Working Group on
Engineered Residual
Stress Implementation

RS Measurements Group Overview
Sep 12, 2019

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TBD, group co-lead

Topics for Today

- Group roster
- Group Goals (still in development)
- Related on-going programs
- Stimulating inter-group interactions
- Summary

Committee roster (please confirm and correct)

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Meetings and Attendance

Sep 12-13, 2019

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-

Feb 6, 2019

- Mike Steinzig
- Scott Carlson
- James Pineault
- Gabe Grodzicki (guest of J Penault)
- Bob Pilarczyk
- Adrian DeWald
- Mike Hill

March 13, 2019

- TJ Spradlin
- Eric Lindgren
- James Pineault
- Mike Brauss
- Gabriel Grodzicki (guest of J Penault)
- Mike Steinzig
- Adrian DeWald
- Scott Carlson
- Mike Hill

Jan 9, 2019

- TJ Spradlin
- Scott Carlson
- Bob Pilarczyk
- Eric Burba
- Mark Obstalecki
- Eric Lindgren
- Marcias Martinez
- Mike Hill

Brief statement of Goals (subject to concurrence)

"A good goal is Quantitative, Realistic, and has a Useful end-state"

- Define and document *repeatability* of residual stress measurement data (in-lab variability)
- Define and document *reproducibility* of residual stress measurement data (lab-to-lab variability)
- Develop residual stress *inter-method comparisons* (e.g., ND to x-ray to contour)
- Develop *measurement-model comparisons* (e.g., for CX holes)
- Engage UQ/statistical methods relative to residual stress data
- Document *exemplar* datasets (leverage prior work and drive new work)
- Assess/Quantify/Define *effects of texture and anisotropy* on residual stress measurement
- Develop a summary of relevant past work (recent and historical)
- Develop a compendium of relevant on-going or recent work

Discussion of goals

Goal: Repeatability of residual stress data (precision)

- Make repeated measures of residual stress in identical parts with one method, in one lab, by one operator, in short intervals of time
- Past work has evaluated repeatability for
  - Surface XRD (no depth profile, just surface)
  - Depth profiling (stress vs depth)
    + Hole drilling, Slotting, Slitting, and XRD + layer removal
  - 2D stress mapping (contour method)
- Focus new work on relevant materials, processes, and measurement techniques

Goal: Reproducibility of residual stress data (precision)

- Make repeated measures of residual stress in identical parts with one method, in multiple labs, following a defined protocol or standard
- Some examples in the literature for hole drilling and XRD + layer removal
  - A few prior published studies show large lab-to-lab variability

Goal: Inter-method comparisons (bias)

- Use multiple techniques to establish residual stress in specific parts
- Uncovers potential for systematic error and bias

Discussion of goals

Goal: Measurement-model comparisons

- How well do model outputs and experimental data correlate?
- Comparisons support model validation

Goal: Engage UQ/statistical methods

- Measurements have uncertainty and potential for bias
- UQ and statistical methods can assess impact of uncertainty and bias on downstream analyses and decision making

Goal: Exemplar data sets

- Document cases where residual stress measurement data are
  - Enabling in the solution of structural integrity challenges (success cases)
  - Or otherwise (negative cases: not helpful, misleading, problematic)

Discussion of goals

Goal: Effects on texture and anisotropy

- Directionality of mechanical properties can lead to errors in residual stress measurements
  - Elastic anisotropy affects diffraction and mechanical techniques equally
  - Texture can affect diffraction methods, but not mechanical techniques
  - Document these effects in relevant materials

Goal: Summary of past work

- Develop a summary of past efforts
  - Use prior test data to address new challenges
  - Avoid repeating prior work

Goal: Summary of recent or on-going work

- See following charts

Goal: Summary of recent or on-going work

Motivation

- ERSI is a volunteer/unfunded initiative
- It is difficult to make significant progress in a timely manner with this constraint
- Opportunities may exist to build on or utilize existing funded programs to further the goals and objectives of the Residual Stress Measurements Sub-group

Objective

- Develop compendium of ongoing (recently complete okay) programs related to ERSI Residual Stress Measurements Sub-group

Approach

- Requested self-report of on-going programs using a simple template

Results

- On following pages

Template

Program name/title: < enter name/title >

Program schedule: < start date > to < end date >

Funding organization: < enter funding organization >

Team members:

- < Enter first team member >
- < Enter second team member >

< Enter program graphic >

Program objectives:

- < Enter first objective >
- < Enter second objective >

Relationship to ERSI goals and objectives:

- < Describe how this efforts relates to one or more of the ERSI Residual Stress Measurements Sub-group goals and objectives listed on the following slide >

Summary of outputs to be shared with ERSI:

- < Enter brief description of first item that can be shared and when it should be expected >

Summary of responses

Requests to RS Measurement Group members (21 ppl)

Responding organizations – 3

Programs – 10

Yielded ring and plug

Program schedule: June 2019 to December 2019

Funding organization: LANL

Team members:

- LANL

Program objectives:

- Create residual stress standard with quantified RS
- Demonstrate RS standard with near yield and yielded regions

Relationship to ERSI goals and objectives:

- Standards can be used to test lab to lab variability

Summary of outputs to be shared with ERSI:

- Product will be made available for measurement. Method will be made available for duplication

Textured ring and plug

Program schedule: June 2019 to December 2019

Funding organization: LANL

Team members:

- LANL

Program objectives:

- Create residual stress standard with quantified RS
- Demonstrate RS standard in characterized textured material

Relationship to ERSI goals and objectives:

- Standards can be used to test lab to lab variability

Summary of outputs to be shared with ERSI:

- Product will be made available for measurement. Method will be made available for duplication

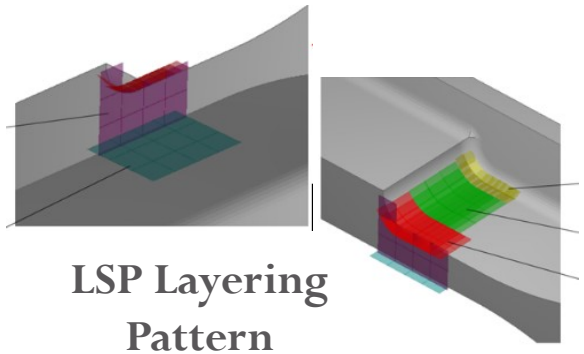
LSP of 7085 Forgings

Program schedule: 2015 to 2020

Funding organization: F-35 Joint Program Office

Team members:

- Lockheed Martin - Aeronautics



LSP Layering Pattern Development

Program objectives:

- Determine optimal LSP parameters to eliminate subsurface cracking
- Enhance crack formation/nucleation and crack growth performance of 7085 forgings

Relationship to ERSI goals and objectives:

- Through this effort over 60 different measurements have been made using the contour method
  - Many of these had multiple replicates
  - Provides a robust residual stress database for a range geometries
  - Fatigue tests of almost all conditions has been performed with crack front shapes developed via marker banding

Summary of outputs to be shared with ERSI:

- It is hoped that residual stress data can be shared for a range of conditions

LSP of Ti6Al4V BA ELI Forgings

Program schedule: 2017 to 2020

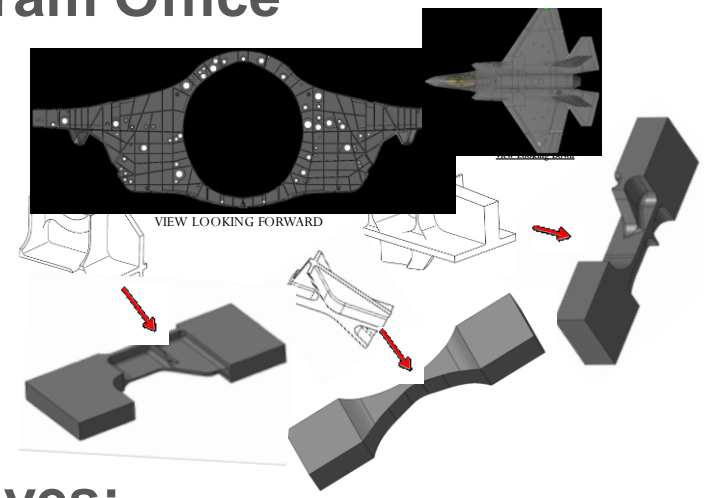
Funding organization: F-35 Joint Program Office

Team members:

- Lockheed Martin - Aeronautics

Program objectives:

- Determine optimal LSP parameters to eliminate subsurface cracking
- Enhance crack formation/nucleation and crack growth performance of Ti6Al4V BA ELI forgings



Relationship to ERSI goals and objectives:

- This effort will quantify the residual stress in 3 different geometries via the contour method
- Fatigue testing of these conditions will also be performed
  - No replicate fatigue tests will be performed

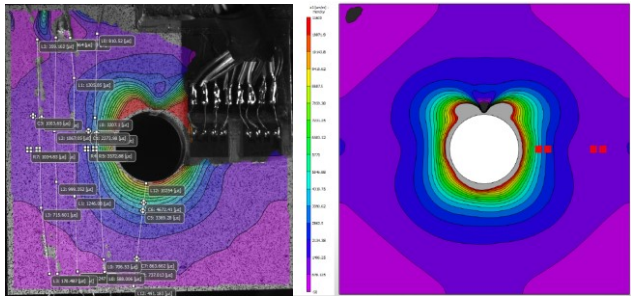
Summary of outputs to be shared with ERSI:

- It is hoped that residual stress data can be shared for a range of conditions

2inch x 2inch Cold Expanded Coupons

Program schedule: 2016 - 2020

Funding organization: A-10 ASIP, FTI, NRC, AFRL



Team members:

- Many individuals and companies

Program objectives:

- Perform the Cold Expansion process on simple geometry in 2024-T351 and 7075-T651 plate at ”Low” and “High” applied expansion levels
  - Use multiple methods to quantify surface residual stresses while performing the Cx process
  - Have coupon sets interrogated by many different residual stress determination/quantification techniques to include:
    - + Strain gauge
    - + DIC
    - + LUNA fiber optics
    - + Surface XRD
    - + ED XRD (APES, CHESS)
    - + Neutron Diffraction
    - + Neutron Emission
    - + Contour Method

Relationship to ERSI goals and objectives:

- Investigate multiple techniques to quantify differences in results
- Use as a validation dataset for FEA simulation

Summary of outputs to be shared with ERSI:

- Residual stress/strain data from all the different techniques
- A set of the coupons is also final reamed but this set has had a smaller set of techniques applied to it

Residual stress quality system

Program schedule: May 2017 to July 2018

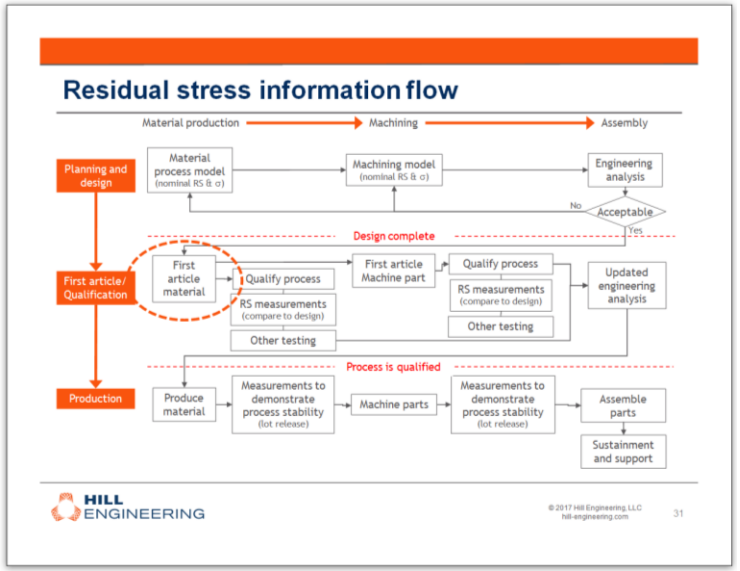
Funding organization: AFRL (SBIR and MAI)

Team members:

- Hill Engineering, Arconic, Lockheed Martin, AFRL

Program objectives:

- Quantify residual stress in large aluminum bulkhead forgings
- Estimate expected part-to-part residual stress variability for large aluminum bulkhead forgings
- Develop comparisons between residual stress measurements and process models
- Prepare a draft residual stress quality system specification for large aluminum bulkhead forgings



Relationship to ERSI goals and objectives:

- Develop inter-method residual stress comparisons
  - Hole drilling to ring core, Contour to neutron diffraction
- Develop measurement-model comparisons
  - Cold worked aluminum die-forgings
- Engage UQ/statistical methods relative to residual stress data
  - Statistical methods used to process results

Summary of outputs to be shared with ERSI:

- Comparison between residual stress measurement results and residual stress process models
- Inter-method residual stress comparisons
  - Hole drilling to ring core
  - Contour to neutron diffraction

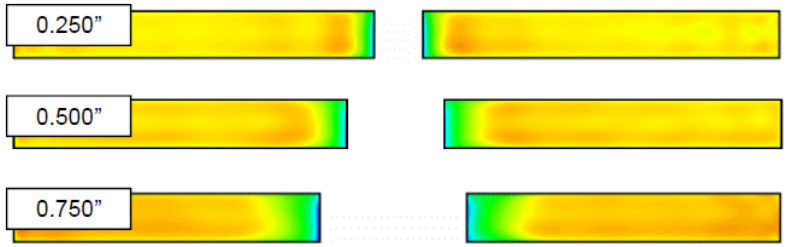
A-10 ASIP Modernization

Program schedule: November 2016 to June 2020

Funding organization: A-10 ASIP

Team members:

- A-10 ASIP
- Hill Engineering



Program objectives:

- Experimentally measure residual stress magnitudes & distributions and develop models
- Develop analytical methods for damage tolerance analysis accounting for residual stress effects
- Validate analytical methods and/or tools through fatigue testing
- Demonstrate the benefits compared to the existing methodology

Relationship to ERSI goals and objectives:

- Develop benchmark datasets
  - Residual stress measurements for select Cx hole conditions

Summary of outputs to be shared with ERSI:

- Residual stress measurement results for Cx holes

Regularization uncertainty

Program schedule: January 2018 to December 2019

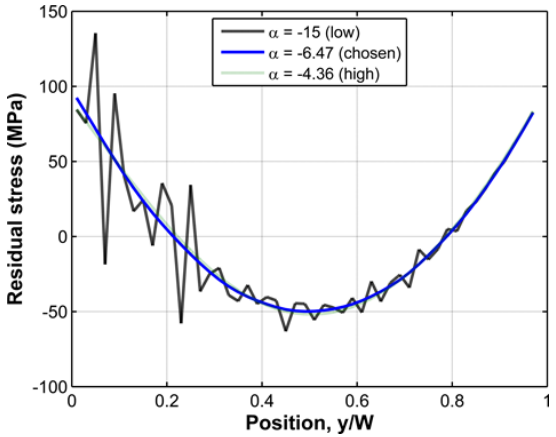
Funding organization: Hill Engineering

Team members:

- Hill Engineering

Program objectives:

- Develop a method to estimate the uncertainty associated with regularization used in the integral method of stress calculation



Relationship to ERSI goals and objectives:

- Engage UQ/statistical methods relative to residual stress data
  - Using UQ/statistical methods to improve uncertainty estimates

Summary of outputs to be shared with ERSI:

- Improved uncertainty estimates for hole drilling and slitting – December 2019

Bulk residual stress measurement

Program schedule: June 2014 to March 2017

Funding organization: AFRL (SBIR)

Team members:

- Hill Engineering
- AFRL

Program objectives:

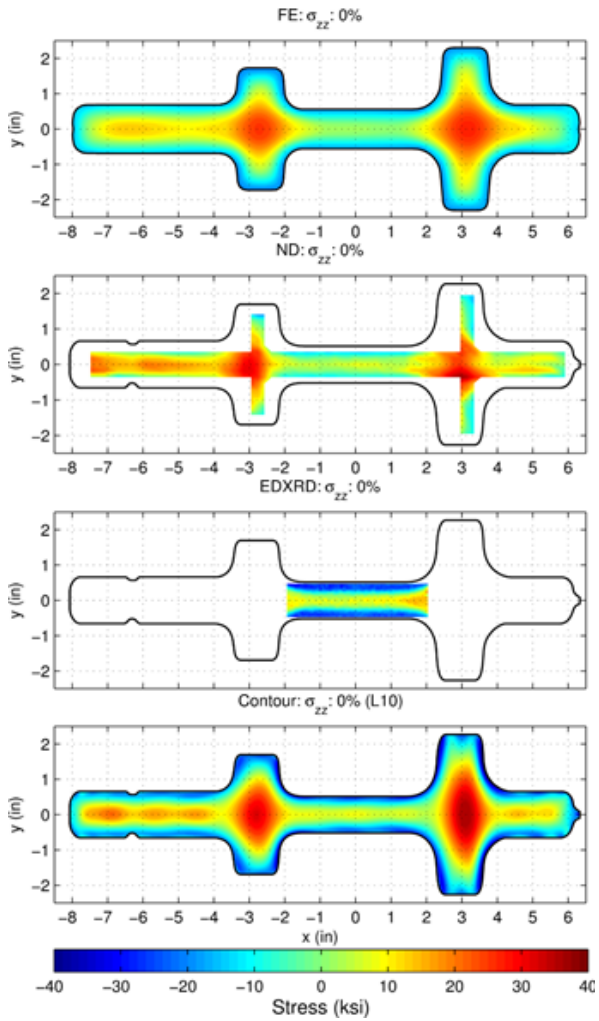
- Standardize the uncertainty estimate for contour method measurements
- Quantify the repeatability (precision) of contour method measurements
- Refine the approach for mapping multiple residual stress components
- Validate the results from multiple residual stress components mapping using independent measurements

Relationship to ERSI goals and objectives:

- Develop intra-laboratory repeatability
- Develop inter-method residual stress comparisons
  - Residual stress measurements for a variety of specimens using different techniques
    - Contour method vs. slitting vs. neutron diffraction vs. high-energy x-ray diffraction

Summary of outputs to be shared with ERSI:

- Contour method repeatability data (5-10 replicates, 5 different parts)
- Inter-method residual stress comparison summary



Steel Cx holes

Program schedule: May 2018 to December 2019

Funding organization: FTI and Hill Engineering

Team members:

- FTI
- Hill Engineering

Program objectives:

- Quantify residual stress in steel Cx specimens
- Compare residual stress measurement results to process model

Relationship to ERSI goals and objectives:

- Develop measurement-model comparisons (e.g., for CX holes)
  - Comparison between contour method and process model for steel Cx hole

Summary of outputs to be shared with ERSI:

- Summary of residual stress measurement to model comparison – December 2019

Stimulating inter-group interactions

We want to promote interaction with other ERSI groups

- RS measurement would like to link up with:
  - Simulation
  - Quality Assurance and Data Management
  - NDE
- Motivations
  - Facilitate cross-talk
  - Define and work joint efforts
  - Define and deliver outputs that feed overall ERSI objectives
- Do we want to define a format for such interactions?

Summary of Topics for Today

Group roster

Group Goals (still in development)

Related on-going programs

Stimulating inter-group interactions

Summary

Thank You