

Mechanical Property Variation in Metal Lattice Struts

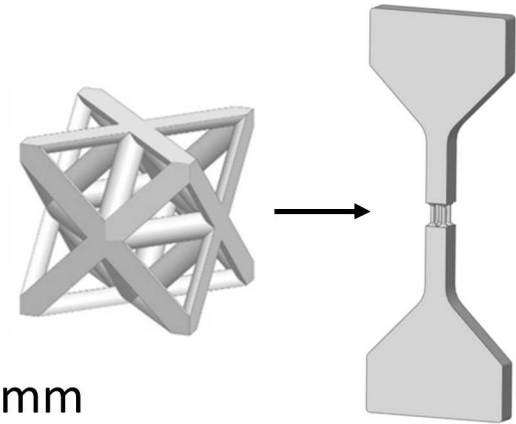
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Department of Mechanical Engineering
The University of Texas at Austin

GOAL

Improve the understanding of how defects impact mechanical properties to enhance designers' ability to manufacture metal lattice structures reliably.

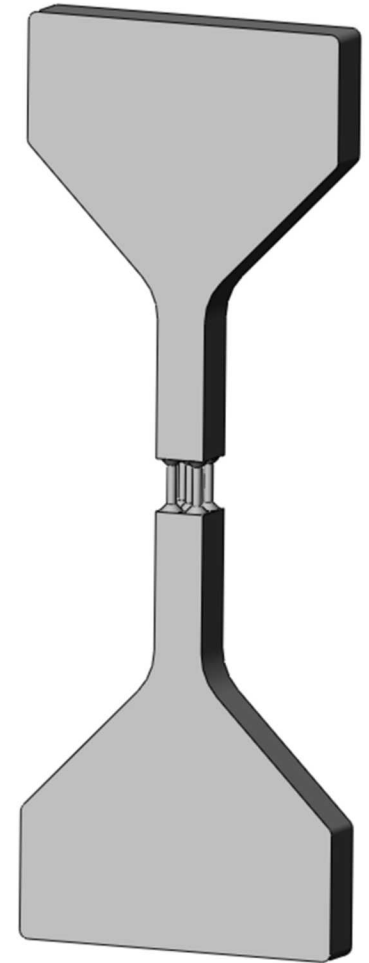
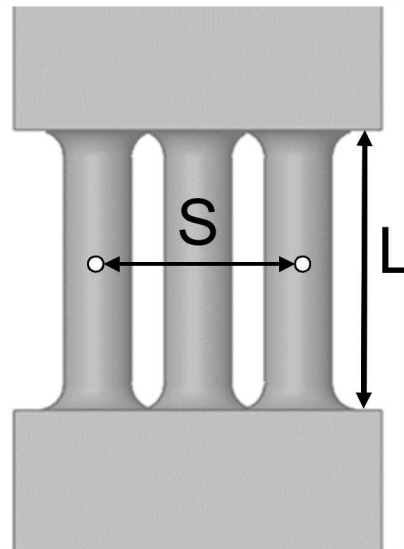
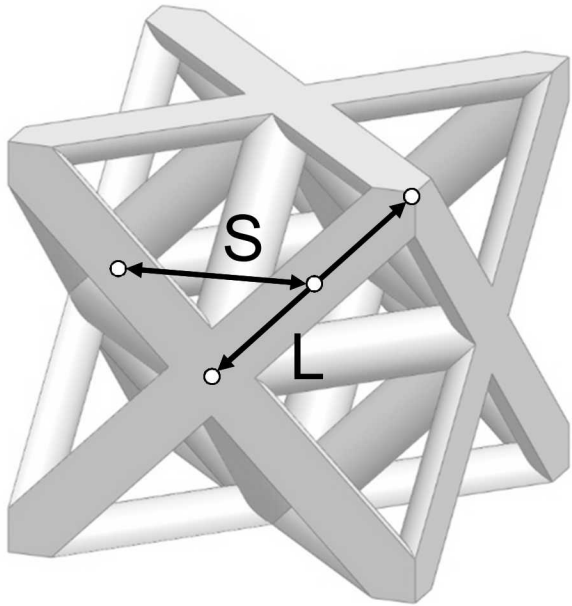
Overview

- Evaluate properties of lattice struts
 - EOS M270
 - Stainless steel 17-4 PH powder
- Vary size and orientation
 - Strut diameters: 0.5 mm, 0.65 mm, and 0.82 mm
 - Vertical and horizontal build orientations
- Non-destructive evaluation of parts
 - Geometry characterization
 - Density measurements
 - CT scans
- Destructive evaluation
 - Tensile tests
 - Failure analysis

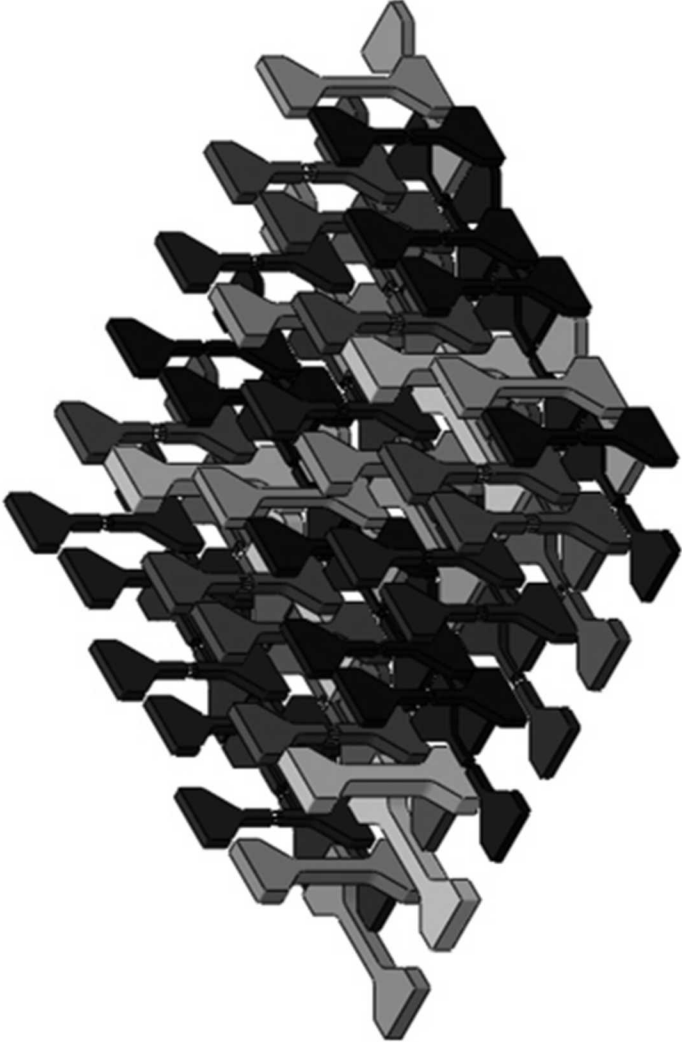
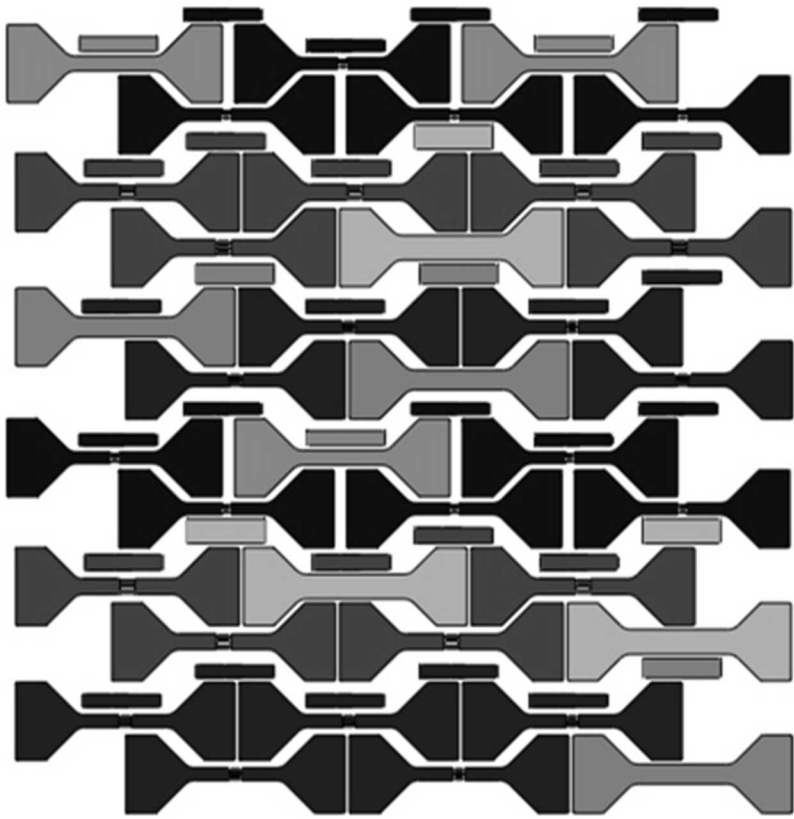


Vertical Strut Builds

- Spacing based on the octet truss design
- Horizontal and vertical copies
- Three different sizes (representing 3, 4, and 5 mm unit cells)



Build Layout



Build Process

1. DMLS the 17-4PH steel parts on an EOS M270
2. Heat treat while on build platform: Austenitizing by heating (solutionizing) to 1900°F for an hour, then air/oil cool
3. Remove from build platform
4. HIP with the following parameters: 2125±25 °F x 240±60 min x 14.75±0.25 ksi
5. Heat treat again: Austenitizing by heating (solutionizing) to 1900°F for an hour, then air/oil cool, and then complete the H1150 heat treatment.

NON-DESTRUCTIVE EVALUATION

Geometric Characterization

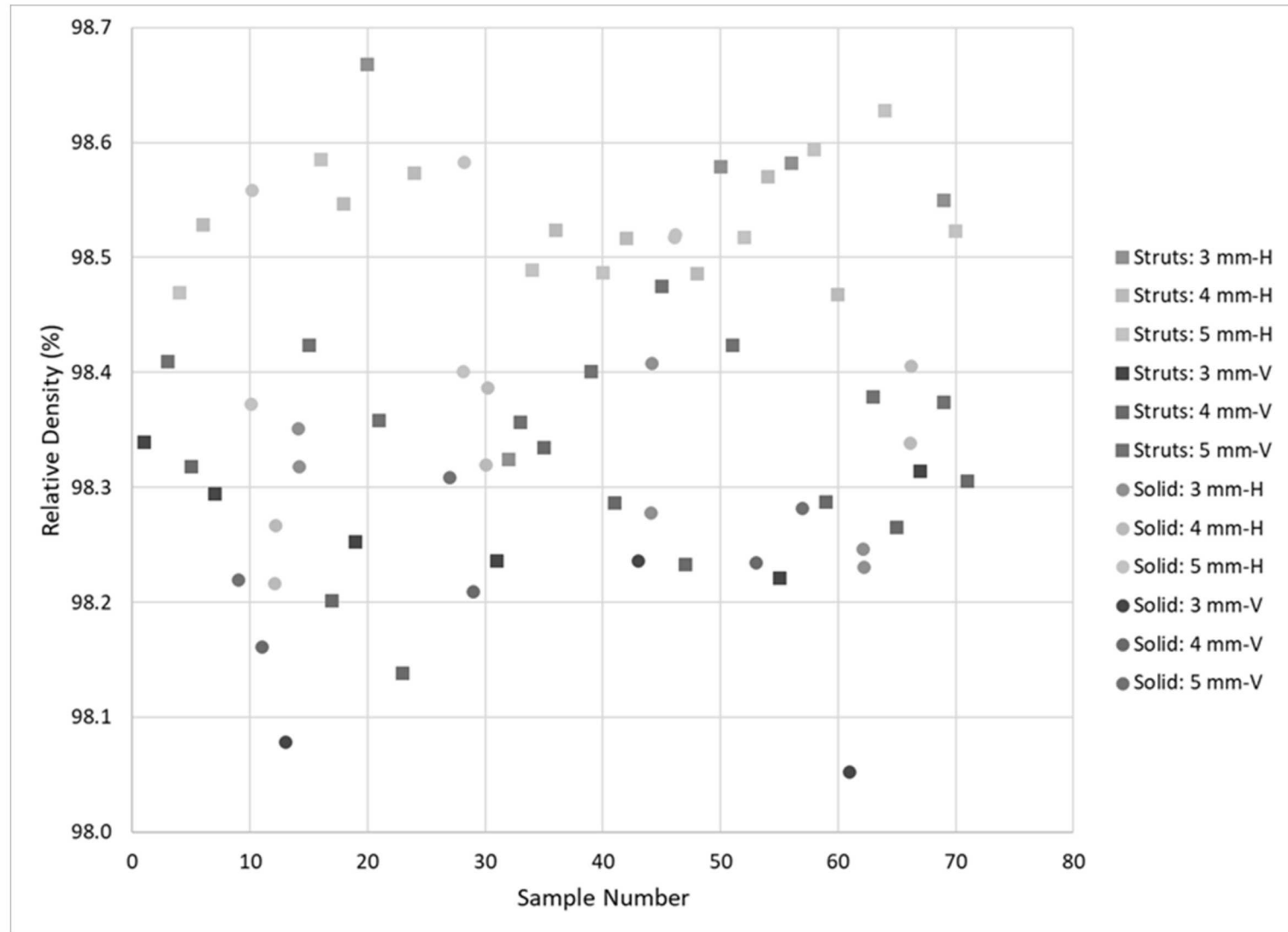
The screenshot displays a software interface for geometric characterization. The main window shows a circular image of a part with various geometric features and measurement lines. The features are labeled as follows:

- [1] ANGLE001
- [2] ANGLE002
- [3] LN-LN001
- [4] LN-LN002
- [5] LN-LN003
- [6] PT-PT001 [DIST]
- [7] ANGLE003
- [8] LN-LN004
- [9] LN-LN005
- [10] LN-LN006

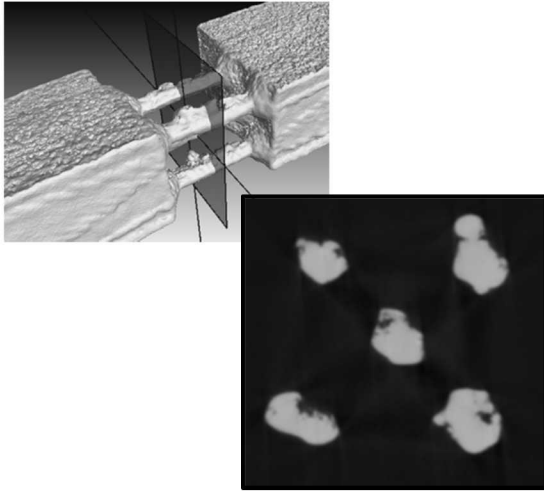
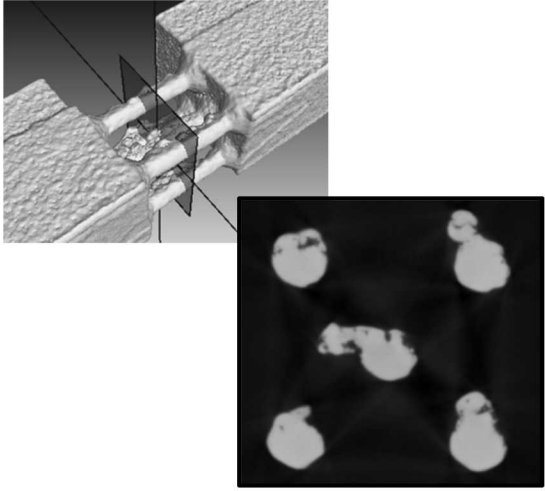
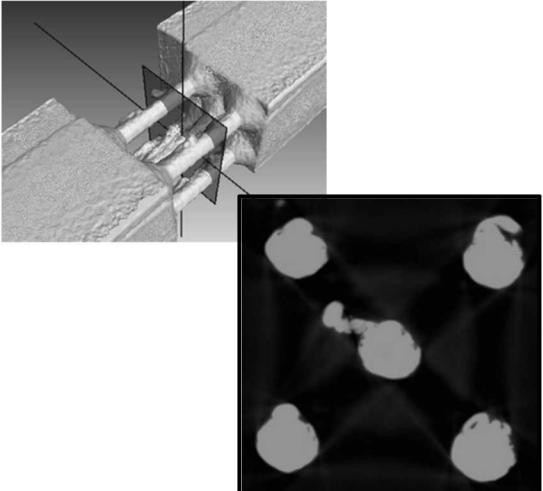
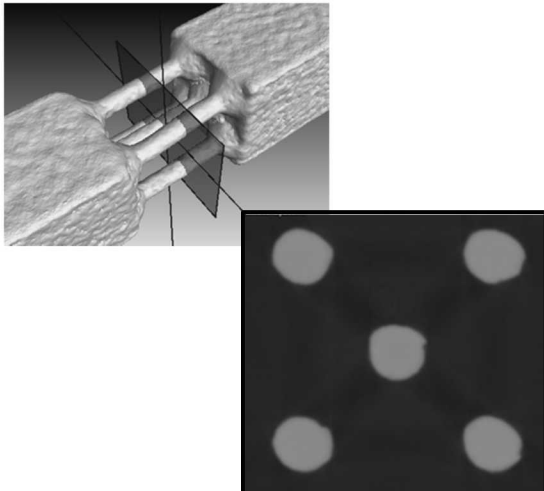
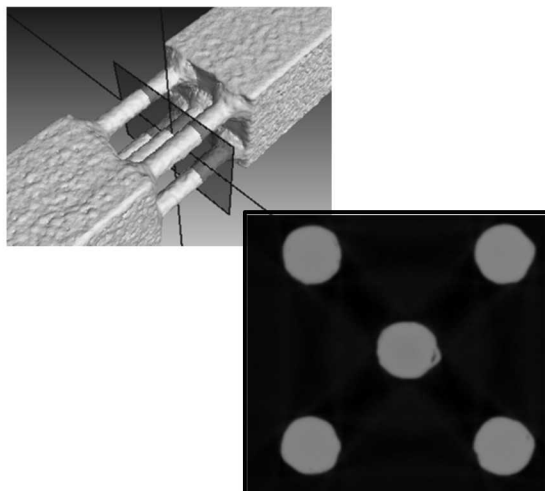
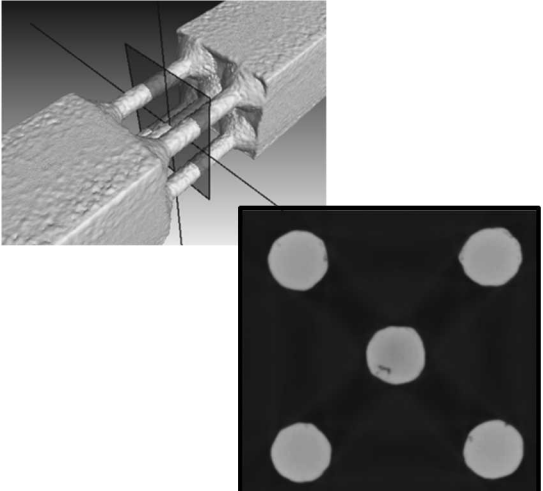
The right sidebar is titled "Multi Measurement Mode" and contains the following sections:

- Measurement Setting Data:** Includes a dropdown menu for "Dressler_Strut_5", and input fields for "Lot Number", "Serial Counter" (0001), and "Name".
- Measurement settings data thumbnail images:** A smaller version of the main measurement view.
- Options:** Checkboxes for "Zoom display" (checked) and "Display results in the descending order of errors" (unchecked).
- Buttons:** "Measure" (disabled), "Playing" (active), "Delete Result", "Print", and "Save Report".

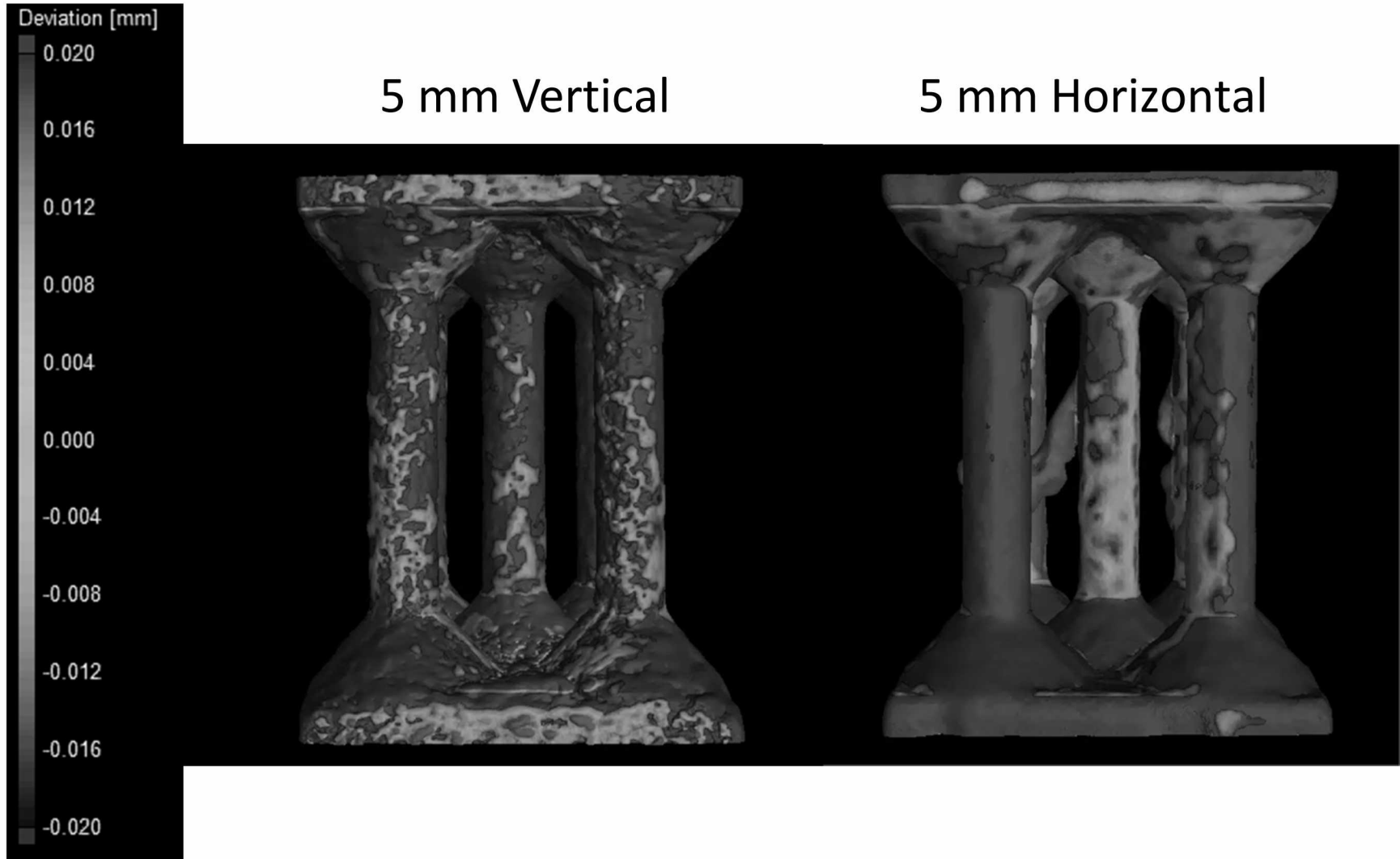
Density Measurements



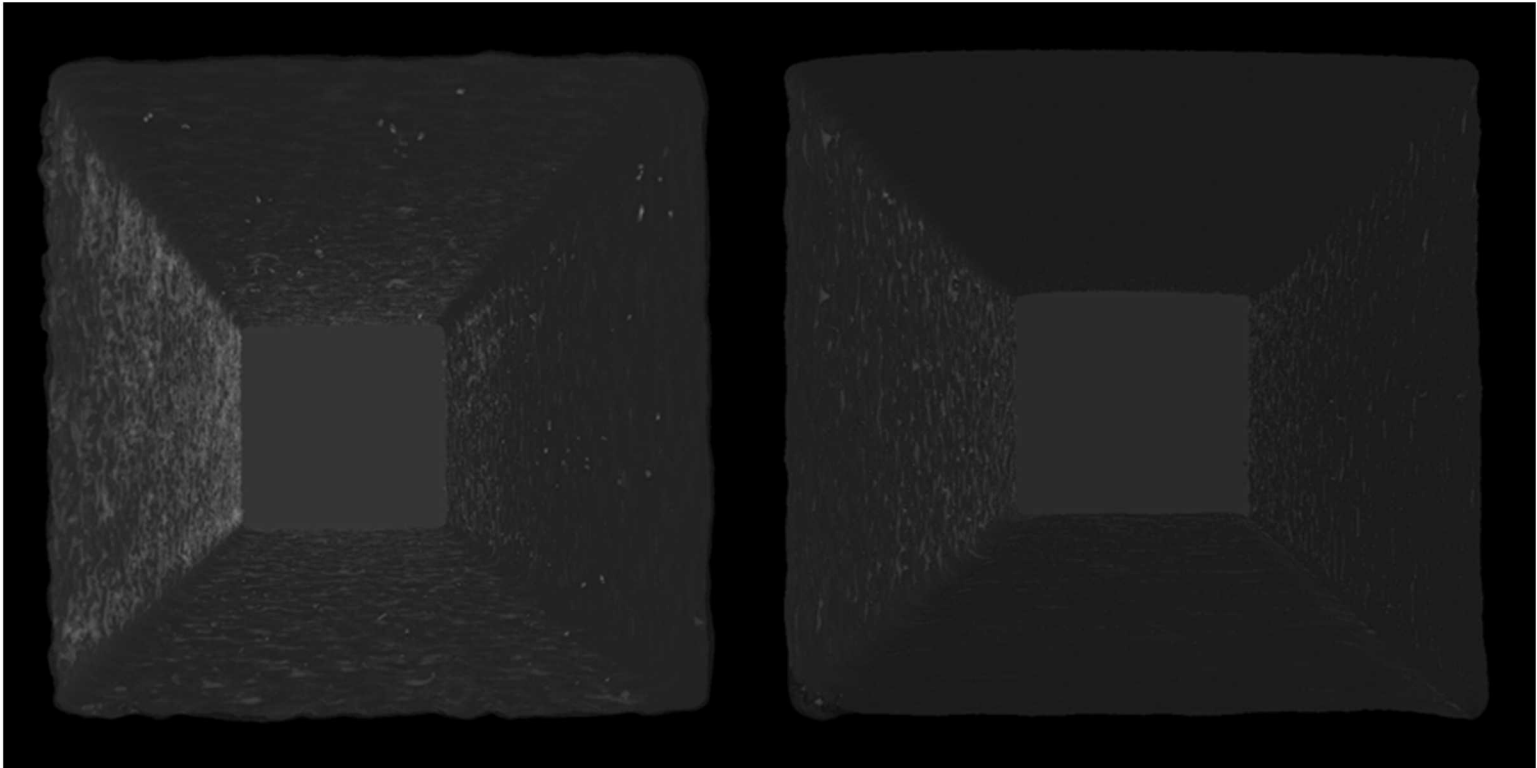
CT Results-Configuration Comparison

	'3 mm Bar'	'4 mm Bar'	'5 mm Bar'
Horizontal Bar	 <p>This panel shows a 3D model of a horizontal bar with three 3 mm diameter bars. The CT slice below shows four bright spots, indicating the presence of the bars.</p>	 <p>This panel shows a 3D model of a horizontal bar with four 4 mm diameter bars. The CT slice below shows four bright spots, indicating the presence of the bars.</p>	 <p>This panel shows a 3D model of a horizontal bar with five 5 mm diameter bars. The CT slice below shows four bright spots, indicating the presence of the bars.</p>
Vertical Bar	 <p>This panel shows a 3D model of a vertical bar with three 3 mm diameter bars. The CT slice below shows four bright spots, indicating the presence of the bars.</p>	 <p>This panel shows a 3D model of a vertical bar with four 4 mm diameter bars. The CT slice below shows four bright spots, indicating the presence of the bars.</p>	 <p>This panel shows a 3D model of a vertical bar with five 5 mm diameter bars. The CT slice below shows four bright spots, indicating the presence of the bars.</p>

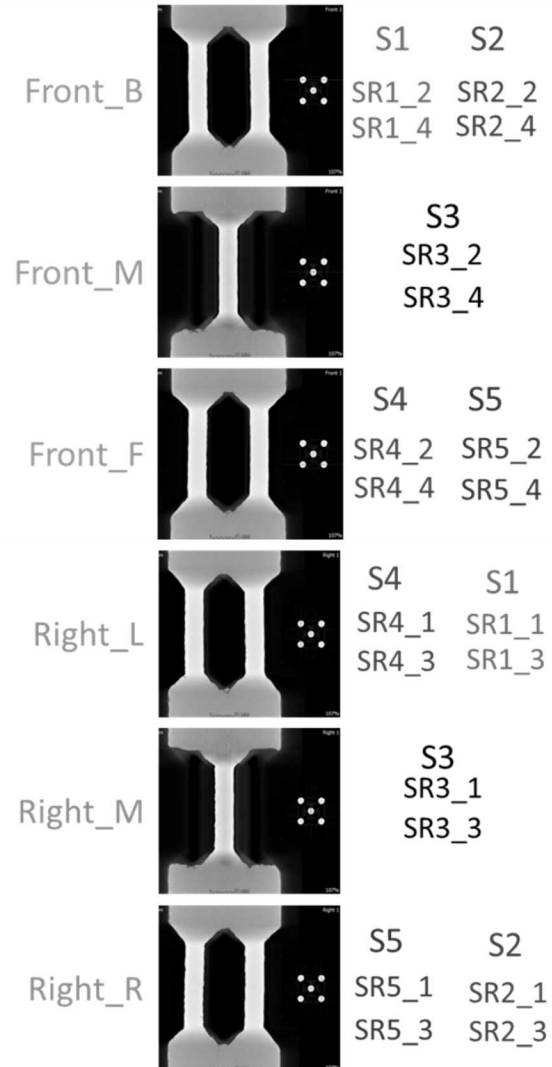
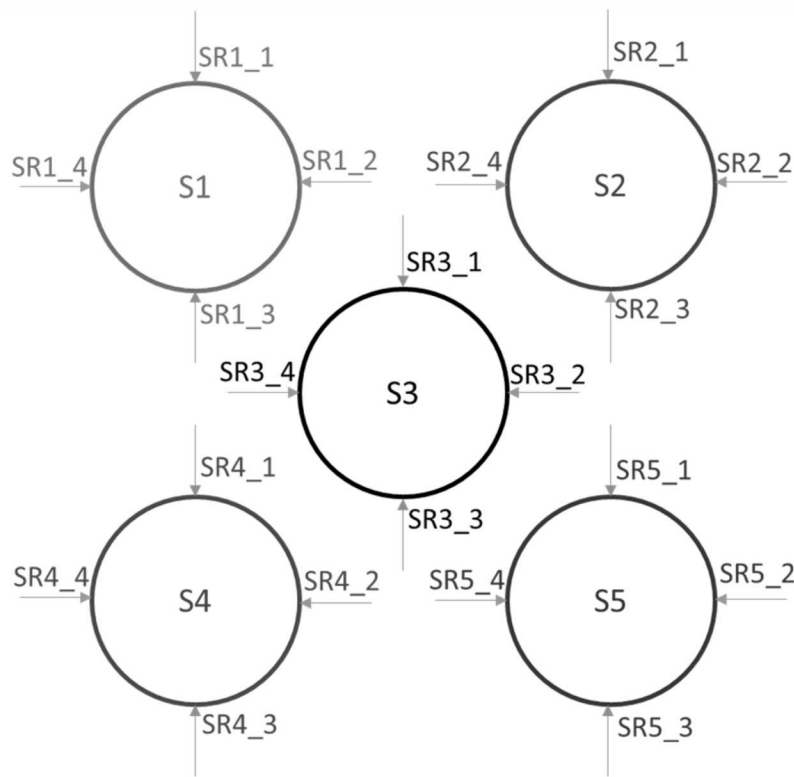
CT Results-Comparison to Nominal



Porosity Analysis



Roughness Measurements



DESTRUCTIVE EVALUATION SOLID BARS

Test Setup

Data Acquisition: 15 Hz

Image Acquisition: Varied

Actuator Rate:

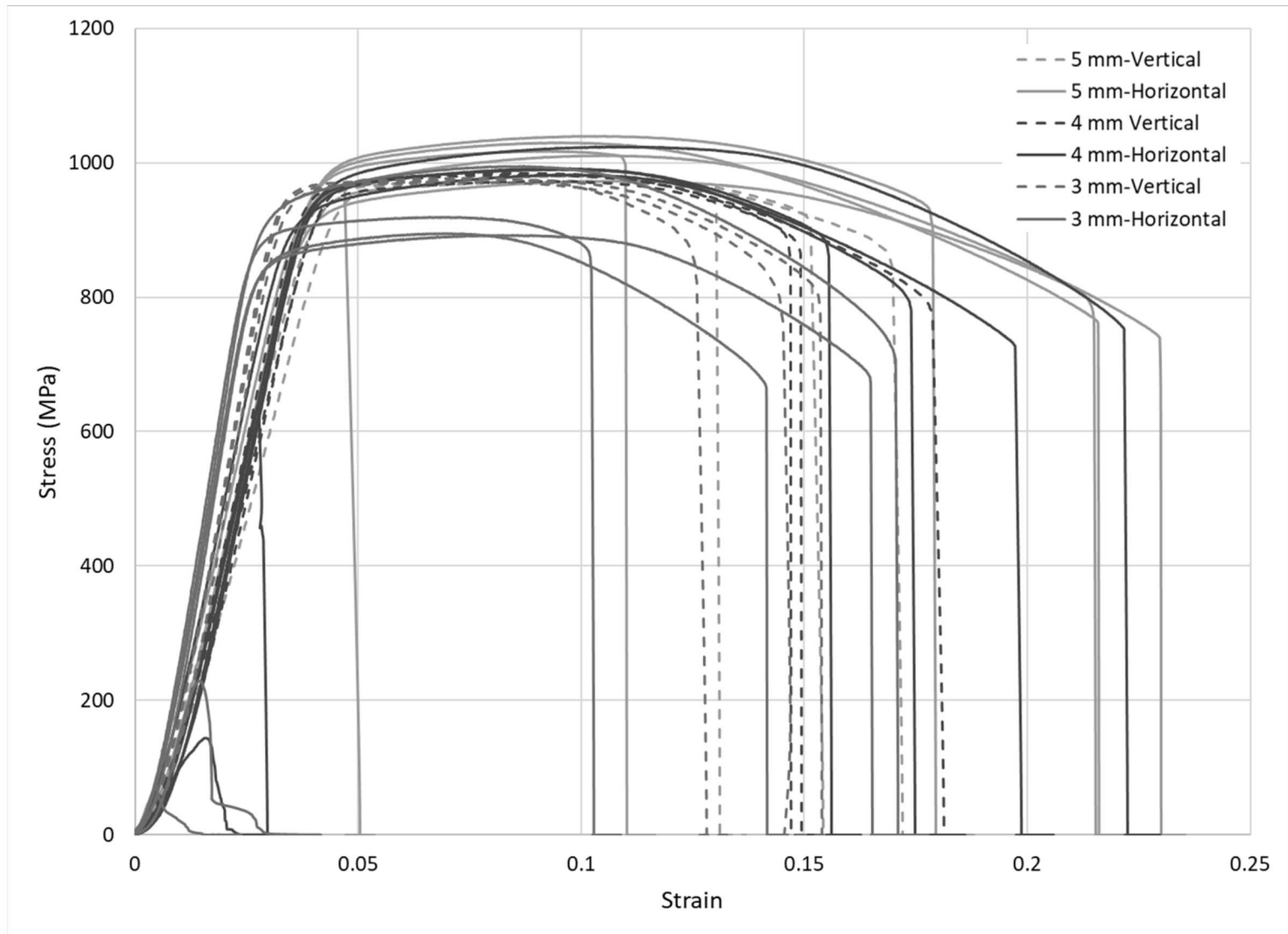
3 mm- 1.9 mm/min

4 mm- 2 mm/min

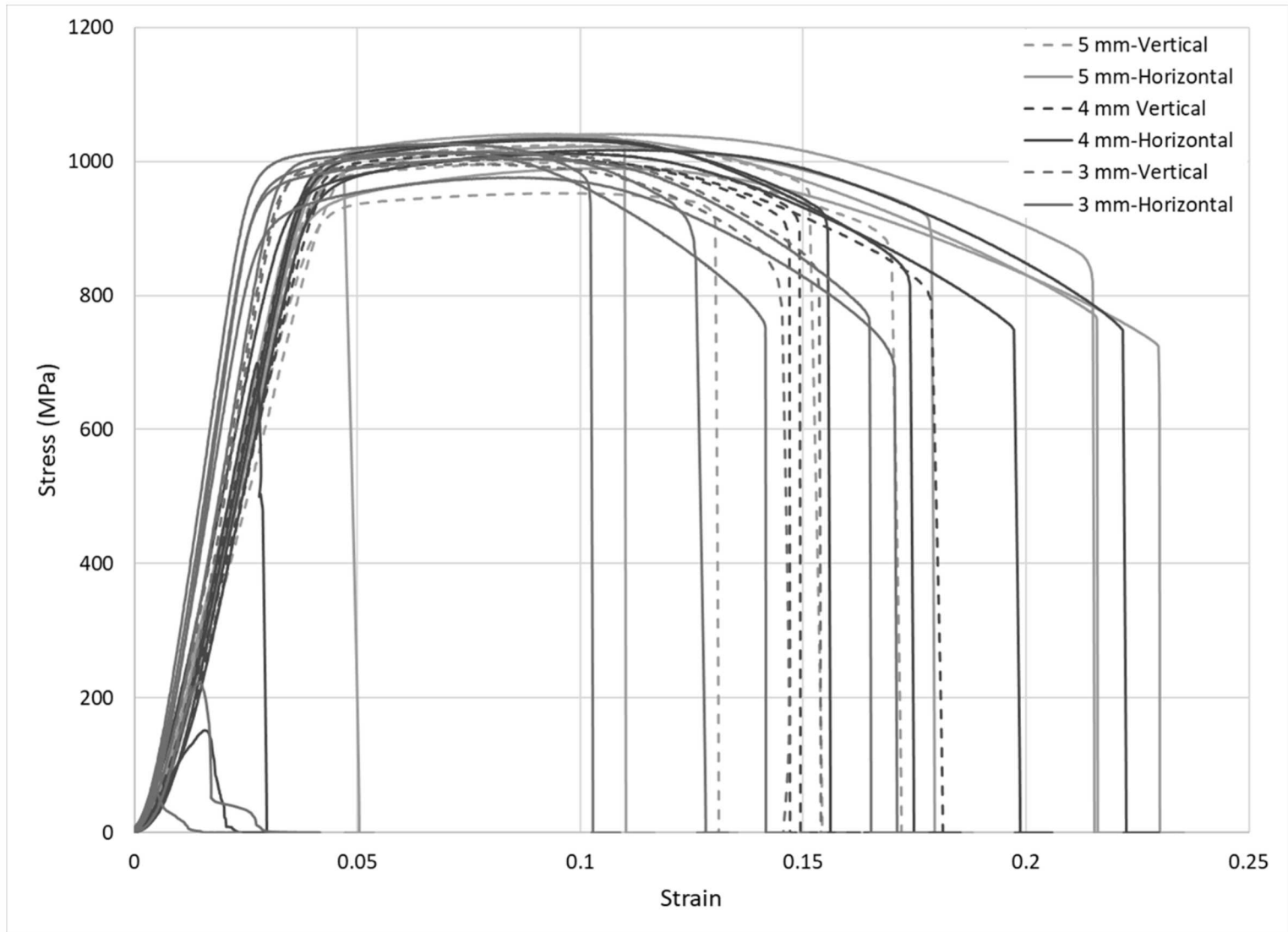
5 mm- 2.1 mm/min



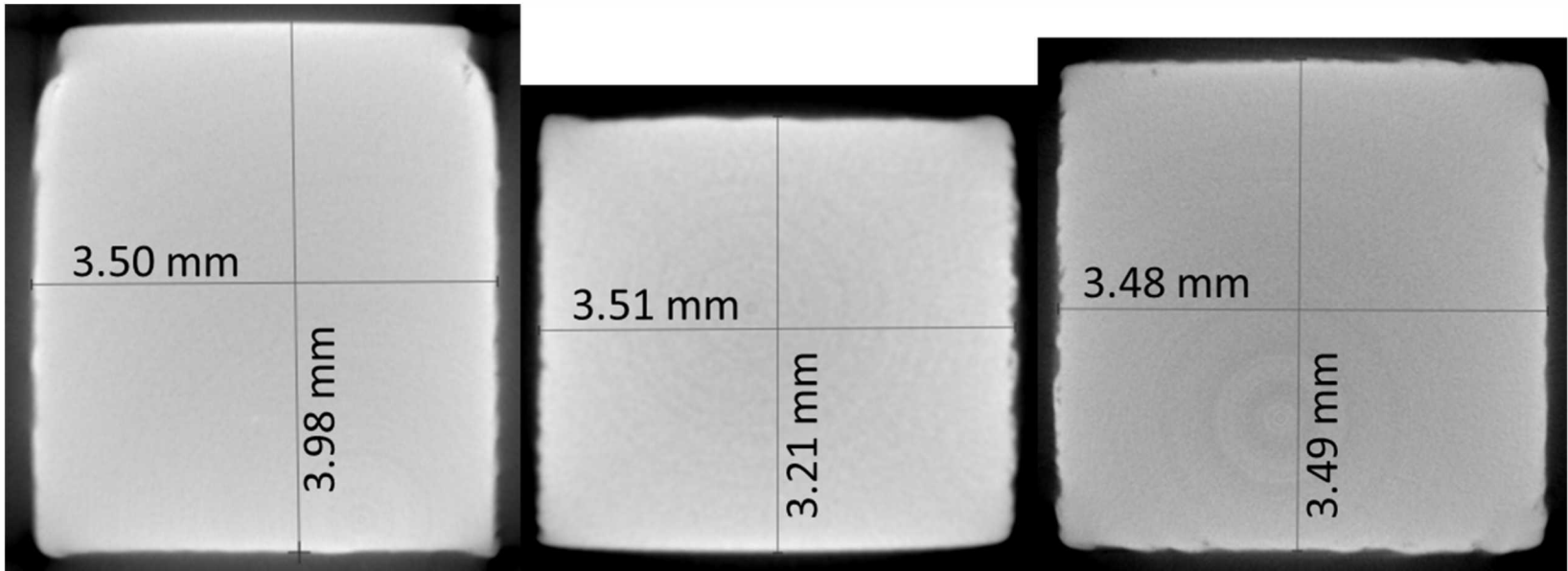
Stress-Strain: As Designed Area



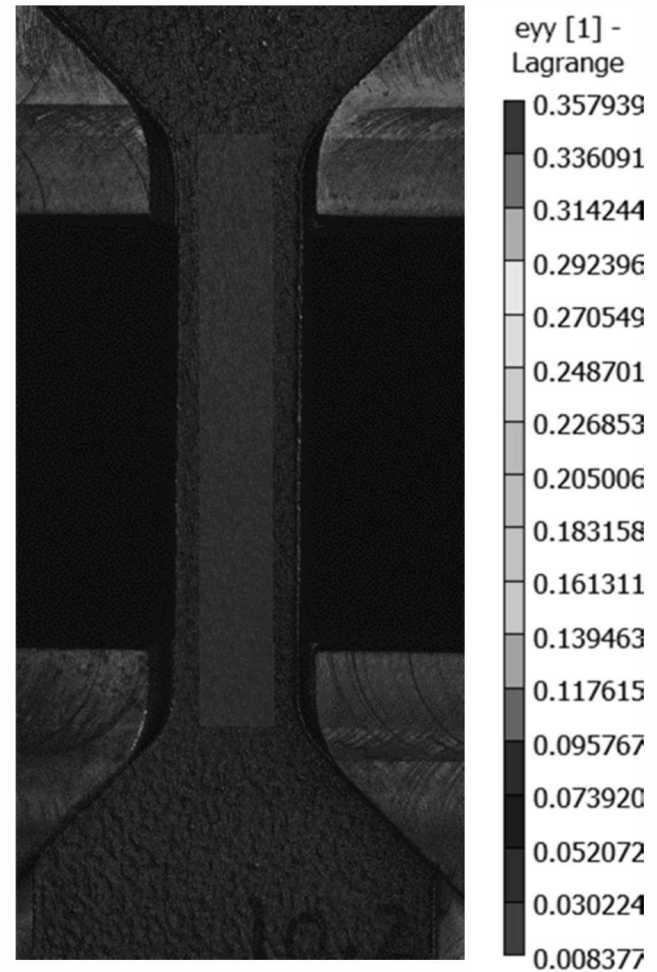
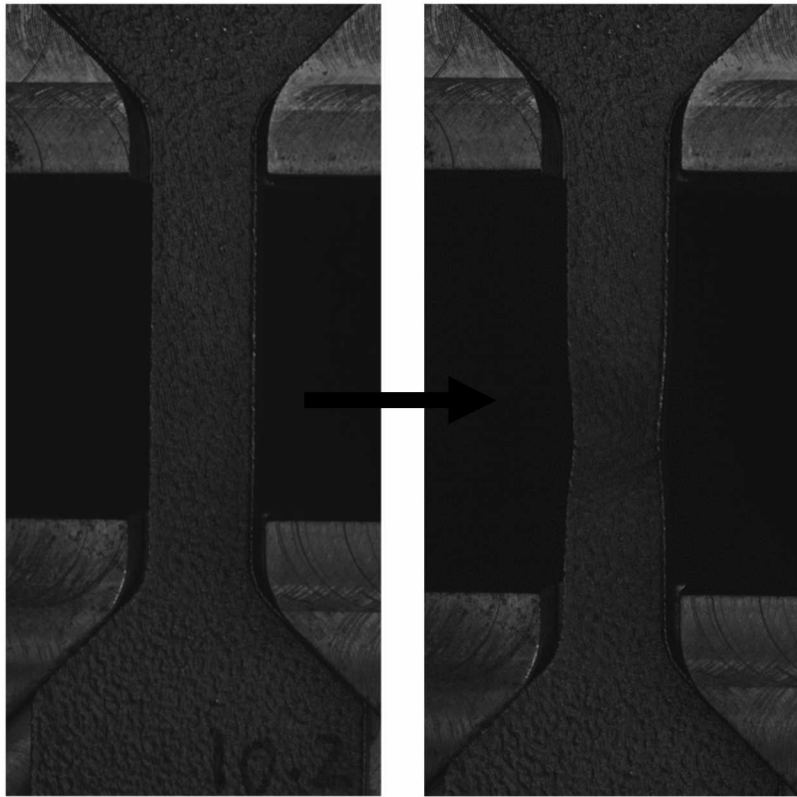
Stress-Strain: As Built Area



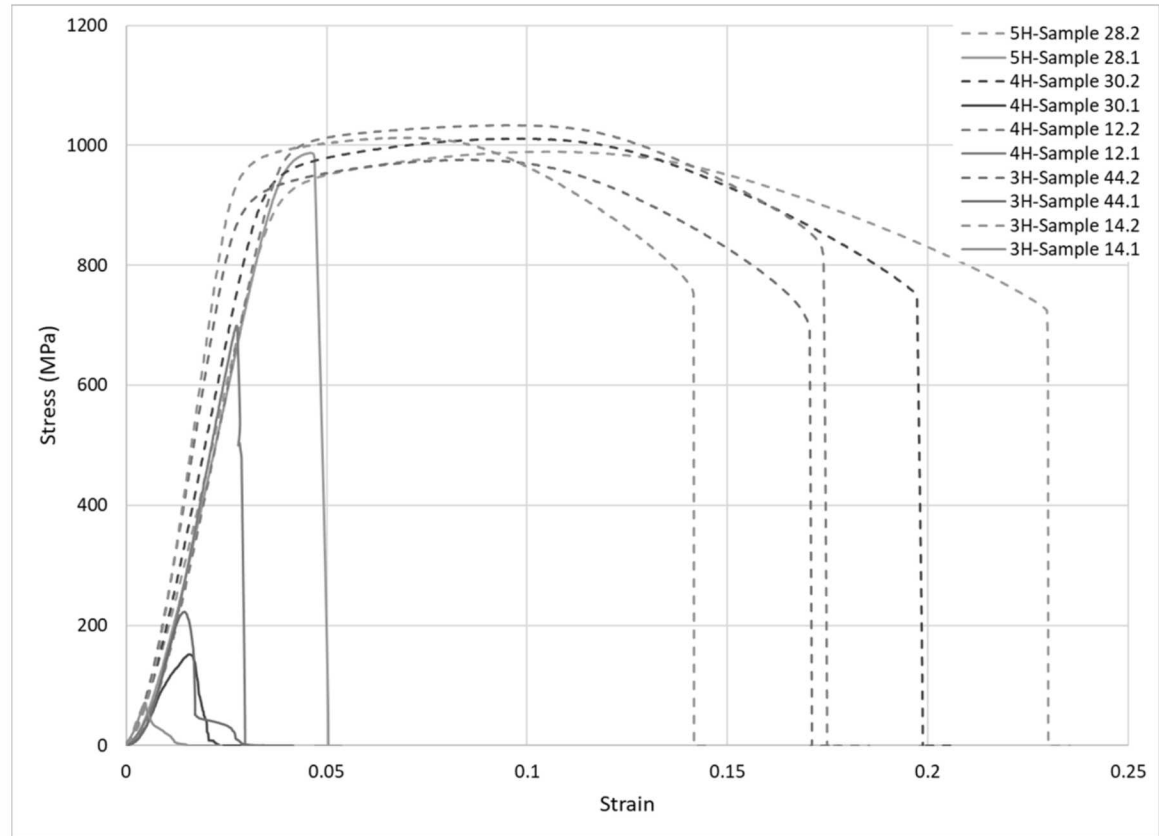
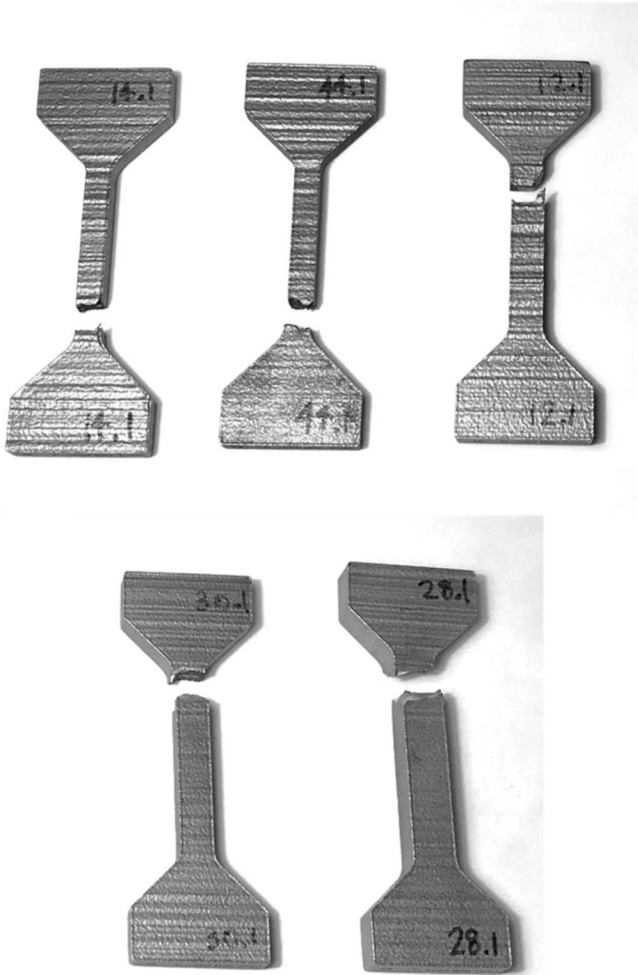
Why Designed Area Adds Variation



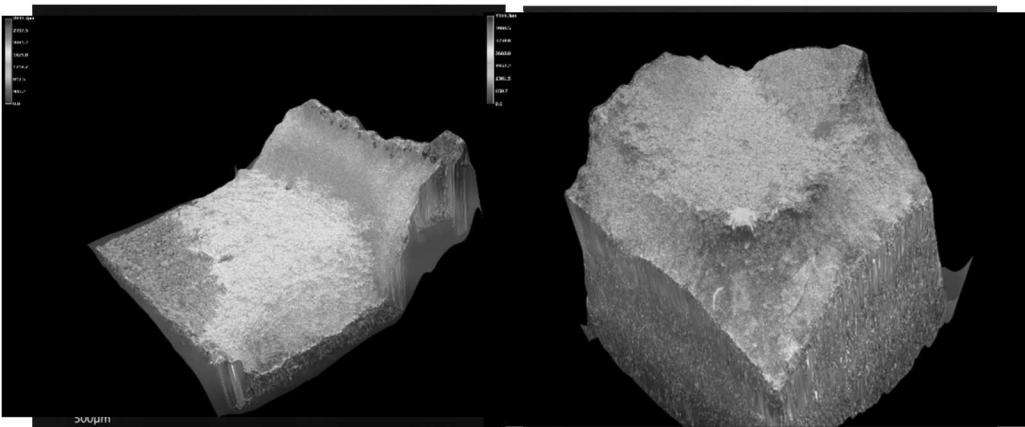
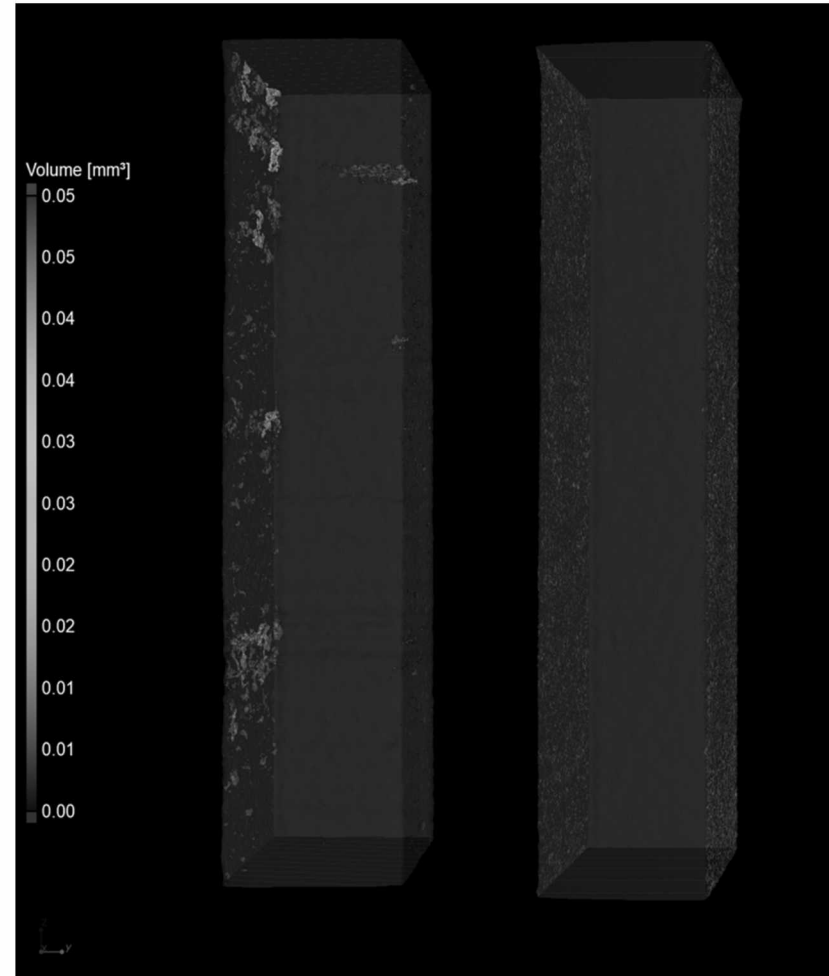
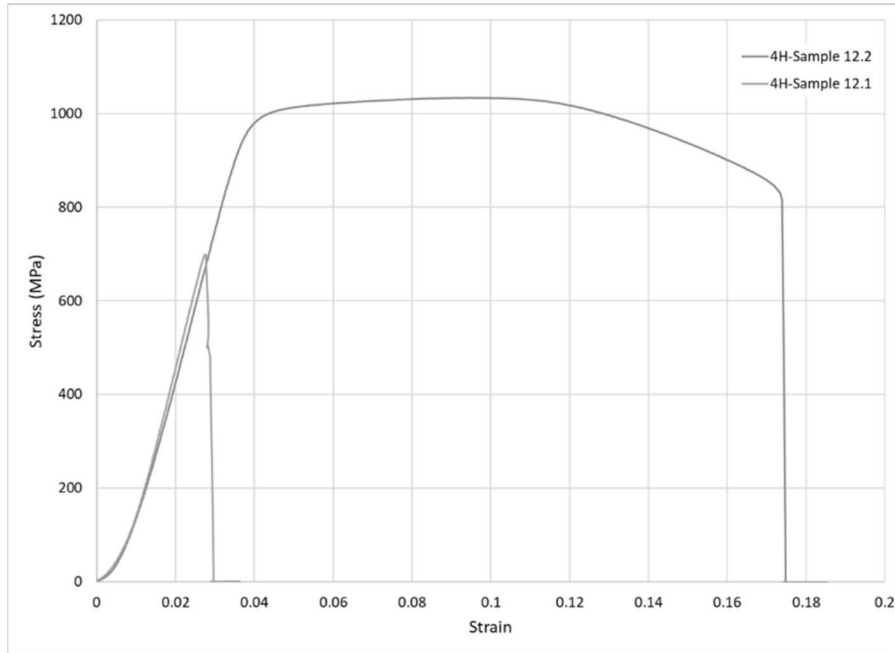
Strain through Digital Image Correlation



Brittle/Low-Ductility Samples



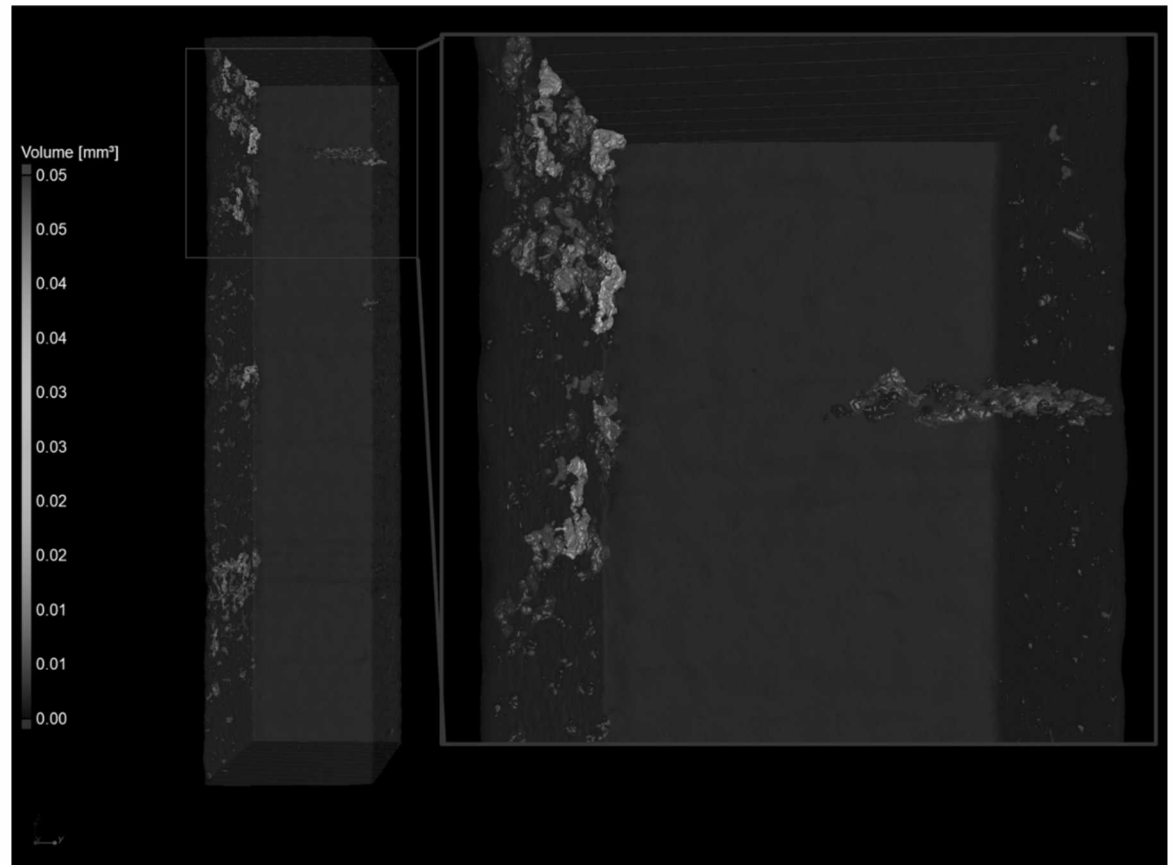
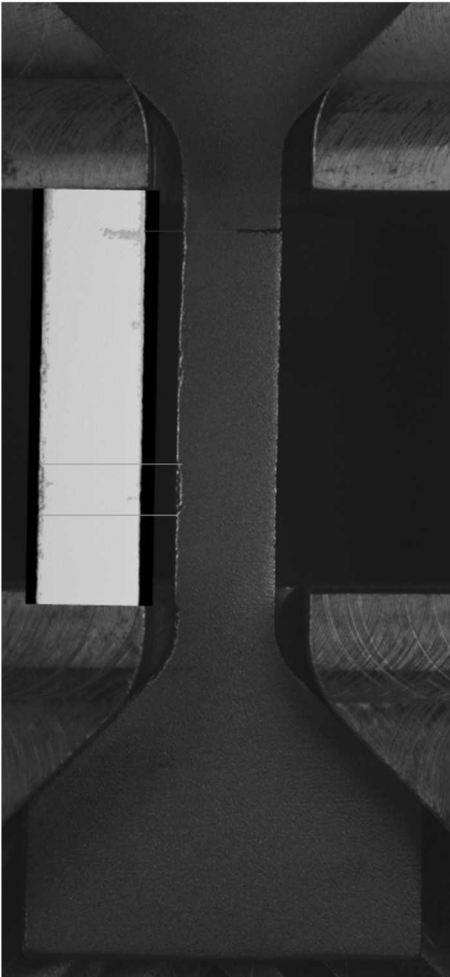
Sample 12.1 Versus 12.2



Sample 12.1

Sample 12.2

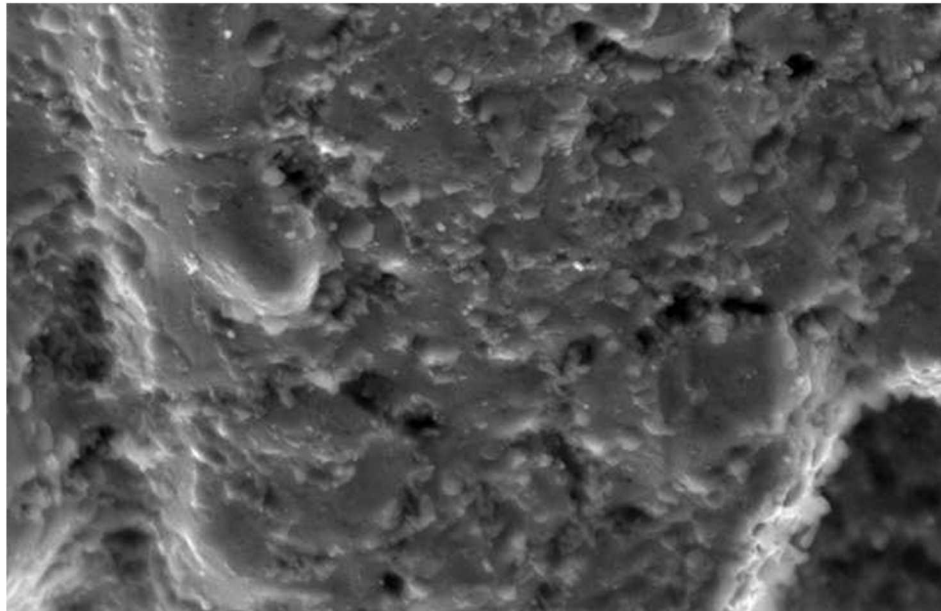
Porosity in Sample 12.1



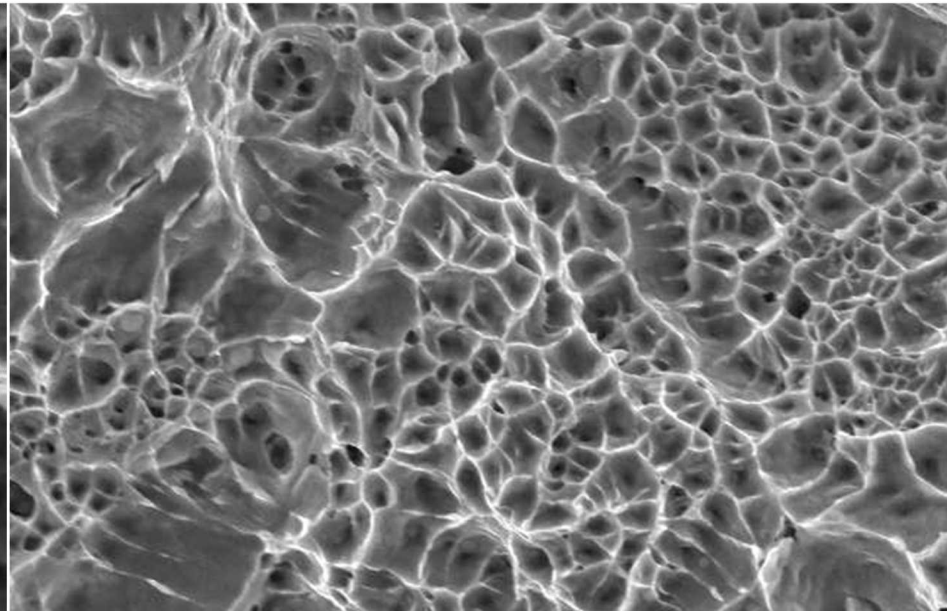
Fractography

Sample 12.1

Sample 12.2

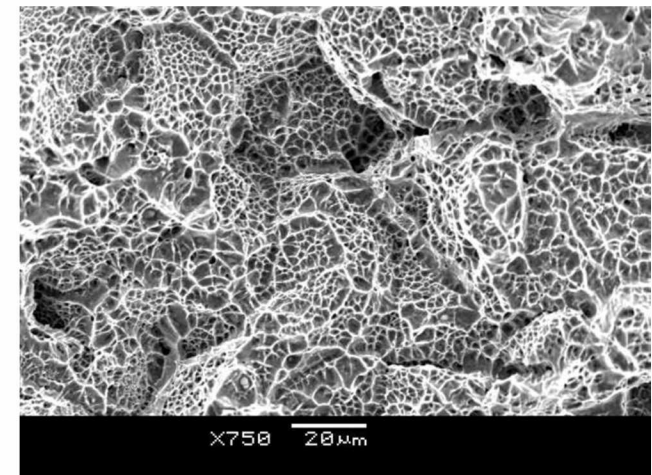
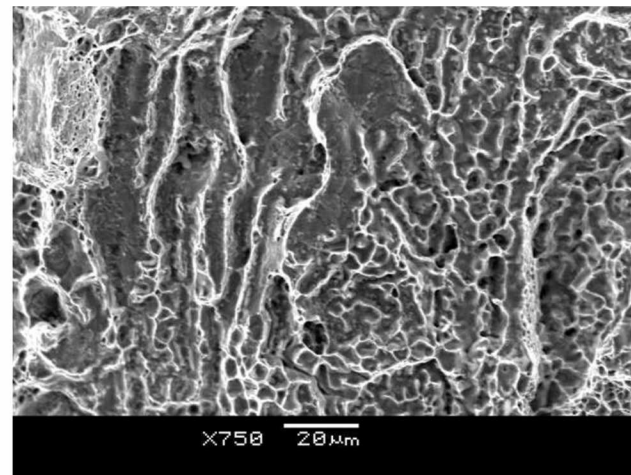
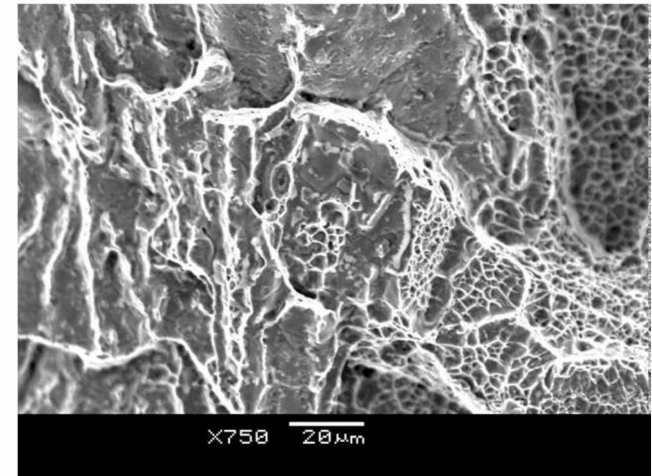
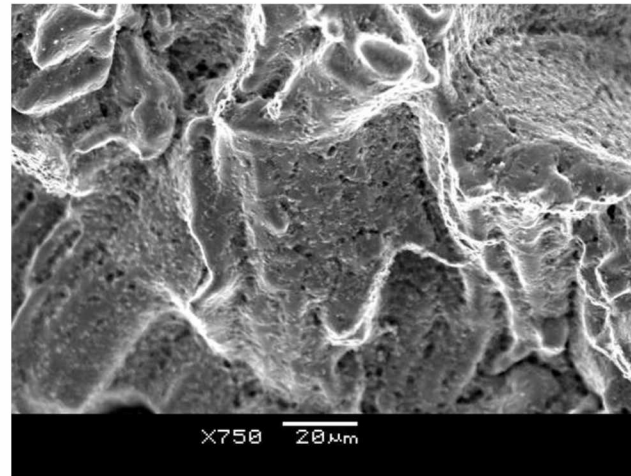
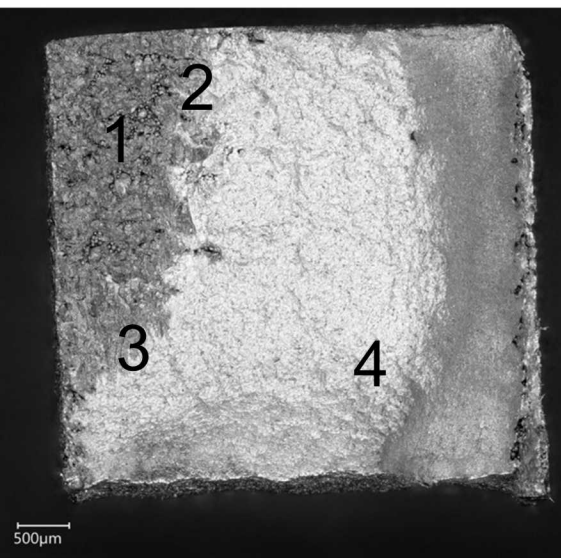


X2,500 10µm



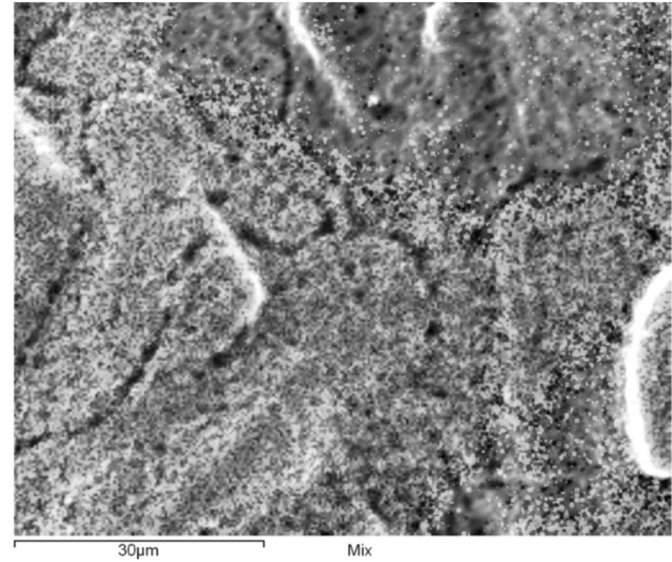
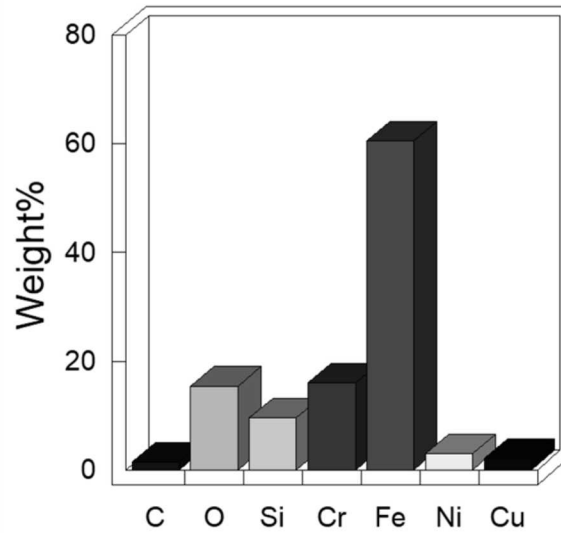
20kV X2,500 10µm

Regions of Interest in Sample 12.1

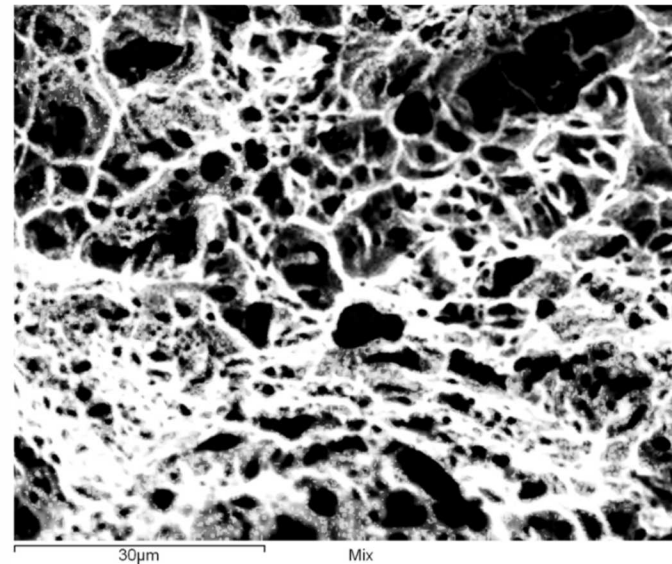
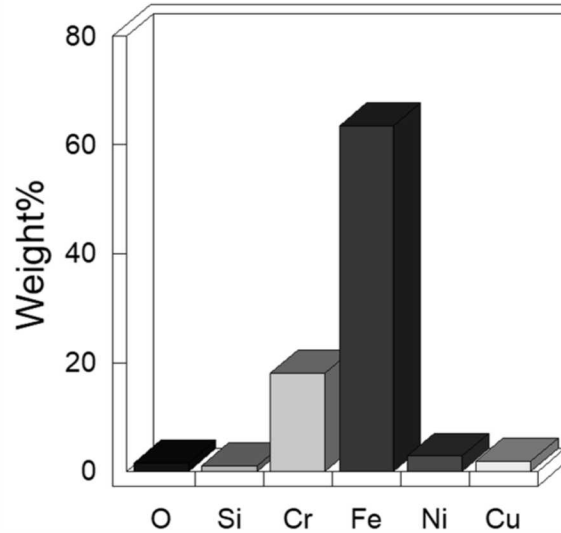


Sample 14.1 Versus 14.2

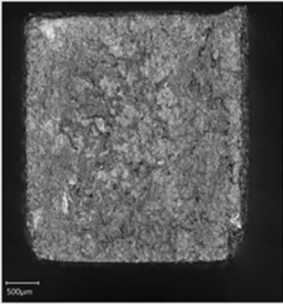
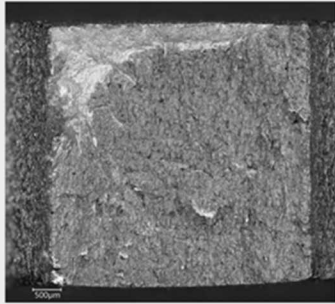
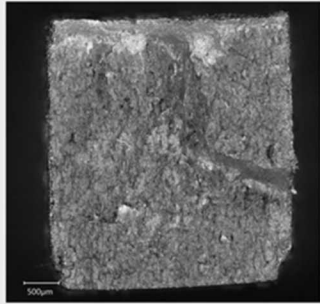

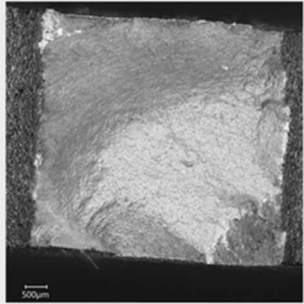
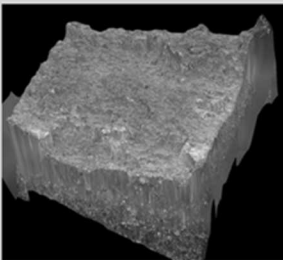
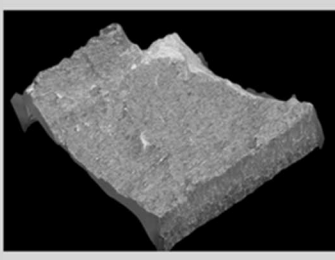
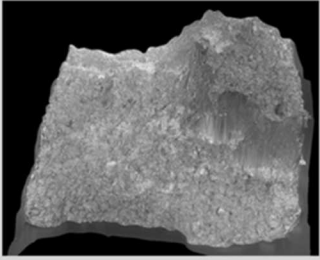
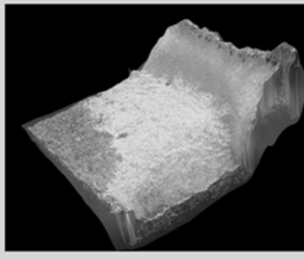
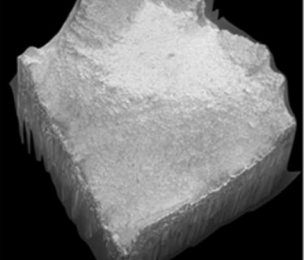
Sample 14.1



Sample 14.2

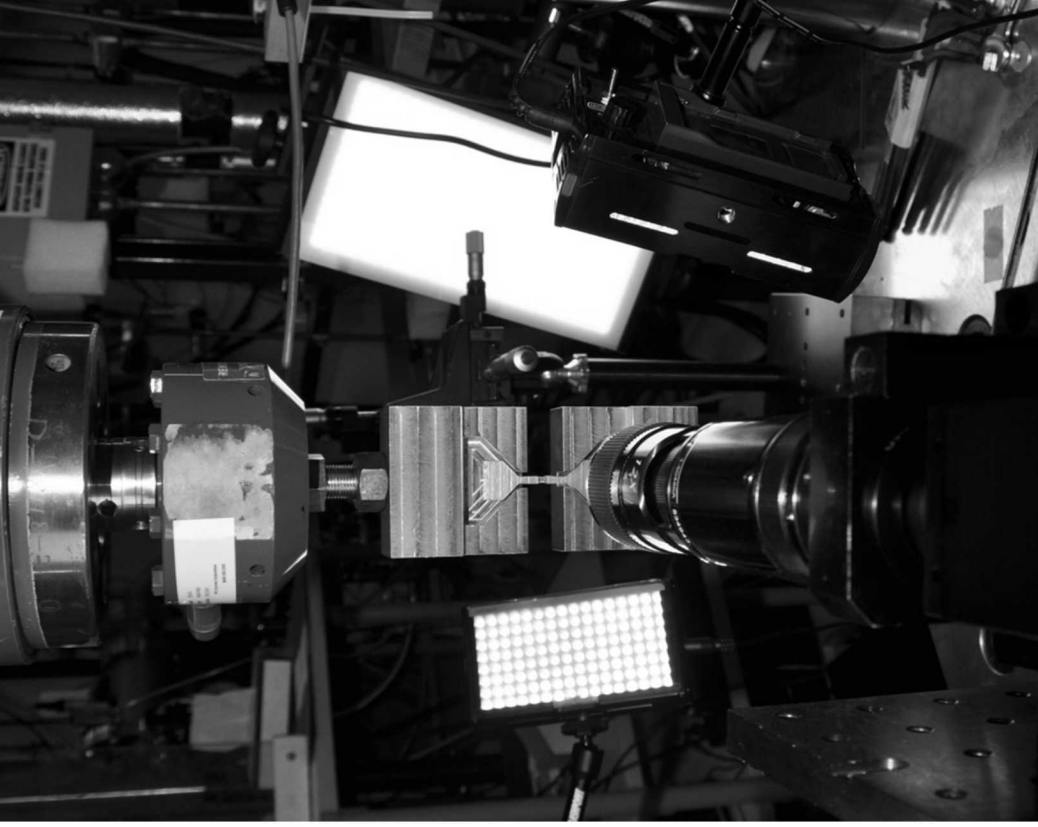


Impact on Performance

	Sample 14.1 (3 mm)	Sample 30.1 (4 mm)	Sample 44.1 (3 mm)	Sample 12.1 (4 mm)	Sample 28.1 (5 mm)
Max Stress	71 MPa	152 MPa	223 MPa	699 MPa	988 MPa
Discoloring					
Height Map					

DESTRUCTIVE EVALUATION STRUT BARS

Test Setup



Data Acquisition: 15 Hz

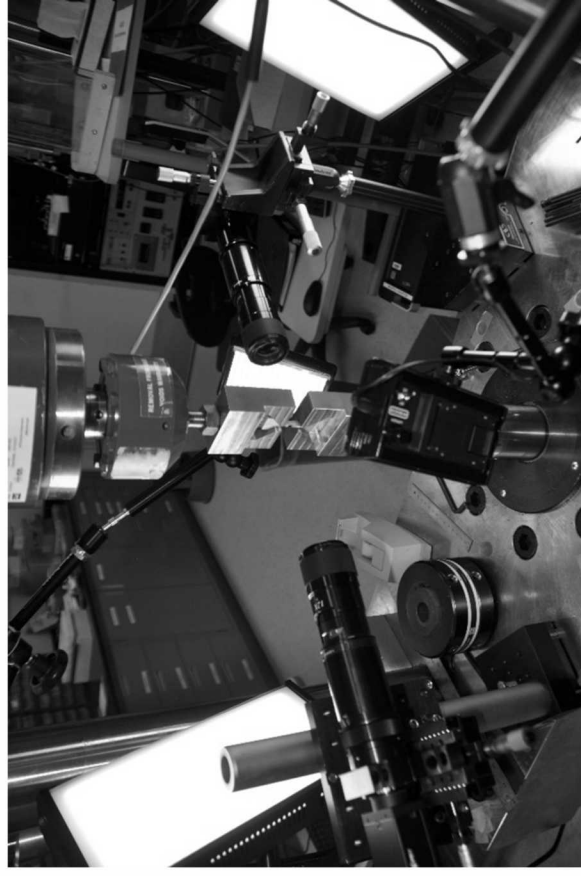
Image Acquisition: 1 Hz

Actuator Rate:

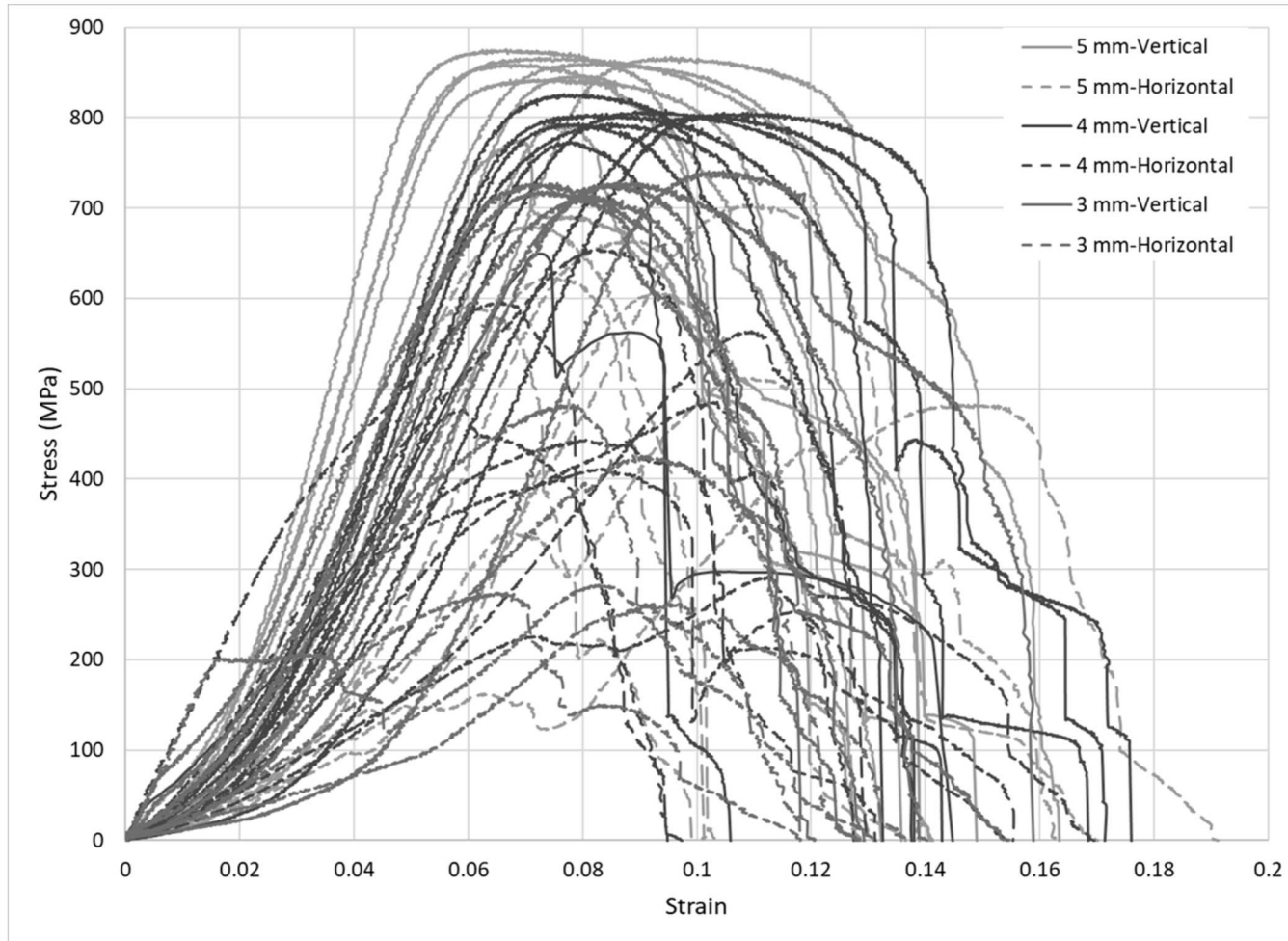
3 mm- 0.225 mm/min

4 mm- 0.3 mm/min

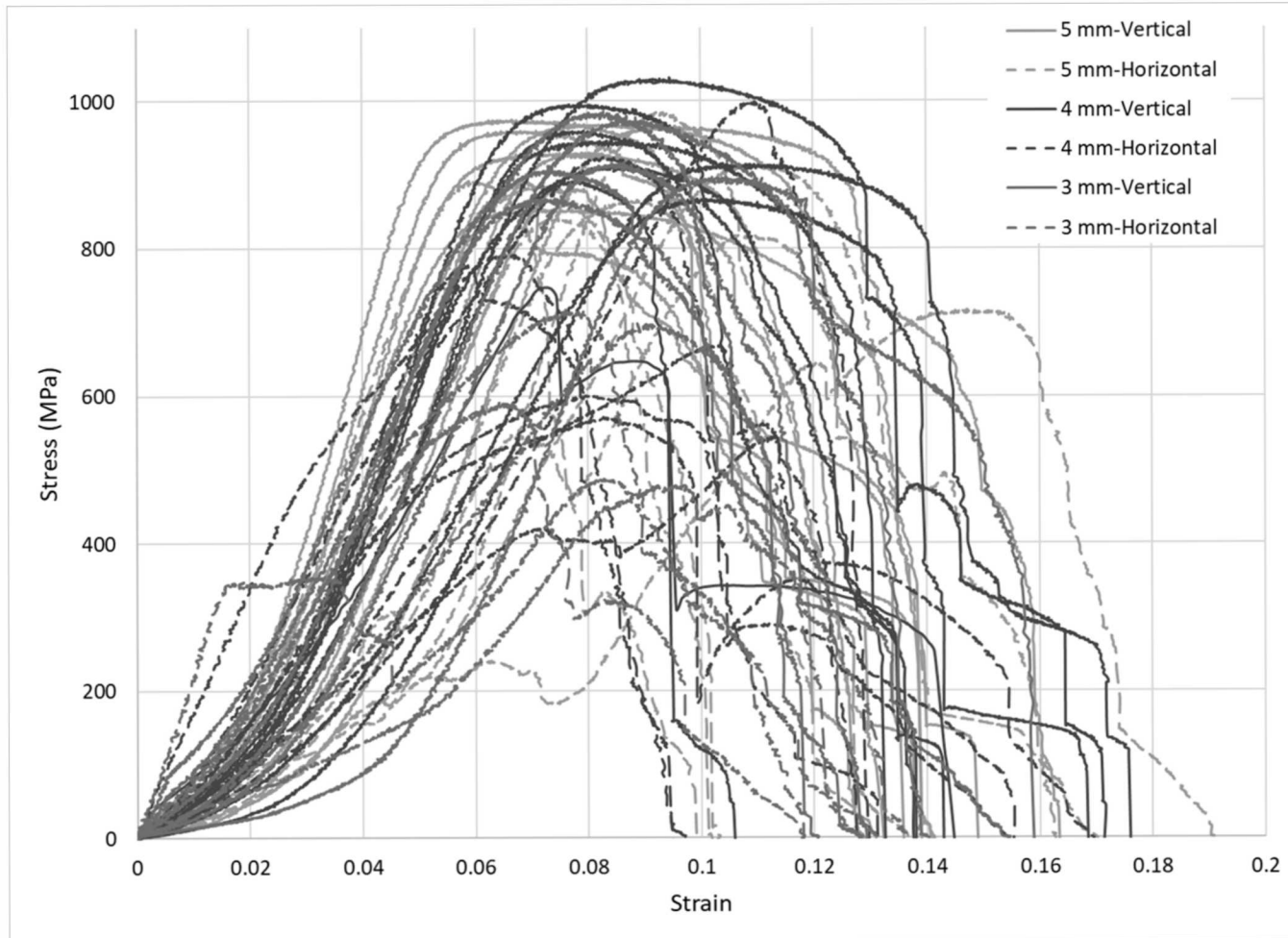
5 mm- 0.375 mm/min



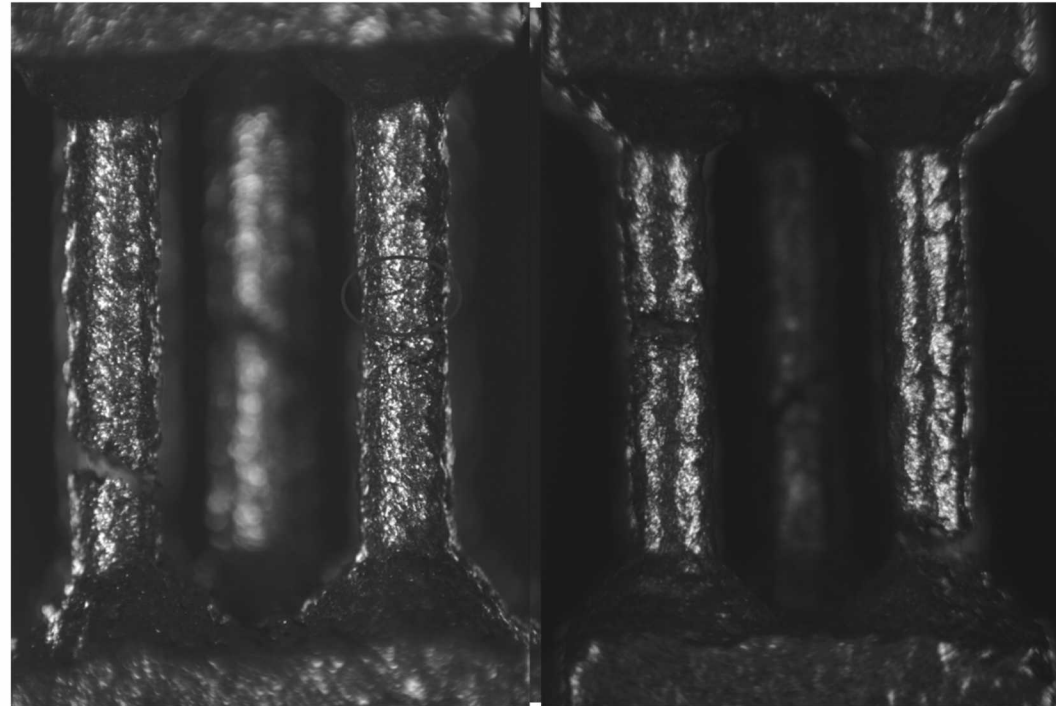
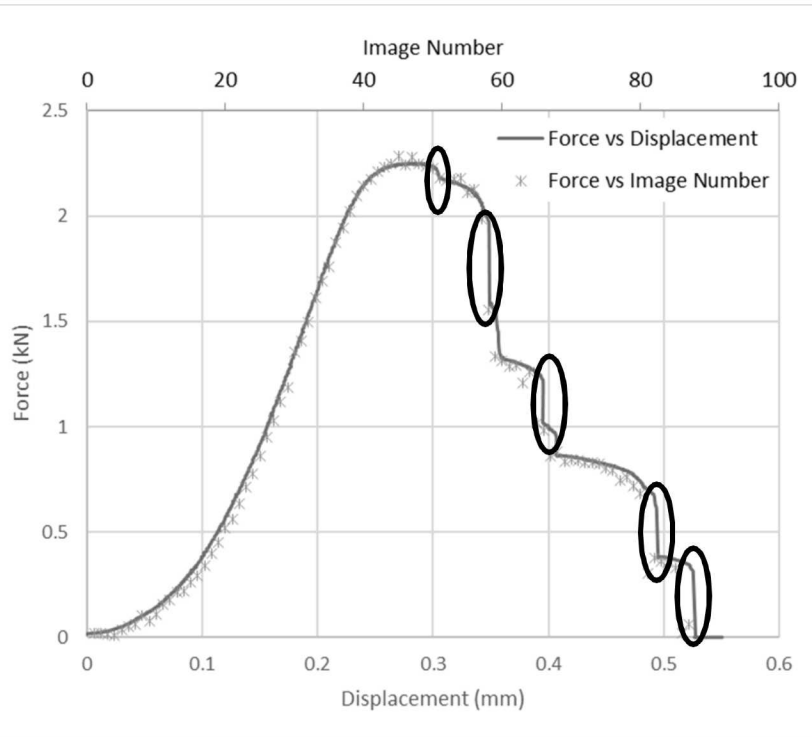
Stress-Strain: As Designed Area



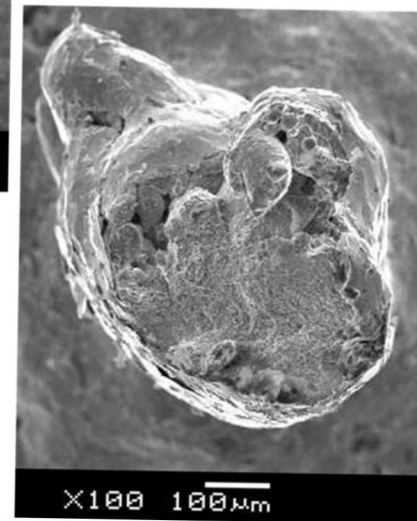
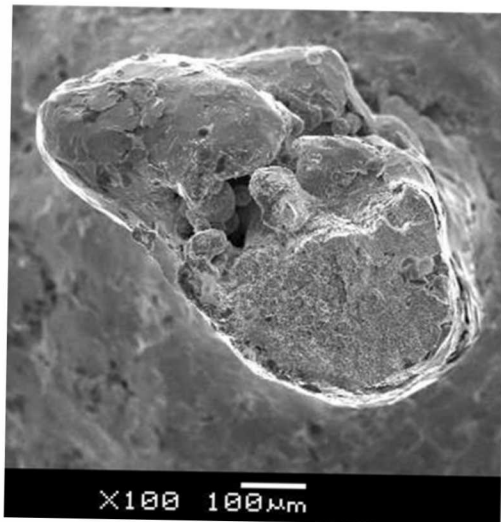
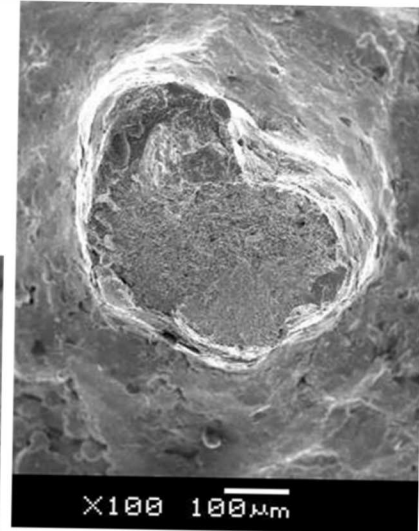
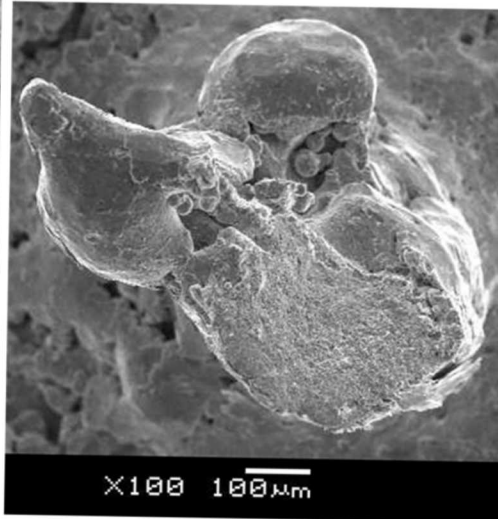
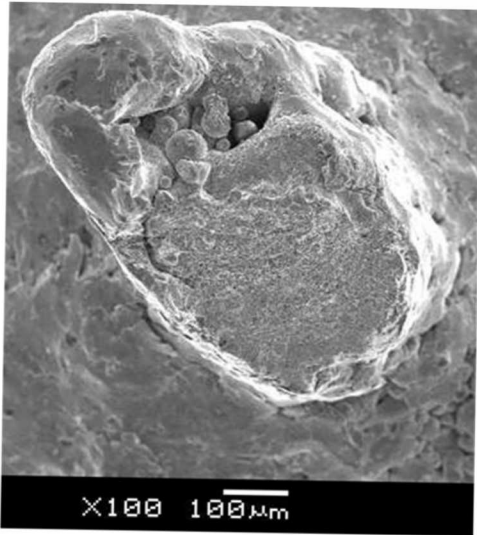
Stress-Strain: As Built Area



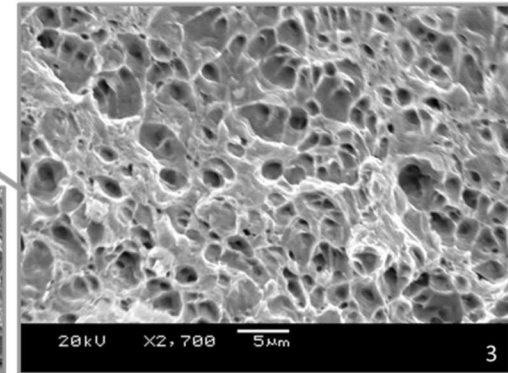
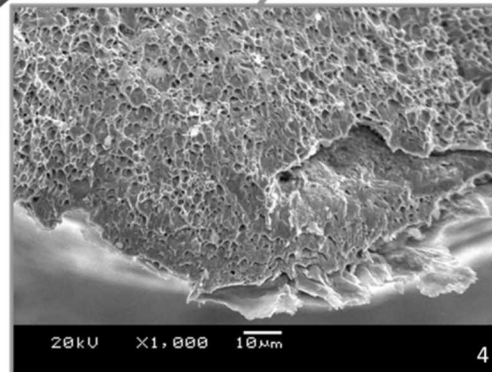
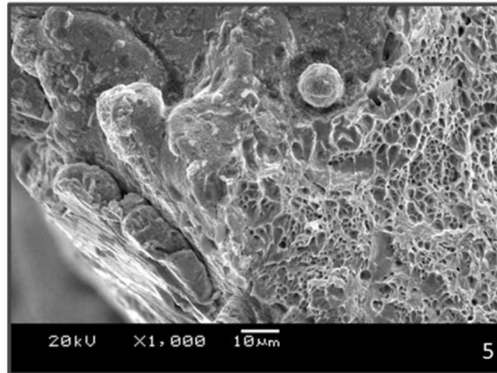
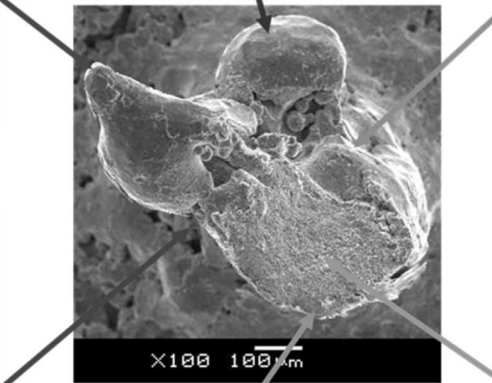
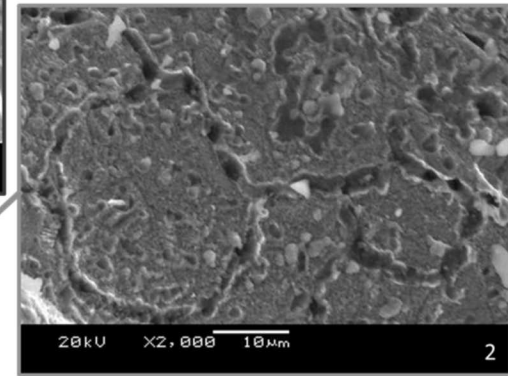
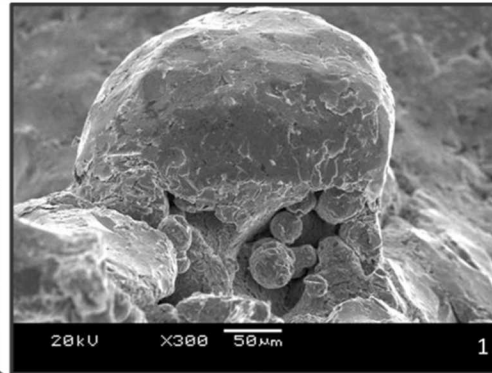
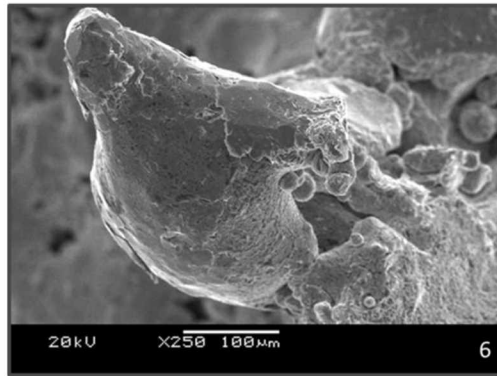
Crack Propagation Through Sample



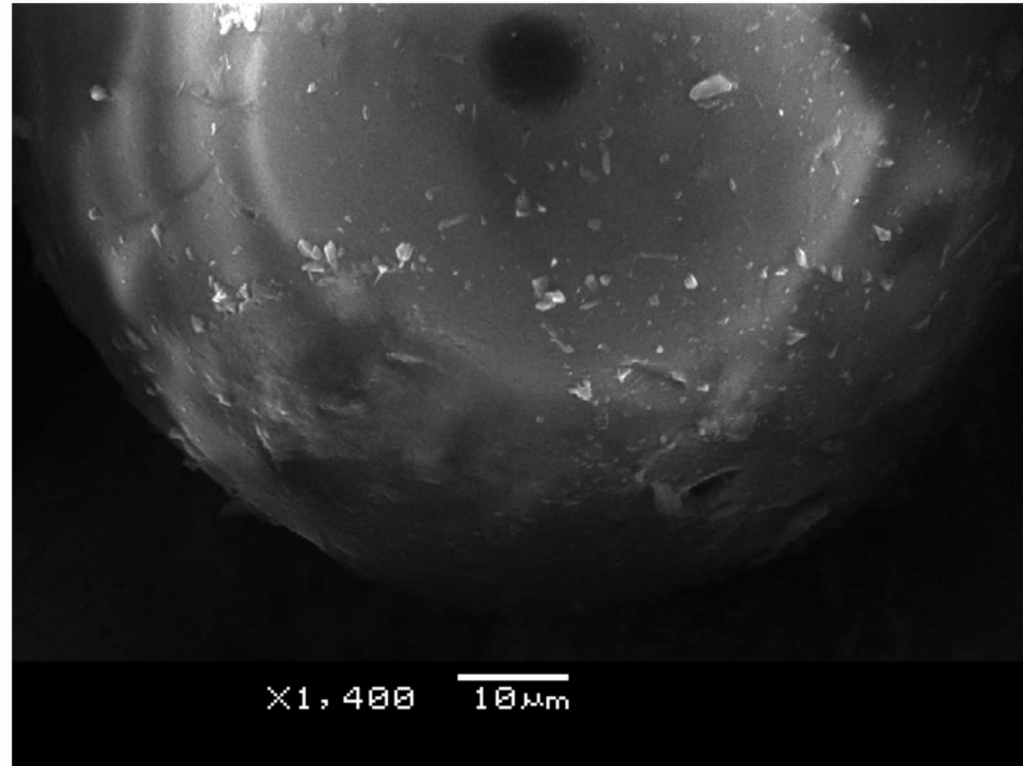
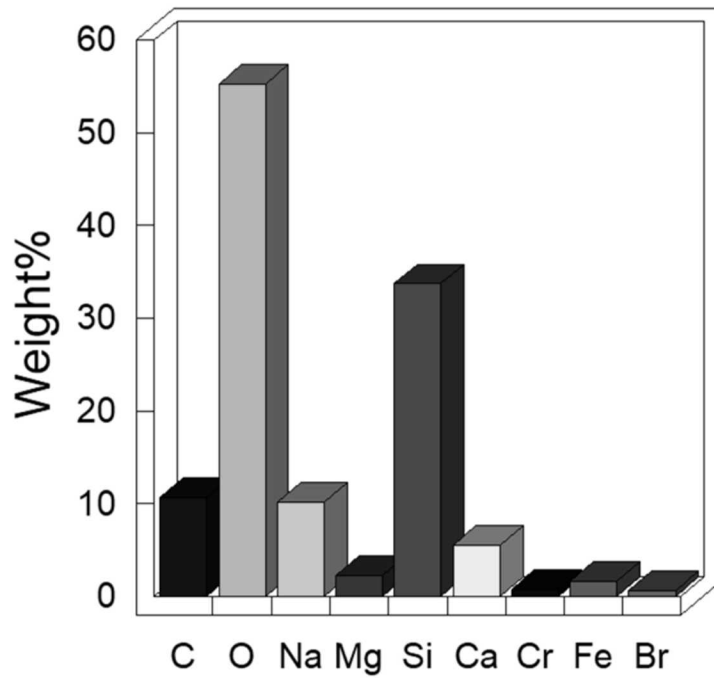
Fractography-Sample 68



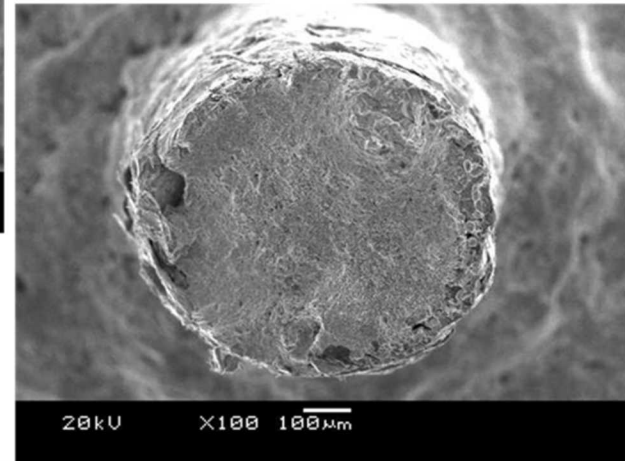
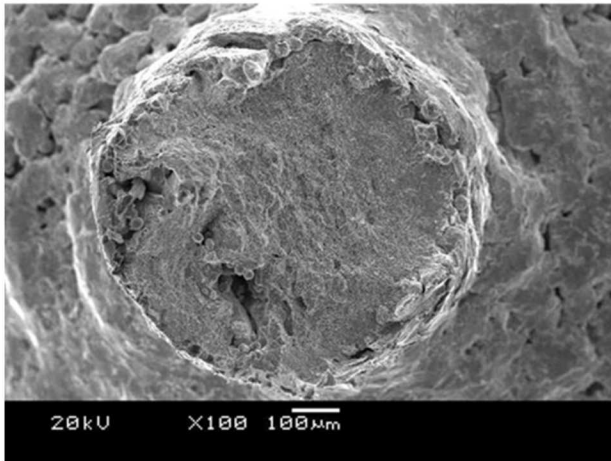
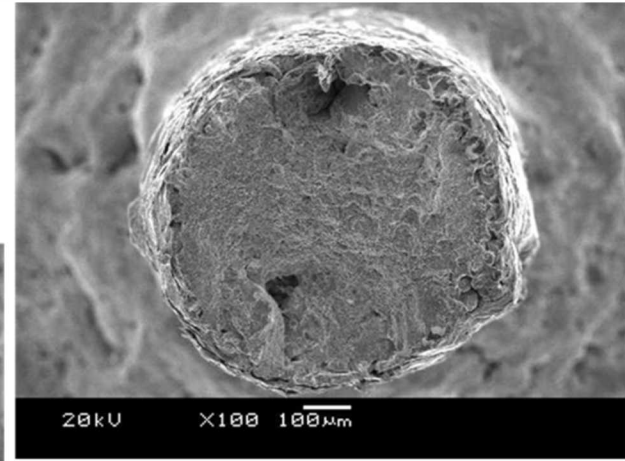
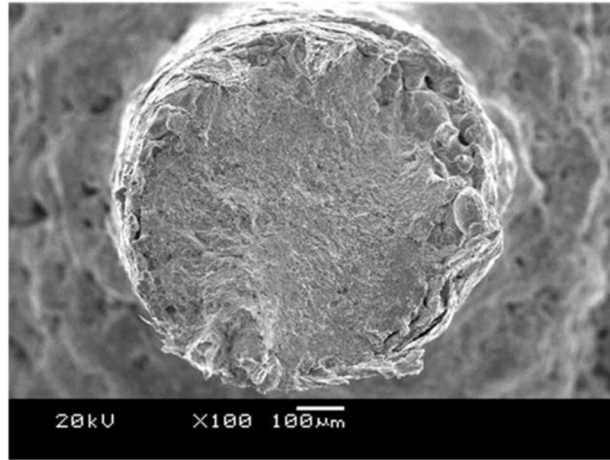
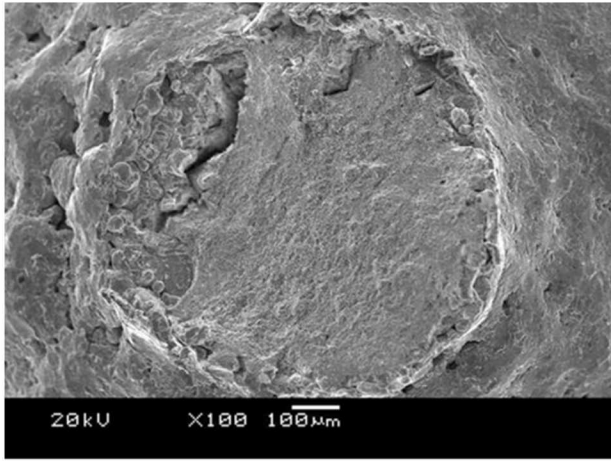
Sample 68-Center Strut



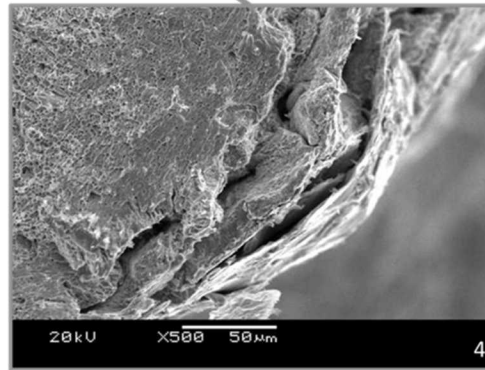
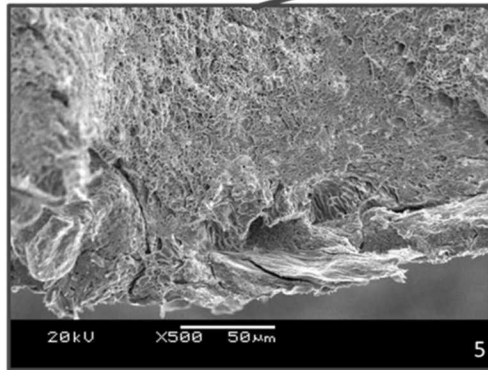
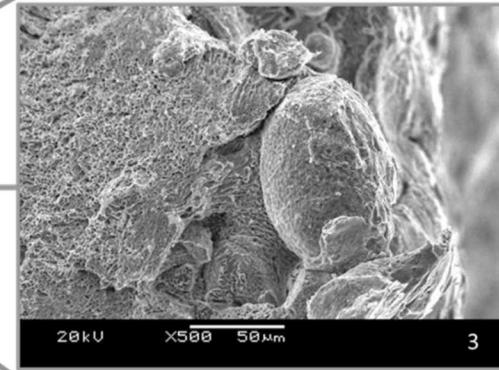
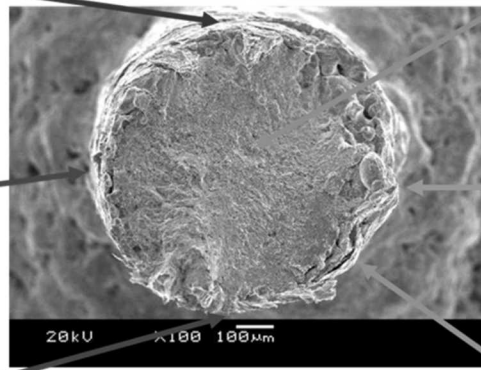
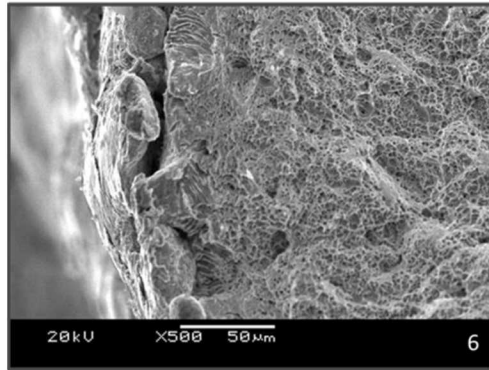
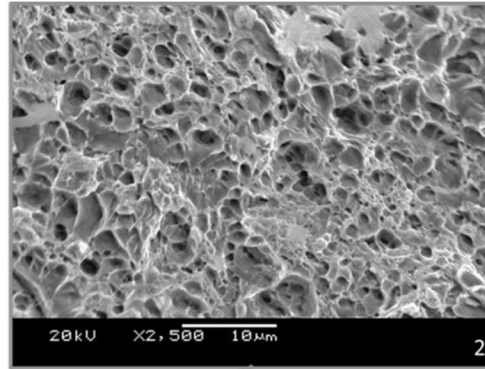
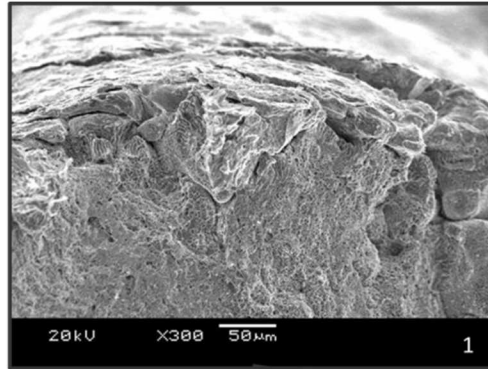
Impurity in Sample 6



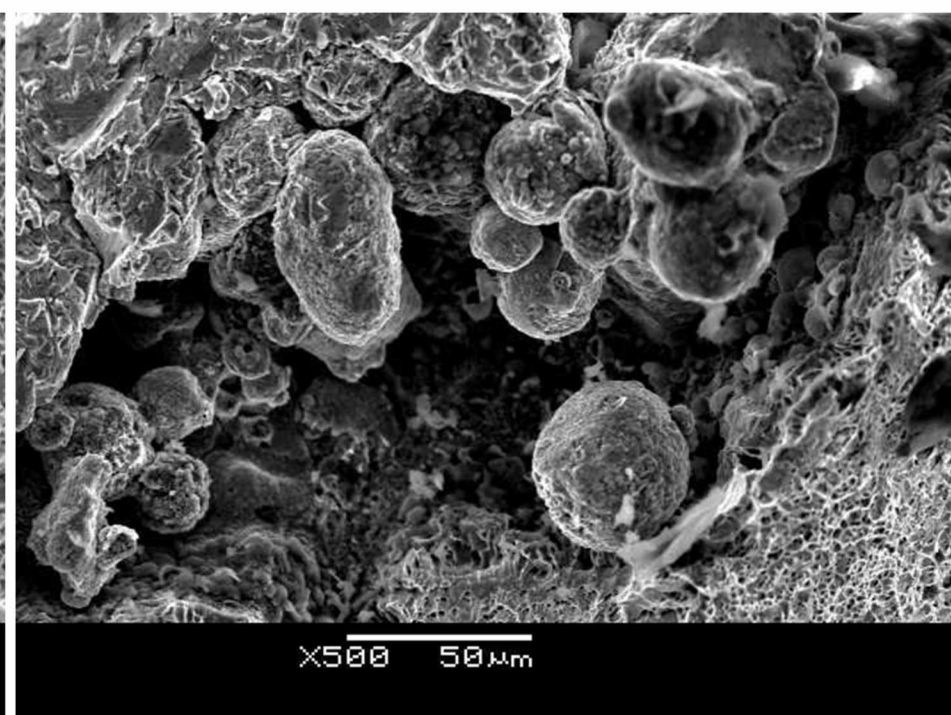
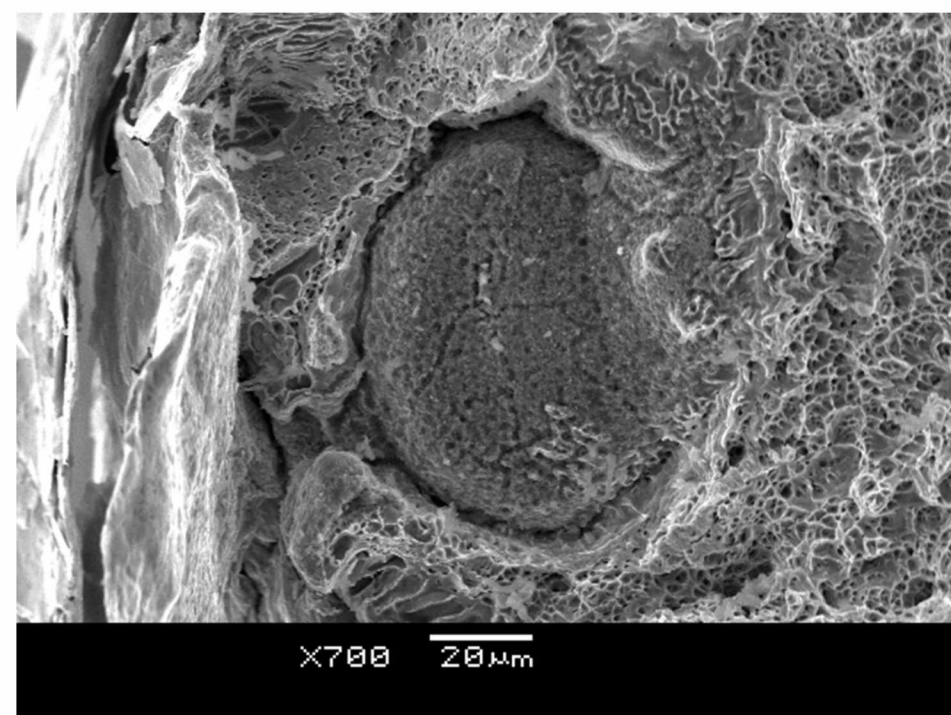
Fractography-Sample 51



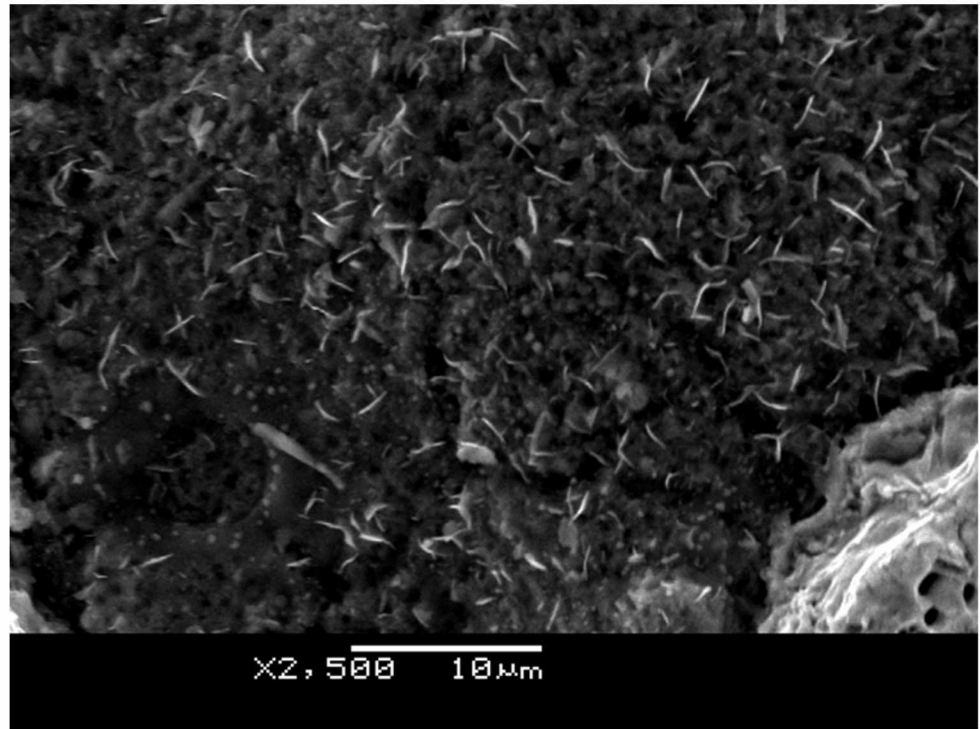
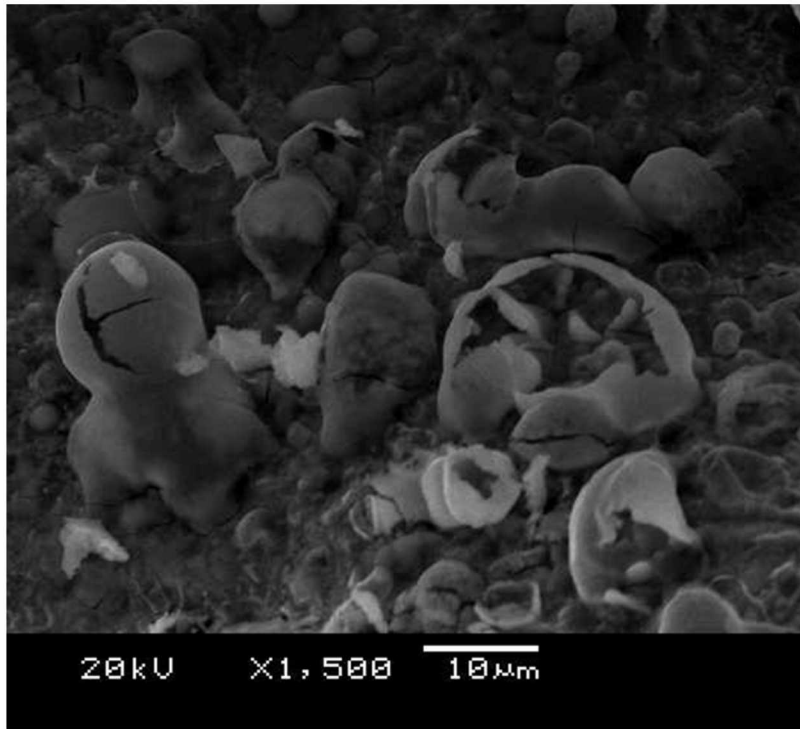
Sample 51-Center Strut



Variation in Unsintered Particles



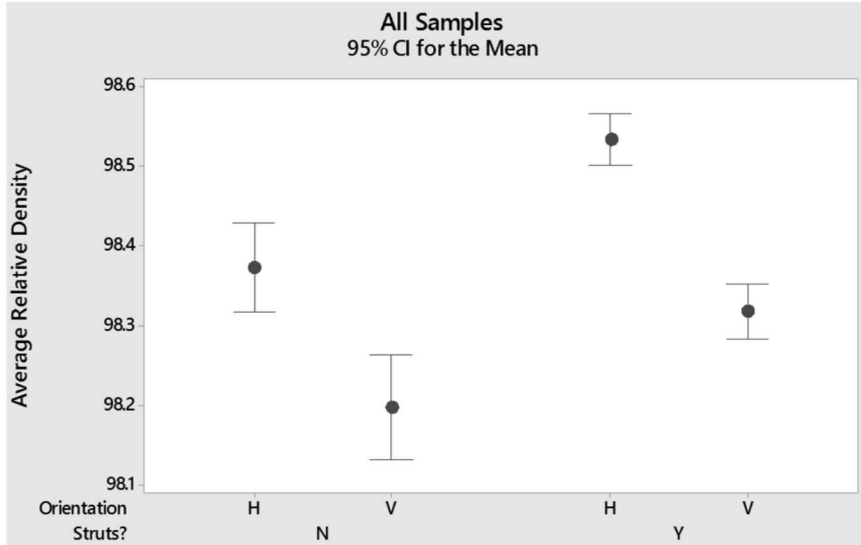
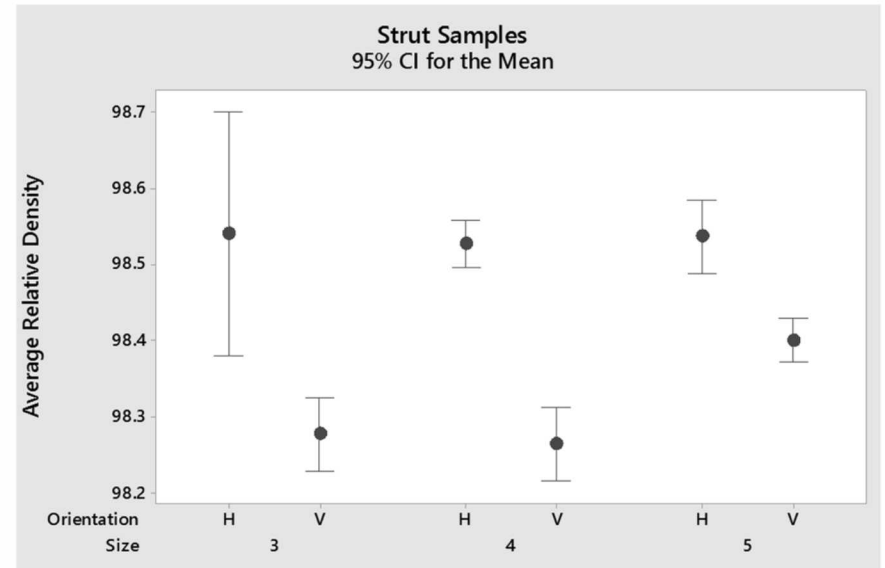
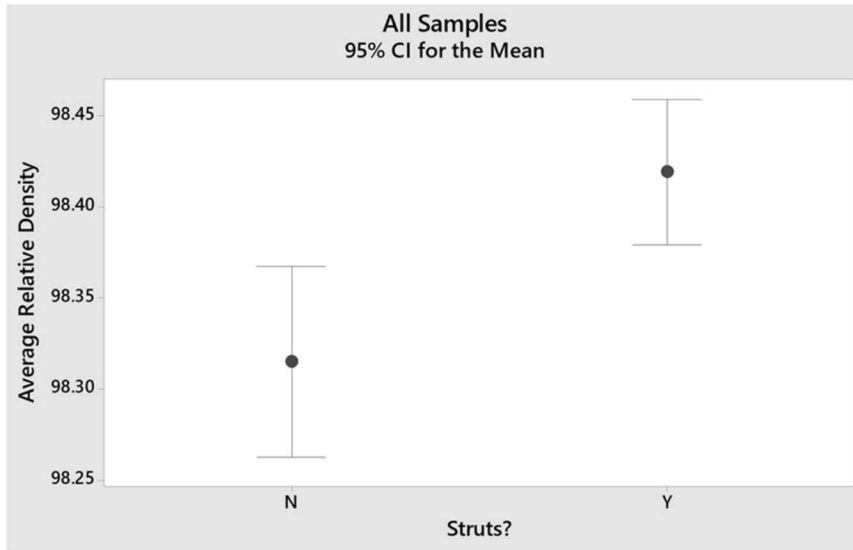
Unidentified Fracture Objects





DATA ANALYSIS

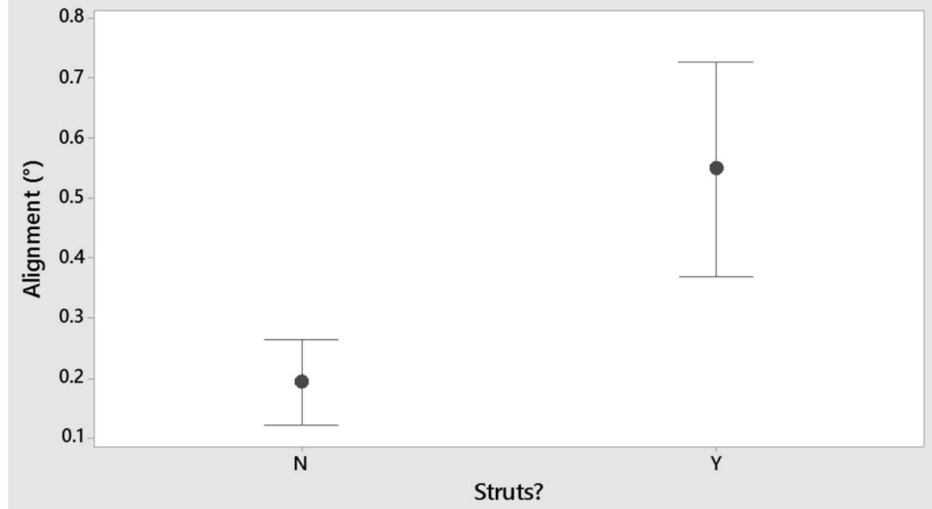
Density



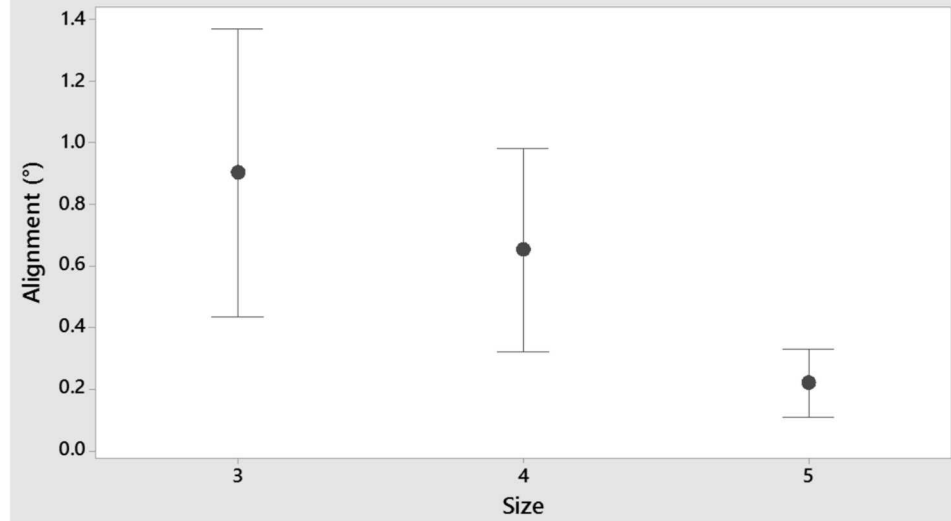
Gage R&R attributes
40% of variation to
measurement
replications

Grip Alignment

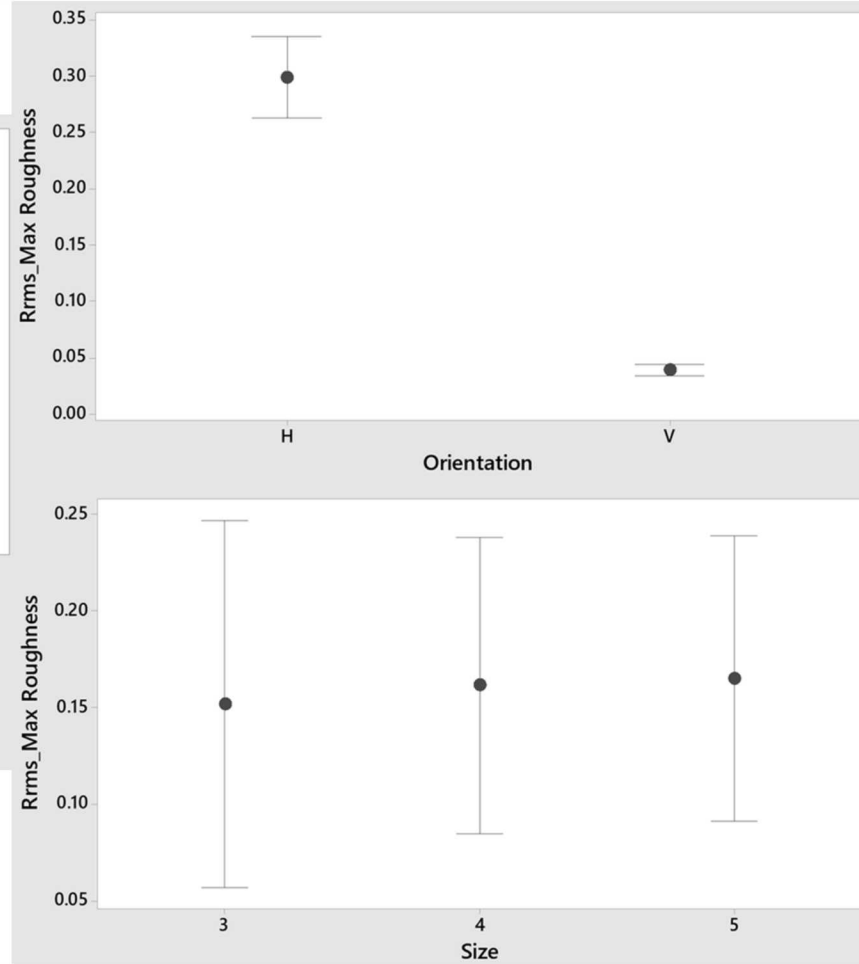
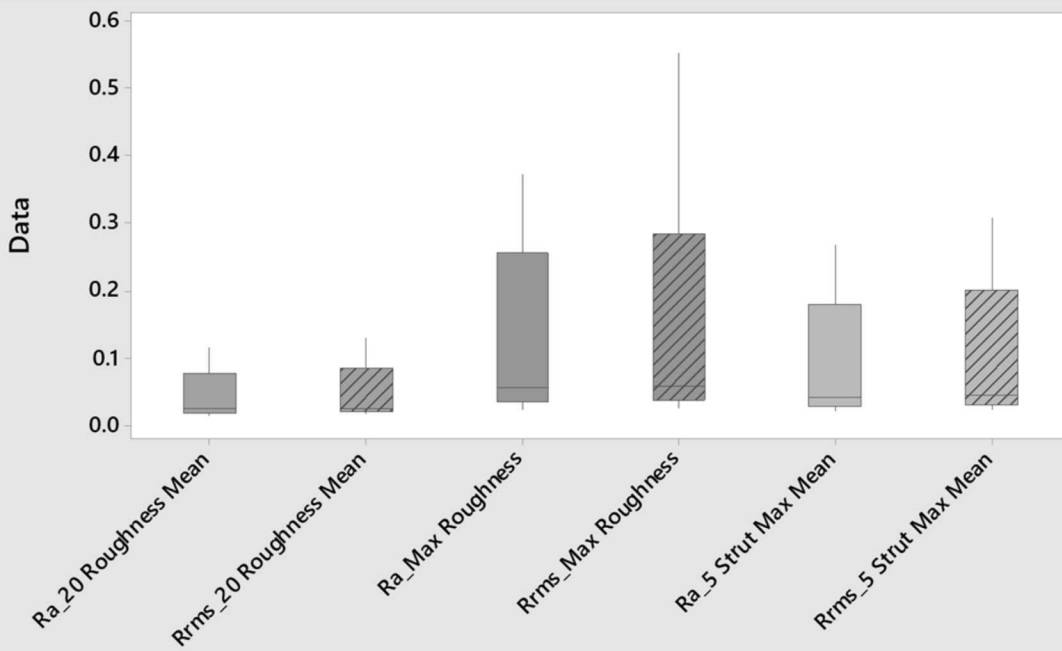
All Samples
95% CI for the Mean



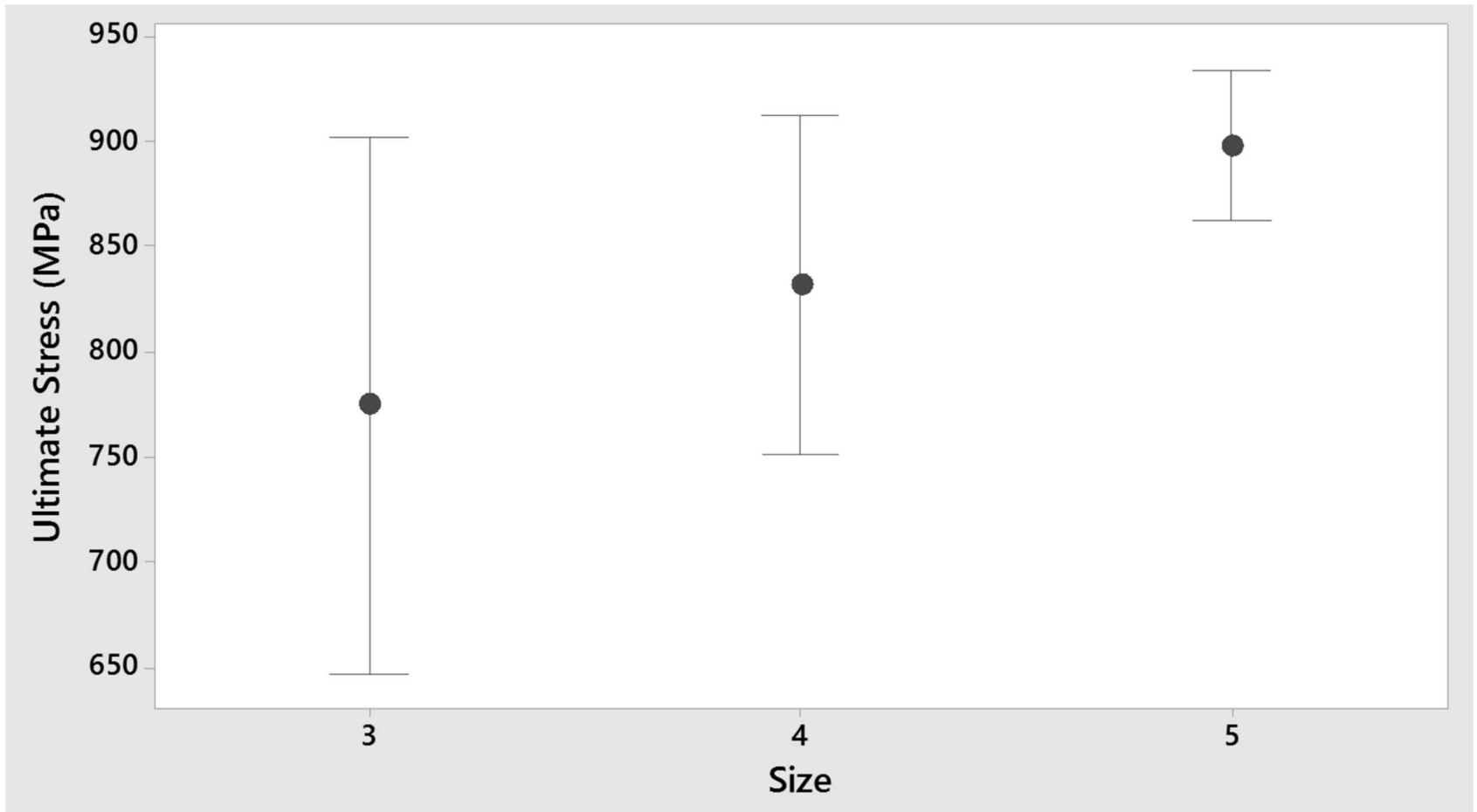
Strut Samples
95% CI for the Mean



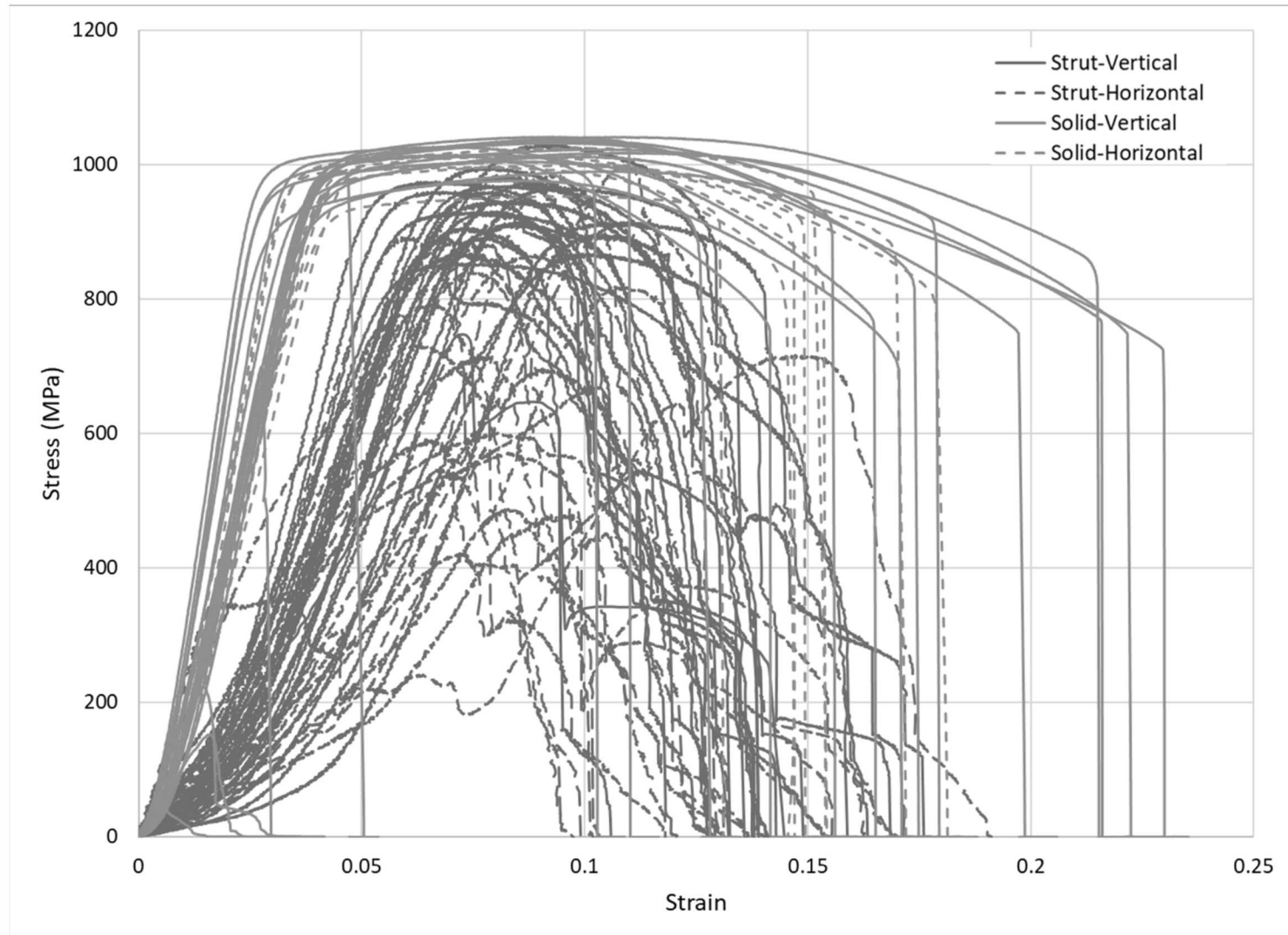
Strut Roughness



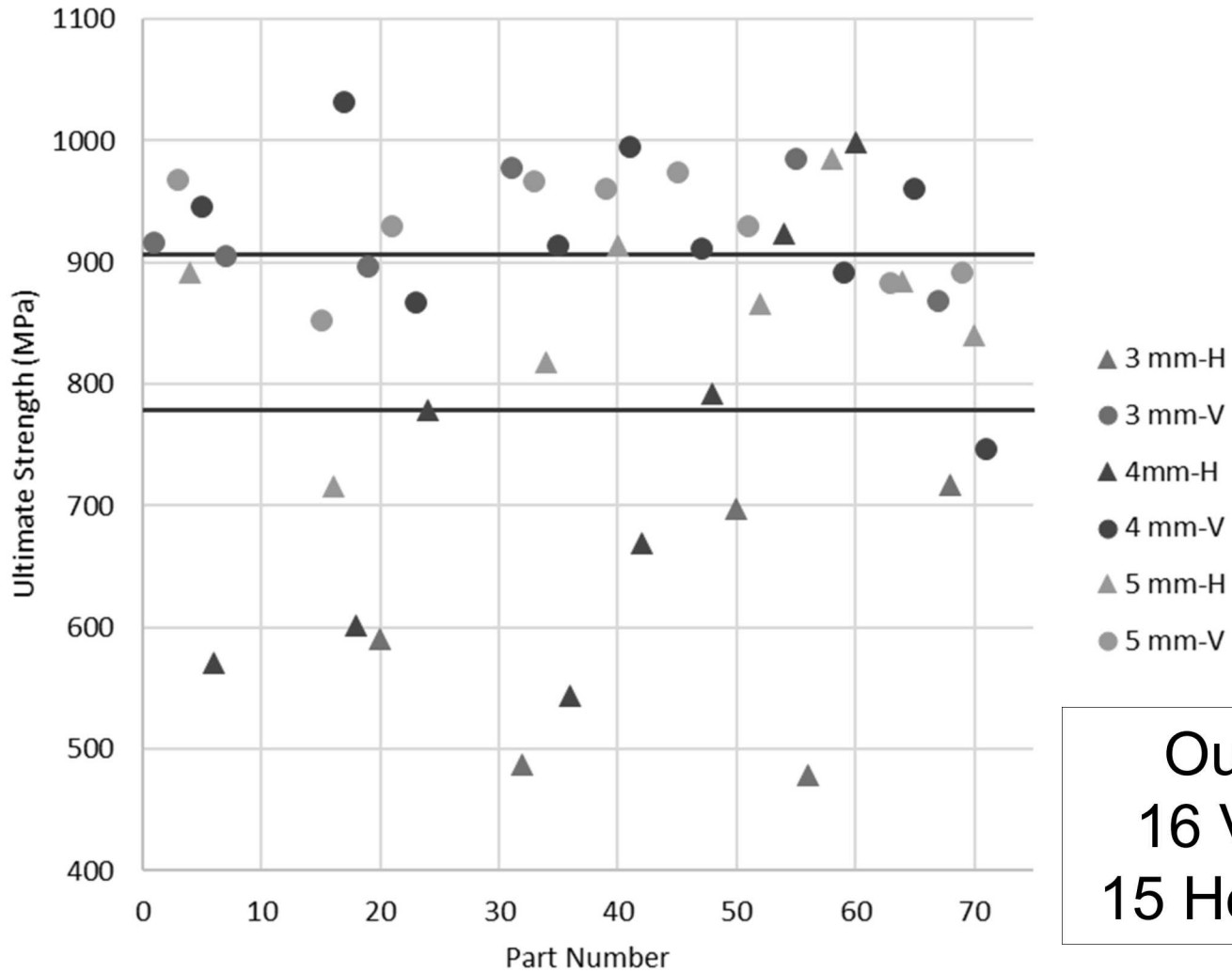
Ultimate Stress of Strut Samples



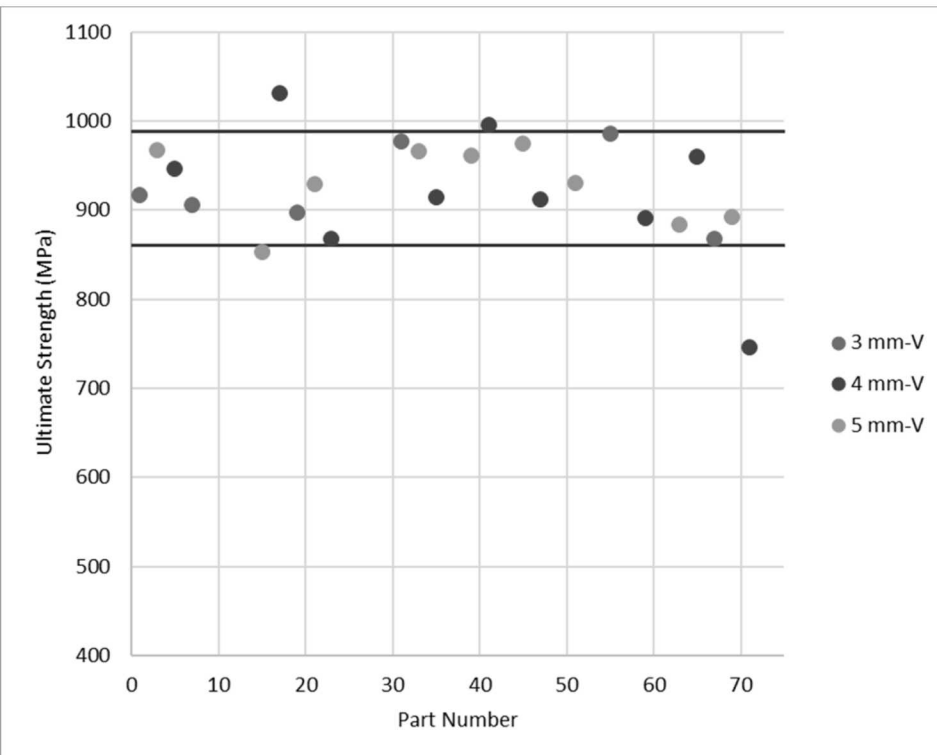
Comparison of All Samples



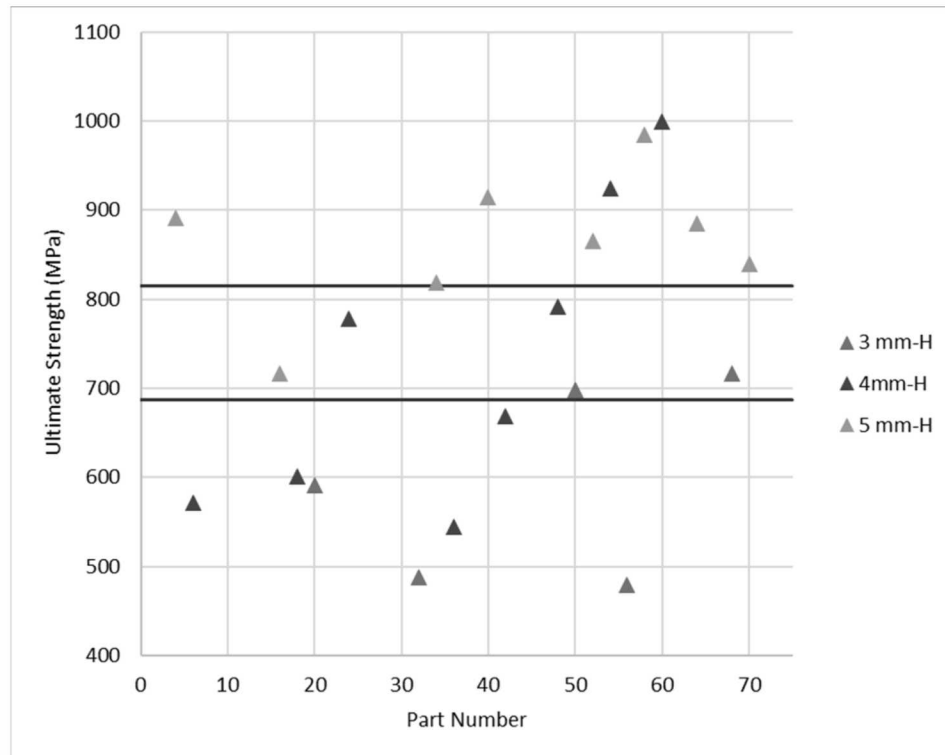
Struts: Ultimate Strength Outliers



Struts: Ultimate Strength Outliers

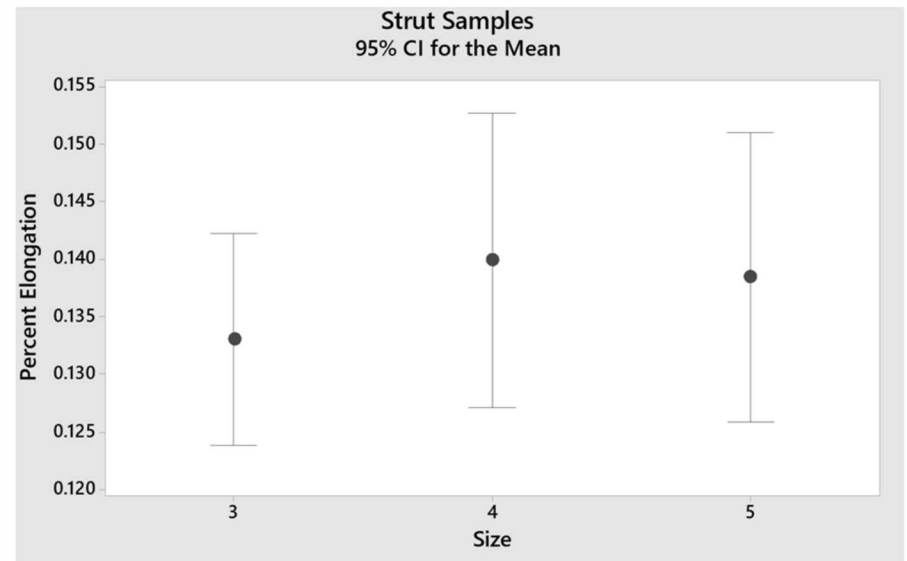
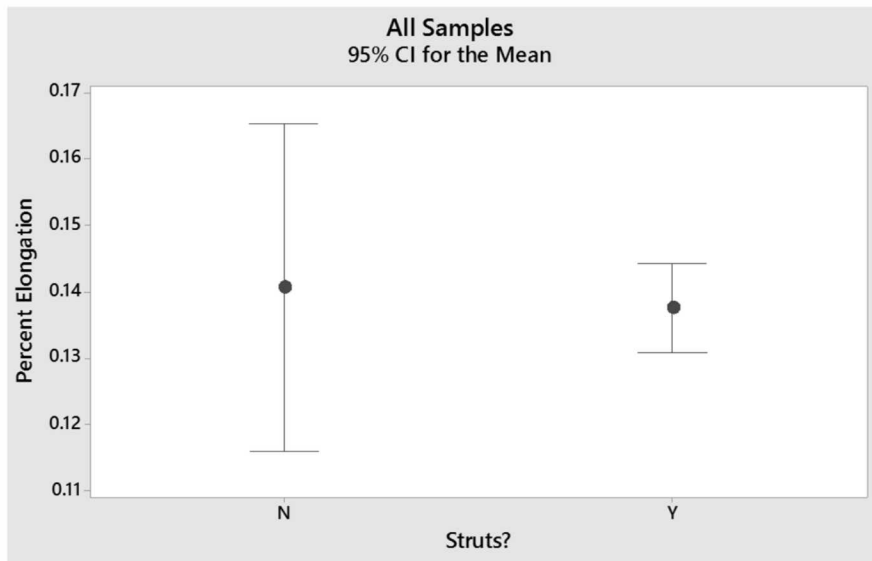


4 Outliers



16 Outliers

Percent Elongation



Conclusions

- Parts are generally smaller than designed
- Porosity can have a large impact on part performance
- Unsupported features have large variation in part geometry and performance
- Powder handling needs to be controlled
- Robust design depends on priority
 - Ultimate Stress- 5 mm
 - Percent Elongation- 3 mm
- Still much to learn about performance of additive parts

Acknowledgements

- Sandia National Labs
 - Allen Roach
 - Brad Boyce
 - Tommy Woodall
 - David Moore
 - Andrew Lentfer
 - Laura Swiler
- Stratasys Direct Manufacturing
 - Ryan Ramon
 - Ashley Chipman
- Dr. Taleff



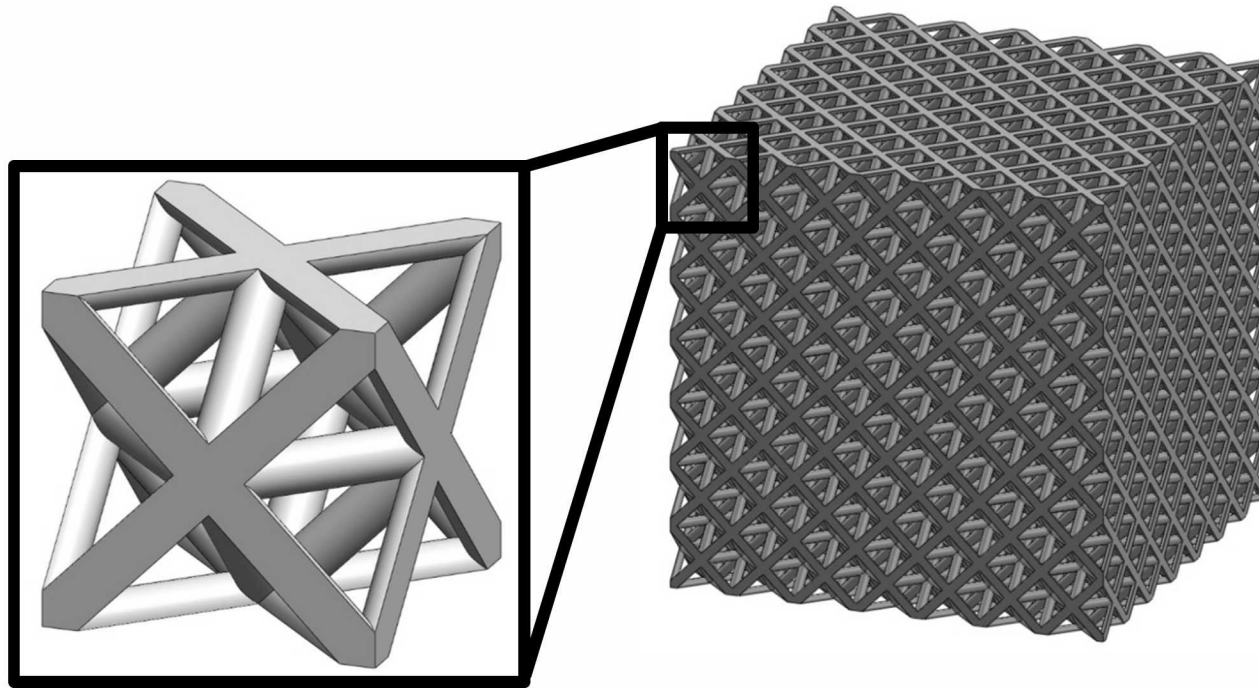
THANK YOU!

QUESTIONS?



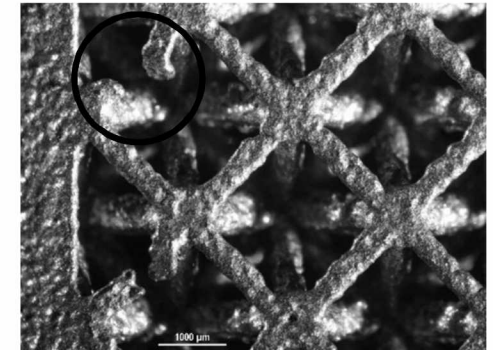
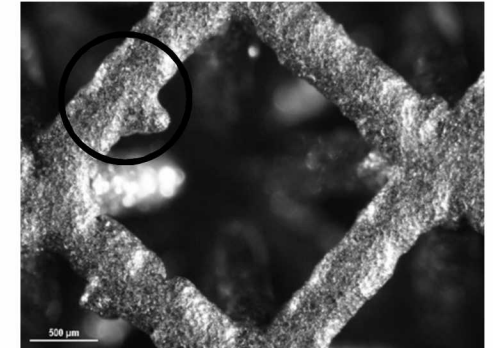
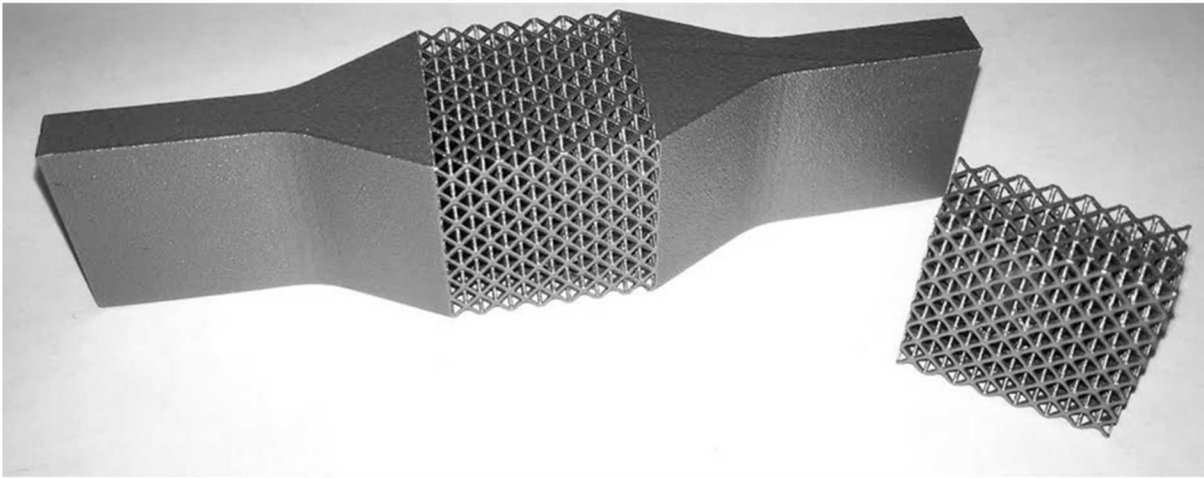
BACKUP SLIDES

Octet Truss Lattice



- Lattice structures offer favorable tradeoffs between strength and weight
- Structurally efficient due to nodal connectivity

Initial Test Parts

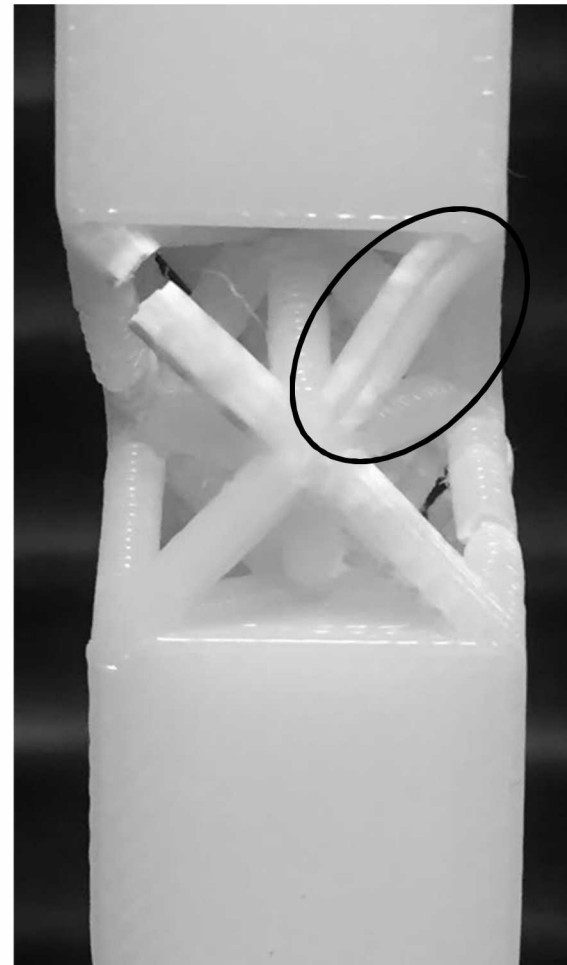
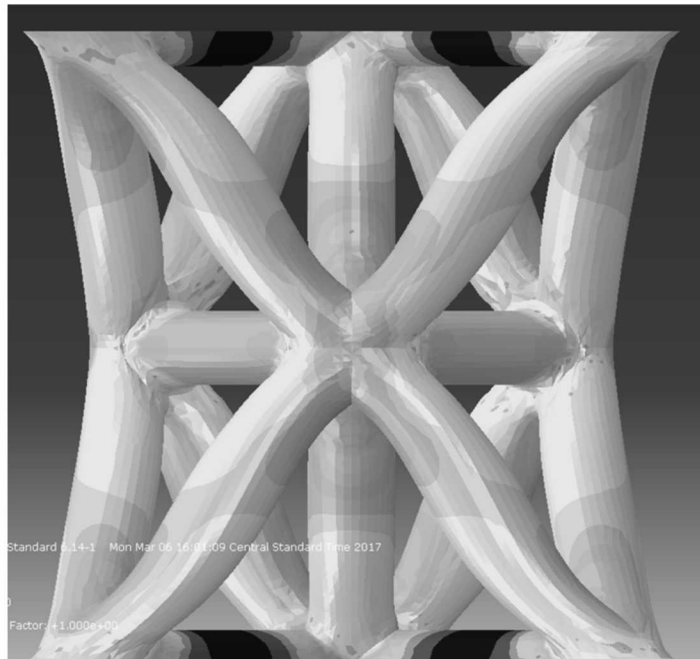


- Small amount of powder remained in the bar
 - Removed with a needle
- Struts were not completely round
- A few struts were missing

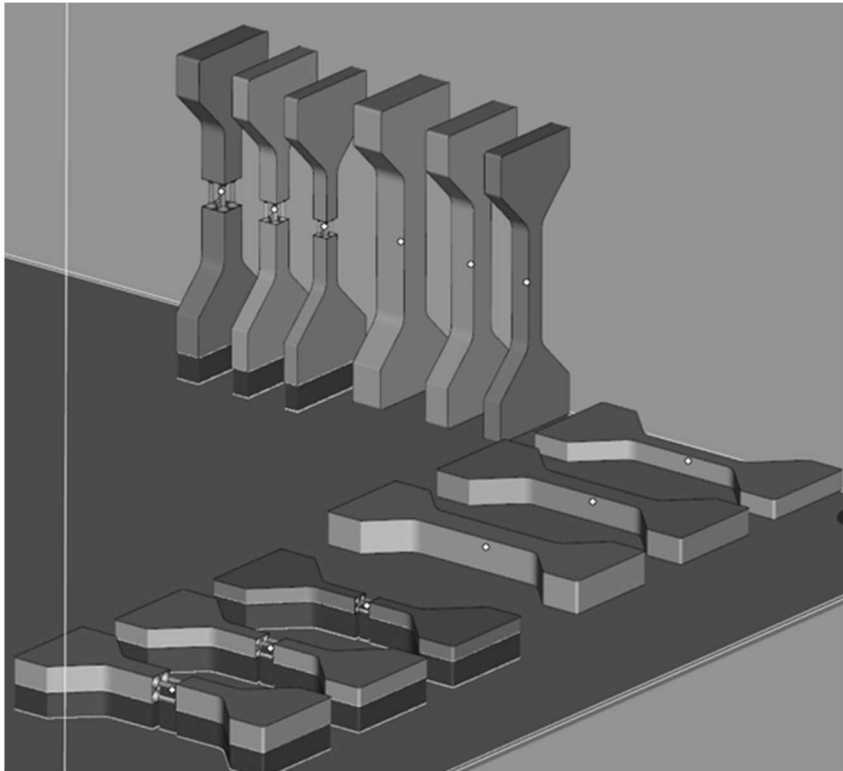
Deformation Studies

Plastic Test

Abaqus Simulation



Learning About Manufacturability



Rebuild Results



Unfortunately, horizontal bars were broken during removal from the build platform.