VOLUME 1
ISSUE 1

ERSI SCREAMER

JANUARY 2018

this issue

2017 ASIP Conf. P.2

Cx Hole Testing P.3

Contour Round Robin P.4

Subcommittee Updates P.5

Screamer Editors & ERSI Organizational Group:

Dallen Andrew
SwRI
210-522-5401
dandrew@swri.org

Scott Carlson
SwRI
210-522-5375
scarlson@swri.org

Robert Pilarczyk
Hill Engineering
916-635-5706
rtpilarczyk@hill-engineering.com

The Who, What, and Why of ERSI

For those who are new to the Engineered Residual Stress Implementation (ERSI) working group, this is the first edition of the ERSI Screamer, a quarterly newsletter designed to facilitate communication across subcommittees. A brief description of the what, why, and who of ERSI is included here.

Sponsoring Organization: This working group is sponsored by the A-10 Aircraft Structural Integrity Program (ASIP) under the direction and guidance of Mr. Chuck Babish.

Purpose:
1.To identify and lay out a roadmap for the implementation of engineered deep residual stress which can be used in the calculation of initial and recurring inspection intervals for fatigue and fracture critical aerospace components.
2.To highlight gaps in the state-of-the-art and define how those gaps will be filled.
3.Then to define the most effective way to document requirements and guidelines for fleet-wide implementation.

Vision: Within 3-7 years have developed a framework for fleetwide implementation of a more holistic, physics-based approach for taking analytical advantage of the deep residual stress field, induced through the Cold Expansion process, into the calculations of initial and recurring inspection intervals for fatigue and fracture critical aerospace components. Then move from there to other deep residual stress inducing processes, like Laser Shock Peening and Low Plasticity Burnishing.

Organization: The Working Group is broken up into 8 subcommittees with a chairperson for each committee, as shown below.

Subcommittee	Chair
INTEGRATOR	Dr. Mark Thomsen, Dr. TJ Spradlin, Dr. Dale Ball
VALIDATION TESTING	Dr. Tom Mills
RESIDUAL STRESS PROCESS SIMULATION	Keith Hitchman
FCG ANALYSIS METHODS	Robert Pilarczyk
DATA MANAGEMENT/QUALITY ASSURANCE	Carl Magnuson
NON-DESTRUCTIVE INSPECTION	John Brausch
RISK ANALYSIS	Laura Domyancic & Lucky Smith
RESIDUAL STRESS MEASUREMENTS	Dr. Mike Hill

ERSI Participation at the 2017 ASIP Conference

This year's ASIP conference hosted a discussion panel entitled 'Incorporation of Residual Stresses in Aircraft Design and Sustainment'

The two hour session was divided into two, hour long sections: 5 panelist presentations followed by an open mic Q&A. Panelists outlined the state-of-the-art, concerns, and technical challenges of incorporating residual stresses, focusing primarily on cold-expanded (CX) holes, into the lifing practices of aircraft during design and sustainment:

- Mr. Chuck Babish (AFLCMC/EZ), 'ASIP Perspective on Accounting for Engineered Residual Stress in Damage Tolerance Analysis'
- Dale Ball (Lockheed Martin), 'Validation of ERS DaDT Analysis'
- David Forsyth (TRI/Austin), 'QA/QC Aspects of Incorporation of Residual Stresses into Aircraft Design and Sustainment'
- John Brausch (AFRL/RXSA), 'Impact of Deep Residual Stress on NDI Methods'
- Mark Thomsen (AFLC MC/WWAEJ), 'Incorporation of Residual Stresses into Aircraft Design and Sustainment: An ASIP Manager's Perspective'

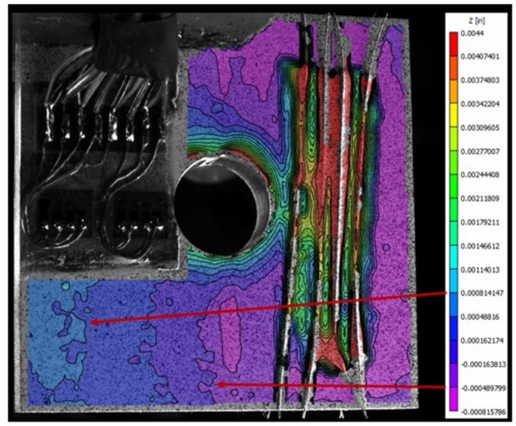
These presentations framed the conversation for the second hour, which included over 45 minutes of active questions and discussion. Panelists were queried by the audience and given opportunities to respond. Session materials will be made available through the ASIP Conference website, which will include the session pre-amble, panelist presentations, and a transcript of the Q&A session. Below is a quick synopsis of that session:

- **There are three pillars through which USAF will build a schema for safely incorporating residual stresses in aircraft sustainment:**
    1. Validated DaDTA methods *How do we account for residual stresses in lifing?*
    2. Non-destructive evaluation (NDE) *How do we know what the residual stresses are?*
    3. Non-destructive inspection (NDI) *How do we inspect for cracks in the presence of residual stresses?*
- **This schema will be documented in a 'living' structures bulletin (SB) outlining how to account for residual stresses in damage tolerant applications:**
    - First iteration of the SB focused on delaying initial inspection versus recurring inspections
    - Subsequent updates will improve on capabilities as the research addresses them
- **Urgency for research:**
    - Quality control (QA) or NDE is the largest concern for multiple panelists and the audience agreed: this is very challenging from a technical perspective
    - Validated DaDTA methods for compressively loaded problems needs much more work to be on par with our understanding of tensile scenarios
    - Because the first SB iteration will be focused on delaying an initial inspection, NDI is currently lower in urgency but still critical
- **Aerospace has been using CX for decades but confidence in residual stress state is much lower than say, laser peening.**
    - Human-in-the-loop is a major source of uncertainty for CX that is mitigated in processes like laser peening through use of a robot and computer controller for the laser
- **With budgets growing tighter this SB, and the research that supports it, represents a massive potential savings fleetwide**
- **Data management will continue to be a challenge and will only increase in importance**

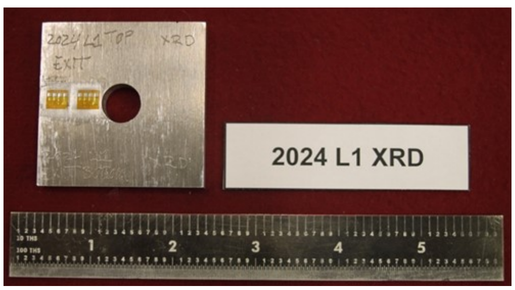
The last 15 minutes of the second hour were used to determine the priority of topics discussed by soliciting the audience for their opinion. Feedback from the larger structures community supported a majority of the research topics being pursued within ERSI. Overall, this was a highly successful panel with near unanimous support of a structures bulletin outlining how to incorporate residual stresses in aircraft sustainment.

POC: Dr. TJ Spradlin (USAF/AFRL/RQVS); (937) 656-8813; Thomas.Spradlin.1@us.af.mil; 88ABW-2018-0093

Open Hole Cx Residual Stress Determination Experiments



In 2017 a research program was developed that would allow for cross-validation of residual stress determination methods and for the validation of finite element simulations of the Cold Expansion (Cx) process. For this program two aluminum alloys were selected, 2024-T351 and 7075-T651. The level of applied expansion was varied from the "Low" end of the FTI specification at 3.16% to the "High" end at 4.16%. This would allow for the capture of the effect of applied expansion on the residual stress and strain fields. Material for these coupons was provided by the A-10 ASIP Office and were machined at AFRL. Strain gages were installed by FTI and the Cx process was performed at SwRI. Thus this was truly a group effort. An image of one of these coupons is shown with the strain gages installed in the figure below.

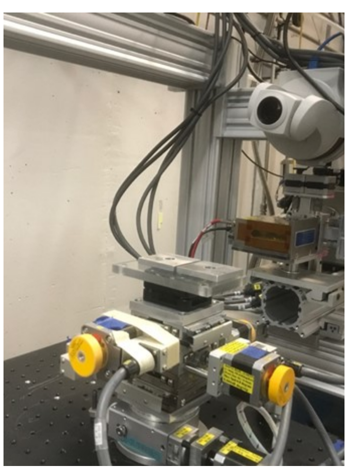


Multiple strain measurement methods were used during the Cx process, including Digital Image Correlation (DIC), a fiber optic system called LUNA, and strain gages. An image of the test setup is shown in the lower right figure. For all but one of these coupons all three of the data capturing methods worked excellent. An image of the post-processed DIC data is provided in the top right figure.

In addition to the strain measurements that were performed during the Cx process, four of the coupons (each representing one of the specific test conditions) were then taken to Argonne National Lab where an Advanced Photon Source (APS) is located and is one of the most advanced synchrotron-radiation light sources in the world. Energy-Dispersive X-ray Diffraction (ED-XRD) measurements were performed on each of the four coupon configurations. An image of the coupon set-up within the experiment chamber can be seen in the figure in the lower left.

After the measurements were performed at the APS these four coupons were then sent to the National Research Council (NRC) – Canada where they were again measured using a surface X-ray Diffraction (XRD) method. These measurements allow for a direct comparison to the DIC, LUNA and strain gage data. It is hoped that through this cross-validation process it will be shown that the DIC results are accurate and provide a spatial resolution that is high enough that it can be used as a reference for other methods that have a higher level of uncertainty at the surface, such as the Contour Method.

The coupons will finish up their international travels and be sent to northern California where they will be processed via the Contour Method at Hill Engineering to determine the residual stresses.



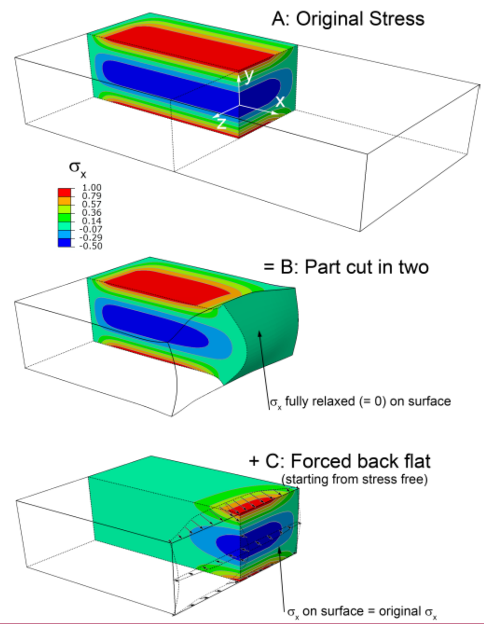
Data reduction and comparisons are already being performed between the surface strain measurements and the data from the APS. In addition to the data reduction from these many residual stress determination methods, FTI has begun the process of developing Finite Element Models (FEM) that represent these specific conditions, to include the sleeve clocking orientation and applied expansion. Through this a series of comparisons will be developed between the residual strains developed via the current state-of-the-art Finite Element Analysis (FEA) of the Cx process and those determined from the measurements taken during and after the Cx process. This work is planned to be published as a first in a series of papers building to the development of a validation process for FEA simulations of the Cx process. These papers are planned to be developed over 2018 and published late in that year or early in 2019.

POC: Dr. Scott Carlson (SwRI); Scott.Carlson@swri.org

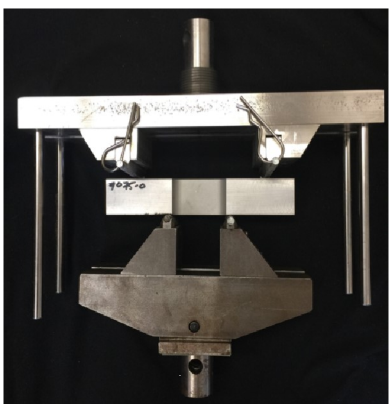
Inter-Laboratory Round Robin Exercise for the Contour Method

One area of research that has received some focused attention is the uncertainty quantification of the methods by which residual stresses within a body are determined. One method that has demonstrated excellent spatial resolution and that can be easily integrated into a fatigue crack growth analysis is the Contour Method. The Contour Method is a destructive method for indirectly measuring the residual stresses within a part or body. This process is accomplished by cutting the part along a plane of interest, then measuring the topography of the two new surfaces. The topography data for each of the two surfaces is then aligned, flattened, smoothed, averaged, and mathematically fit. This fit surface is then used as the boundary condition within a Finite Element Analysis of the part, which is then allowed to come to equilibrium. The resulting residual stresses represent those that were within the part at the time of the cut. See figure at right.

An area that has not been published on is the inter-laboratory variability that is associated with the Contour Method. Without an understanding of this it is difficult to have confidence in results that are provided. With no standard or best practice in place, there is a risk that the uncertainty is too high for use on fatigue and fracture critical structure.



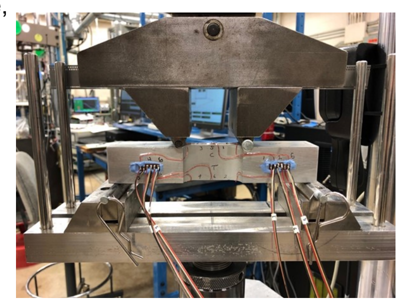
The Contour Method, *Michael B. Prime and Adrian T. DeWald*, 2013, chapter 5 in Practical Residual Stress Measurement Methods, Gary S. Schajer, Editor, pp. 109-138.



In an effort to begin this quantification effort, a group of six international Contour Method practitioners was formed. The first phase of the round robin is designed to quantify the uncertainty associated with only the data processes portion of the Contour Method. Topography data of two cut surfaces has been provided to the group and each member was asked to process the data from these displacements to final residual stresses. A four-point bend test was selected as the experimental test condition as a validation, with a 7075-O condition coupon selected and specially designed fixture procured through AFRL. This fixture and coupon can be seen in the figure at the left.

In November 2017 two coupons for this round robin were bent at SwRI. Each of the two coupons had six strain gages installed along or near the center-line of the coupon. An image of one of these bars within the fixture can be seen in the lower right figure. From these experiments, a tension and a compression-based stress-strain curve can be generated, which can be used to develop a closed-form estimate of the residual stress profile within the bar. This estimate can then be compared to the residual stress results from the Contour Method.

To date, the bending of the two coupons is complete and the coupons are now at Hill Engineering for cutting and topography measurement. This is scheduled to be completed in March 2018. The measurement data will then be supplied to the round robin group for data analysis and calculation of residual stresses. The final results will then be tabulated and compared, both amongst the practitioners and to the closed-form estimation of the residual stress profile, and published in the literature. Those that are involved within this round robin include:



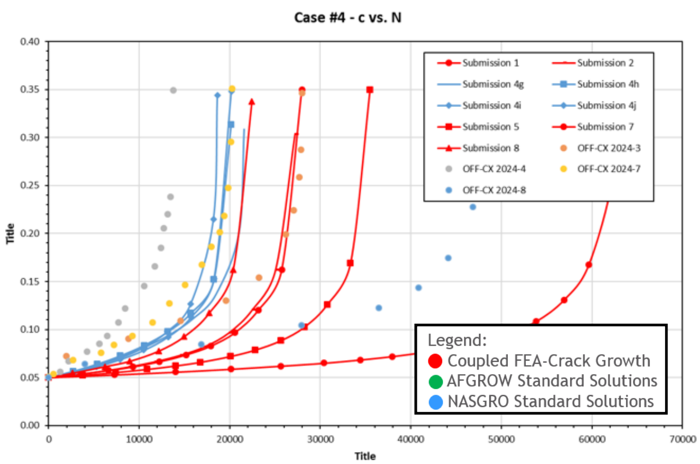
- Dr. Scott Carlson – SwRI
- Dr. Mike Hill – UC Davis, Mechanical & Aerospace Engineering Department
- Mr. Jean-Benoit Levesque – Hydro – Québec Research Institute (Ireq)
- Dr. Jeferson Araujo de Oliveria – StressMap, Open University
- Dr. Mike Prime – Los Alamos Labs
- Dr. TJ Spradlin – USAF AFRL

It is hoped that the next phase of this round robin will include additional aspects of the Contour Method, such as the cutting or topography measurement. These two steps within the Contour Method can introduce systematic errors into the final residual stress results and thus it is important these sources of uncertainty are captured and published.

POC: Dr. Scott Carlson (SwRI); Scott.Carlson@swri.org

Subcommittee Spot

Fatigue Crack Growth Analysis



<u>Round Robin for Cx Holes (Year 1)</u>

The FCG Analysis Methods Subcommittee continues to review and interpret the results of the first Round Robin for Cx Holes. Several individuals have been allowed to revisit their analyses and understand how key factors are influencing their predictions. Additional data comparisons are nearing completion and will be shared with the subcommittee once complete. We've discussed several publication options and are narrowing down to a few journals. See figure at right for sample analysis results.

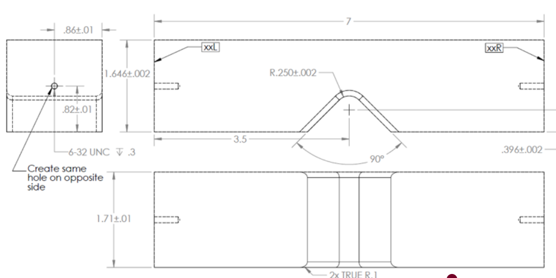
One finding from last year's workshop was our lack of -R fatigue crack growth rate data for the specific round robin coupons. We're currently investigating opportunities to address this gap, either with remnants from the original coupons or new testing for the second year round robin.

<u>Round Robin for Residual Stress (Year 2)</u>

The FCG Analysis Subcommittee has been discussing options for the second year round robin. We're currently looking at two main options:

- Stick with the original round robin datasets and investigate analysis methods and key modeling factors (post-diction) that improve prediction vs. test correlation as well as increasing the fidelity of the fatigue crack growth rate data.
- Complete predictions for a more simplistic condition, laser shock peening of a notched 3-point bend coupon – see figure at left. We're currently reviewing the input data for this round robin to determine if it is a good candidate.

- **Material**
  - 7050-T7451 Tabular material data
  - L-T orientation
  - Extrapolated R curves via Harter-T Method
- **Constant amplitude loading**
  - As machined
    - P_{max} = 5.100 kips
    - R = 0.1
  - LSP
    - P_{max} = 7.449 kips
    - R = 0.5
- **Stress and loads**
  - LSP
  - Applied load
    - 3-pt bend

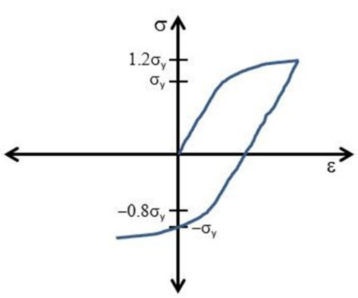


Residual Stress Process Simulation

Subcommittee Spot

<u>Cold Expansion Process Modeling: Determination of Hardening Rule for Material Model</u>

This effort is aimed at characterizing the hardening rule for aluminum 2024-T351 by performing a series of fully reversed uniaxial elastoplastic cycles to specific strain levels. The levels of reverse yielding will establish the degree of isotropic and/or kinematic hardening under uniaxial loading. Evaluation of other dependencies on 2024-T351 hardening behavior that may be valid for hole CX modeling, such as multiaxial or pressure dependent behaviors, are outside the scope of the current effort but are planned to be pursued afterword. A schematic of uniaxial elastoplastic response with kinematic hardening is shown in the figure below. Testing will be performed in the longitudinal (L), long-transverse (LT), and in the off-axis 45° orientation. It is envisioned that testing will also be performed in the short-transverse (ST) orientation, depending on the actual plate thickness.



Currently the RS Sim group has completed manufacture of L-direction E606-style specimens, and those specimens are in the hands of NRC for review. NRC is running the calibration/spare (L) specimens to ascertain impact, before final polishing is completed on the (T) and 45° specimens at FTI in January. The group had hoped to have some drafts in work for the general RS simulation validation plans; we hope to pull this in after a period of inactivity.

We Need You!

We would like to have input from these subcommittees for the following edition of the ERSI Screamer:

- INTEGRATOR
- VALIDATION TESTING
- DATA MANAGEMENT/ QUALITY ASSURANCE
- NON-DESTRUCTIVE INSPECTION
- RISK ANALYSIS
- RESIDUAL STRESS MEASUREMENTS

Announcements

- **Dates for ERSI 2018 are September 13-14 in Layton, UT**
  - Will be held at the same location in the Weber State Continuing Education building
- **ERSI email address has been created!**
  - If you ever have questions, suggestions, complaints, etc., please let us know by sending an email to ERSI@swri.org
- **New ERSI website has been setup!**
  - If you have an account, go to https://member-ersi.swri.org/ and login. If you need an account, please send an email to ERSI@swri.org and an account will be created for you. Please include your name, organization, and contact info.

Who is ERSI?