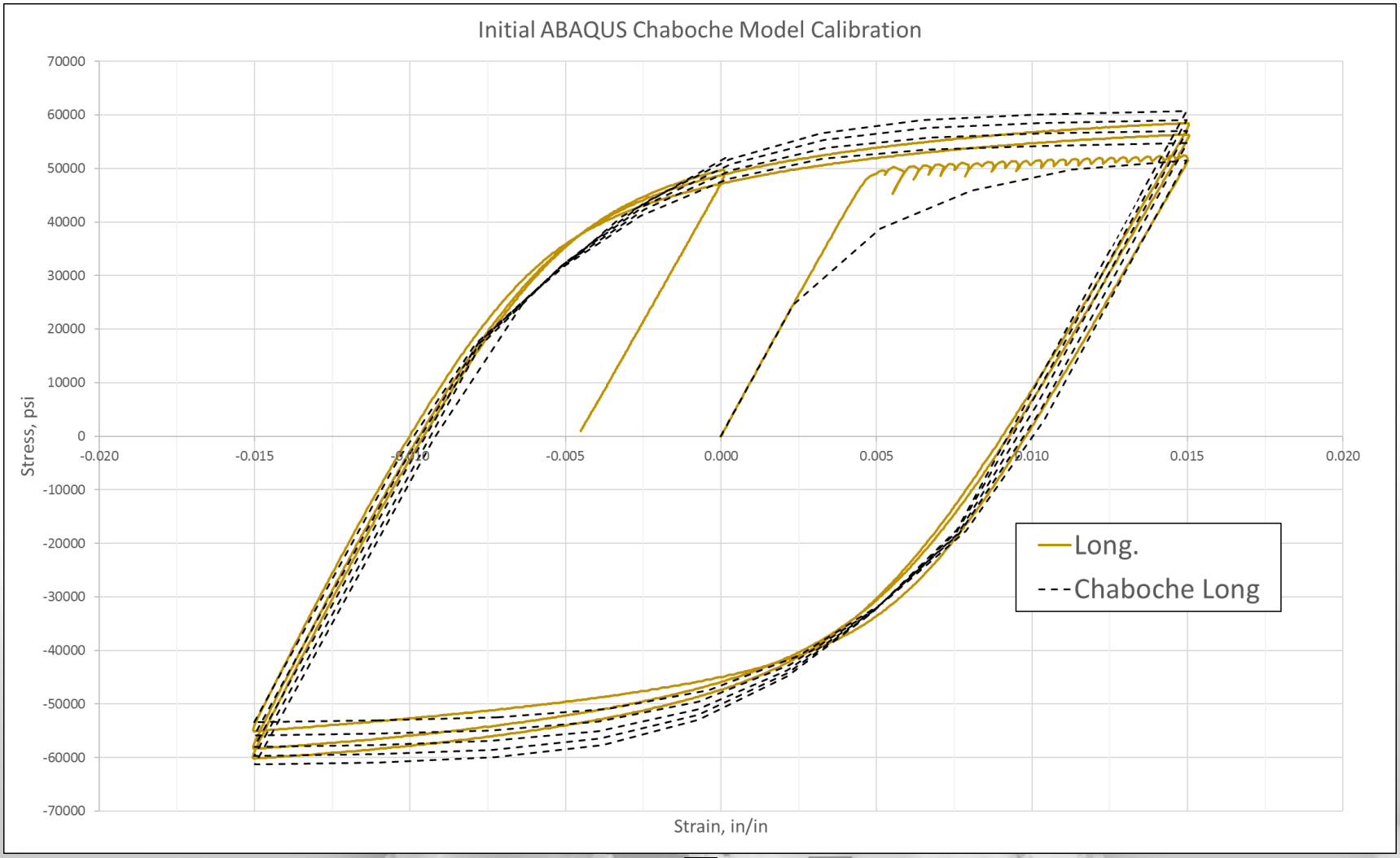


ERSI

FATIGUE TECHNOLOGY

Material Model Testing

Preliminary Abaqus Model Calibration

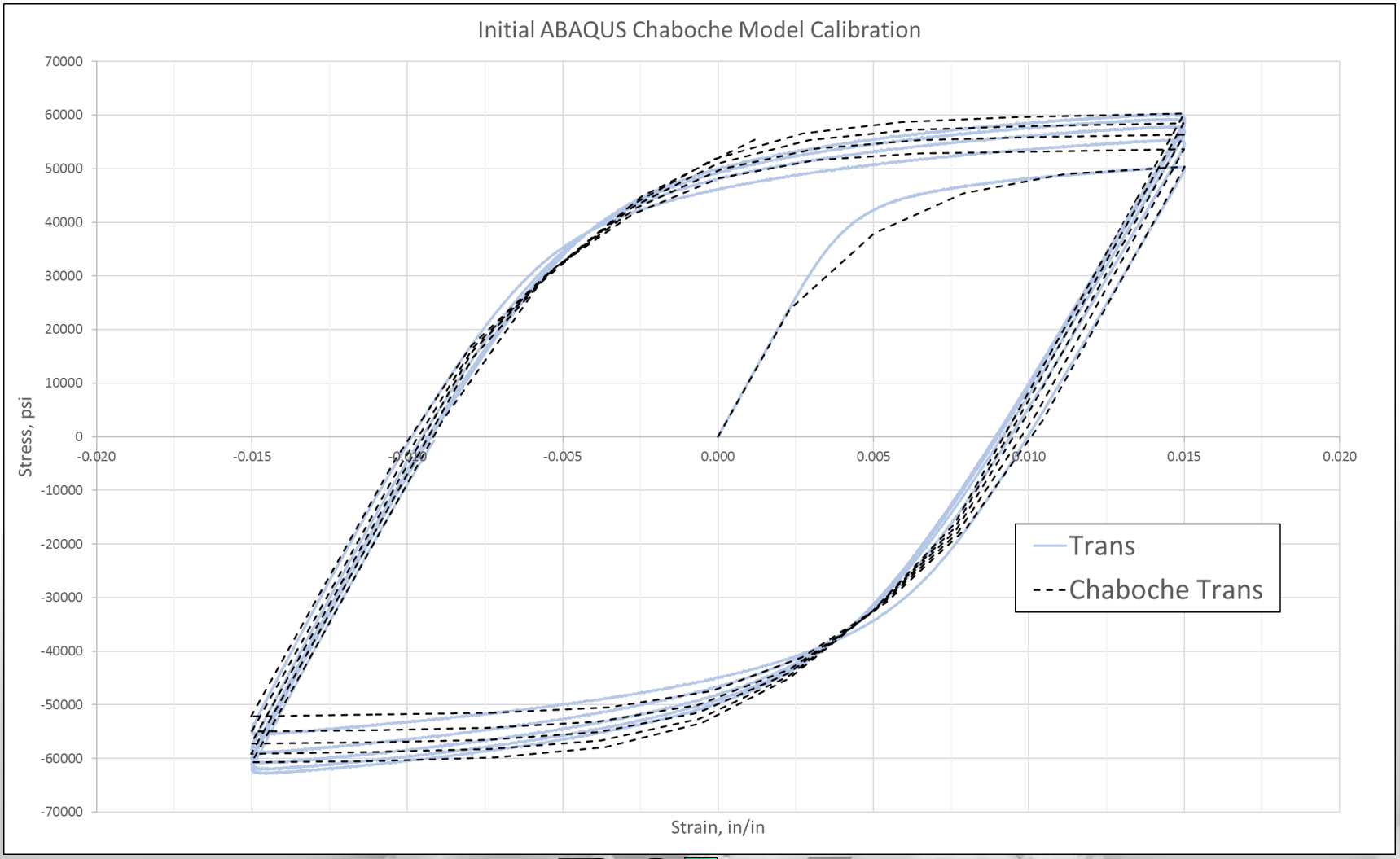


ERSI

FATIGUE TECHNOLOGY

Material Model Testing

Preliminary Abaqus Model Calibration

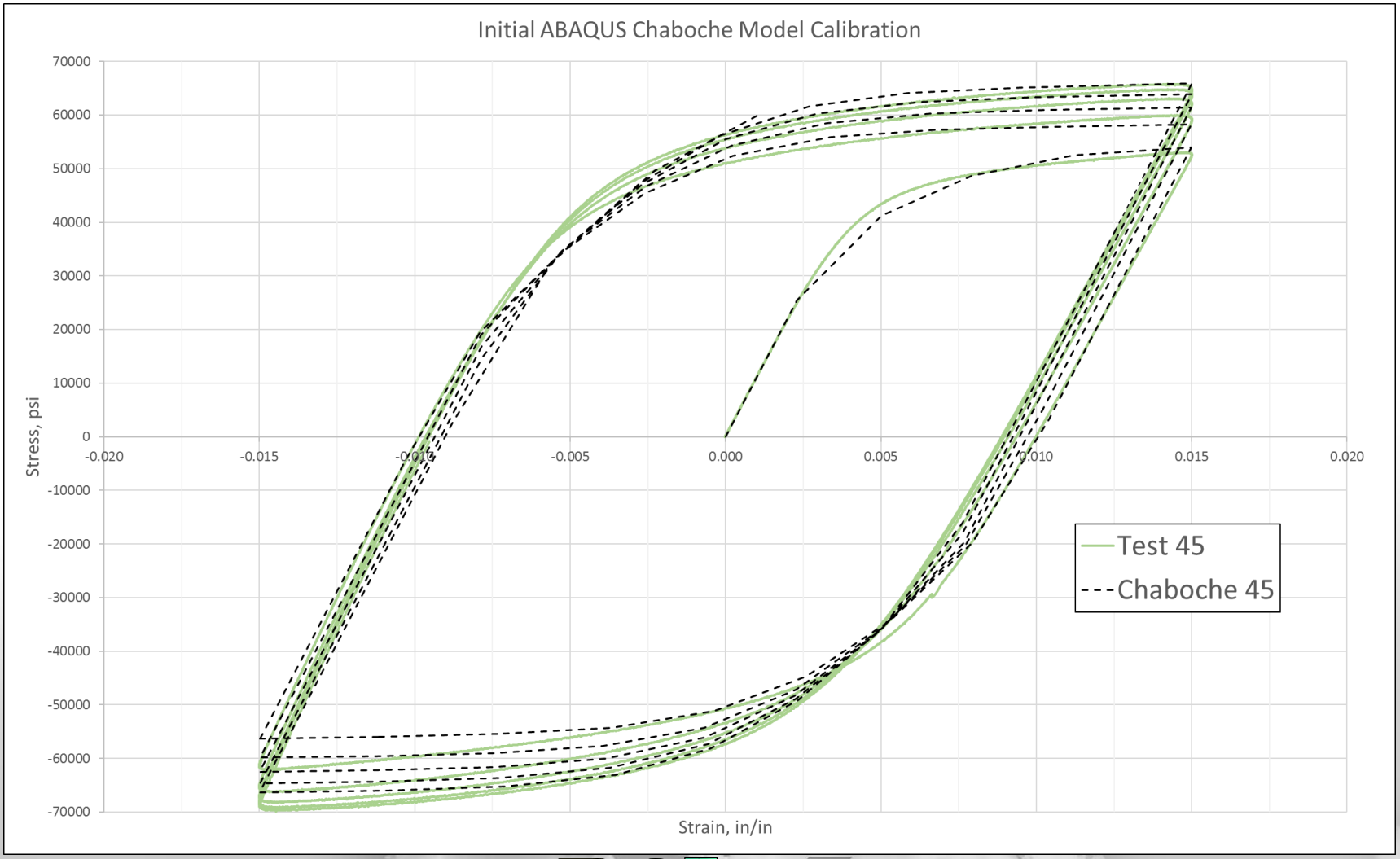


ERSI

FATIGUE TECHNOLOGY

Material Model Testing

Preliminary Abaqus Model Calibration



ERSI

FATIGUE TECHNOLOGY

Material Model Testing

Abaqus Model Calibration Results

Chaboche Parameter	Long.	Trans.	45°	Avg.	Clausen, et. al.*
σ_{ys}, psi	30281	28942	32786	30670	31894
C, psi	7.35e6	8.69e6	8.19e6	8.08e6	9.74e6
Υ	346.88	412.96	399.09	386.31	412.0
Q, psi	21202	21042	20526	20923	23637
b	3.37	3.85	5.53	4.70	7.00
E, psi	10.56e6	10.36e6	11.10e6	10.67e6	10.62e6
ϵ	0.33	0.33	0.33	0.33	0.33

** public.lanl.gov/clausen/Clausen_et_al_PrePrint_SEM_2009.pdf*

ERSI

FTI FATIGUE TECHNOLOGY

RS Process Simulation Validation

Purpose of Program

- Perform Experiments to Capture Surface and Through-Thickness Strains for FEA Process Simulation Validation
  - Quantification of residual stresses through process simulation is a critical path for future ERSI realization
  - Perform Residual Stress Validation Through Comparison of Techniques
  - Limited open literature on cross-comparison of residual stress measurement methods for Cx holes
  - Potential to complement through-thickness techniques with surface techniques for a more accurate understanding of the complete residual stress field
- Current work underway through Process Simulation Subcommittee, with the kind assistance of the *Organization and Execution Group*:

  - Dr. TJ Spradlin (AFRL)
  - Keith Hitchman (FTI)
  - Dr. Marcias Martinez (Clarkson U.)
  - Marcus Stanfield (SwRI)
  - Prof. Michael Fitzpatrick (Coventry U.)
  - Scott Carlson (SwRI)
  - Dr. Min Liao (NRC)
  - Dr. Guillaume Renaud (NRC)
  - Dr. Mike Hill (Hill Engineering)

ERSI

FTI FATIGUE TECHNOLOGY

RS Process Simulation Validation

Test Plan (evolved)

- Material: 2024-T351 & 7075-T651
- Two Applied Expansion Levels: “Low” (3.16%), “High” (4.16%)
- Center Hole Diameter: 16-0-N Tool Set
  - 0.50inch final diameter
  - Hole not reamed
- Finite Element Analysis (various material models)
- Surface Measurement (Exit and Entrance Surfaces)
  - Digital Image Correlation (DIC)
  - Fiber Optics (LUNA)
  - Strain gages
  - X-ray Diffraction (XRD)
- Volume (Through-Thickness) Measurement Techniques
  - High Energy X-ray Diffraction (APS HE-XRD) - Argonne National Labs
  - High Energy X-ray Diffraction (CHESS) - Cornell
  - Neutron Diffraction - Coventry University (UK)
  - Contour Method - Hill Engineering, LLC

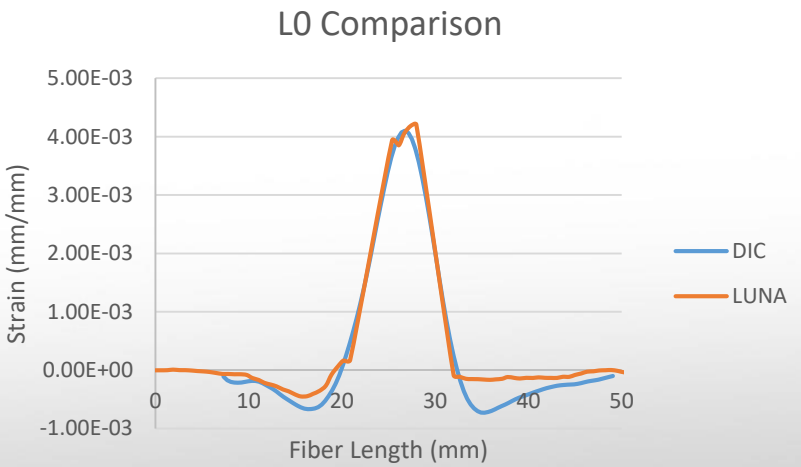
ERSI

FTI FATIGUE TECHNOLOGY

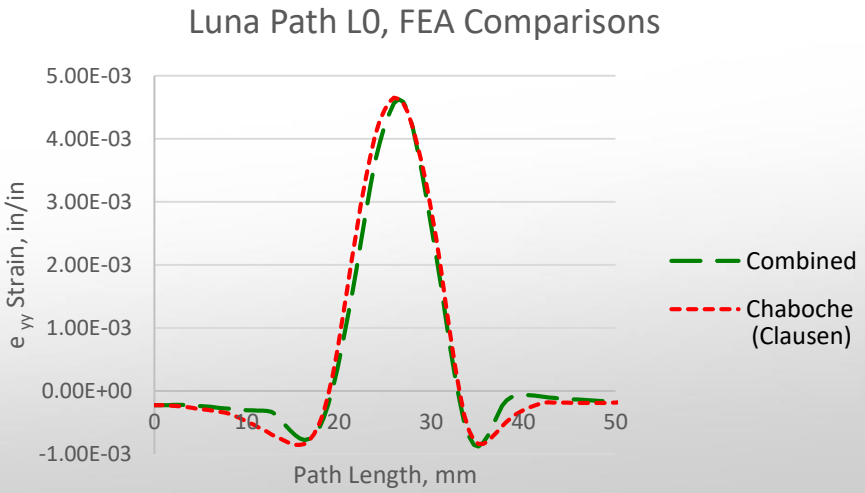
RS Process Simulation Validation

Surface Strain Measurements

- Tabular surface strain measurement data available for correlation:
  - Luna (M. Martinez, Clarkson University)
  - Strain Gage (M. Stanfield, SWRI)
- Working on revised FEA with NRC-based Chaboche
- Full correlation to follow.



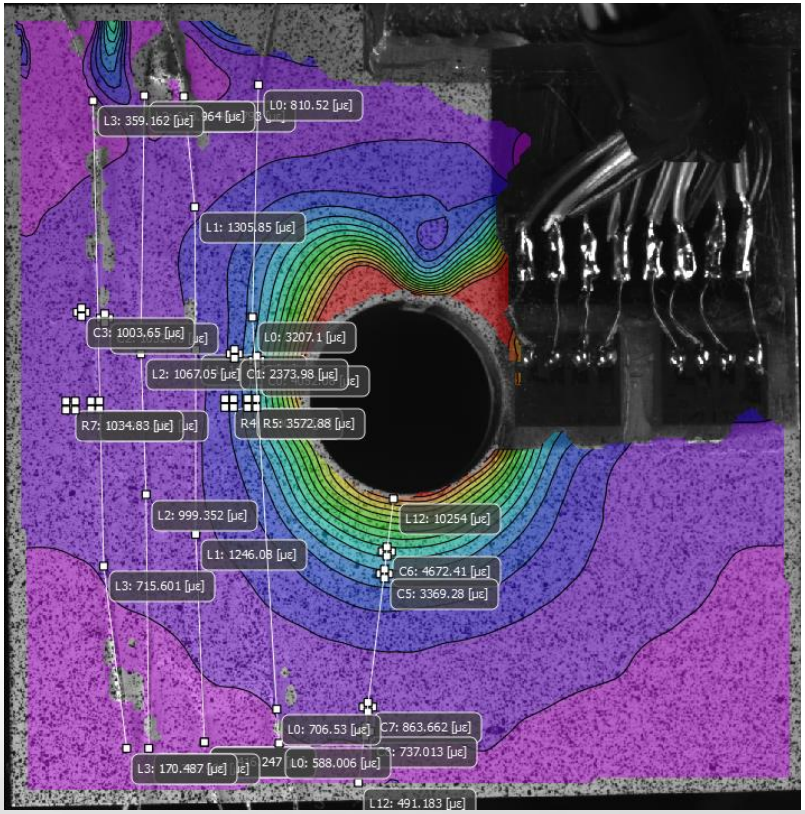
Luna/DIC e_{yy} strains

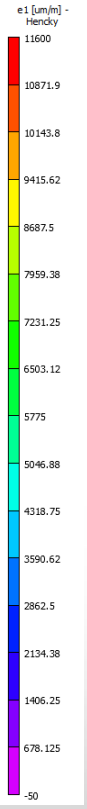


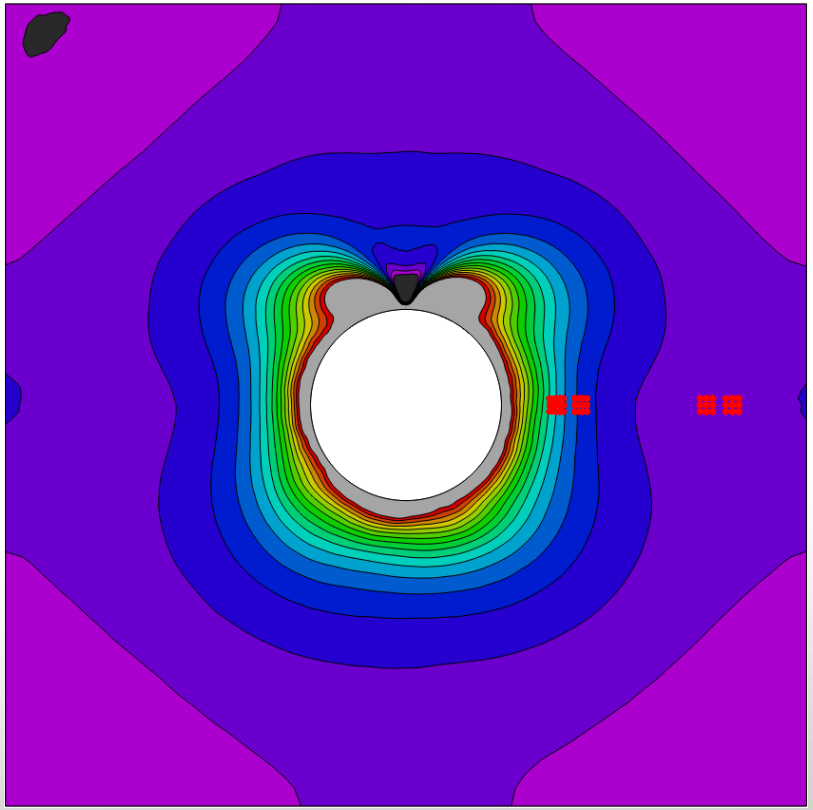
FEA e_{yy} strains

RS Process Simulation Validation

Surface Strains







DIC Hoop strains

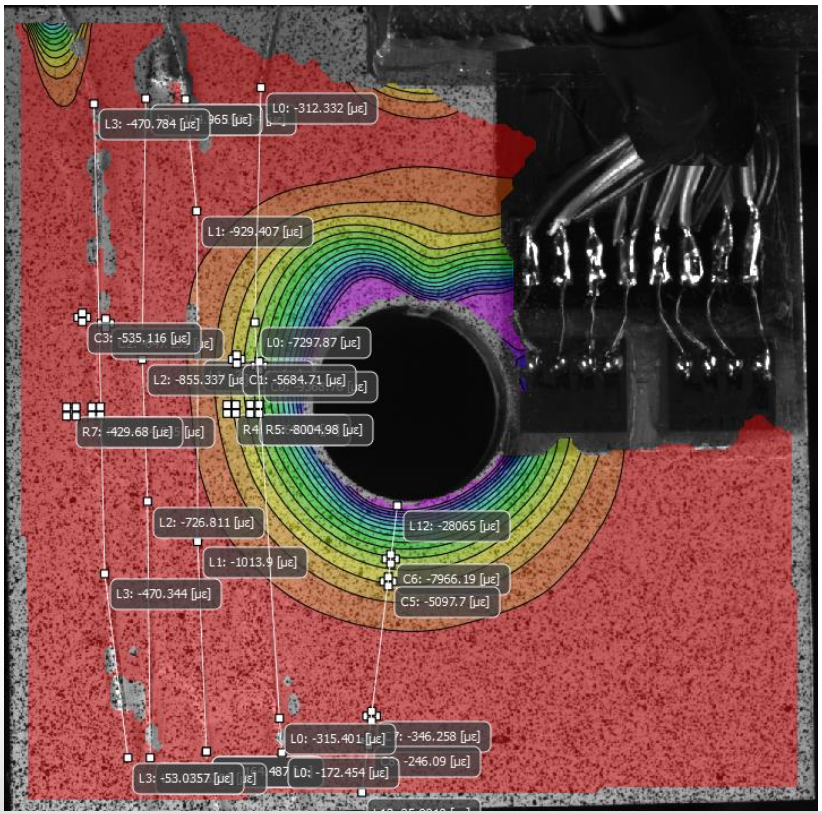
FEA Hoop strains
Chaboche Hardening (Clausen)

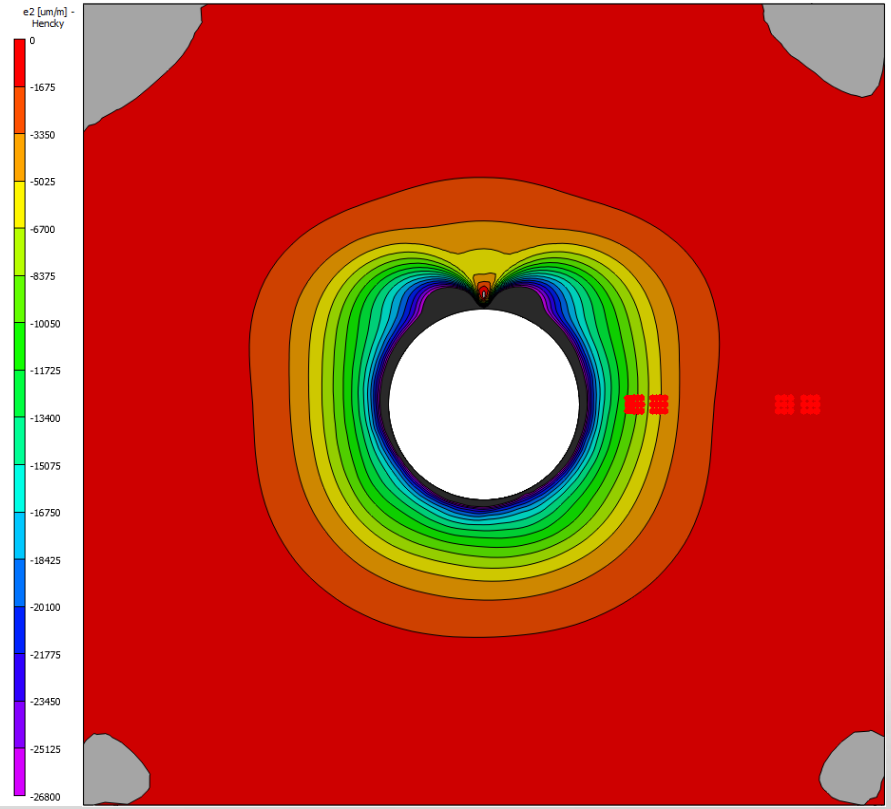
ERSI

FTI FATIGUE TECHNOLOGY

RS Process Simulation Validation

Surface Strains





DIC Radial strains

FEA Radial strains
Chaboche Hardening (Clausen)

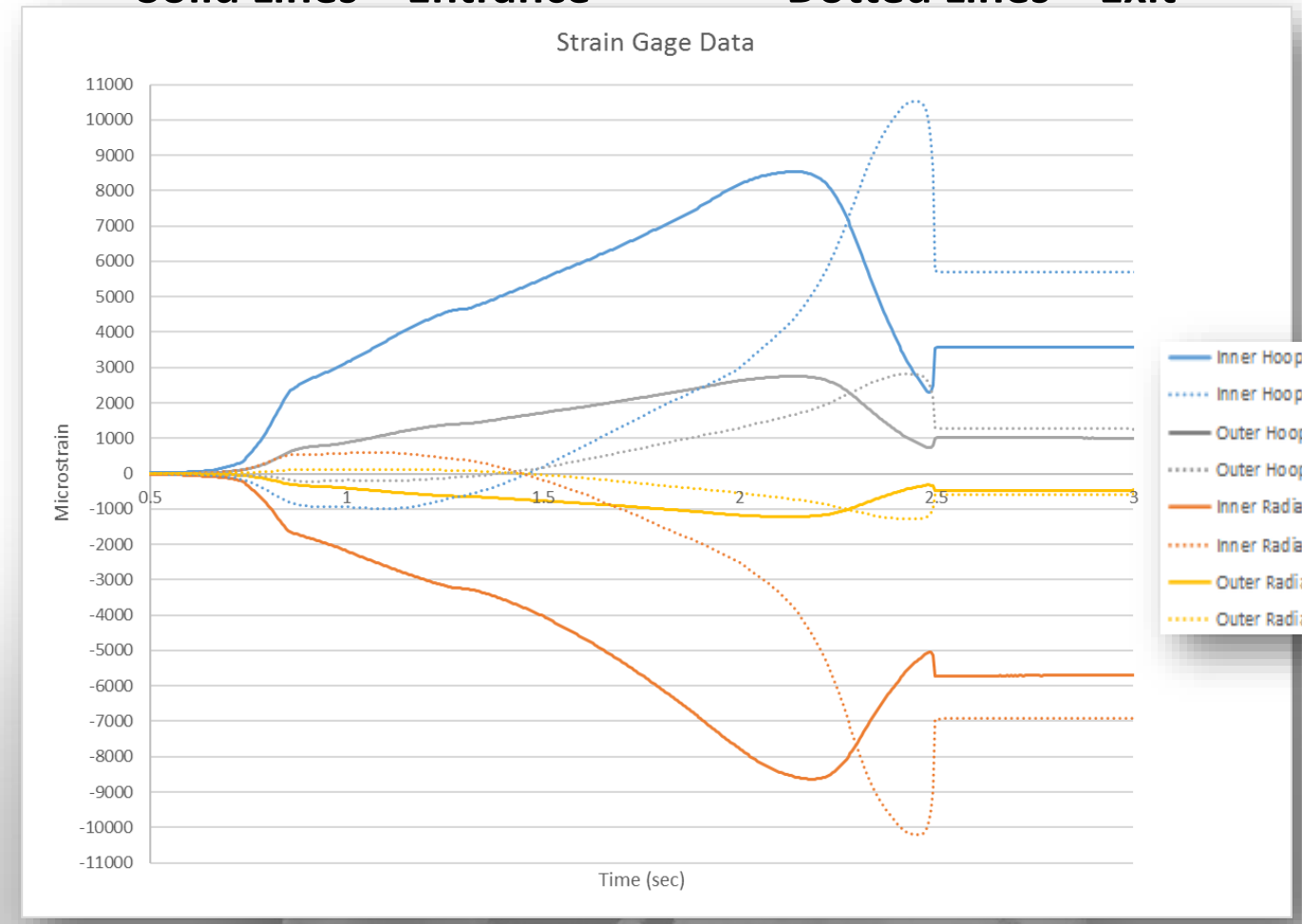
ERSI

FATIGUE TECHNOLOGY

RS Process Simulation Validation

Surface Strains

Solid Lines – Entrance **Dotted Lines – Exit**



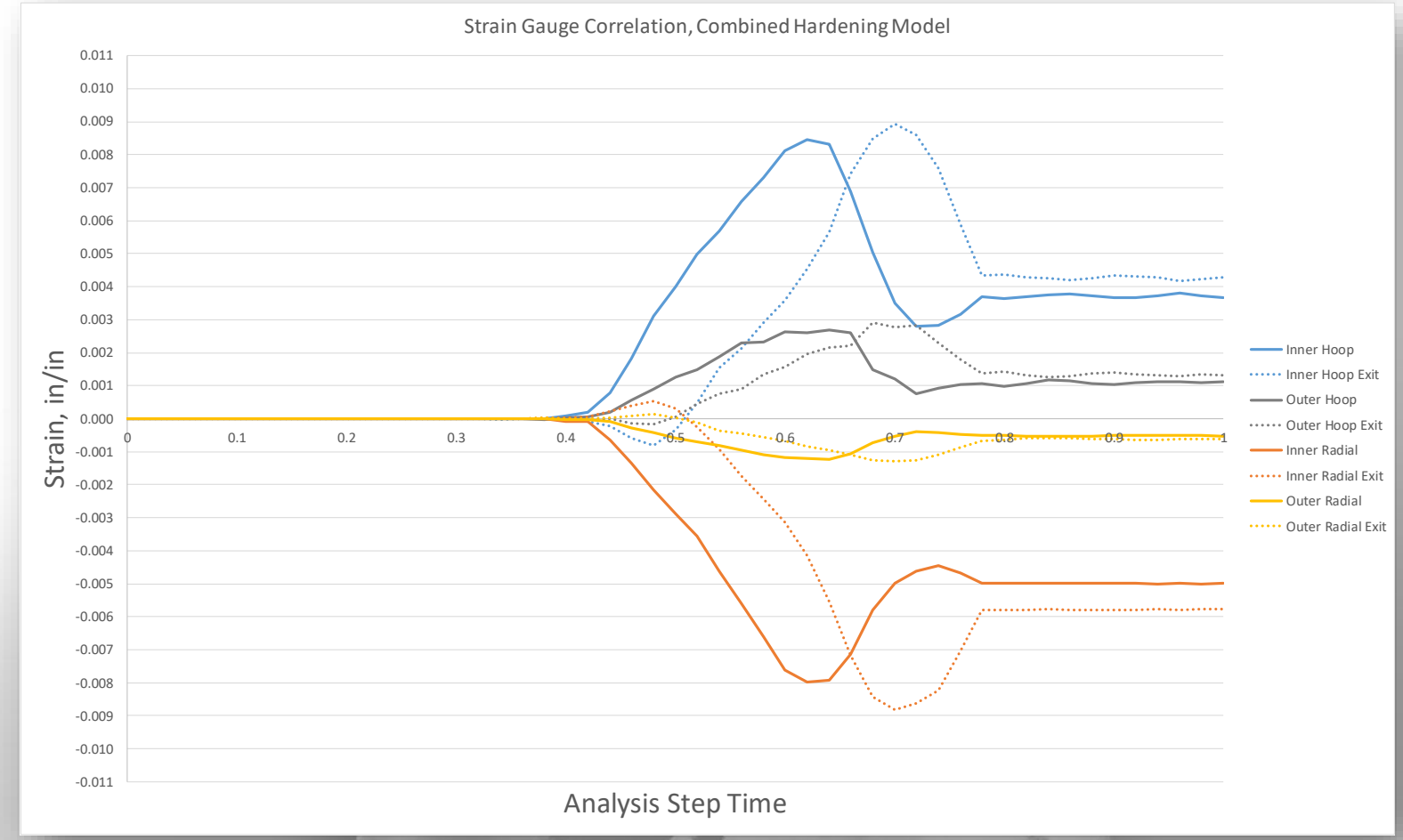
ERSI

FATIGUE TECHNOLOGY

RS Process Simulation Validation

Surface Strains

Solid Lines – Entrance **Dotted Lines – Exit**



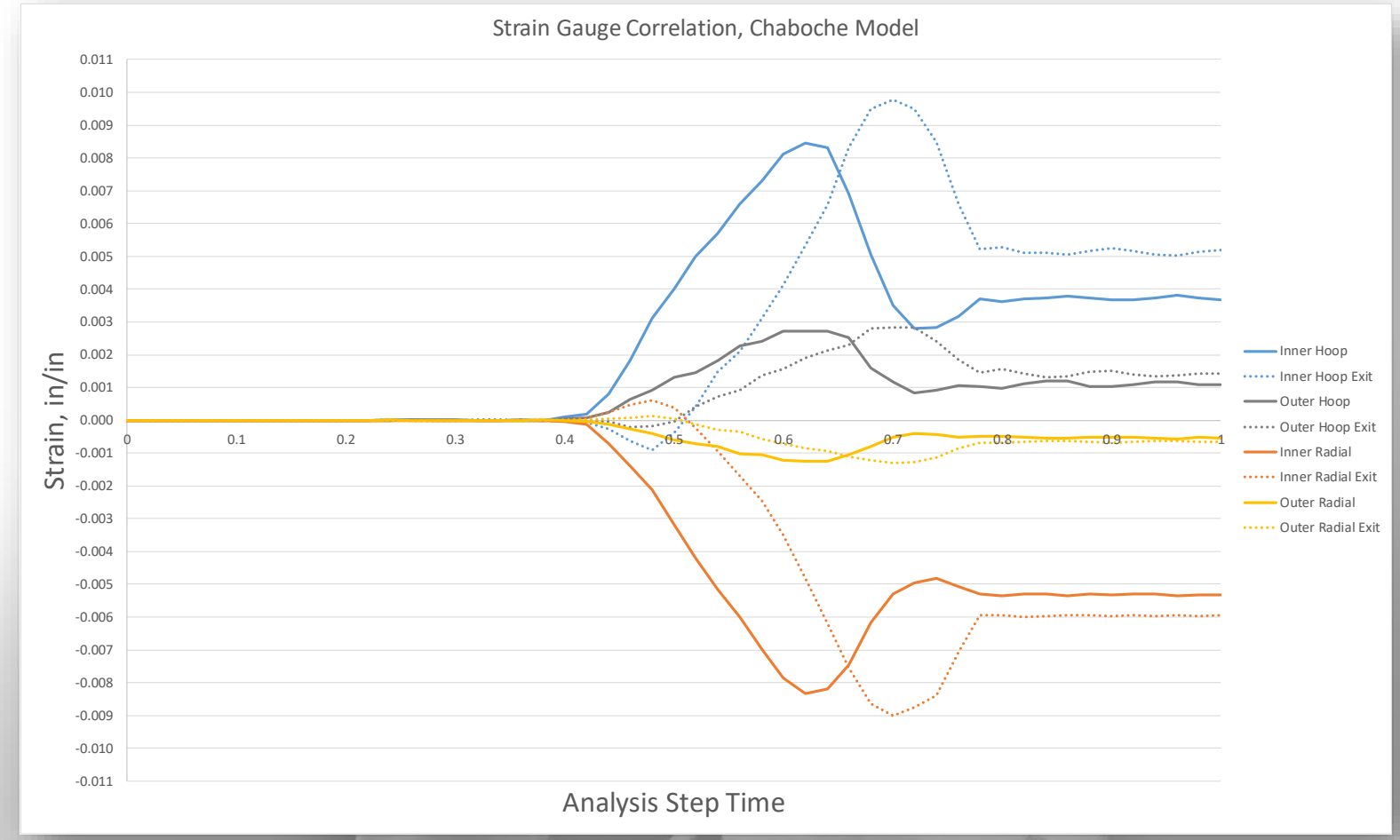
ERSI

FATIGUE TECHNOLOGY

RS Process Simulation Validation

Surface Strains

Solid Lines – Entrance **Dotted Lines – Exit**



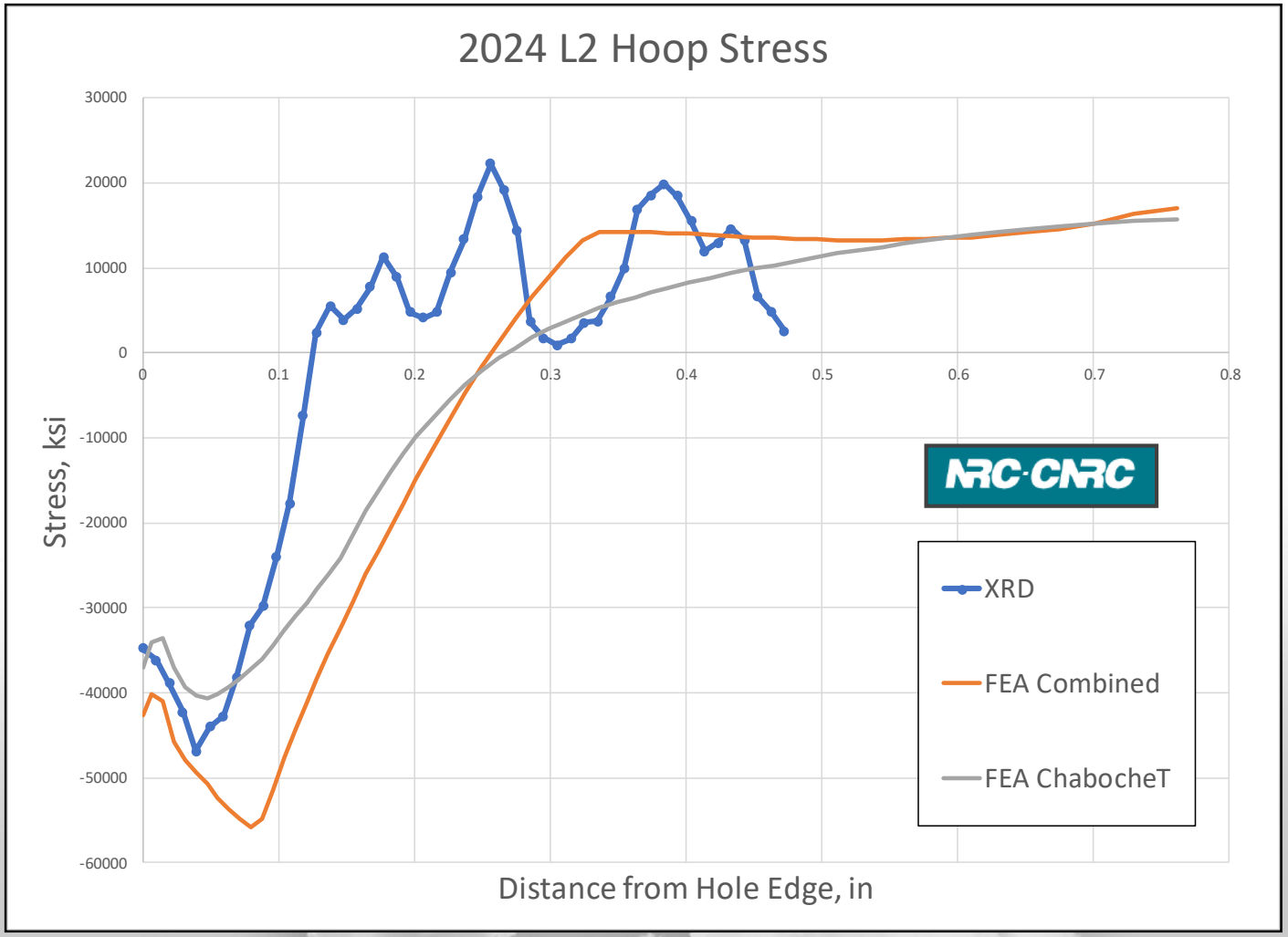
ERSI

FATIGUE TECHNOLOGY

DM#808860

RS Process Simulation Validation

XRD Surface Stress

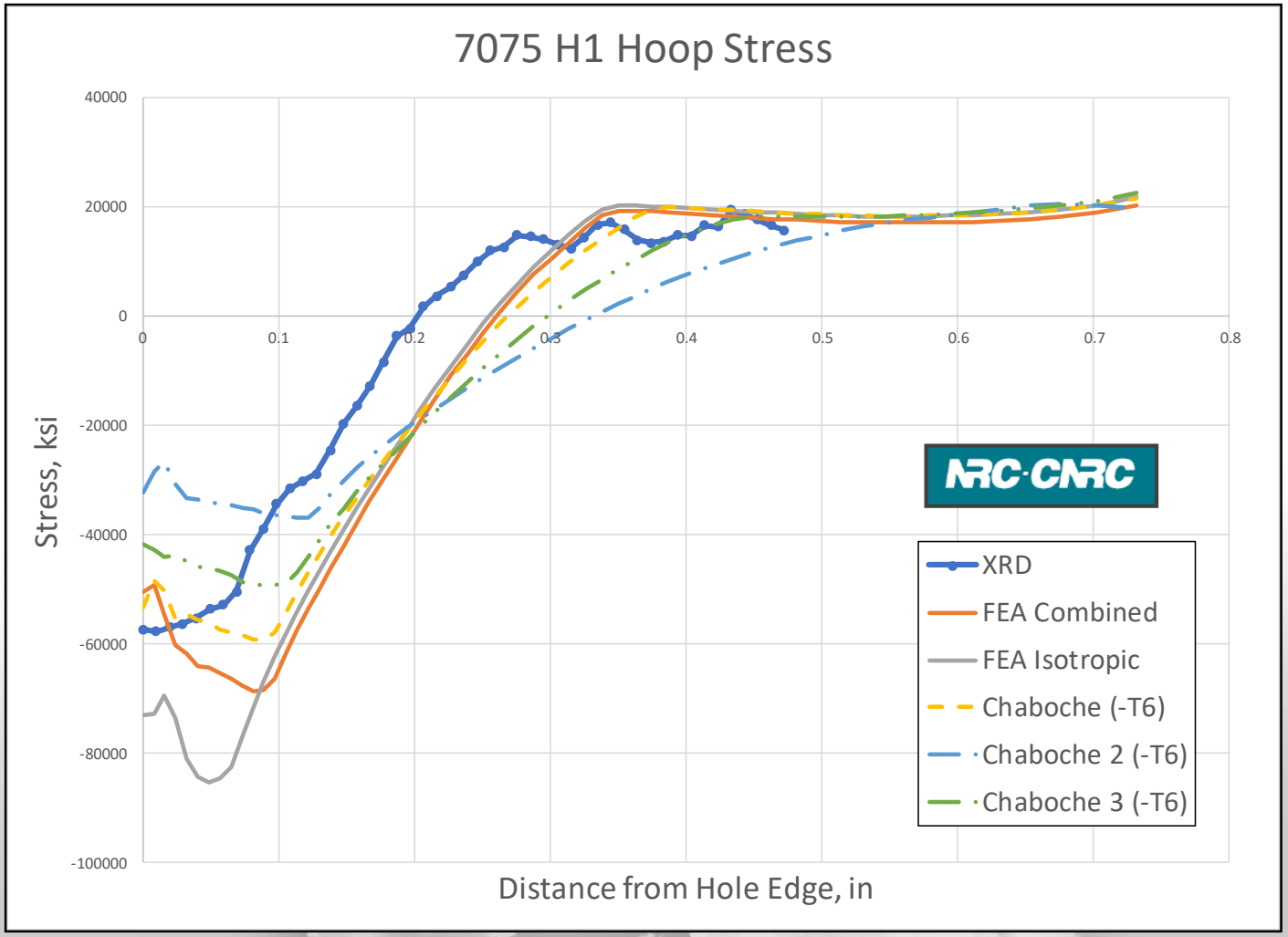


ERSI

FATIGUE TECHNOLOGY

RS Process Simulation Validation

XRD Surface Stress



ERSI

FATIGUE TECHNOLOGY

RS Process Simulation Validation

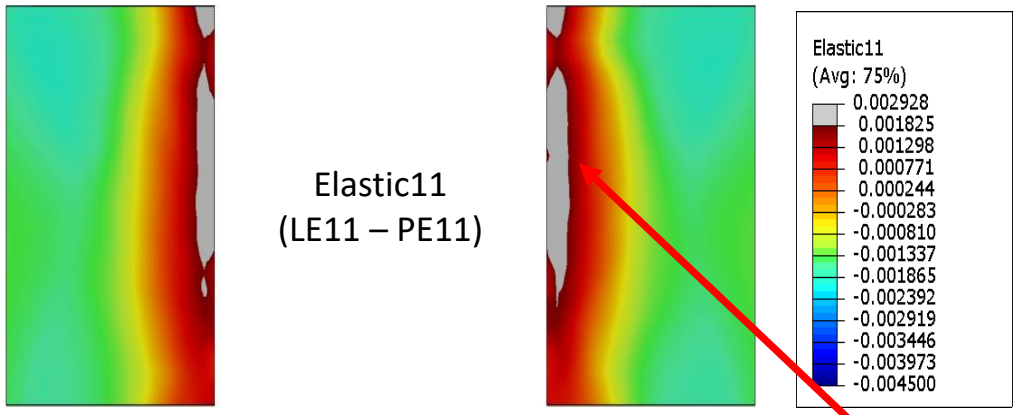
Volume Strain Measurements

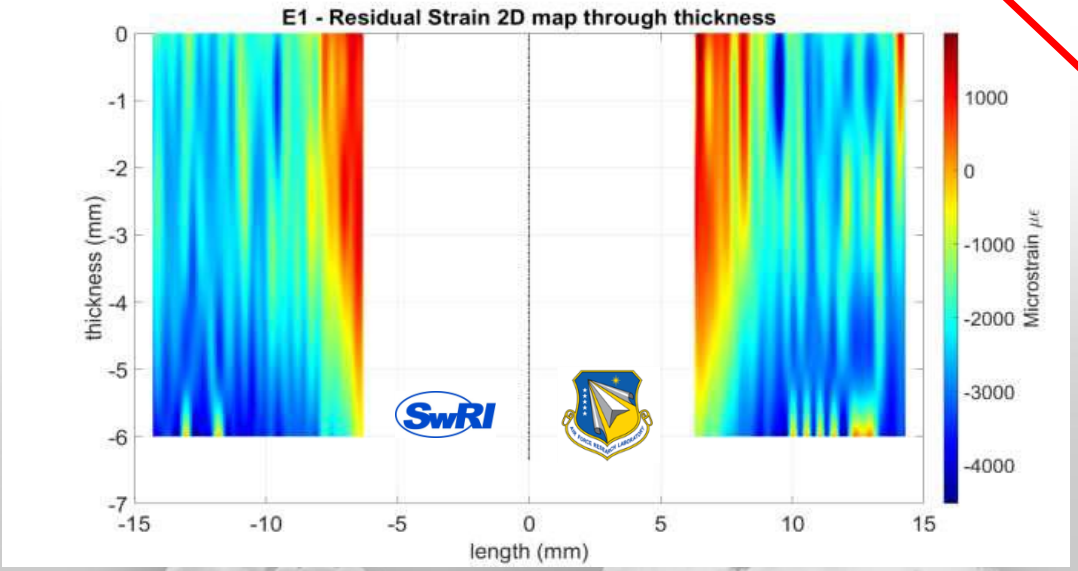
- Raw data still being evaluated and reduced.
- All results and correlations shown are to be considered preliminary examples, and may likely change

RS Process Simulation Validation

APS Preliminary Radial Strain

AA7075-L1 {200} 7075-L1 Combined



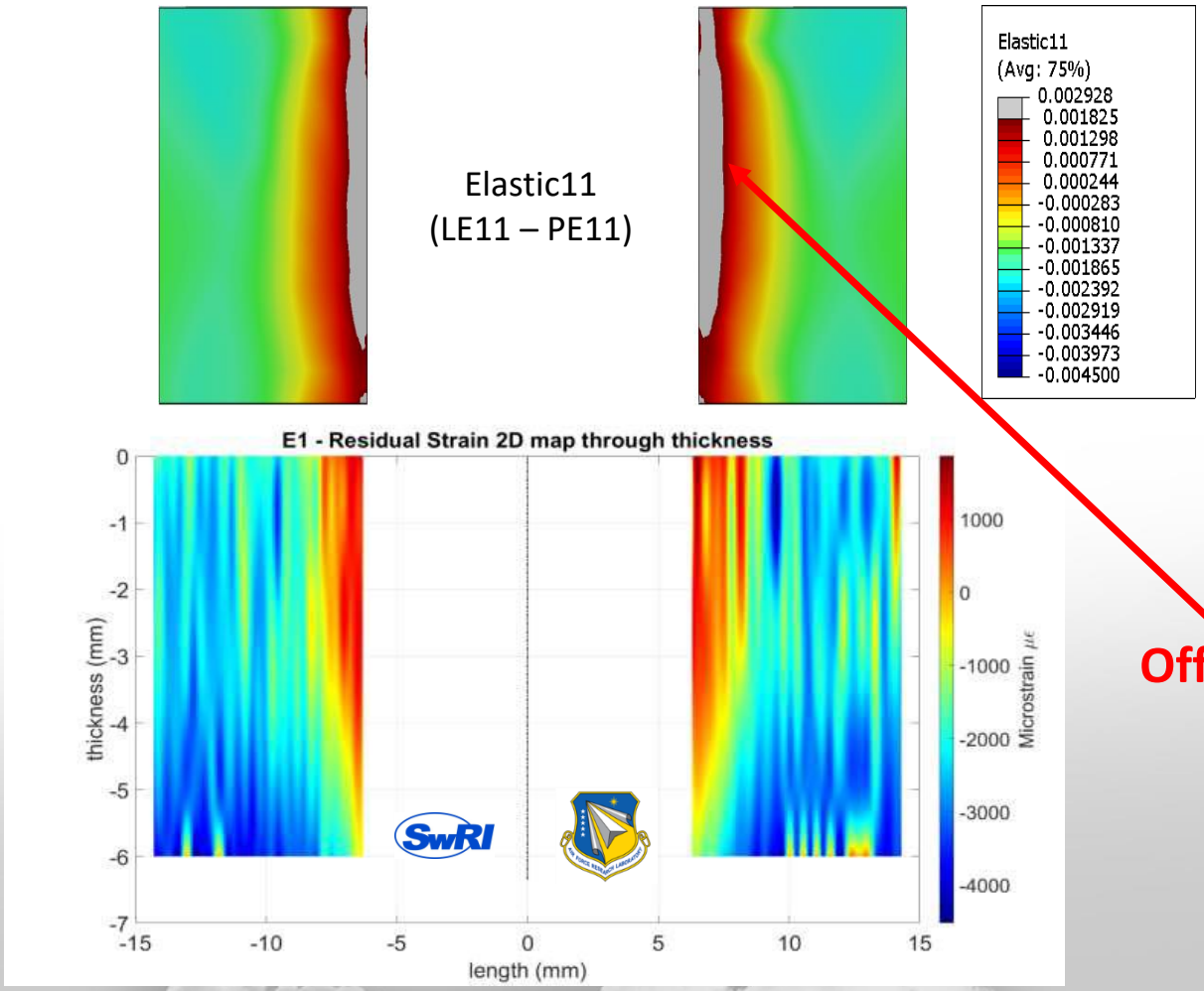


Off scale high

RS Process Simulation Validation

APS Preliminary Radial Strain

AA7075-L1 {200} 7075-L1 Isotropic



ERSI

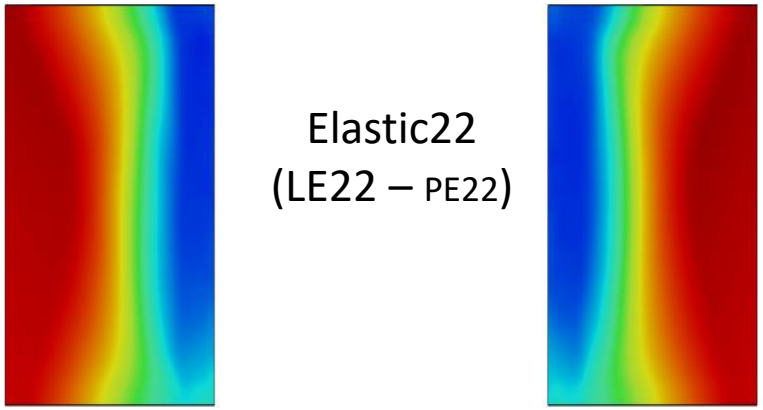
FATIGUE TECHNOLOGY

RS Process Simulation Validation

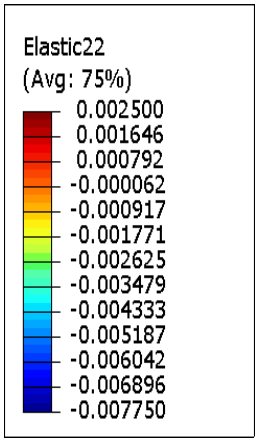
APS Preliminary Hoop Strain

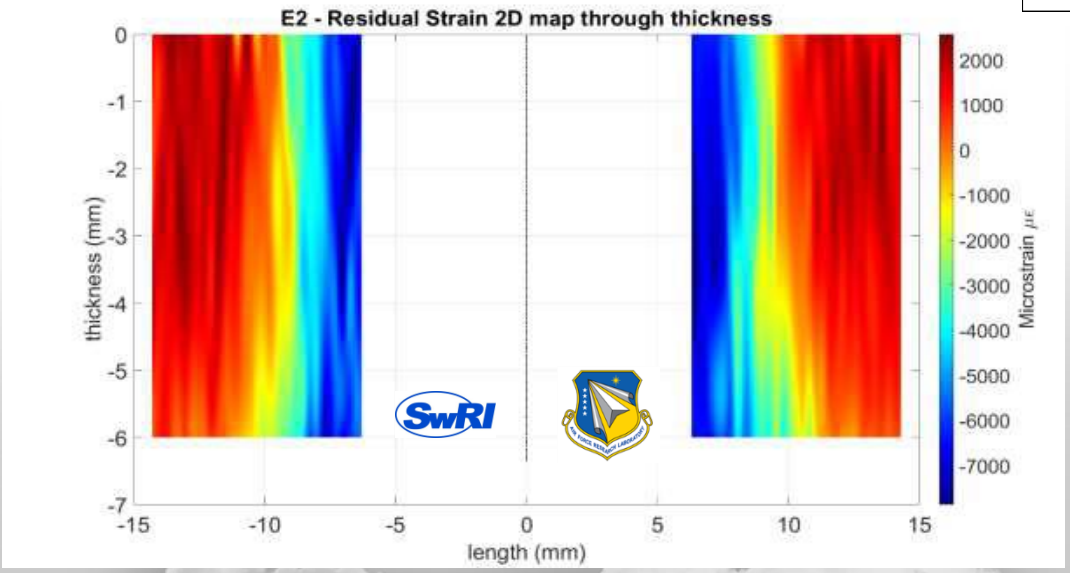
AA7075-L1 {200}

7075-L1 Combined



Elastic22
(LE22 – PE22)





ERSI

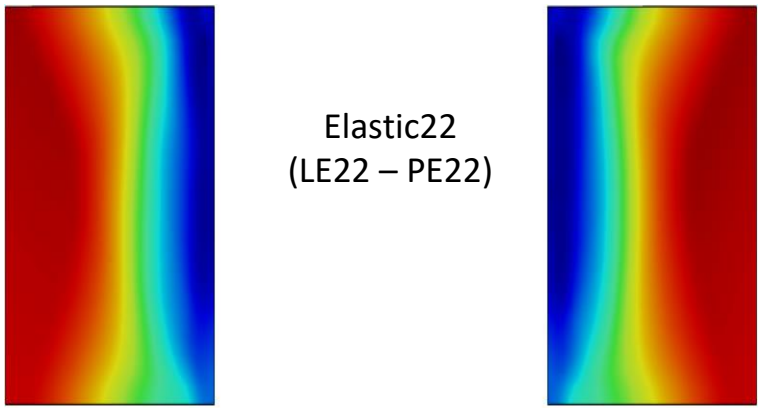
FATIGUE TECHNOLOGY

RS Process Simulation Validation

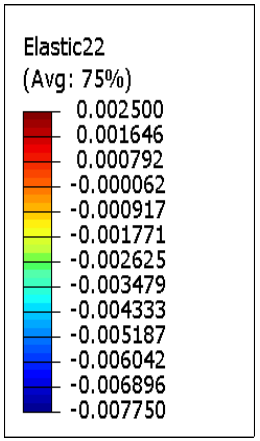
APS Preliminary Hoop Strain

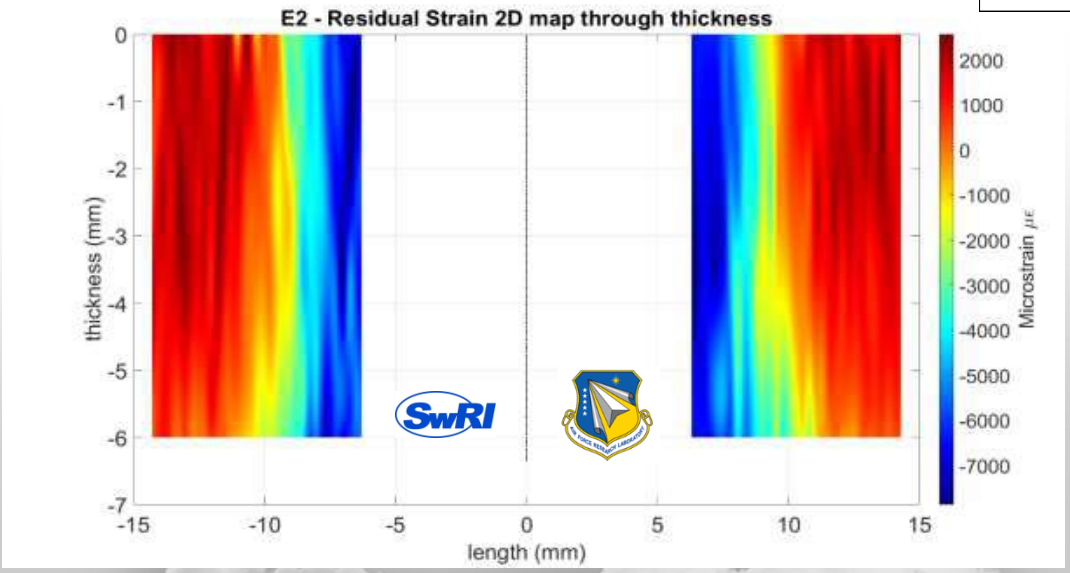
7075-L1 Isotropic

AA7075-L1 {200}



Elastic22
(LE22 – PE22)





ERSI

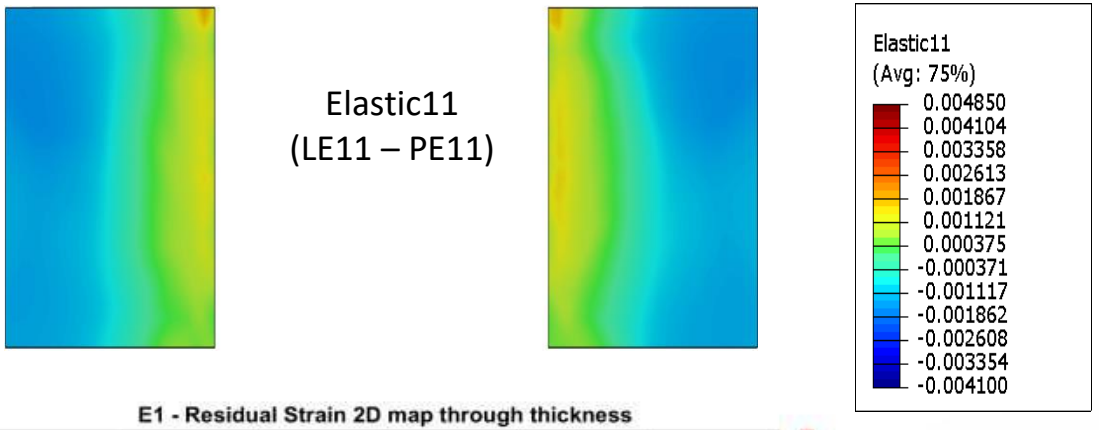
FATIGUE TECHNOLOGY

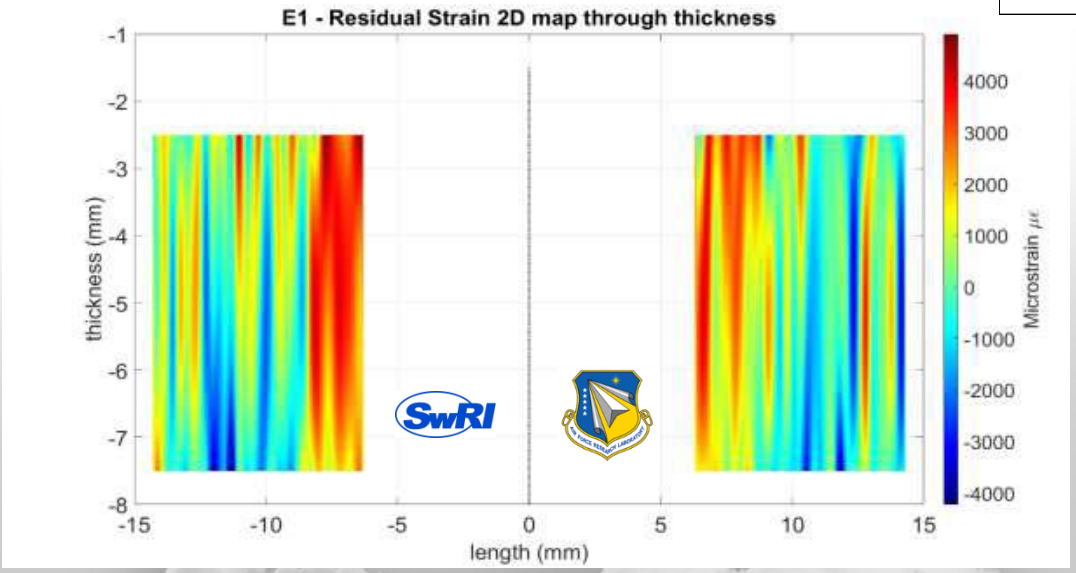
RS Process Simulation Validation

APS Preliminary Radial Strain

2024-L2 Combined

AA2024-L2 (i1) {311}





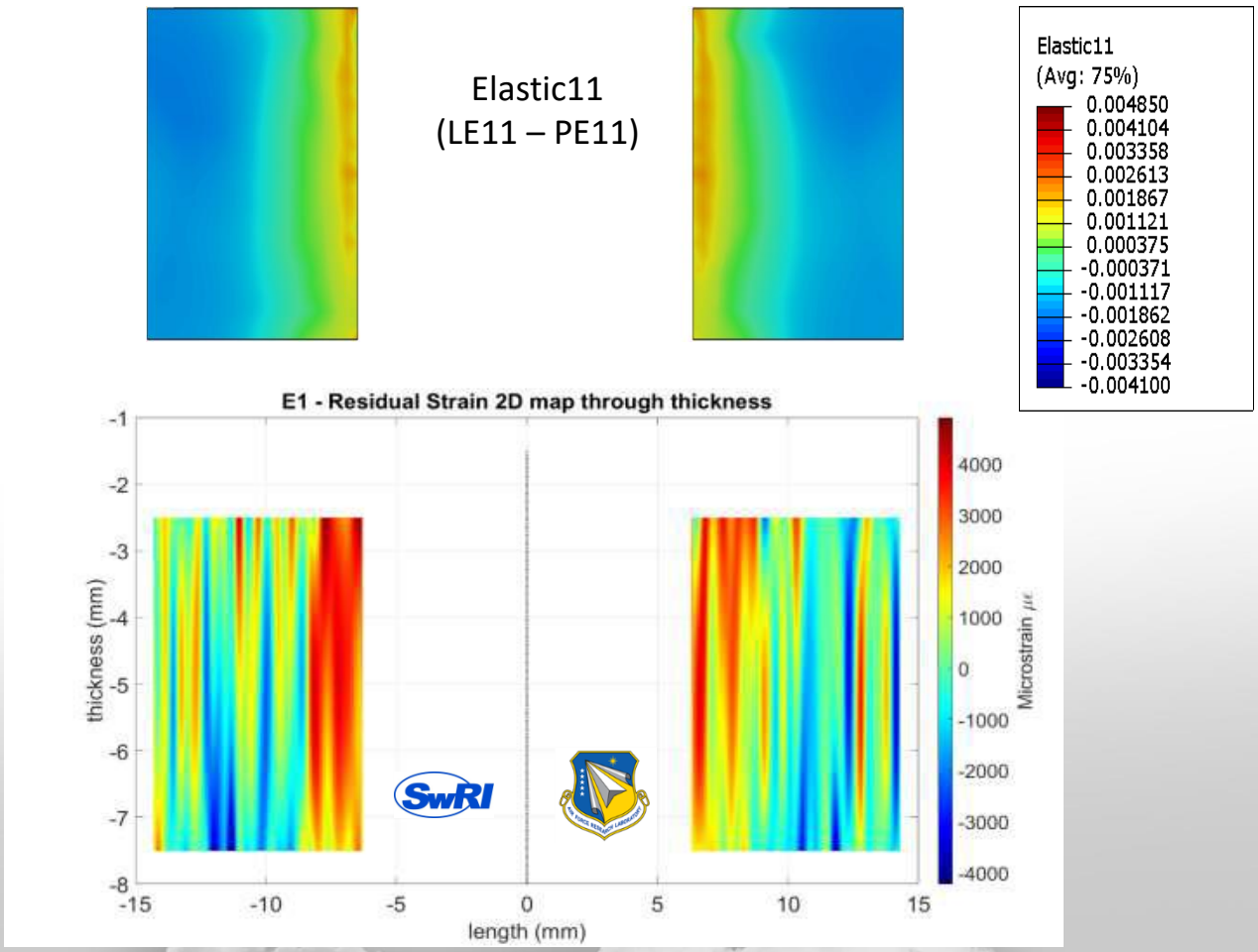
ERSI

FATIGUE TECHNOLOGY

RS Process Simulation Validation

APS Preliminary Radial Strain

AA2024-L2 (i1) {311} 2024-L2 Isotropic



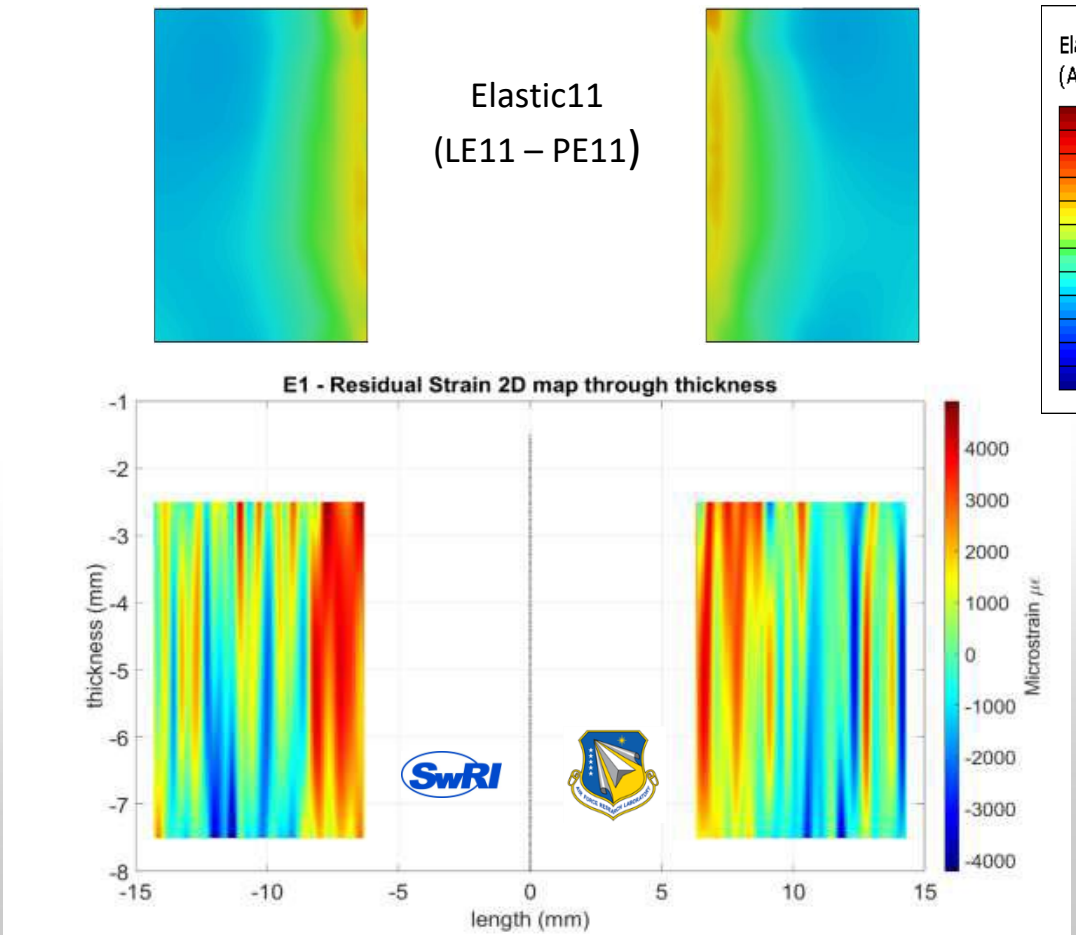
ERSI

FATIGUE TECHNOLOGY

RS Process Simulation Validation

APS Preliminary Radial Strain

AA2024-L2 (i1) {311} 2024-L2 Chaboche



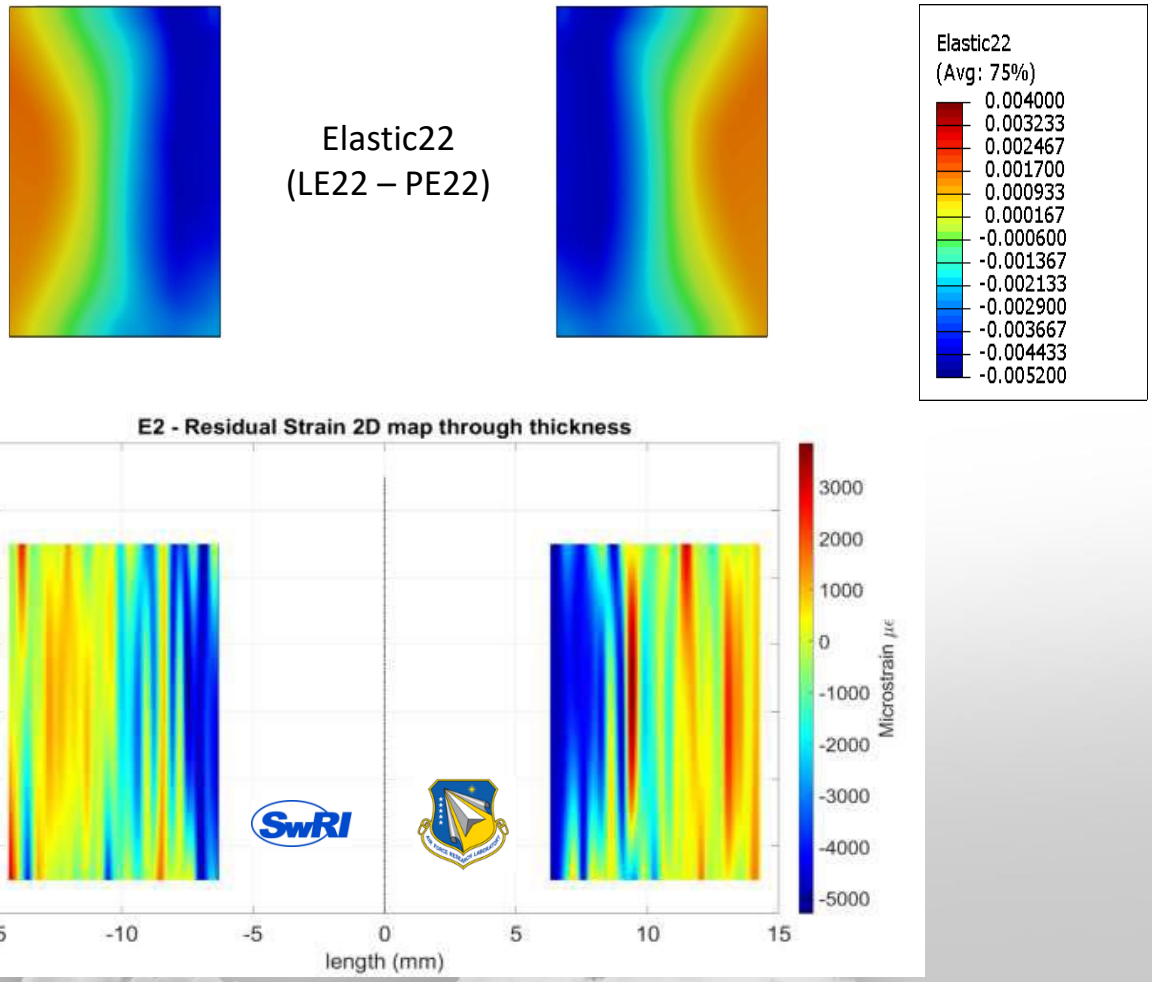
ERSI

FATIGUE TECHNOLOGY

RS Process Simulation Validation

APS Preliminary Hoop Strain

AA2024-L2 (i1) {311} 2024-L2 Combined



ERSI

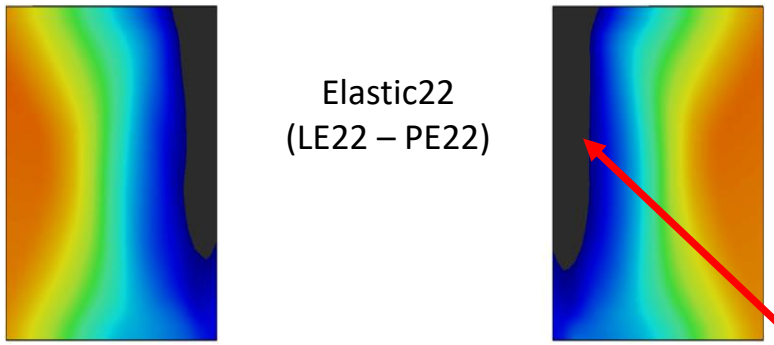
FATIGUE TECHNOLOGY

RS Process Simulation Validation

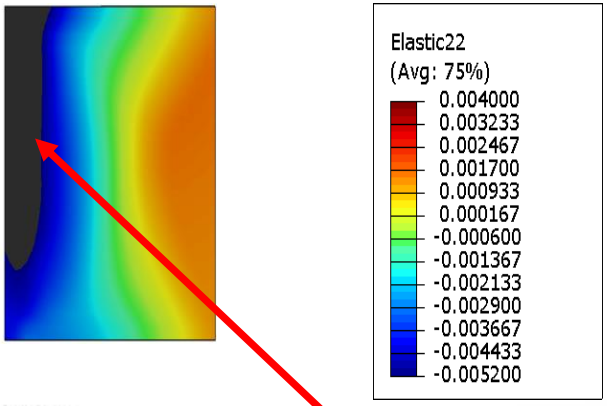
APS Preliminary Hoop Strain

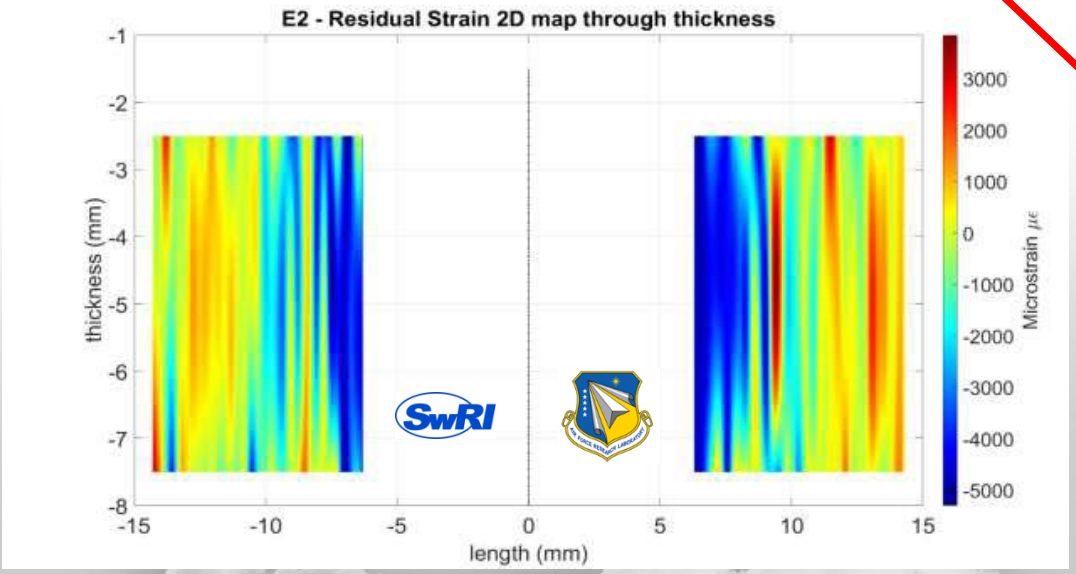
2024-L2 Isotropic

AA2024-L2 (i1) {311}



Elastic22
(LE22 – PE22)





Off scale low

ERSI

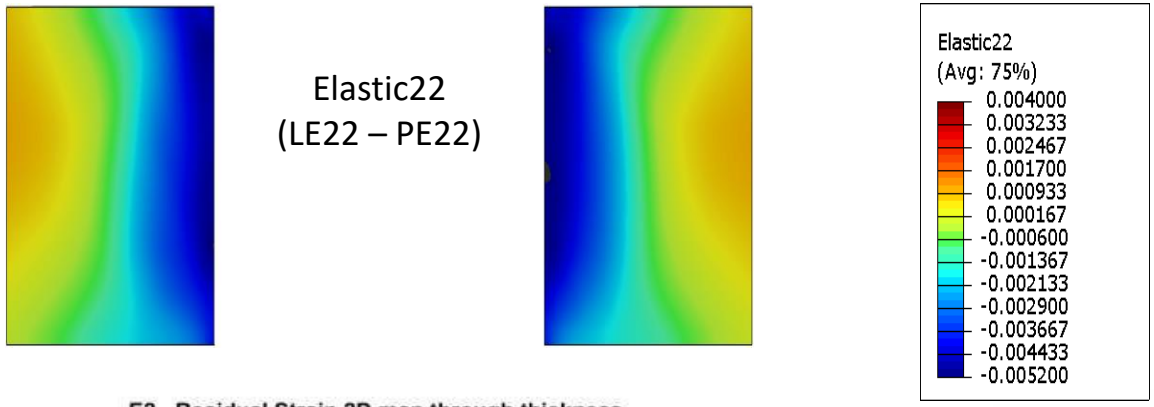
FATIGUE TECHNOLOGY

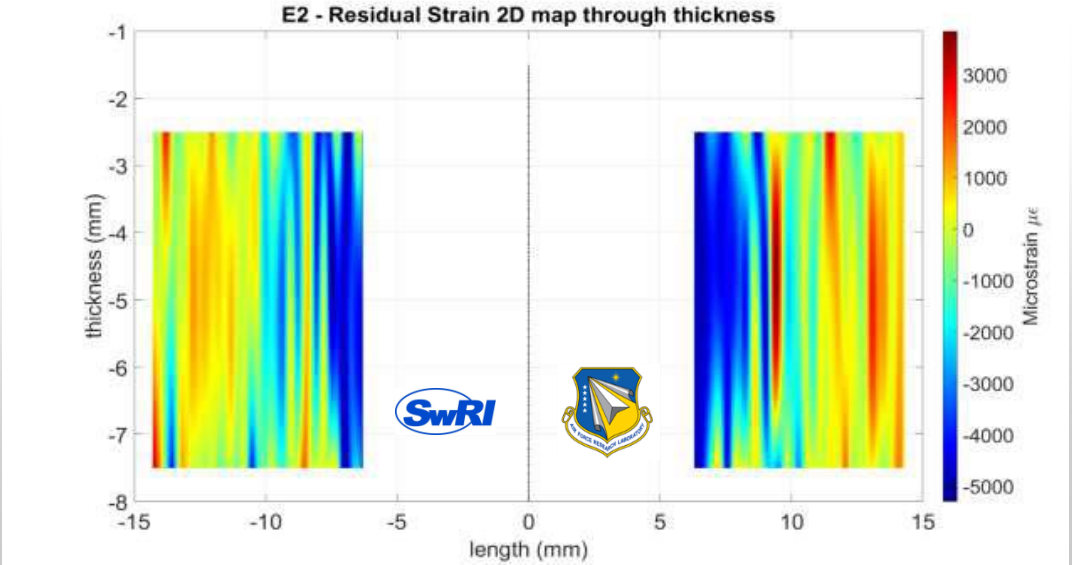
RS Process Simulation Validation

APS Preliminary Hoop Strain

2024-L2 Chaboche

AA2024-L2 (i1) {311}



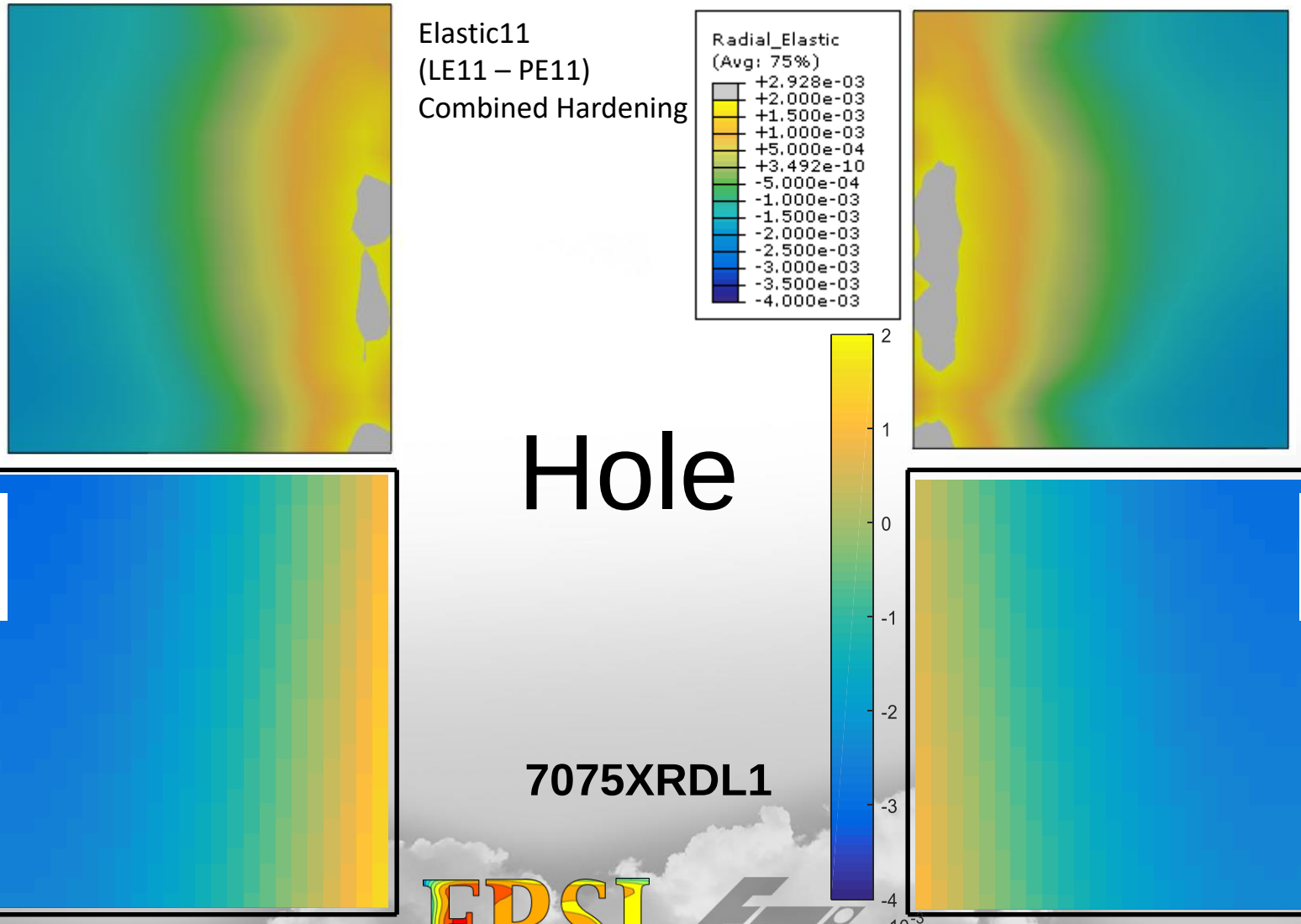


ERSI

FATIGUE TECHNOLOGY

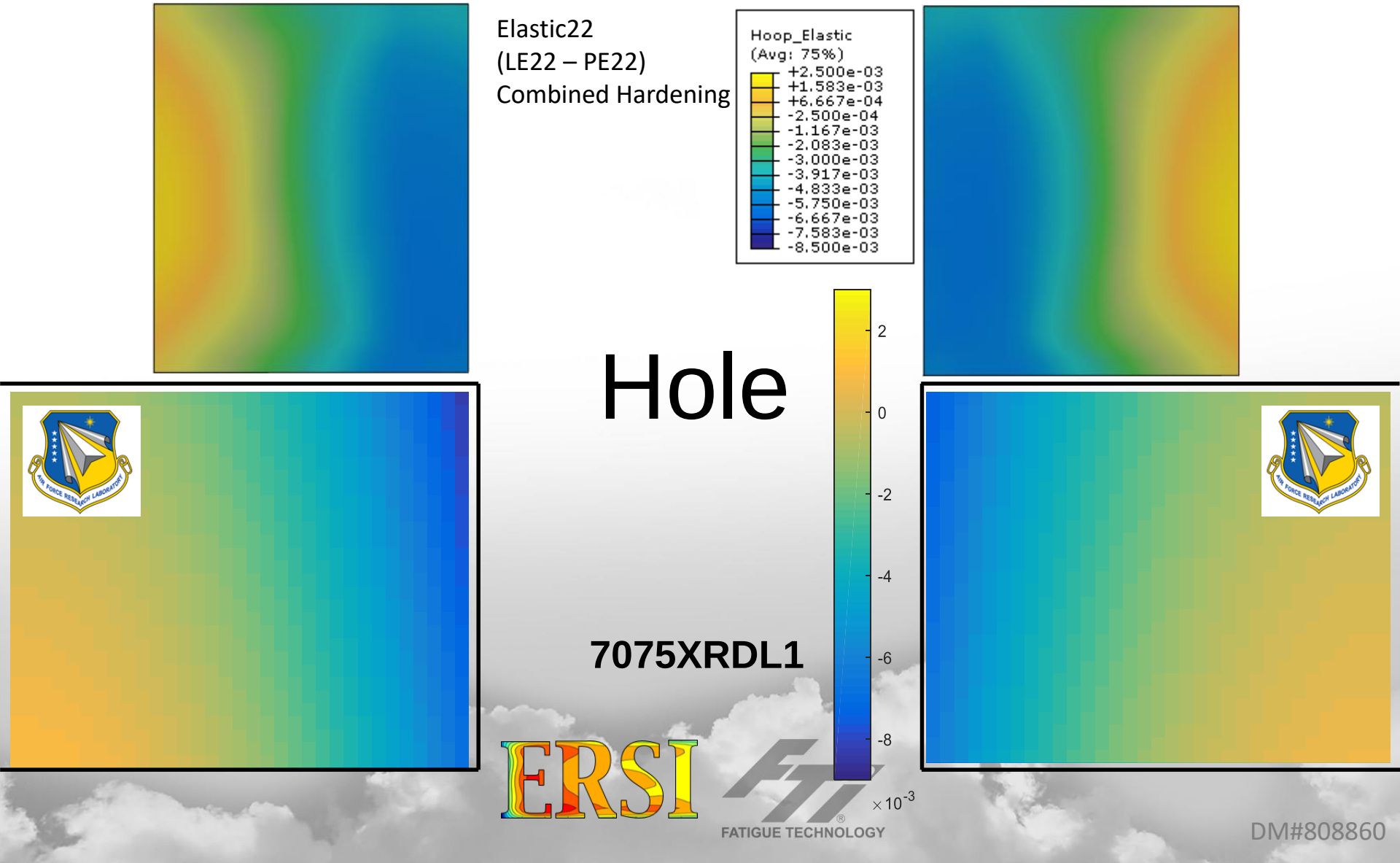
RS Process Simulation Validation

CHESS Preliminary Radial Strain



RS Process Simulation Validation

CHESS Preliminary Hoop Strain



Residual Stress Process Simulation Sub Committee

Dr. Scott Prost-Domasky, Analytical Processes/Engineering Solutions (AP/ES), Inc.
Dr. Guillaume Renaud, National Research Council Canada
Dr. Ralph Bush, United States Air Force Academy
Marcus Stanfield, Southwest Research Institute
Dr. Min Liao, National Research Council Canada
Dr. Marcias Martinez, Clarkson University
Dr. Adrian DeWald, Hill Engineering, LLC
Dr. Keith Jones, Jones Engineering, LLC
Robert Pilarczyk, Hill Engineering, LLC
Dr. Mike Hill, Hill Engineering, LLC
Matt Shultz, Fatigue Technology

Chair:
Keith Hitchman
Project Engineer, Analyst
Fatigue Technology
khitchman@fatiguetech.com
Phone: +1-206-701-7232
Mobile: +1-509-948-8240

FATIGUE TECHNOLOGY