

# The Measurement of Shear Strain in Impact Ice Using a Modified Lap Joint Test and Digital Image Correlation

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# Motivation

- Many current ice adhesion techniques do not account for the evolution of the ice deformation over the duration of an experiment
- If an experiment fails in an unexpected manner the data is discarded or provides limited information regarding the adhesive strength
- Minimal application of digital image correlation (DIC) to ice experiments
  - No literature found for ice adhesion experiments
  - Used to study the behavior of sea ice

# Sample Generation and Testing

- Samples are composed of impact ice accreted onto a stainless-steel substrate using the Icing Research Tunnel at NASA Glenn Research Center
- Mechanically tested using the modified lap joint test
- Previously reported results from this test using the normalized apparent adhesion strength

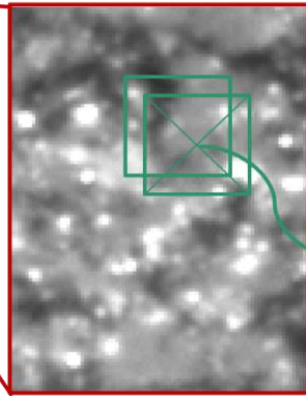
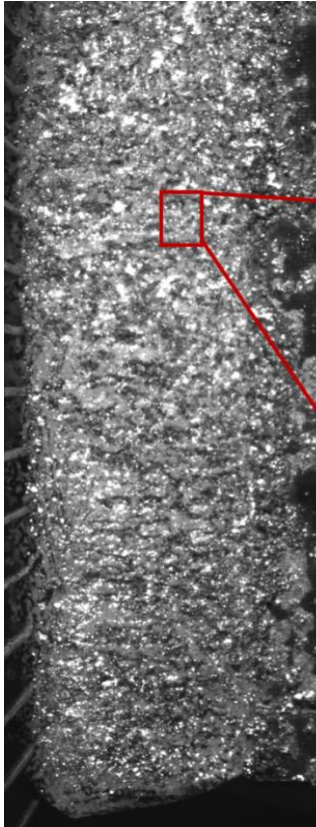


Work, 2020



Work, 2020

# Digital Image Correlation



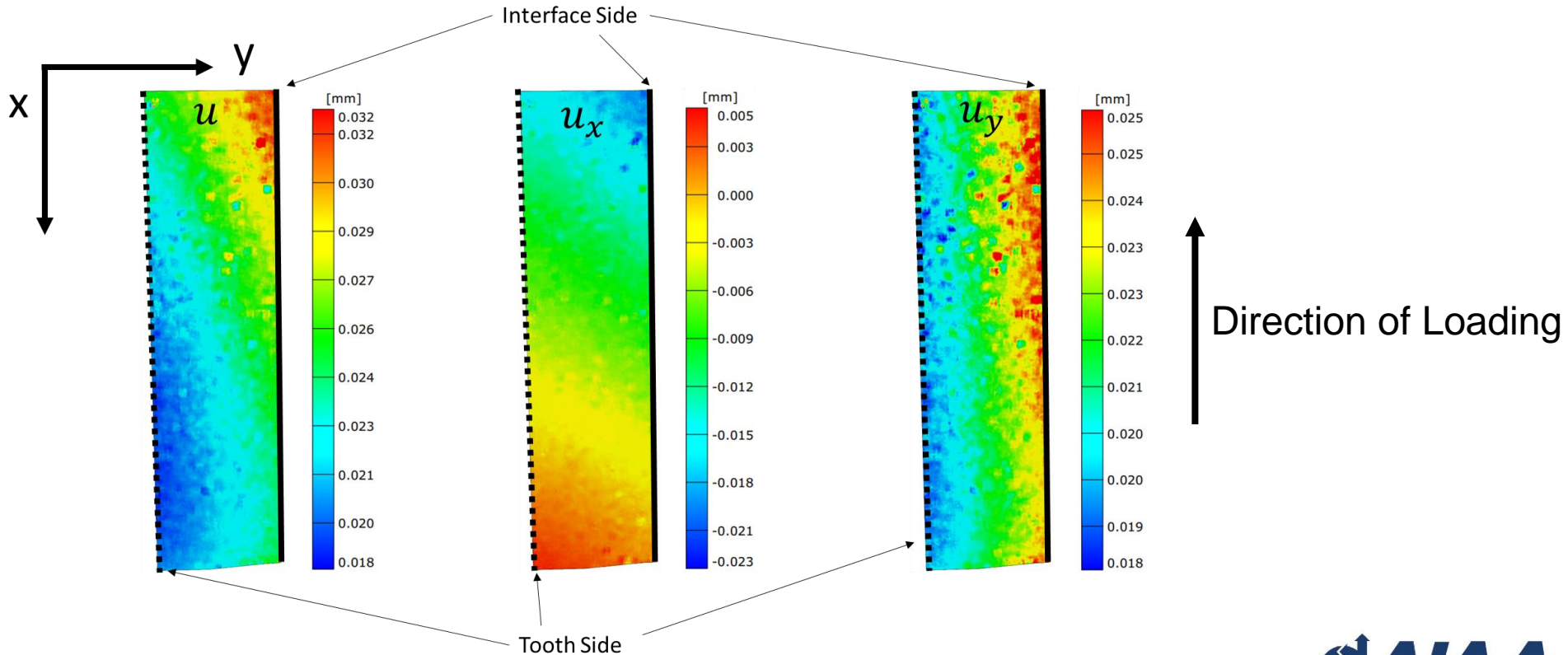
## Sample Surface Preparation

1. Abrade surface with 120 grit sandpaper
2. Apply black spray paint
3. 30-minute dry time

Facets for correlation with the data point being at the center of each facet

- DIC was conducted using GOM Correlate
- Imaged at 15 frames per second
- Resolution: 4096 X 2160
  - $20 \mu\text{m}/\text{Pixel}$

# Displacement Field Results



# Calculating Shear Strain

➤ Shear strain is the angle of the displacement field:  $\gamma_{xy} = \alpha + \beta$

➤ Full Calculation:

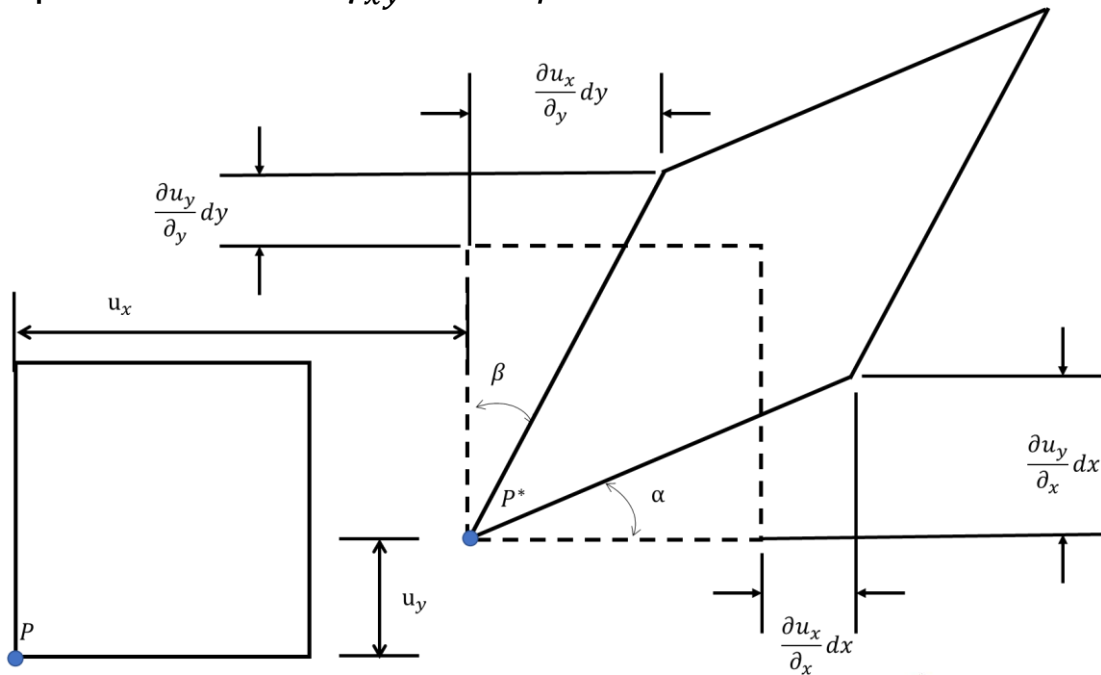
$$\tan(\alpha) = \frac{\frac{\partial u_y}{\partial x} dx}{dx + \frac{\partial u_x}{\partial x} dx} = \frac{\frac{\partial u_y}{\partial x}}{1 + \frac{\partial u_x}{\partial x}}$$

$$\tan(\beta) = \frac{\frac{\partial u_x}{\partial y} dy}{dy + \frac{\partial u_y}{\partial y} dy} = \frac{\frac{\partial u_x}{\partial y}}{1 + \frac{\partial u_y}{\partial y}}$$

➤ Simplified:

$$\alpha \approx \frac{\partial u_y}{\partial x}$$

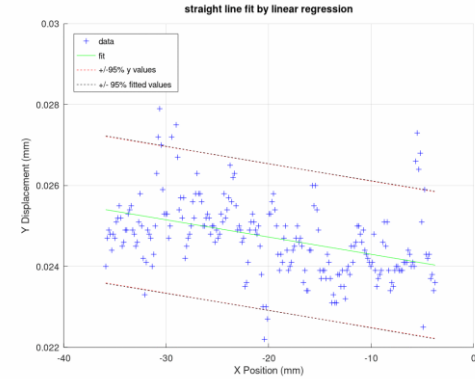
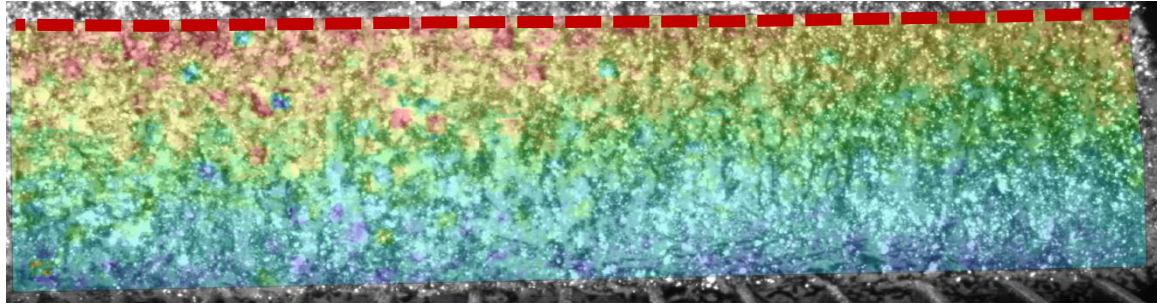
$$\beta \approx \frac{\partial u_x}{\partial y}$$



# Interfacial Derivatives

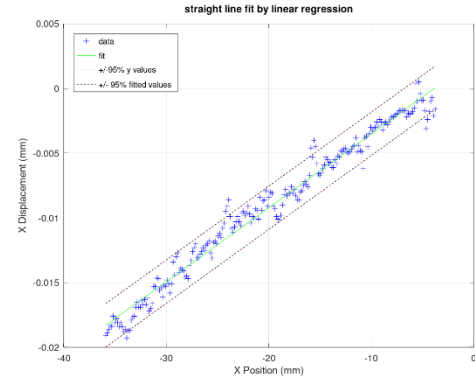
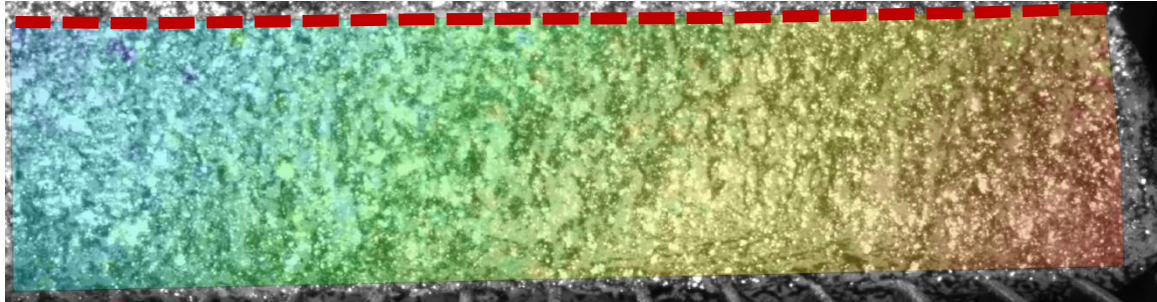
$\overrightarrow{X}$

*Y displacement*



$$\frac{\partial u_y}{\partial x}$$

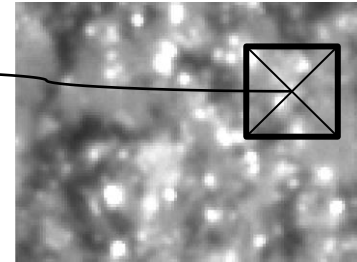
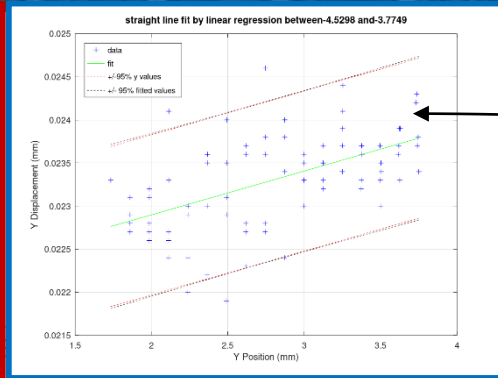
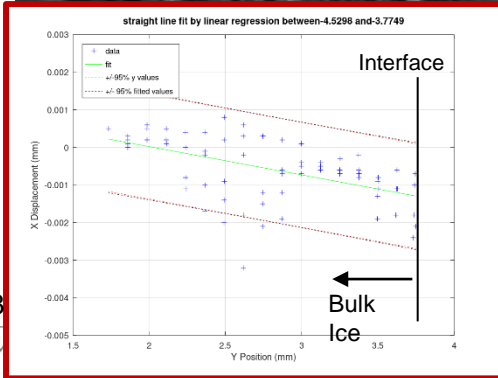
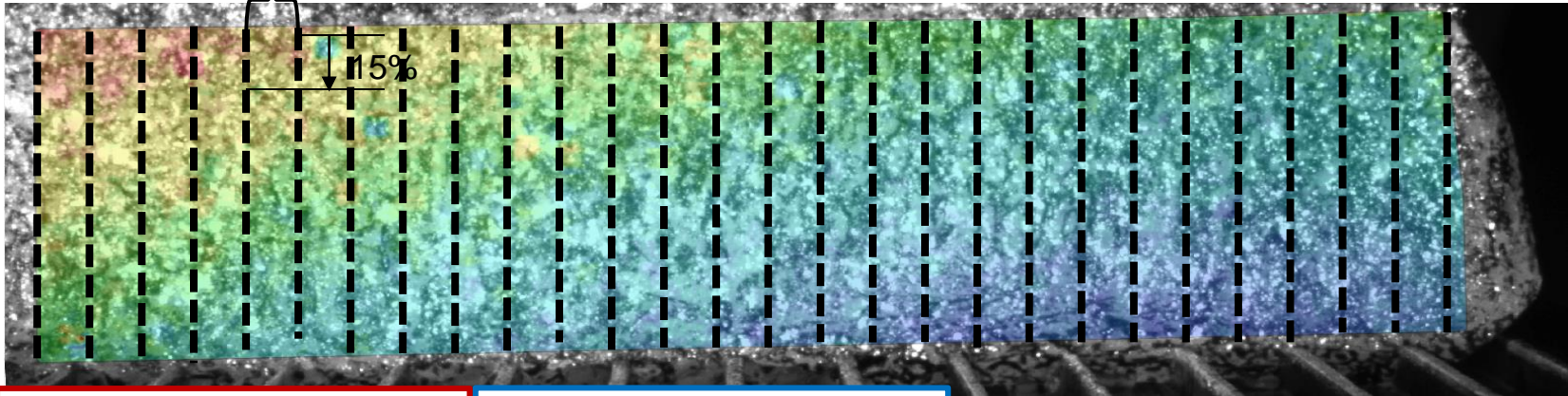
*X displacement*



$$\frac{\partial u_x}{\partial x}$$

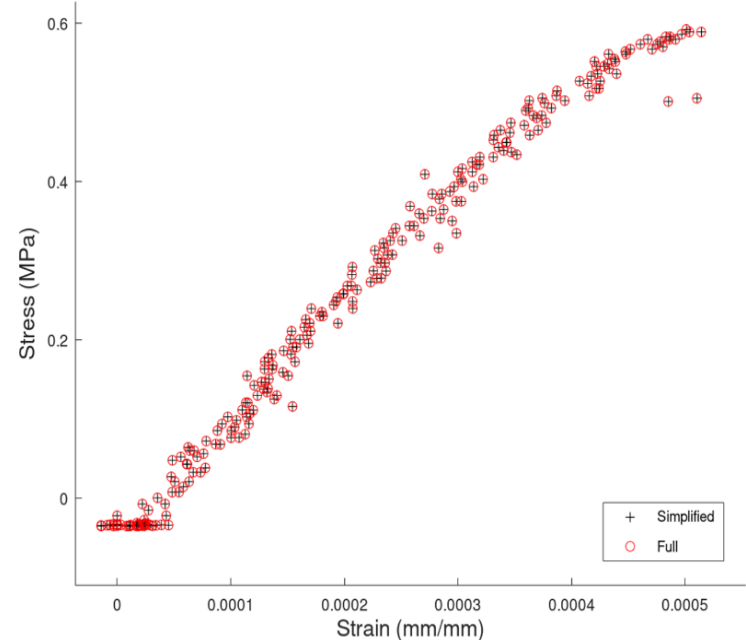
# Bulk Derivatives

Data was sorted into bins, then fit to find the  $\partial u_x / \partial y$  and  $\partial u_y / \partial y$

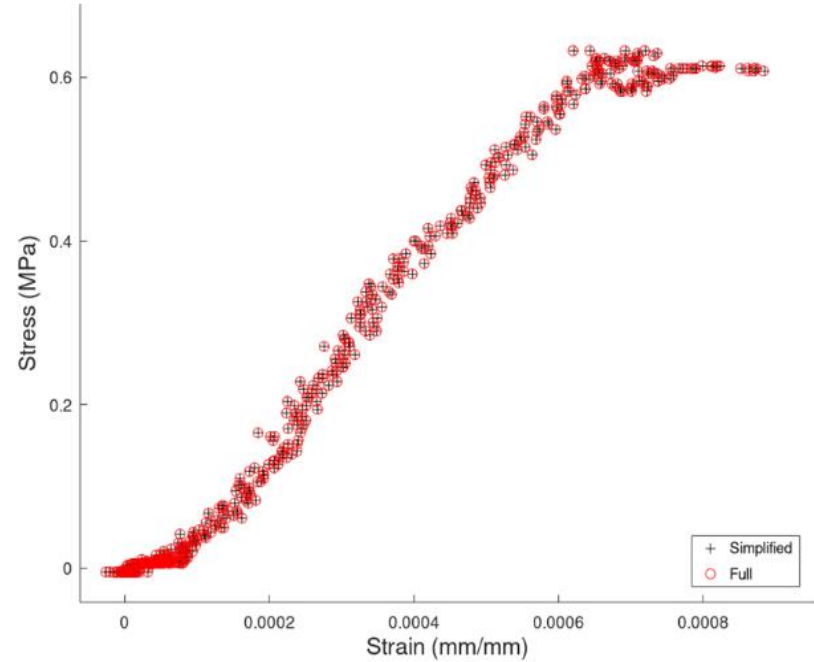
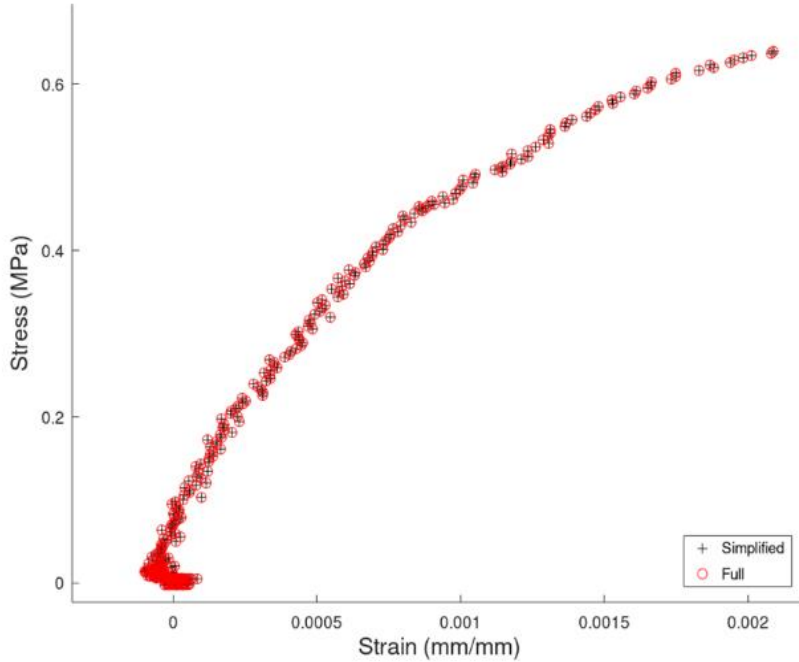


# Shear Strain Results

- Each bin has a calculated shear strain value
  - Averaged to provide a single value per frame
  - Stress was assumed to be the applied load at a given image divided by the area of the test coupon
- Allows for observation of a change in mechanical behavior at higher stress levels

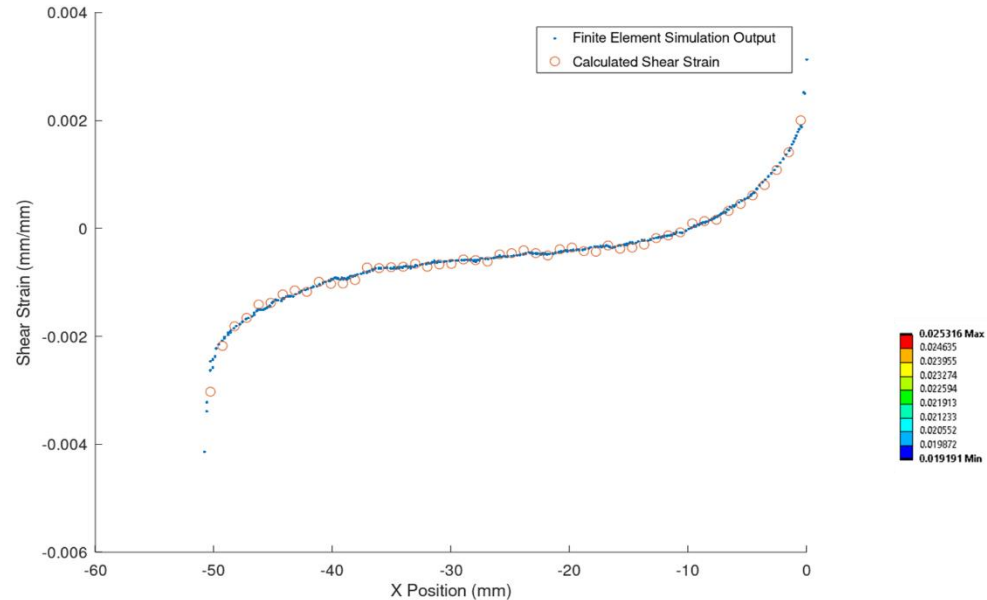
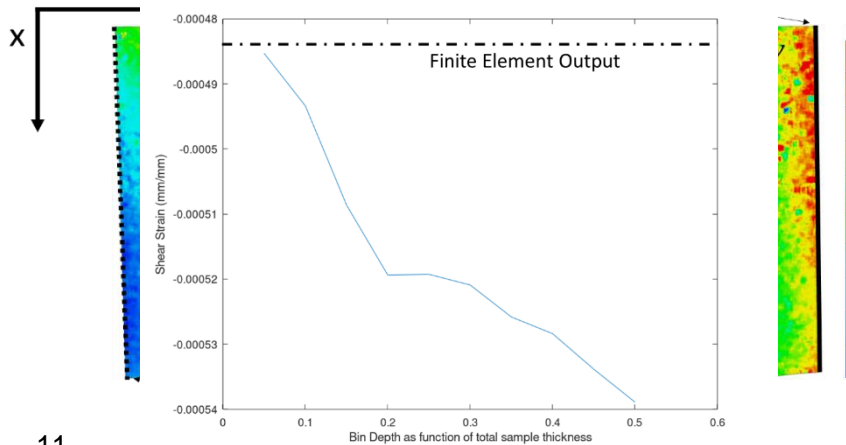


# Additional Samples



# Finite Element Verification

- Extracted boundary conditions from DIC data to generate similar displacement fields
- Handled the FE data using same scripts as the DIC data



# Summary

- Developed process for conducting DIC on impact ice samples undergoing mechanical testing.
- Developed novel methodology for calculating the shear strain near the interface.
- Measured non-linear behavior in impact ice
- Verified the entire methodology using finite element simulations

# Acknowledgements

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