In-Situ Scanning Electron Microscope Experiments for Microscale Mechanical Testing and Validated Modeling of Fiber Reinforced Thermoplastics

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2026 Microscopy & Microanalysis Conference; August 6th, 2026

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GRAY CRUSH

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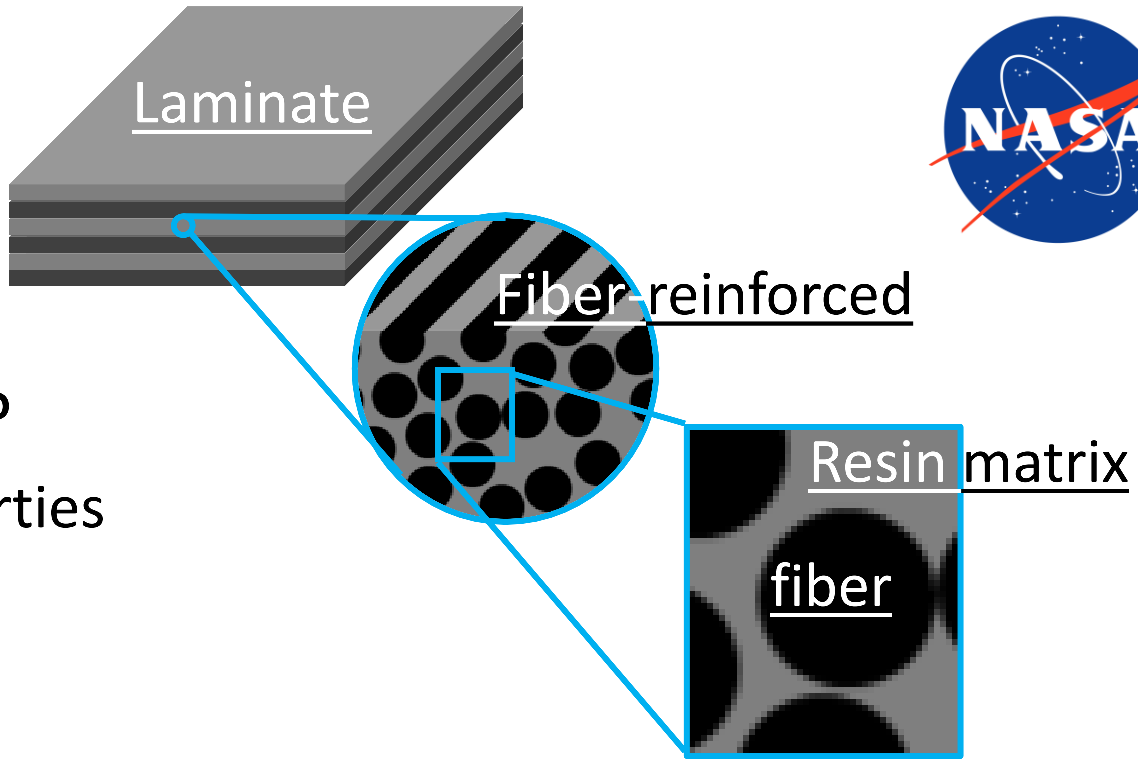
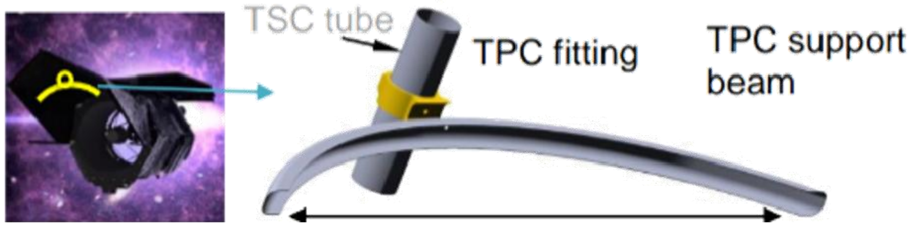
Background

- Polymer Matrix Composites (PMC)
- Why use Thermoplastic composites?
  - Possess exceptional mechanical properties
  - Recyclable



- NASA past and present utilization:

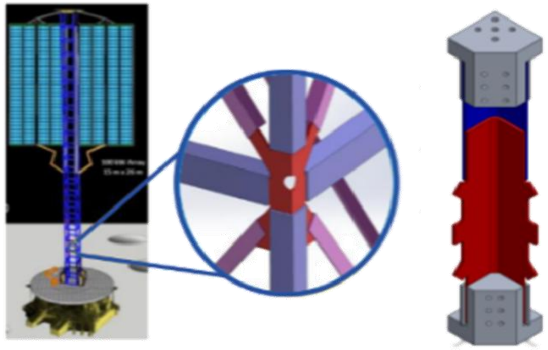
Roman Space Telescope



Thermoplastic Development for Exploration Applications (TDEA)

Hi-Rate Composite Aircraft Manufacturing (HiCAM)

Tall Lunar Tower

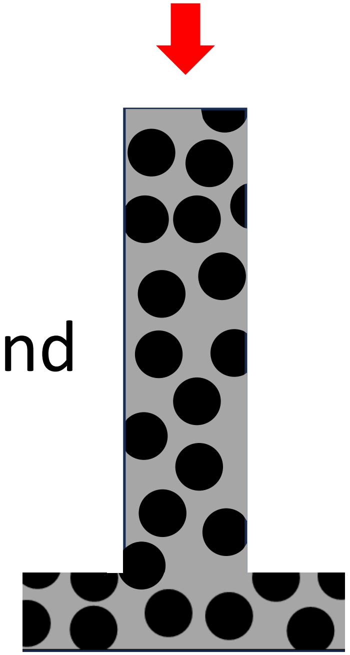


Motivation

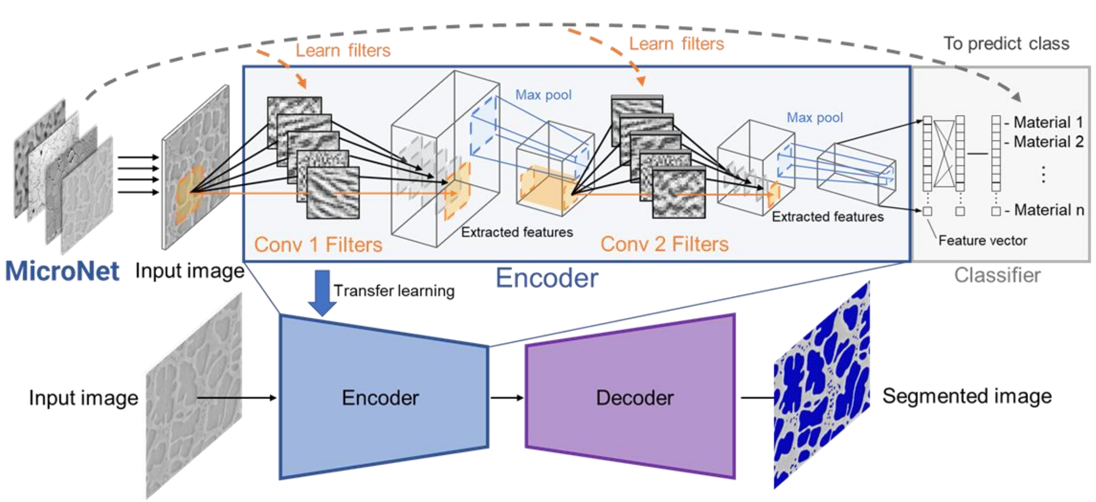
- Macro-level failures initiate from microscale damage
- Fiber and matrix interactions are complex
  - Identifying when and where local cracks form allows for improved predictions of composite failure based on loading and boundary conditions

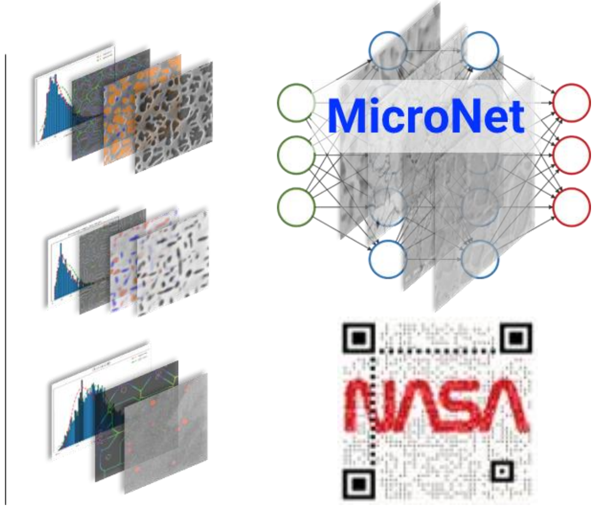
Project Goal

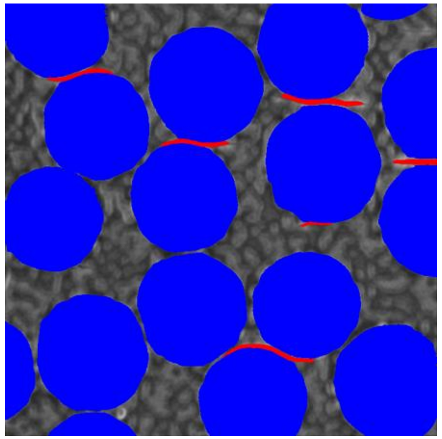
- Fabricate and test micropillar specimen in compression to measure in-situ local strains and observe damage evolution



- Validate NASA-developed micromechanics models—predictive capability!





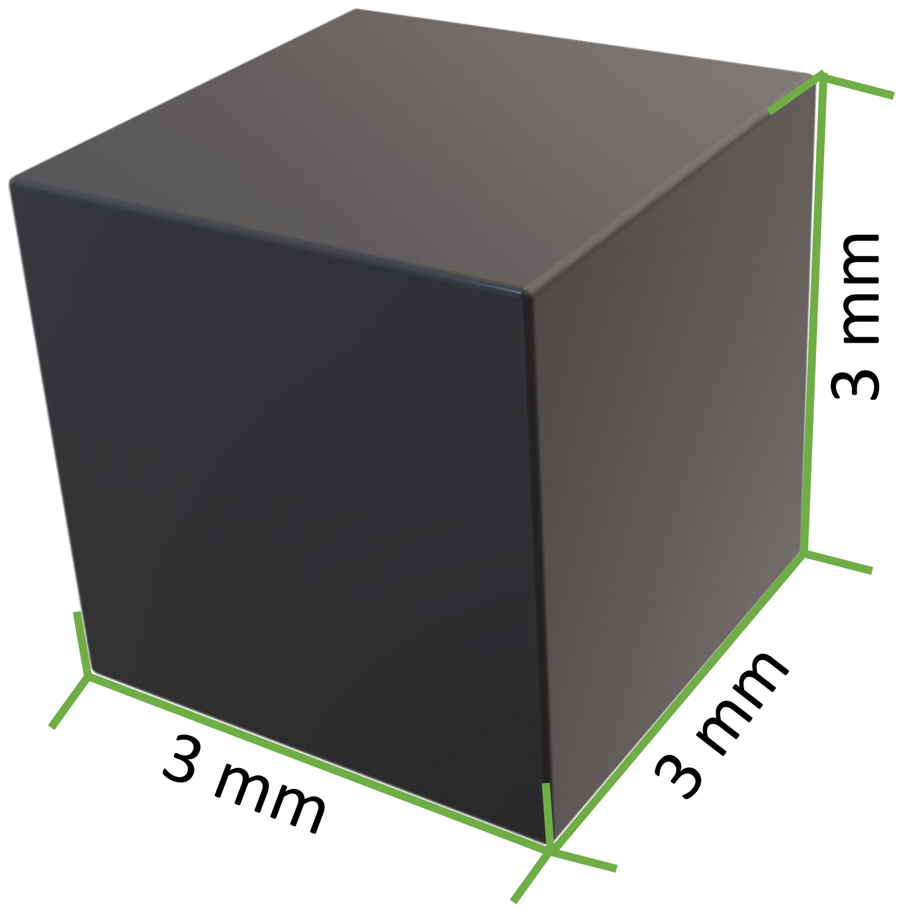


Fabrication

START: 3 mm^3 cube of UD LM-PAEK thermoplastic composite laminate

1. Precision diamond saw to cut rough columns
2. Pillars were FIB-milled out of the columns
3. Ga FIB milling in multiple steps to make final pillars

END: ~30x30 μm^2 by ~70 μm tall pillar



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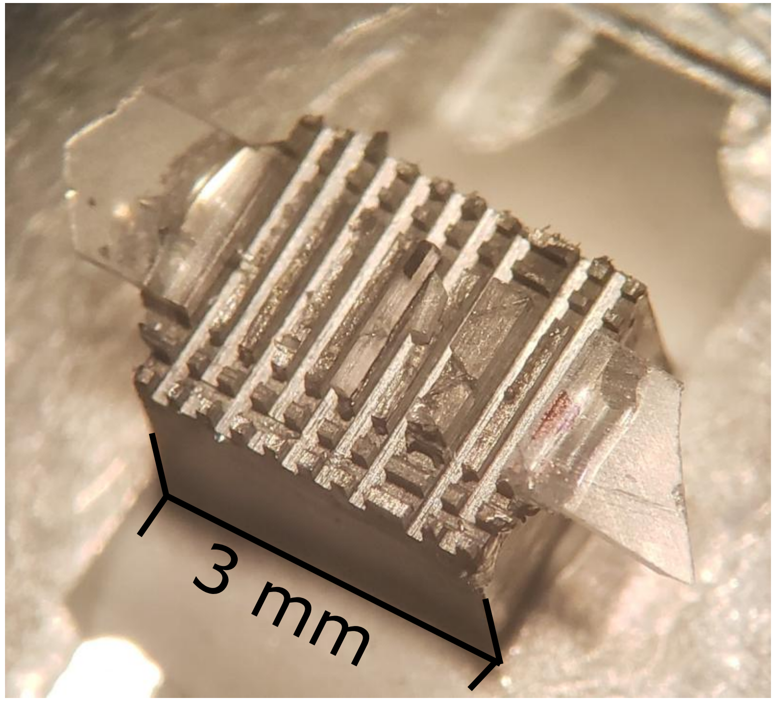

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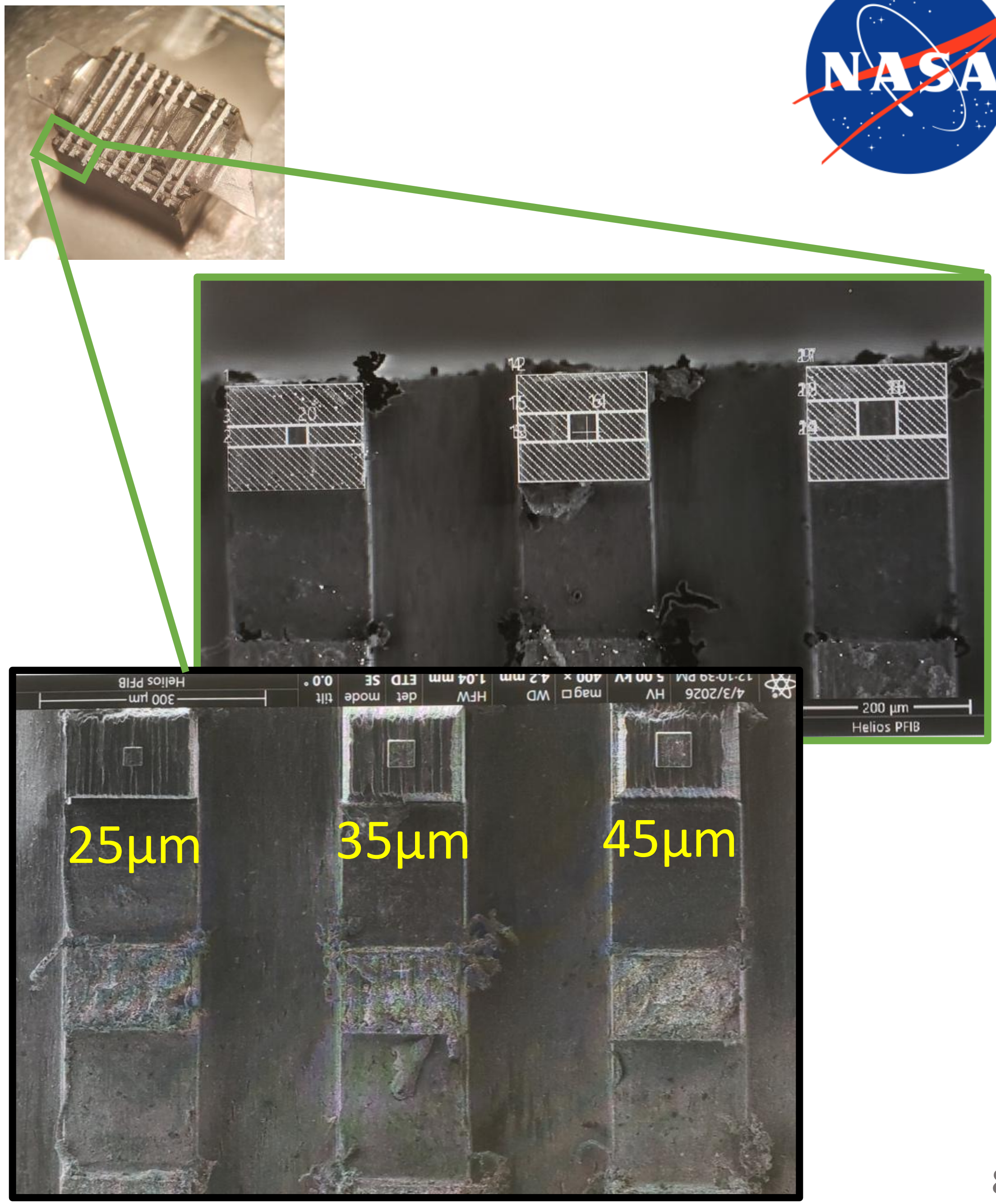

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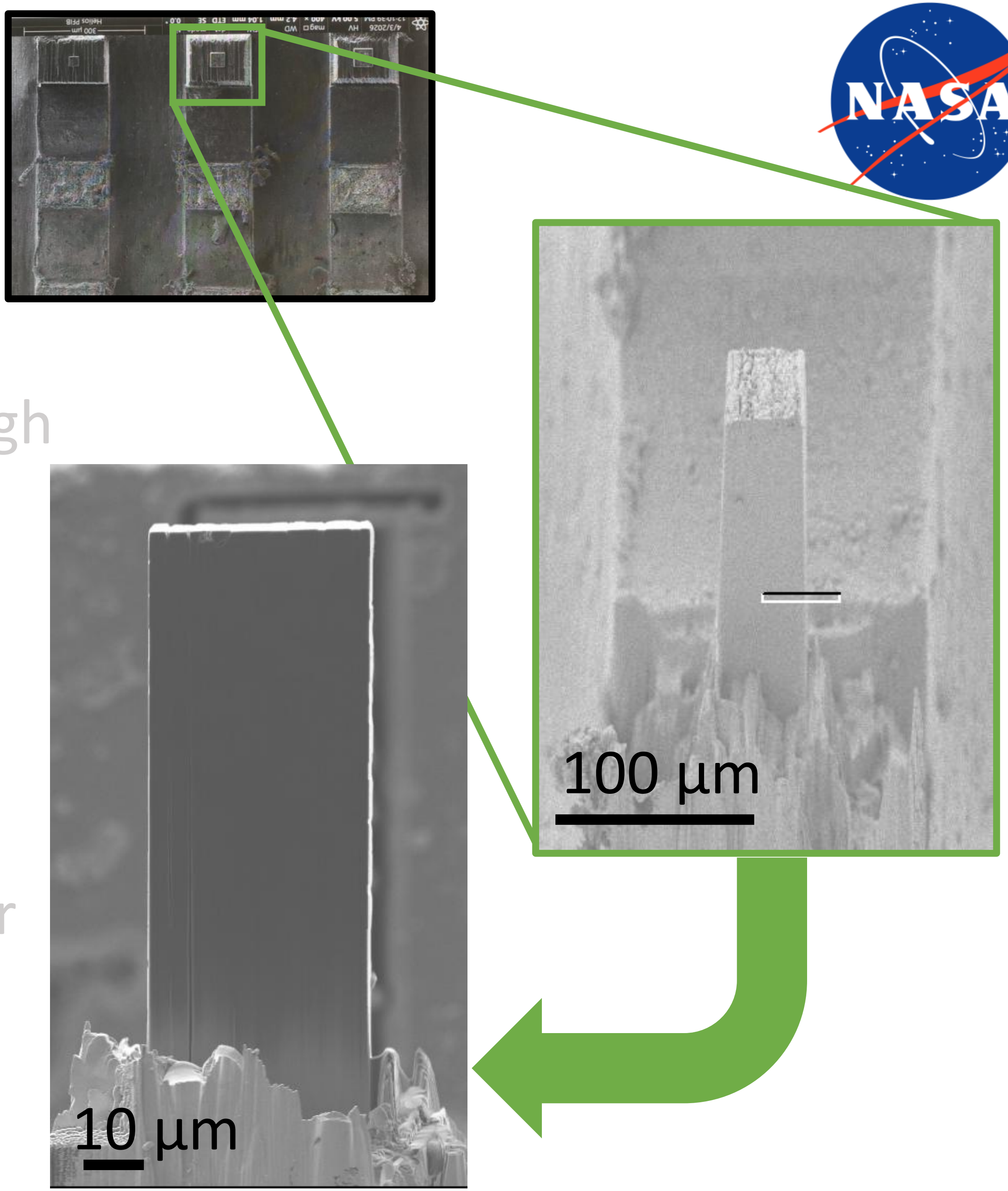

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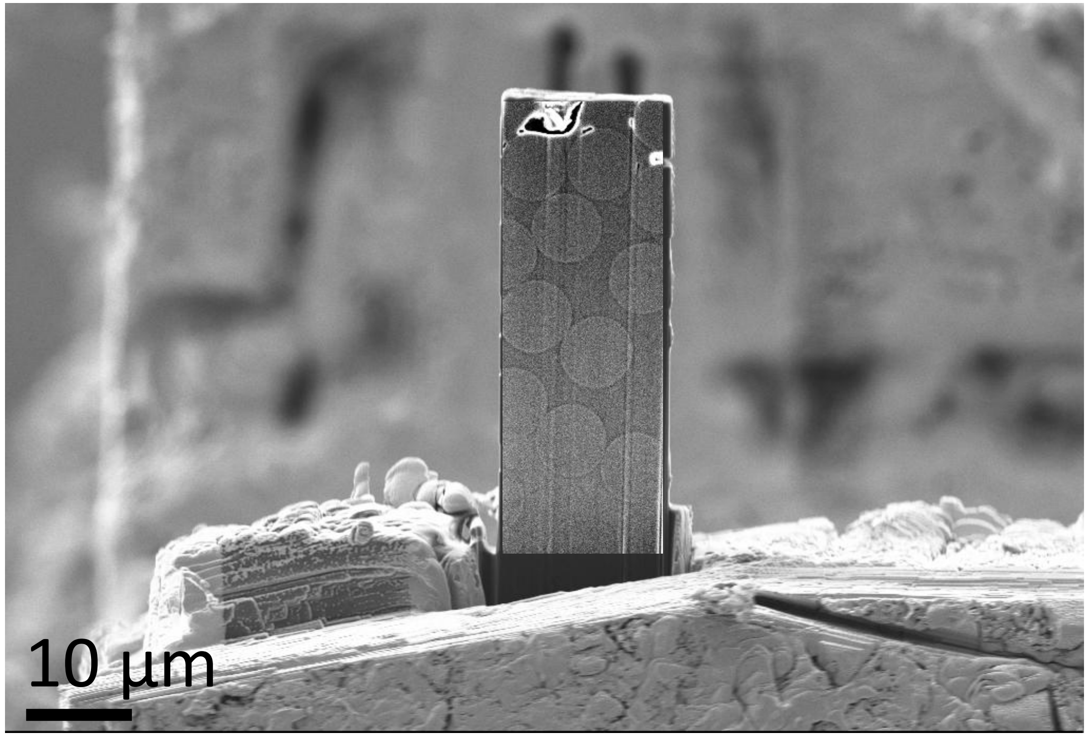
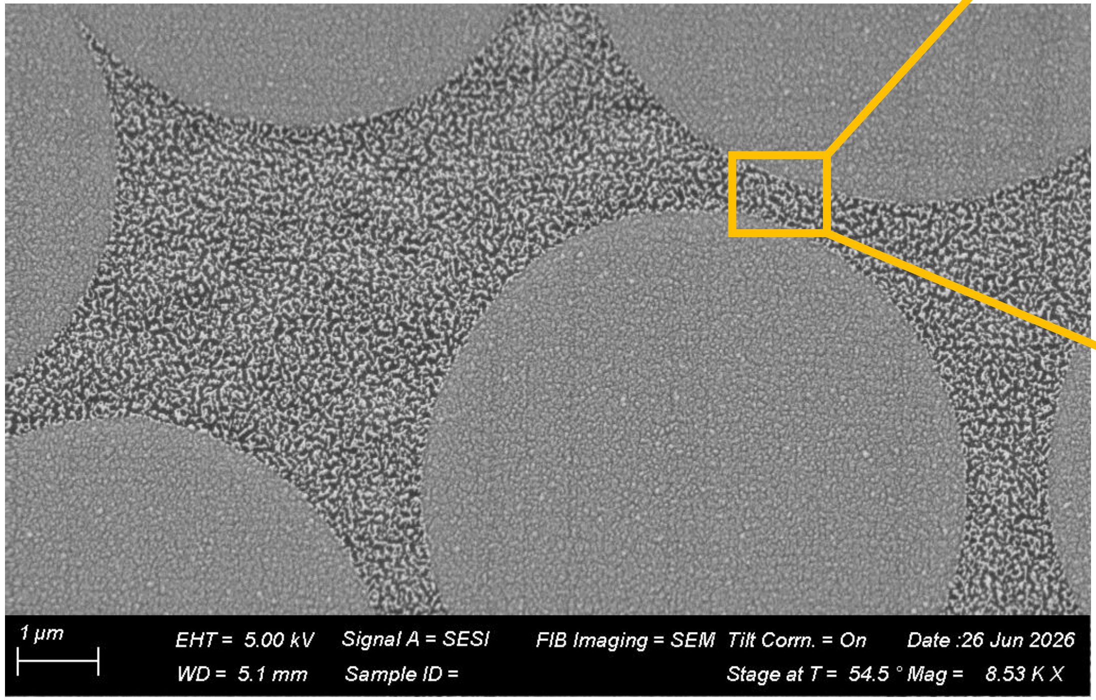
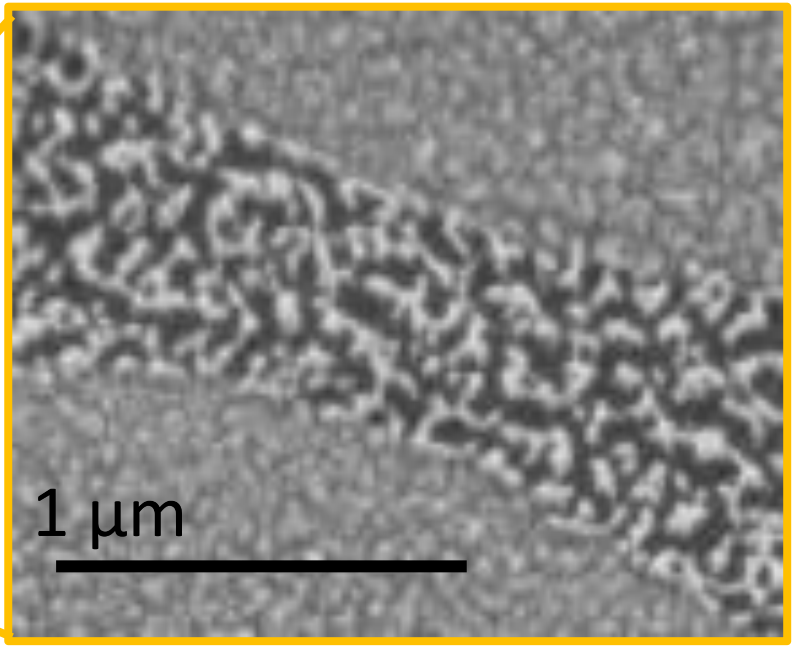


Digital Image Correlation (DIC) Patterning

- Sputter Pt on surface of sample
- Mill away to leave random islands of Pt
  - Low current on Ga FIB
  - Short time bursts until desired pattern achieved

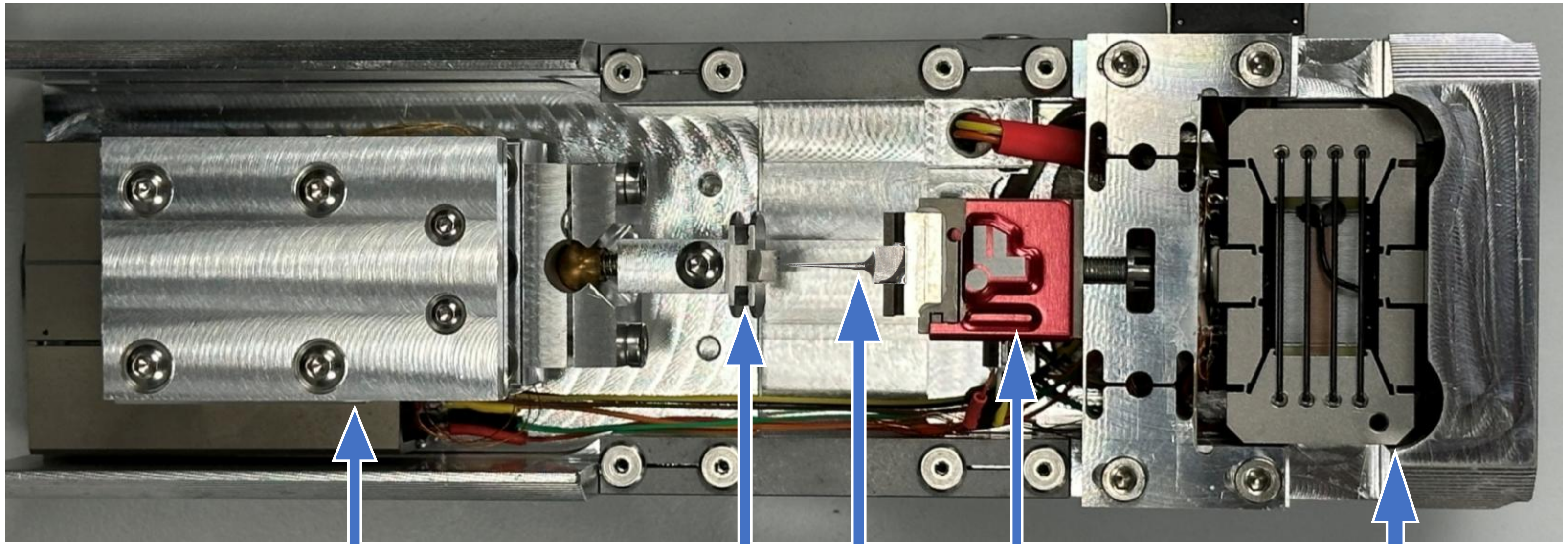




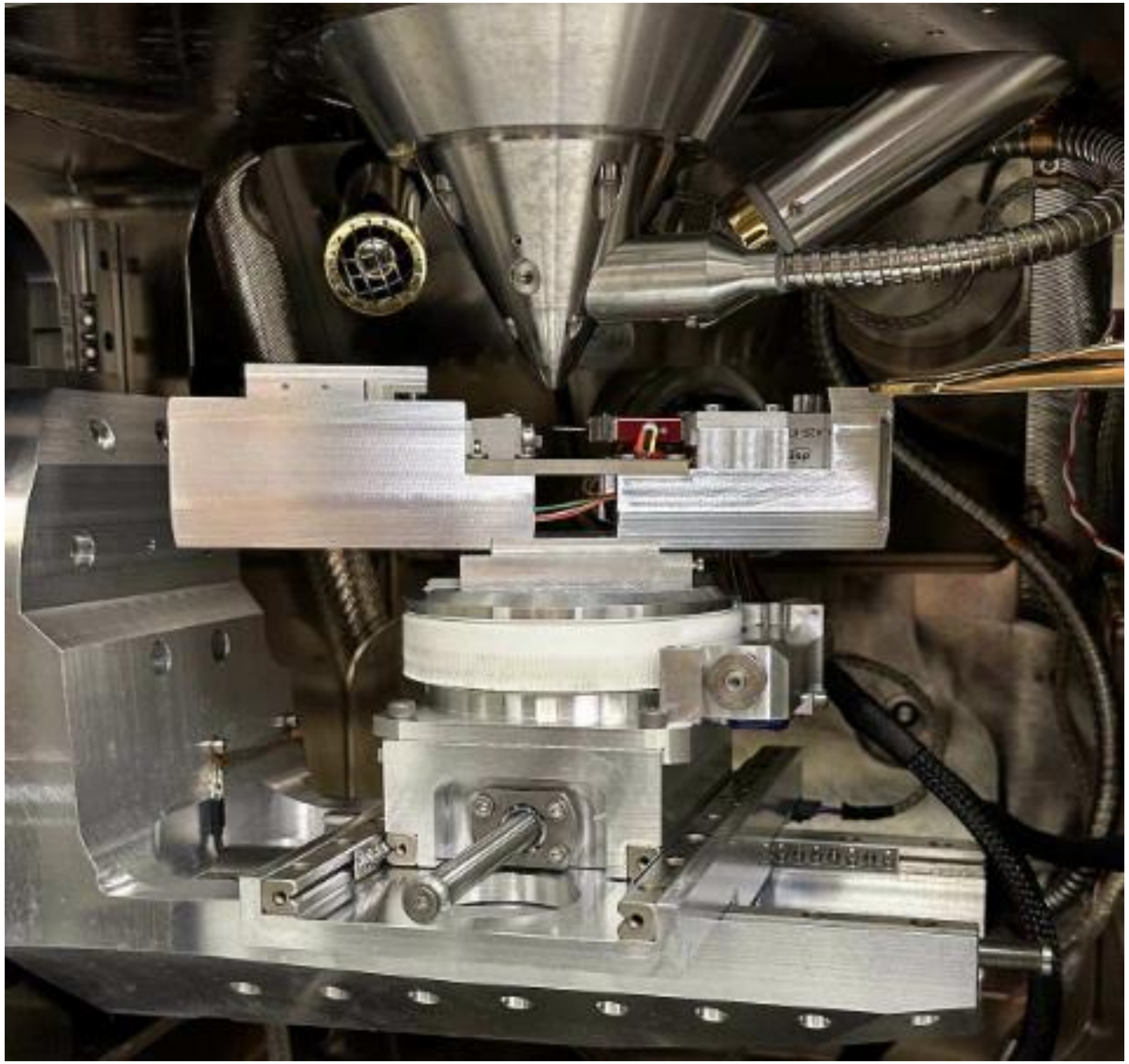
National Administration for Space and Aeronautics. Micro-Speckle for Digital Image Correlation Using Focused Ion Beam. LEW-20922-1, https://invention.nasa.gov/prog/php/topdf.php?rid=1770755687, last accessed 2026/7/21.

Testing: What's Doing the Crushing

- A custom-built piezoelectric actuated micromechanical testing rig built by MicroTesting Solutions LLC



Testing: How the Crushing Happens



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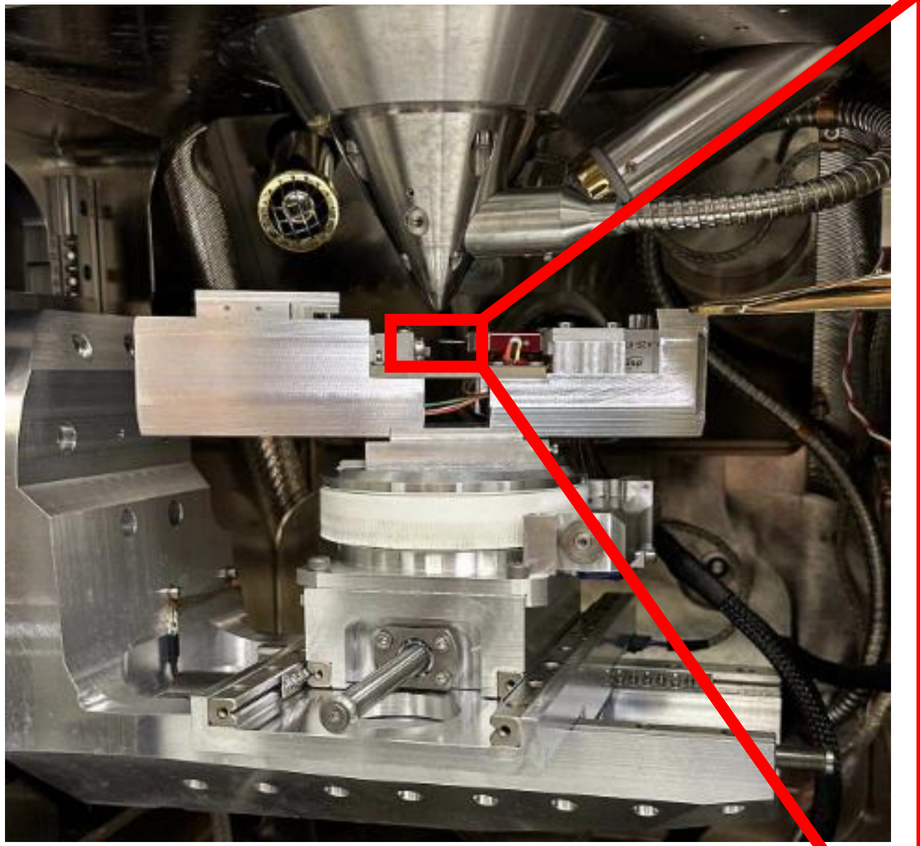
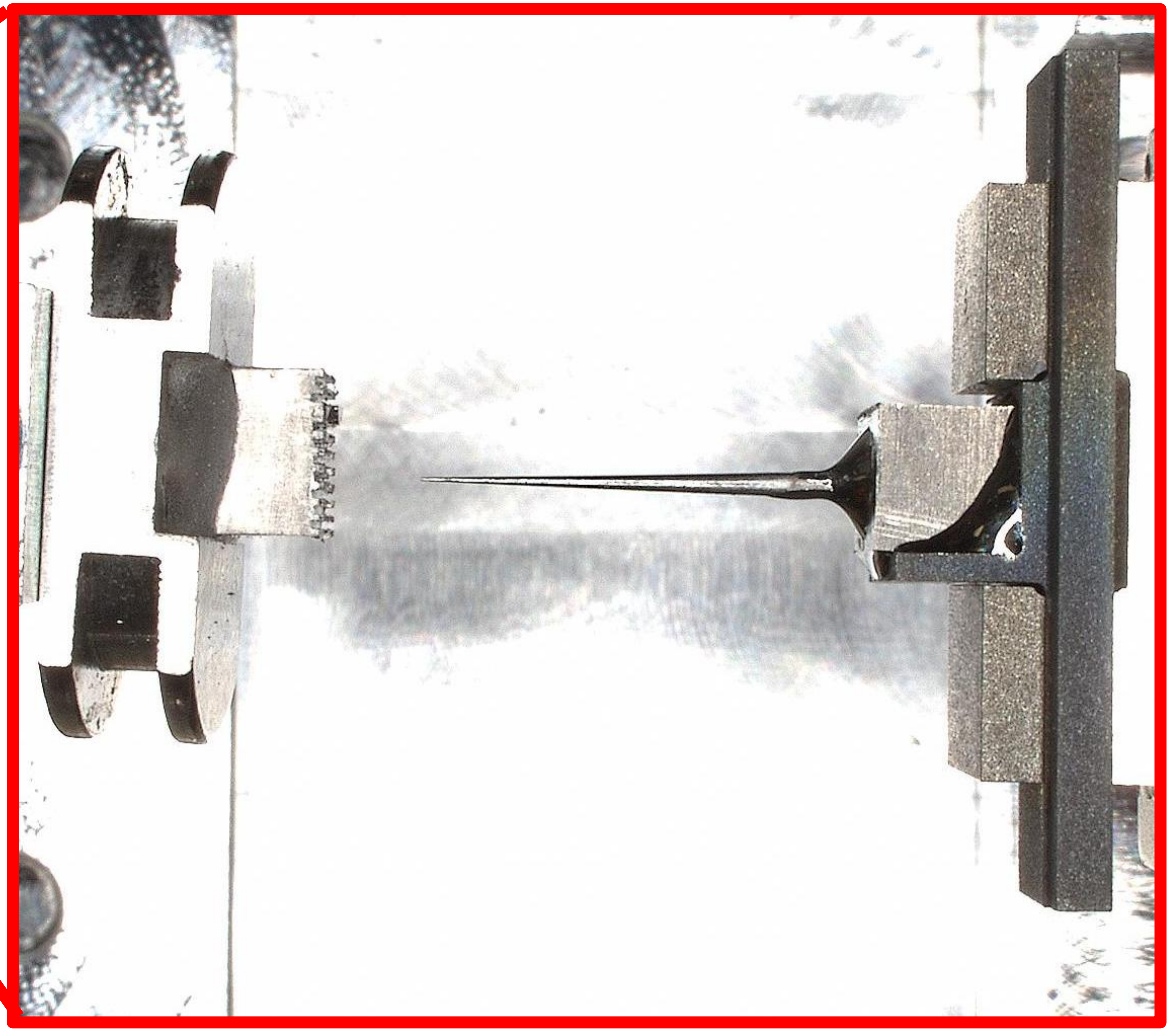
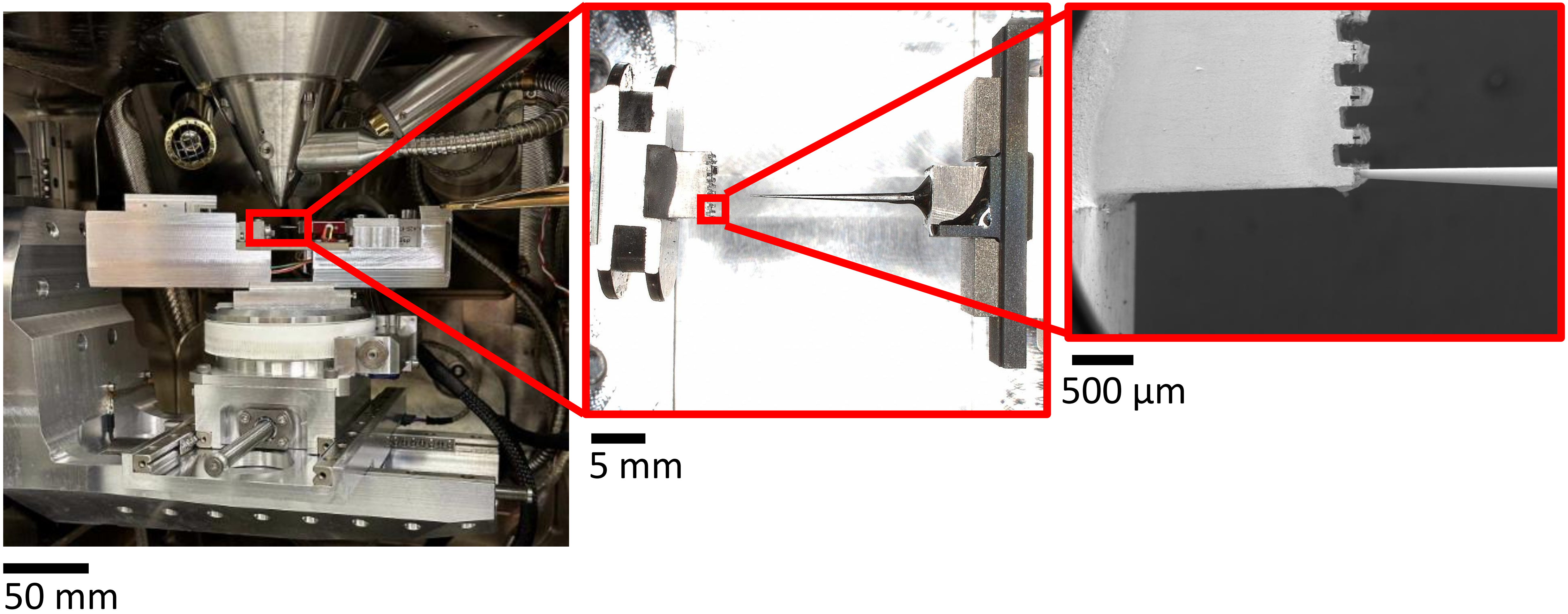


50 mm



5 mm

Testing: How the Crushing Happens



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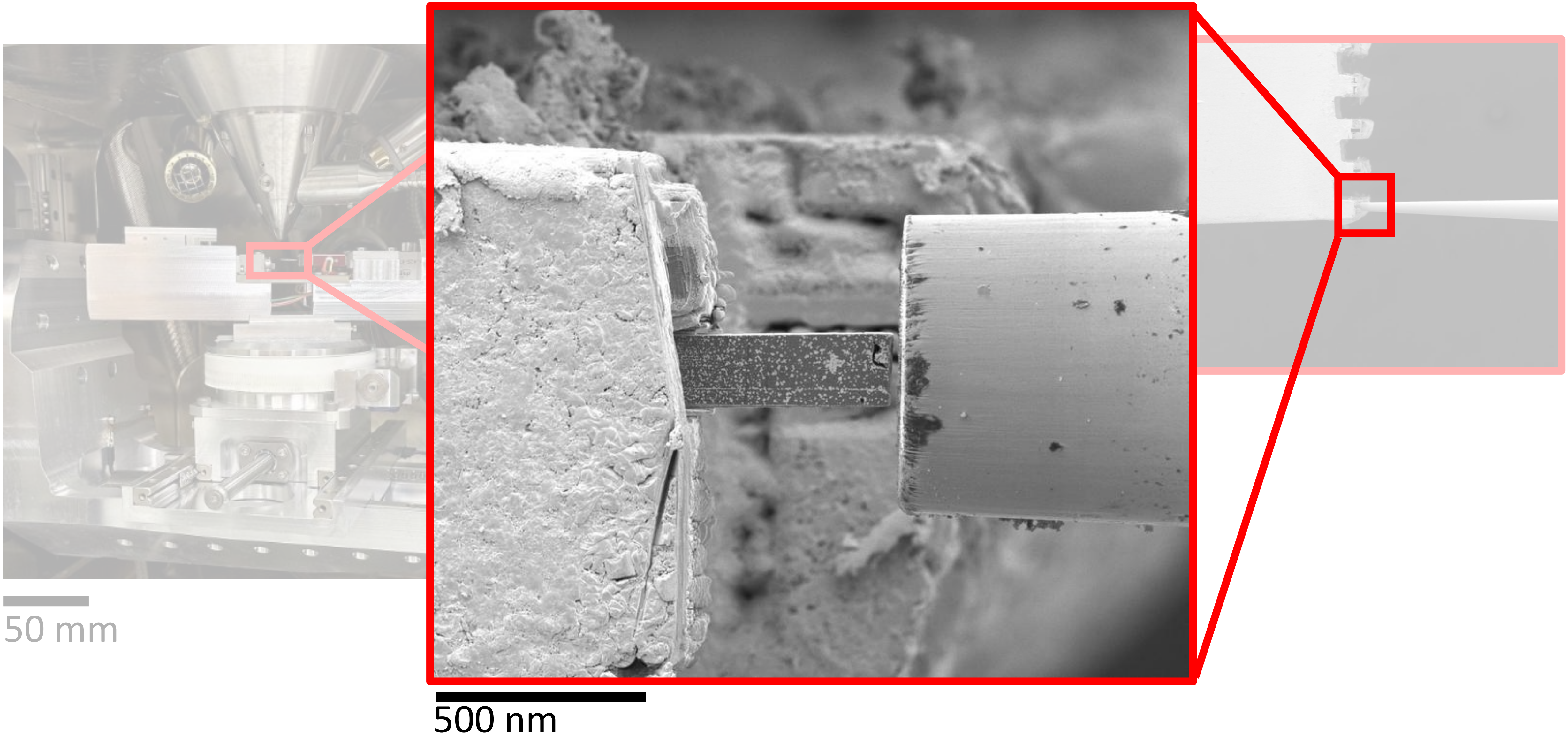
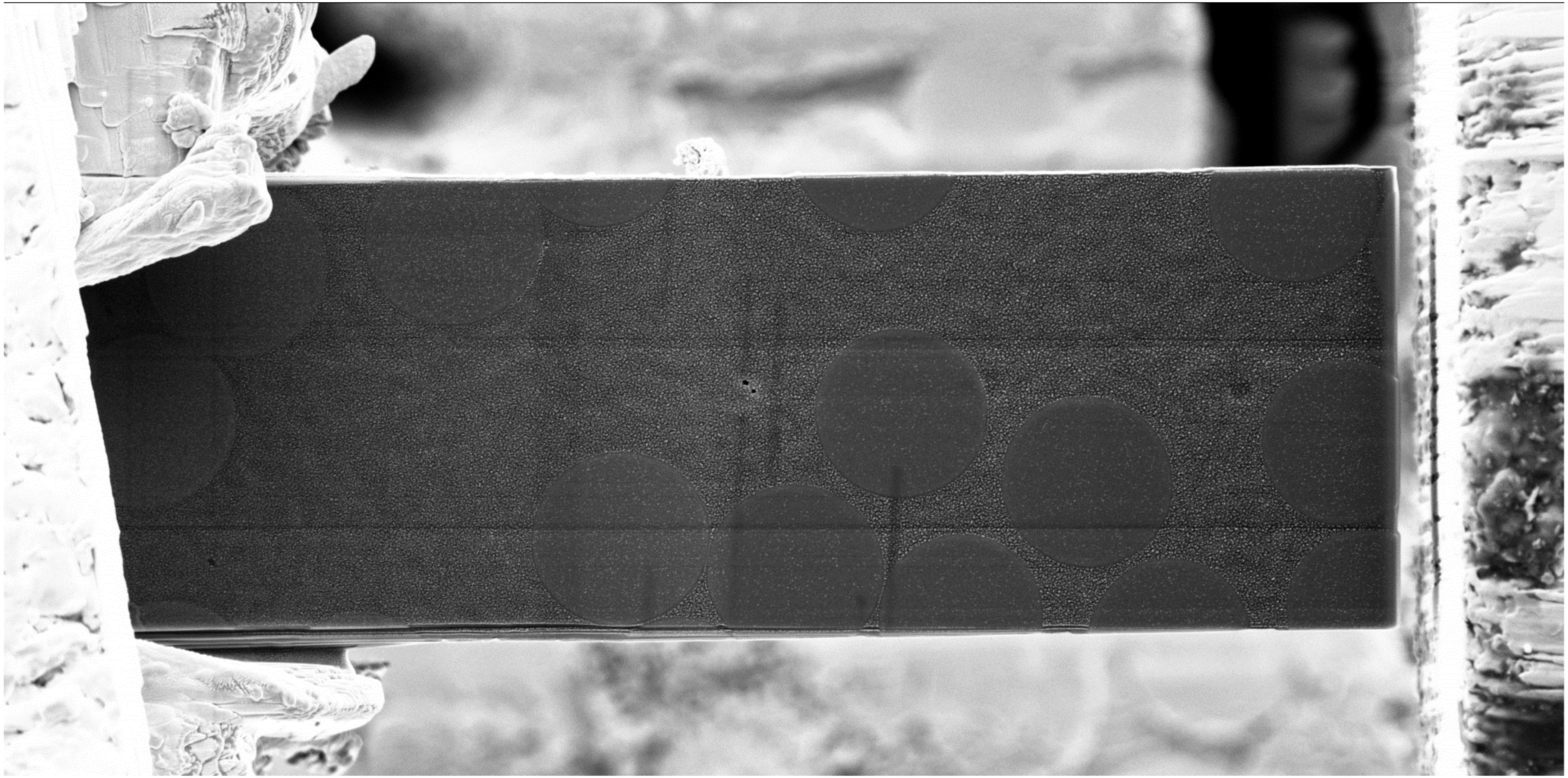
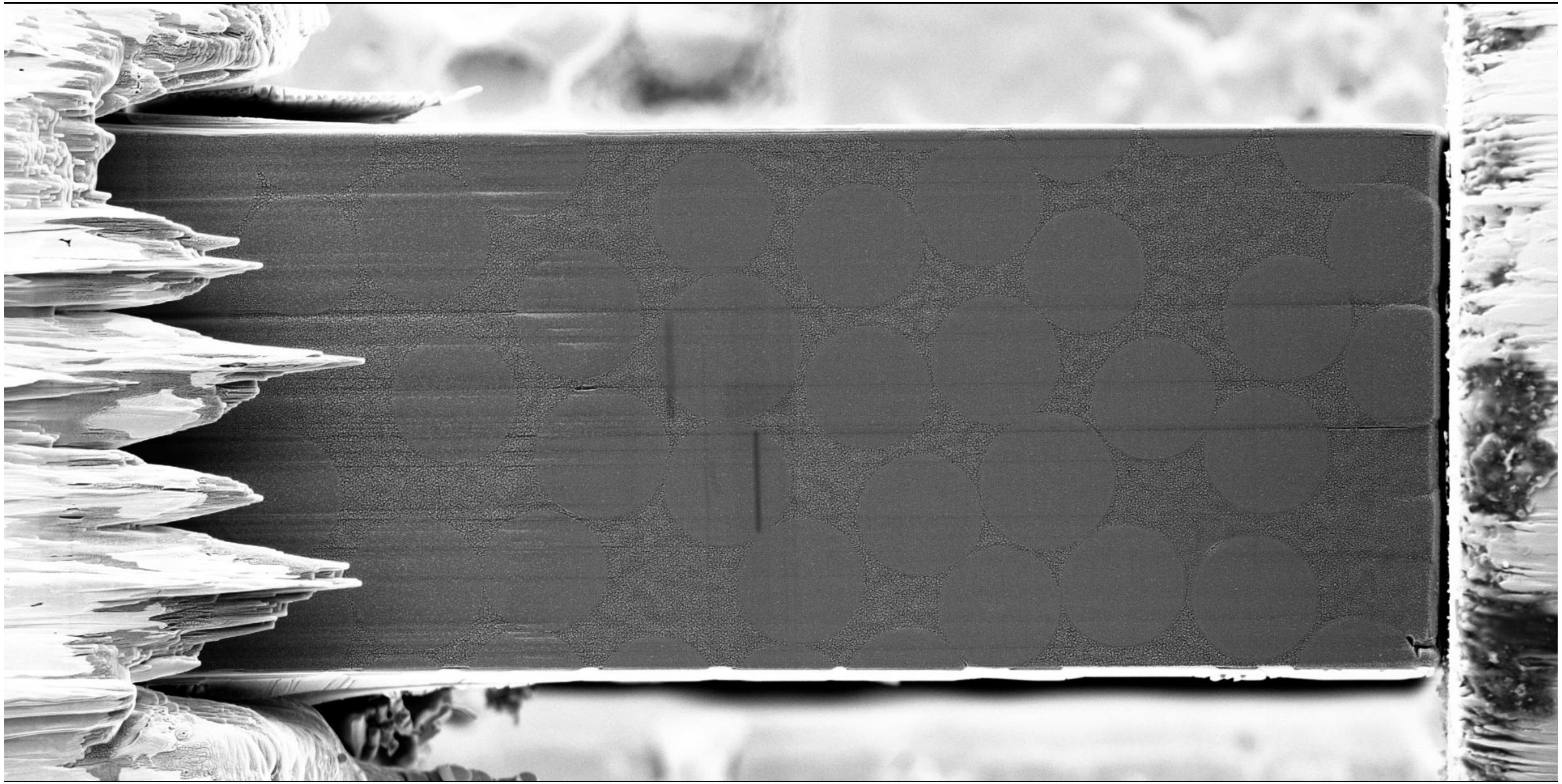


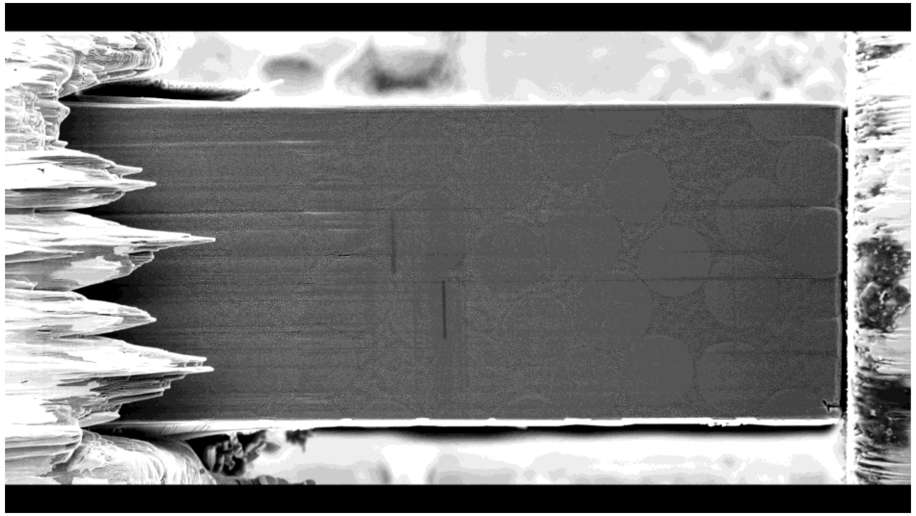
Testing: The Crushing

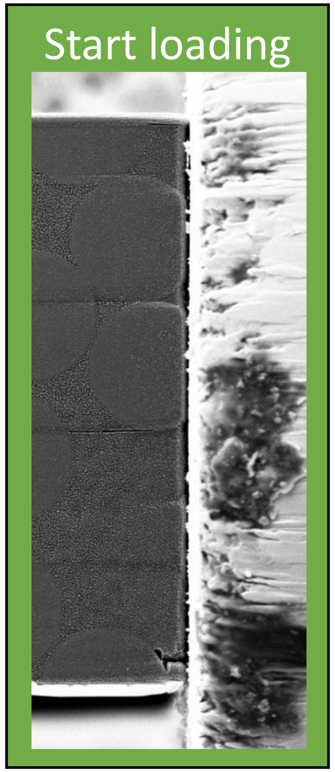


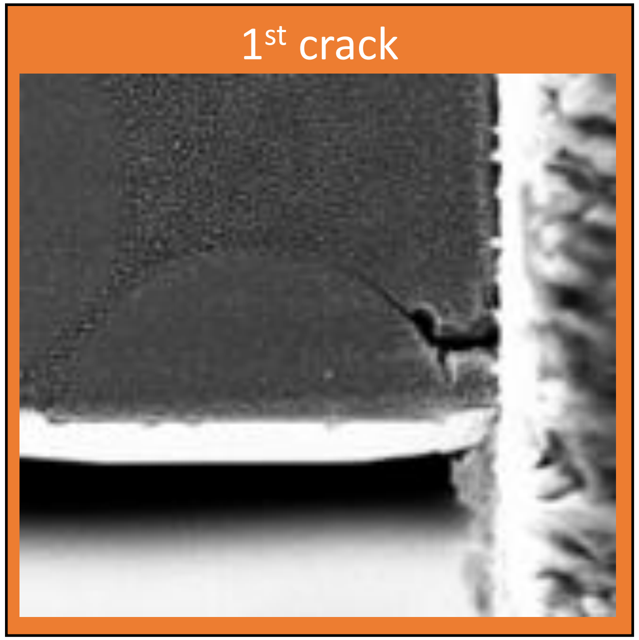
Testing: The Crushing (another)

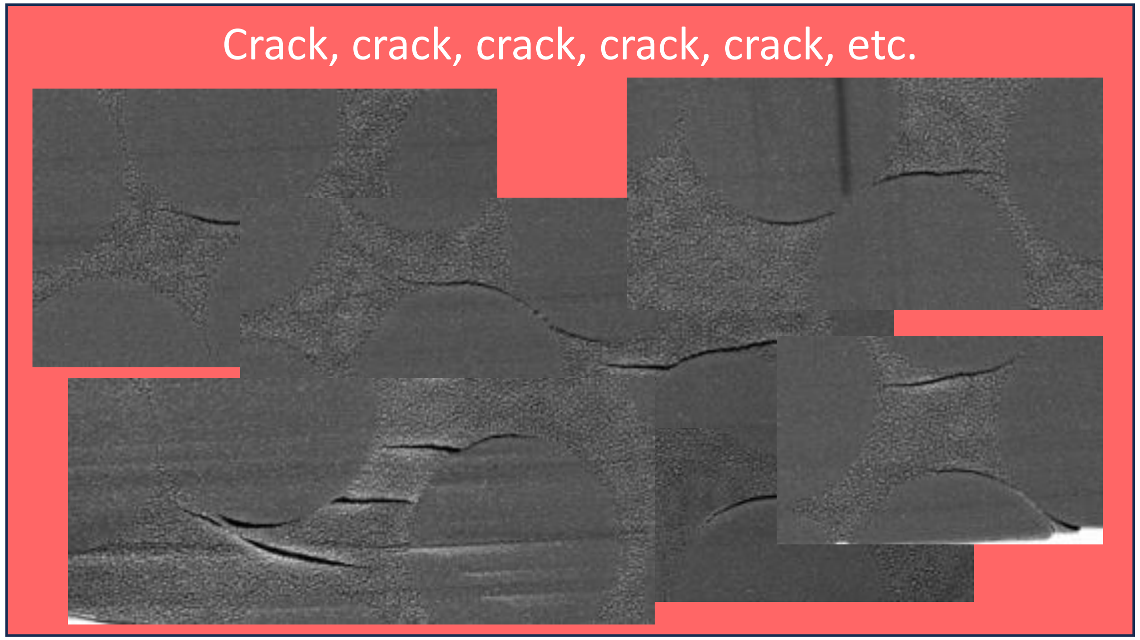


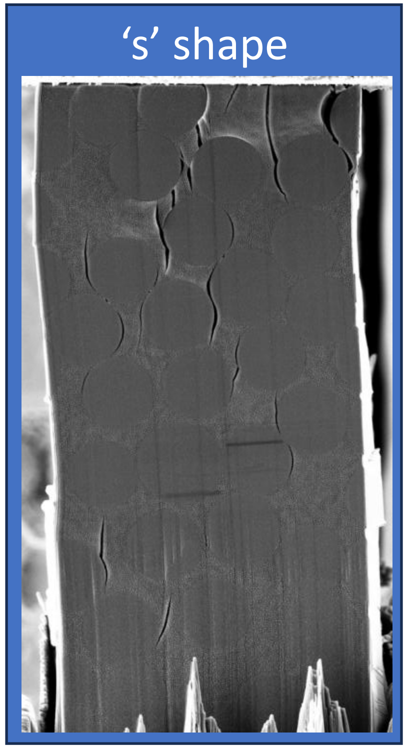
Testing: The Crushing (plus highlights)





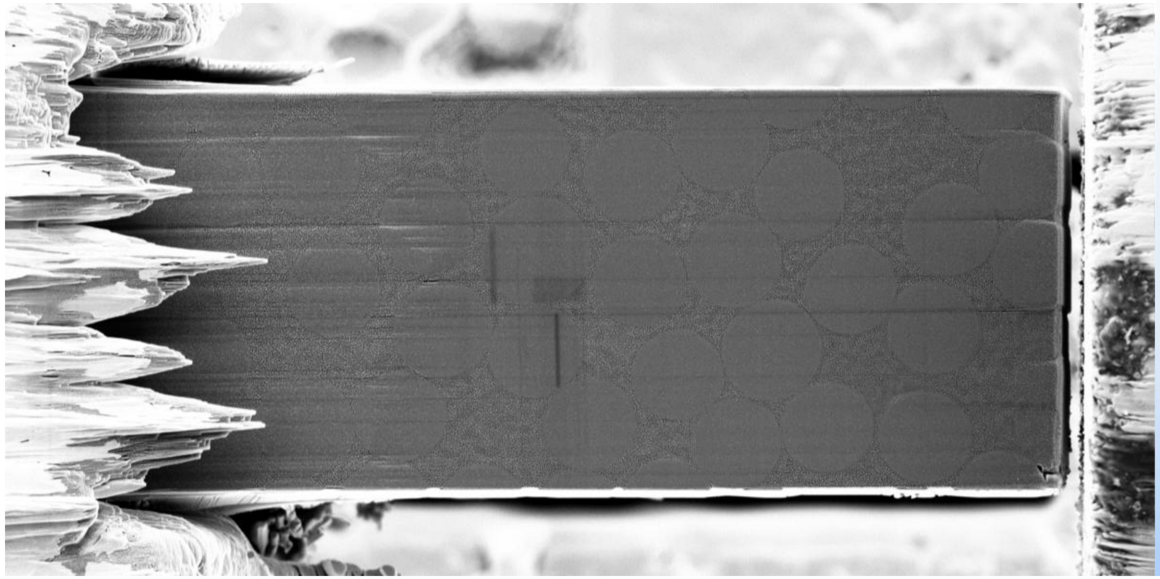


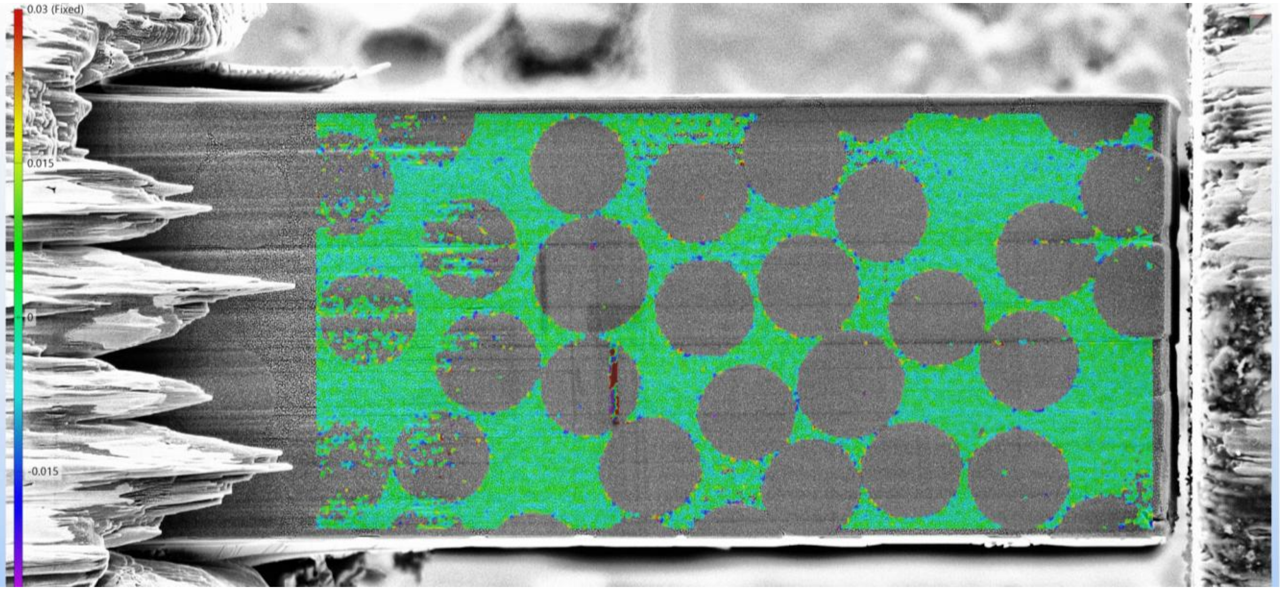




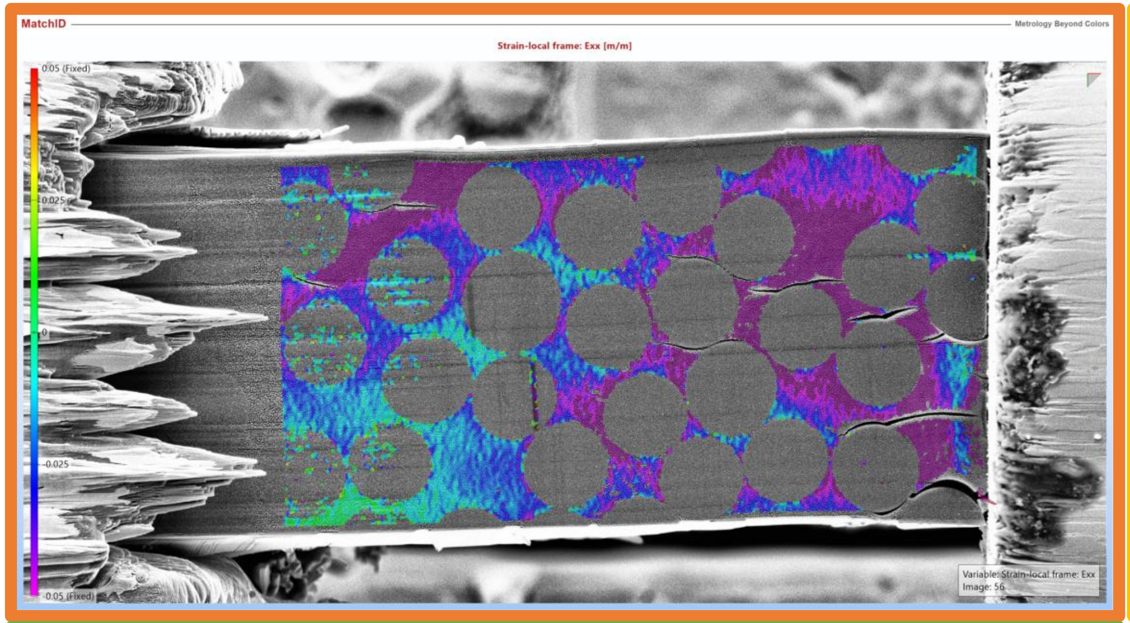
Measure: DIC and ML

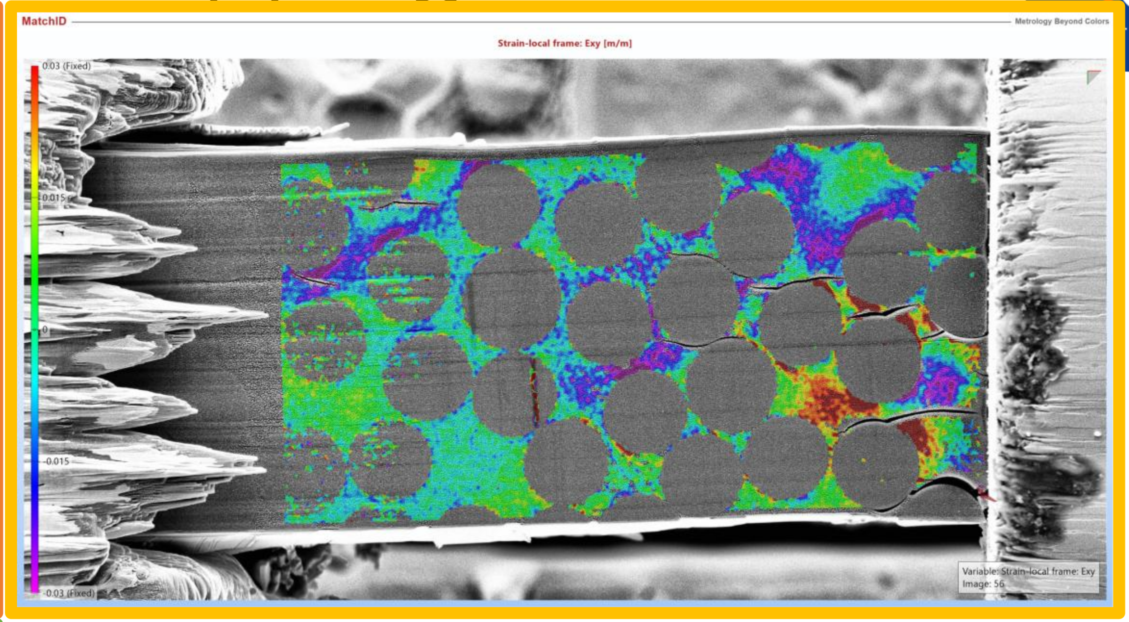
- Using DIC to observe strain in x-y direction

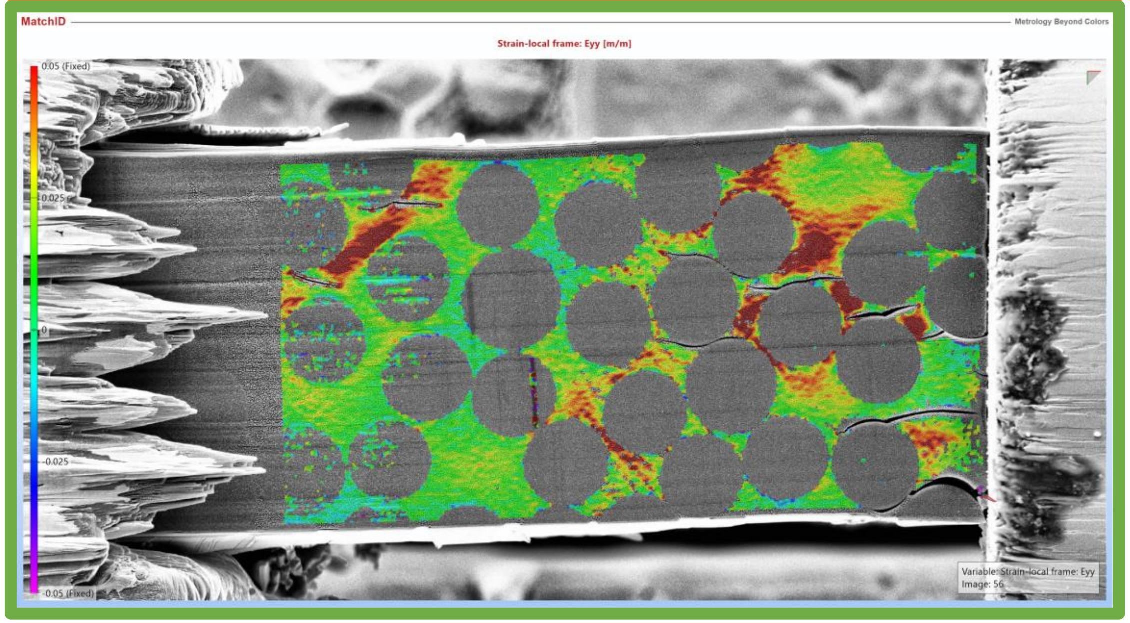




Multi-directional Strain Mapping

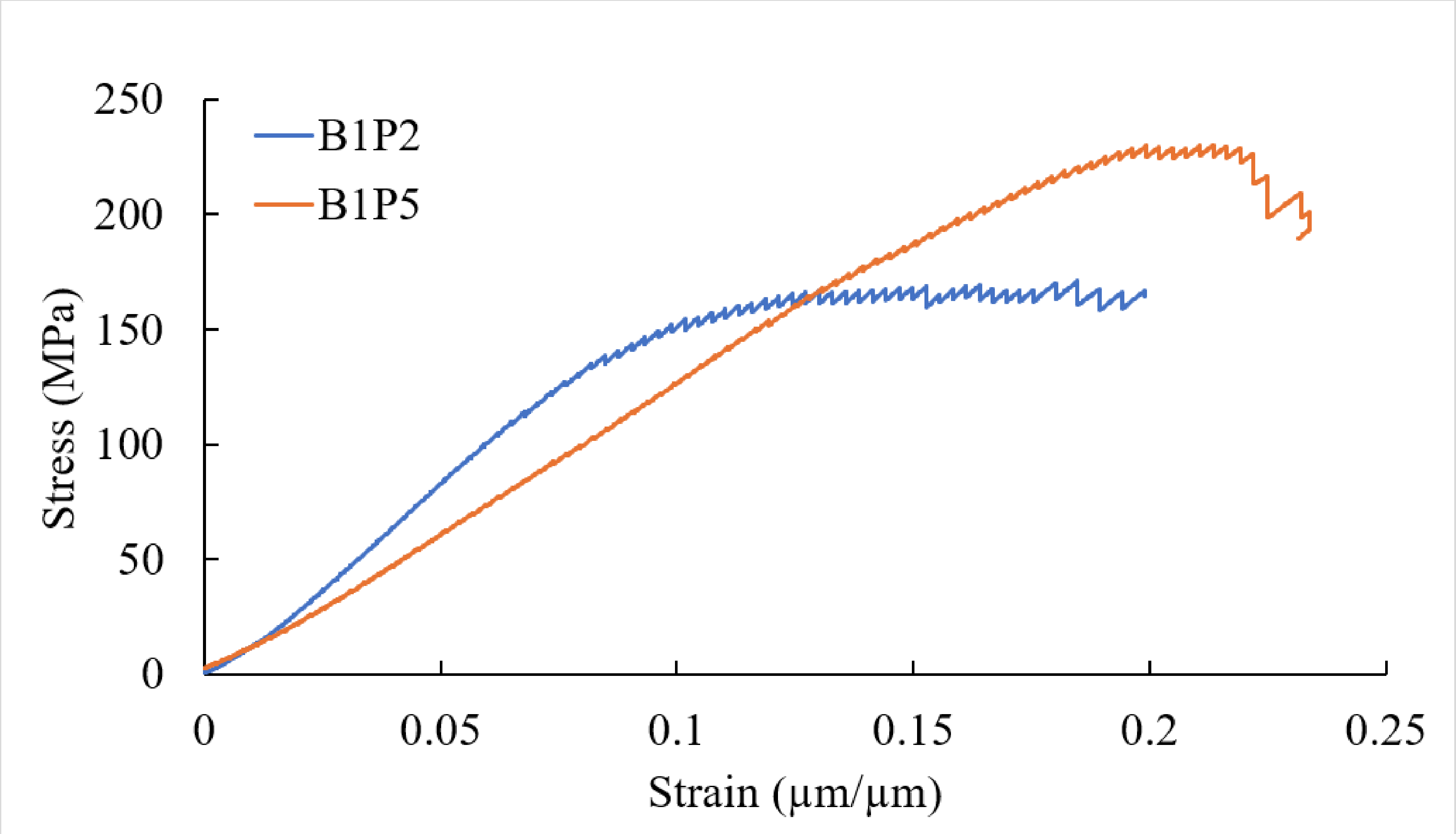






Using DIC to measure strain in x-x, x-y, and y-y

Stress Strain Response



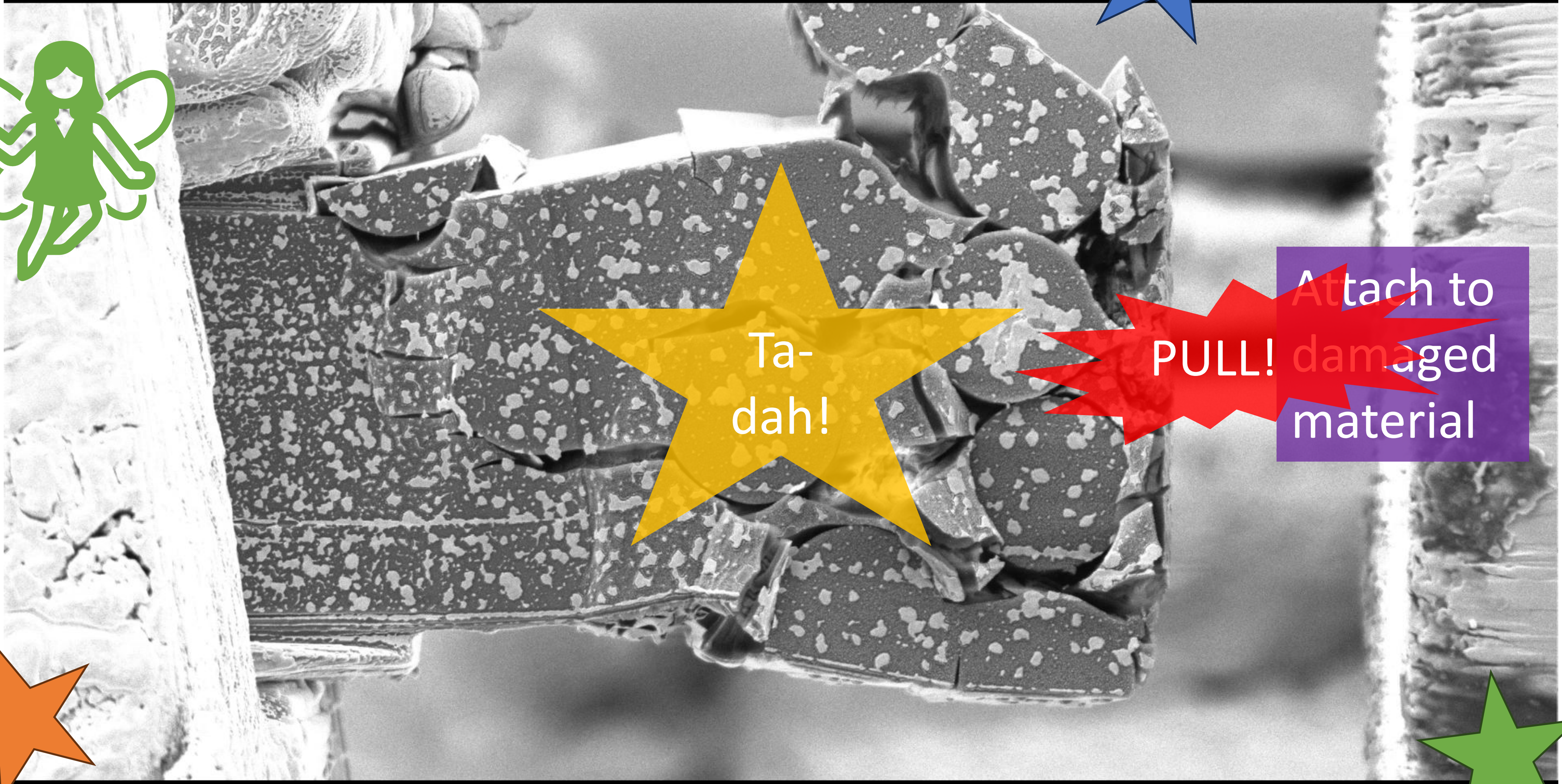
Batch 1 Pillar 2:

16 µm x 19 µm x 43 µm

Batch 1 Pillar 5:

26 µm x 30 µm x 70 µm

“Indefinitely” recyclable



Summary and Next Steps

- Successfully fabricated and tested micropillar specimens
- Developed a novel speckle patterning technique to acquire nano-sized speckles
- Successful in capturing local strains within the matrix using DIC
- Developed a test procedure for testing micropillar composite specimens in compression
- Next:
  - Tension and 3-point bend testing
  - Ceramic matrix composites (CMCs) and welded thermoplastic composites

Questions?

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