Mechanical and Aerospace Engineering
University of California, Davis

Contour Method Reproducibility Experiment A (CMRE-A)

Summary for ASM-RTC

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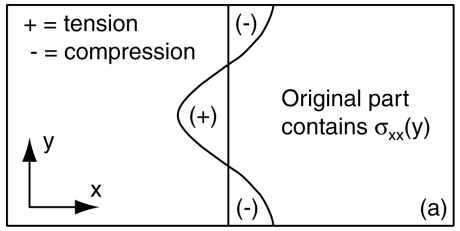
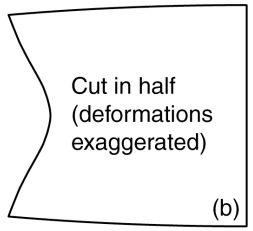
Background: Contour Method

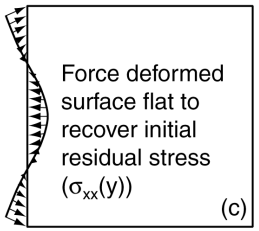
- **Contour method generates a 2D map of residual stress normal to a plane**

- **Contour method steps (illustrated for 2D body)**
  - Part contains unknown RS (a)
  - Cut part in two: stress release ⇒ deformation (b)
  - Measure deformation of cut surfaces
  - Apply reverse of average deformation to finite element model of body (c)
  - Map of RS normal to surface determined
  - Same procedure holds for 3D

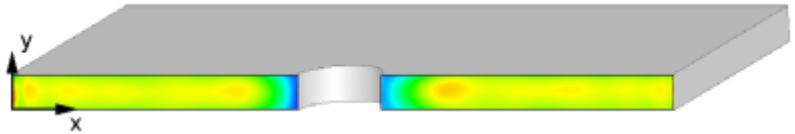
M. B. Prime, "Cross-Sectional Mapping of Residual Stresses by Measuring the Surface Contour After a Cut," JEMT, 123, 2001.

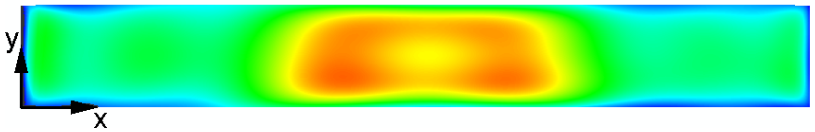






Cut → measure → FEM → 2D residual stress map





Background: Contour Method

- **Published in the literature 20+ years**
- **No widely accepted standard available**
  - Various techniques for measurement practice by different groups
- **Few published studies related to measurement precision**
  - Intra-laboratory repeatability (Olson)
- **Broad adoption in structural applications requires better understanding of reliability**
- **Team approach to normalize application of contour method**
  - Inter-laboratory reproducibility of data processing only (D'Elia)
  - CMRE-A represents team effort to quantify contour method reproducibility

D'Elia, C. R., Carlson, S. S., Stanfield, M. L., Prime, M. B., Araújo de Oliveira, J., Spradlin, T. J., Lévesque, J. B., Interlaboratory Reproducibility of Contour Method Data Analysis and Residual Stress Calculation. *Experimental Mechanics,* 60, 833-845, 2020. https://doi.org/10.1007/s11340-020-00599-0

Olson, MD, DeWald, AT, & Hill, MR. Repeatability of contour method residual stress measurements for a range of materials, processes, and geometries. *Mater Perform Charact*, 7(4), 20170044-20170044, 2018. http://dx.doi.org/10.1520/MPC20170044

CMRE-A Study Results Submitted for Publication in Experimental Mechanics

- Submitted Feb 2022

Interlaboratory Reproducibility of Contour Method Data in a High Strength Aluminum Alloy

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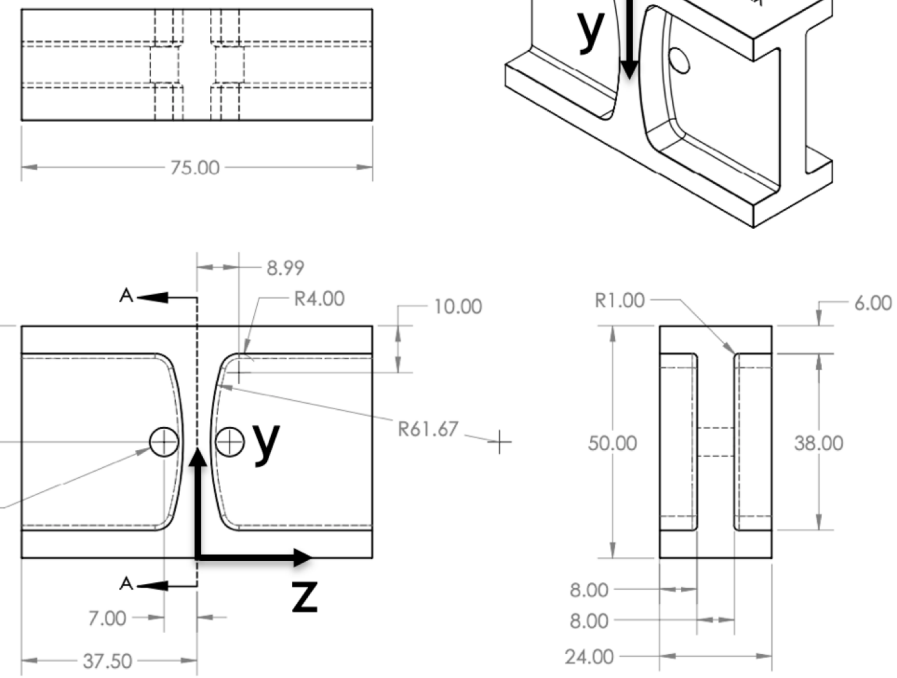
ABSTRACT

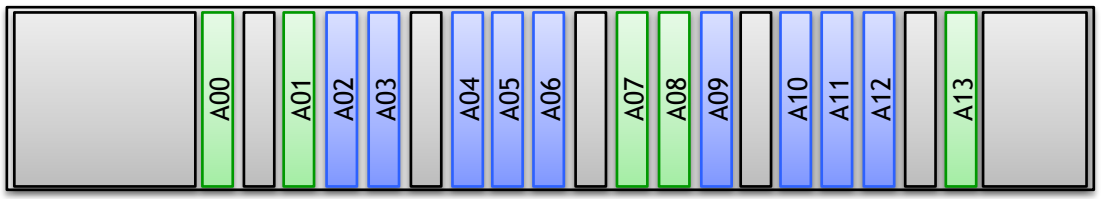
Background: The contour method for residual stress measurement has seen significant development, but an experimental reproducibility study has not been published. Objective: A double-blind reproducibly study is reported, having scope beginning with EDM cutting and ending with residual stress calculation. Methods: A reinforced I-beam sample geometry is identified for its unique residual stress profile when extracted from residual stress bearing quenched aluminum bar (7050-T74). Contour measurements are prescribed on a midplane of symmetry with dimensions 24 mm by 50 mm. Fourteen identically prepared samples are fabricated from a single long bar with well characterized and uniform residual stress. Five

Accepted for publication April 2022

CMRE-A Sample

- **Interest in bulk stress fields, neglecting machining or other near-surface stresses**
- **Several blanks cut from a single residual stress bearing bar**
  - 7050-T74 high-strength aluminum alloy
  - Approx. ±100 MPa in bar
  - Residual stress from quench/age of T74
- **Mill identical samples 50 x 75 x 24 mm**
  - Plane of interest A-A, 50 x 24 mm
  - Representative of heavy structural elements
- **Fabricated 14 samples A00 to A13**





Not used

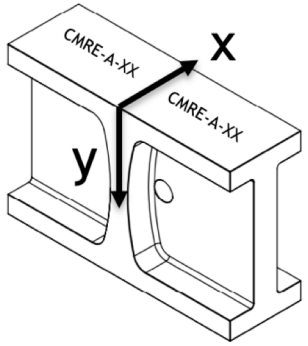
Planning

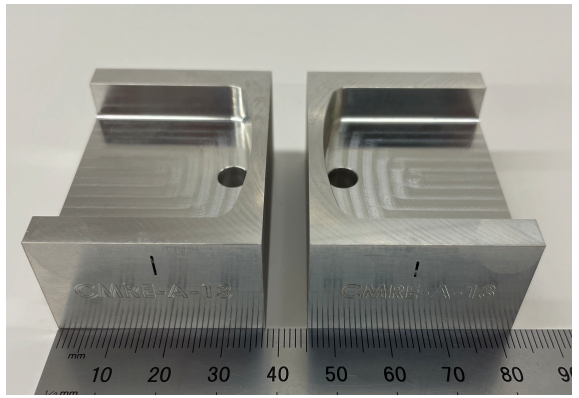
Participants

CMRE-A Measurements

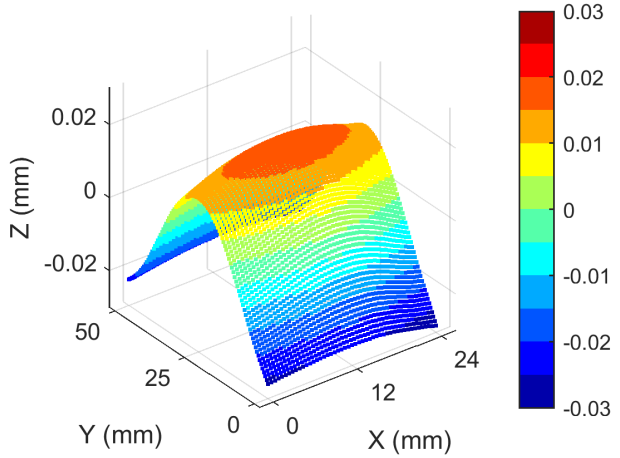
- **Planning Measurements:**
  - 3 contour measurements to assess uniformity of material condition and measurement repeatability (UC Davis) (Samples A01, A07, A13)
  - Neutron diffraction measurement at HFIR (Oak Ridge National Lab) (Sample A08)
  - Hole-drilling at surfaces (UC Davis) (Sample A00)
- **Participants Measurements:**
  - International group of 8 participants from industry and academia provide contour measurement results on Plane A-A

1) Cut the part (wire EDM)

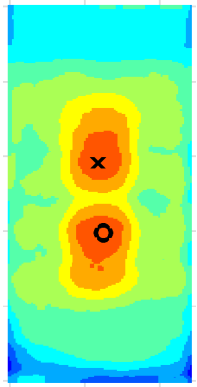


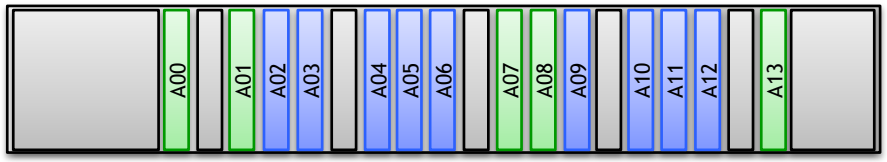


2) Measure the cut surface form



3) Compute RS (FEA)

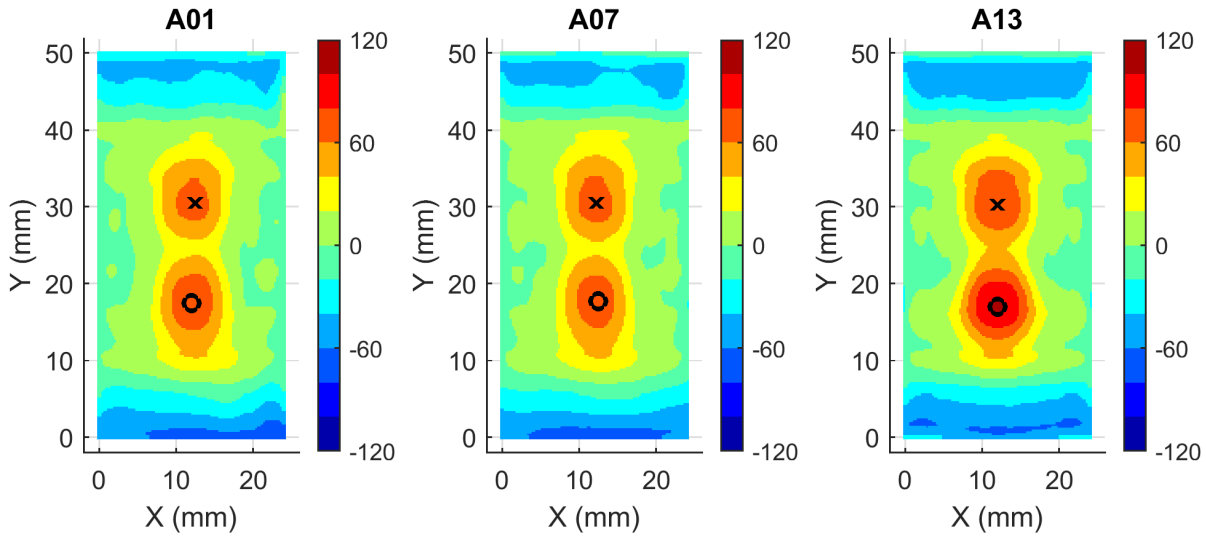


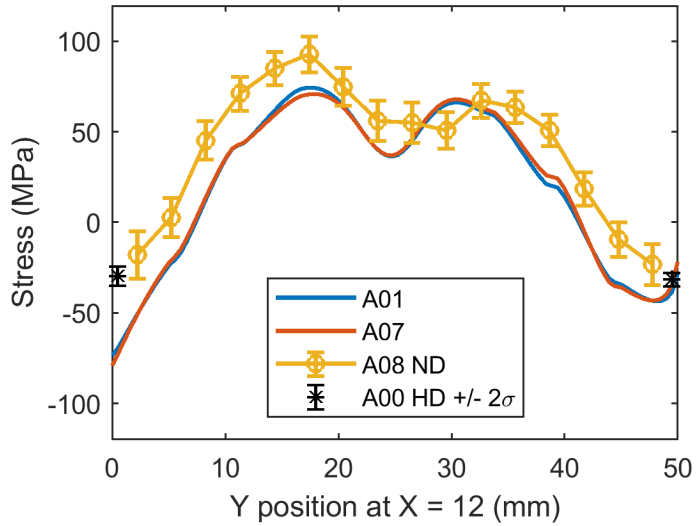


Not used
Planning
Participants

CMRE-A Planning Measurements

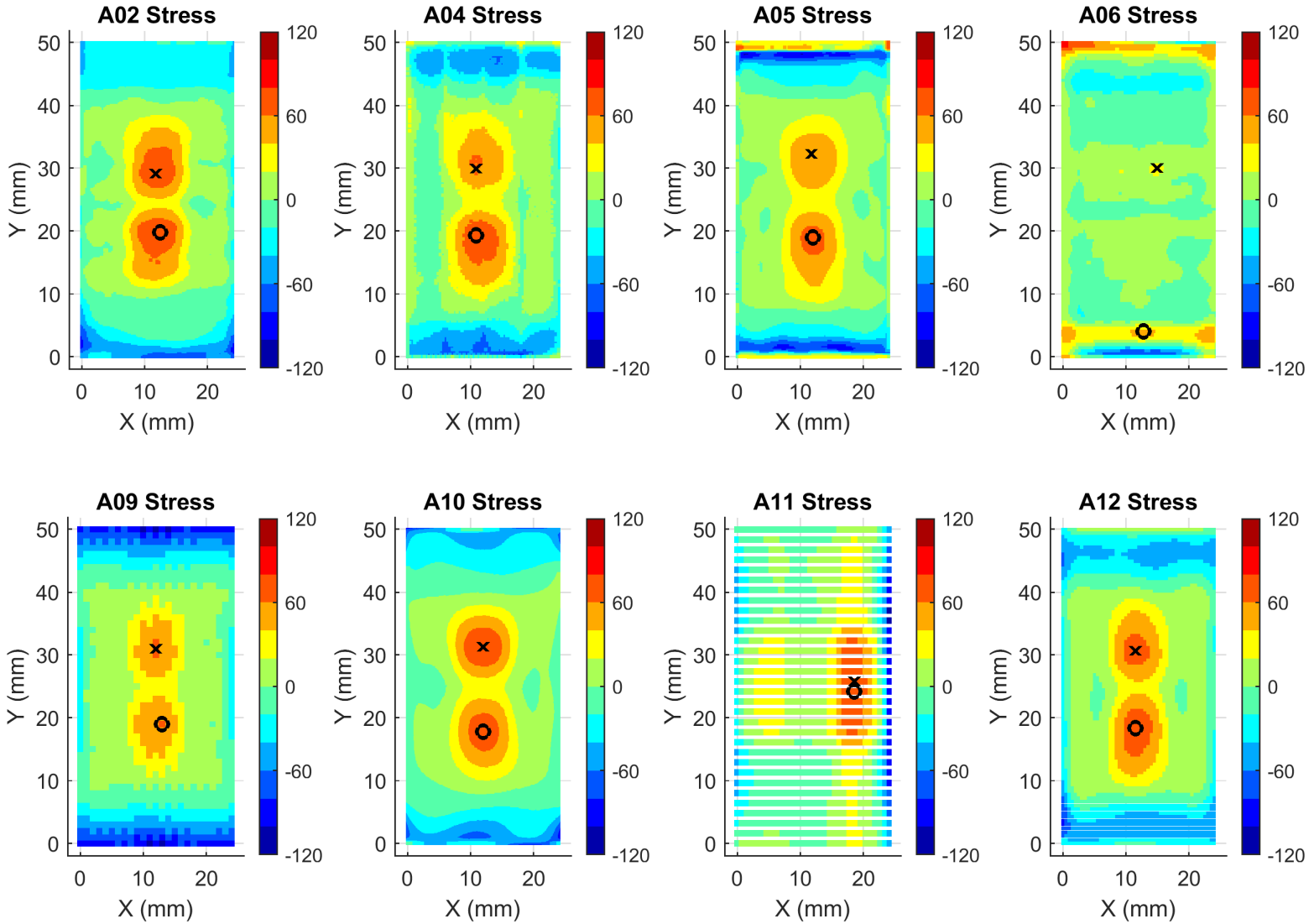
- **Contour results:**
  - A01 and A07 are nearly identical
  - Magnitude higher for A13
    - Likely due to proximity to end of bar (see Olson 2015)
    - Distant from participant samples
  - Spatial distribution of stress is similar along length of bar
- **Neutron diffraction results:**
  - Similar spatial form, offset of ~ 25 MPa (within expectation)
- **Hole-drilling results:**
  - Near surface stress symmetric





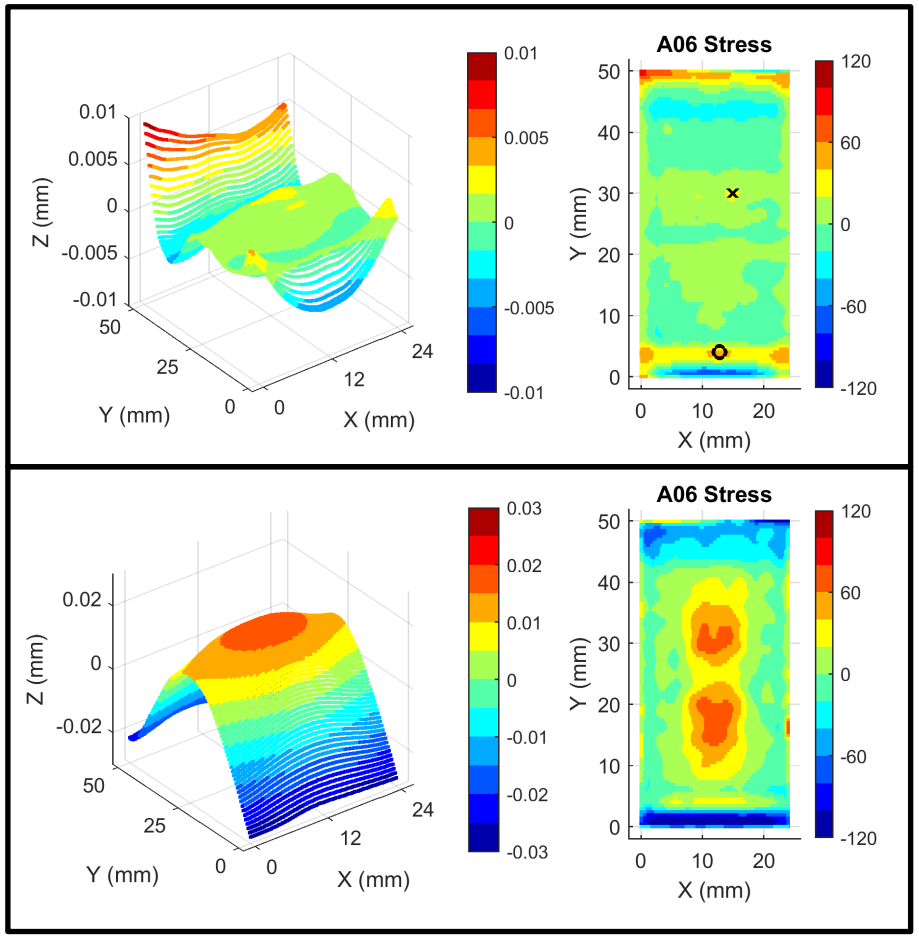
Olson, M.D., Hill, M.R. A New Mechanical Method for Biaxial Residual Stress Mapping. *Exp Mech* 55, 1139–1150 (2015). https://doi.org/10.1007/s11340-015-0013-5

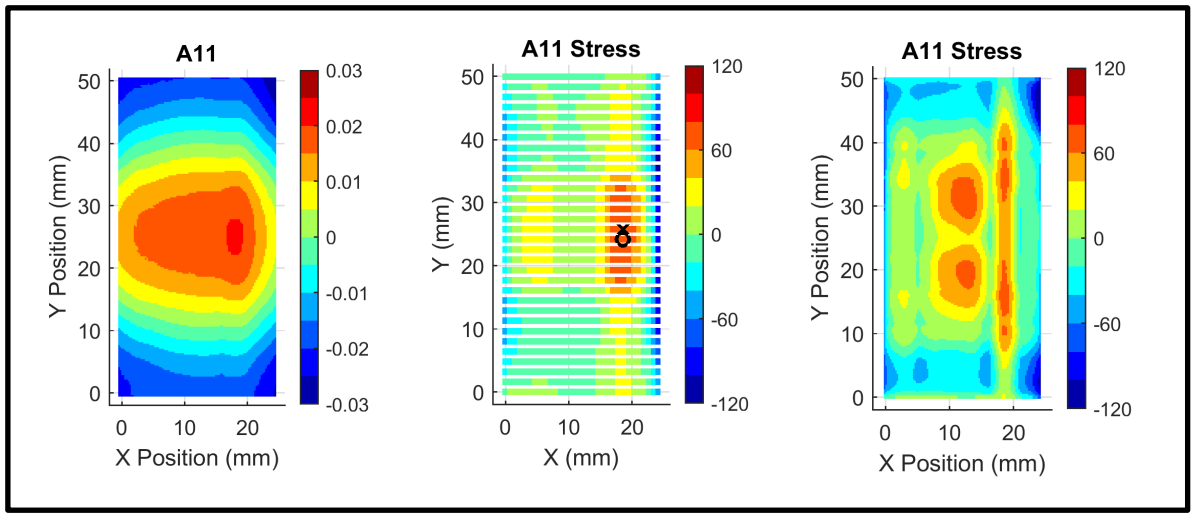
CMRE-A Results: Participant Reported Stress



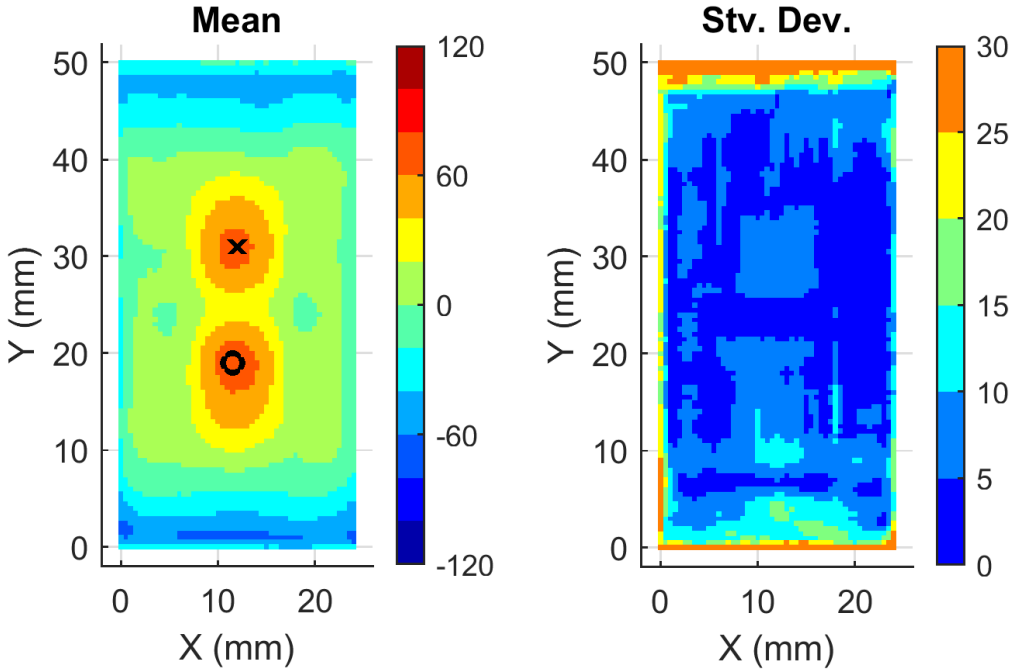
CMRE-A Results: Outliers

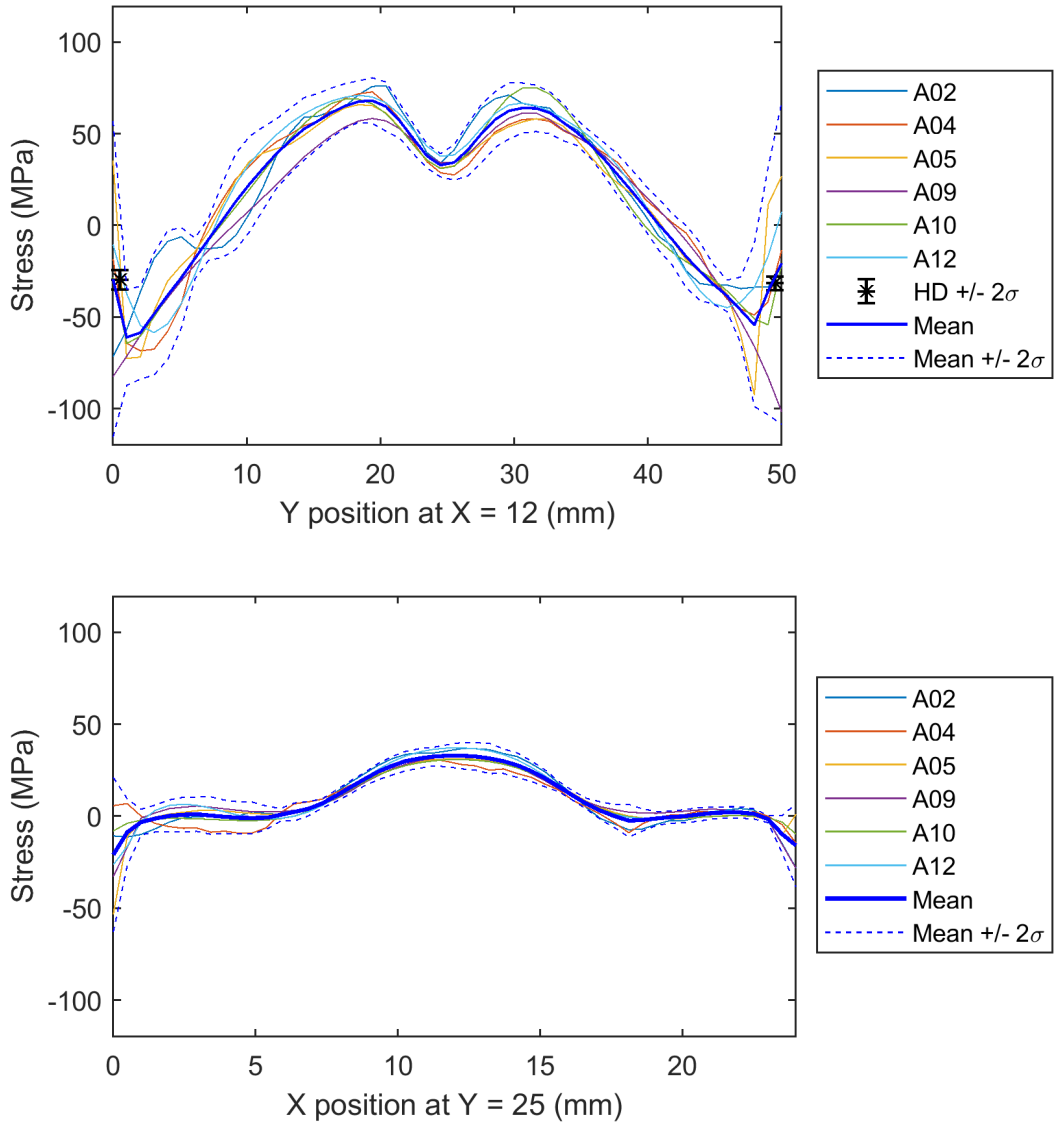
- **CMRE-A-06**
  - Surface measurement problem
  - New surface form measurements provided results consistent with others
- **CMRE-A-11**
  - Wire EDM cutting problem
    - Cut surface of stress-free material would be non-flat (called a “cutting artifact”)
  - Analysis problem
    - Overly simplistic geometry





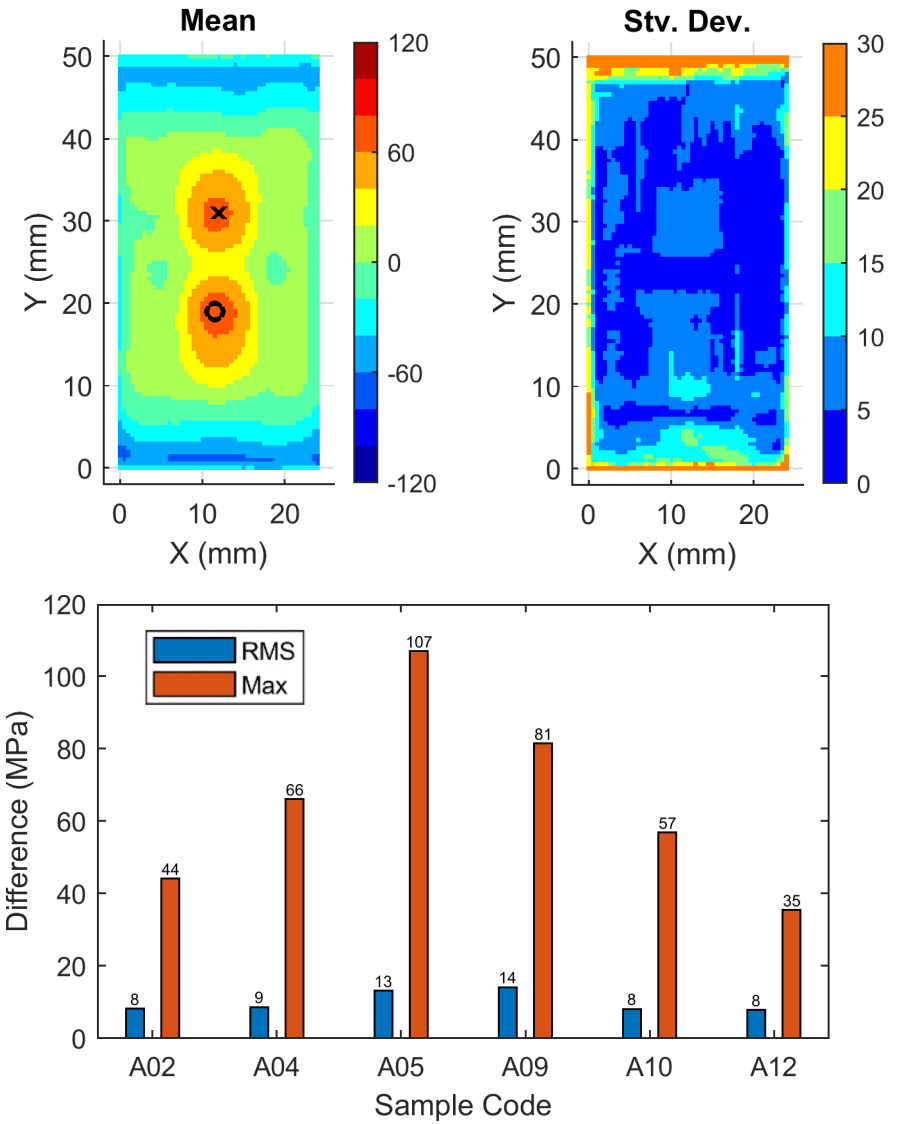
CMRE-A Results: Non-outlying





CMRE-A Results: Reproducibility (excluding outliers A06, A11)

- **Observed interlaboratory reproducibility**
  - 8.1 MPa average for all locations
  - 6.1 MPa on interior
  - 17.6 MPa near boundary (within 1 mm)
- **Observed reproducibility similar to intra-laboratory repeatability reported earlier (Olson, et al, 2018)**
  - 9.0 MPa on interior
  - 18 MPa near boundary
- **Differences from group mean vary among participants**
  - RMS differences range 7.8 to 14.1 MPa
  - Maximum differences range 35.5 to 107 MPa



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