SAND2017-8400C

Mechanical Property Variation in Metal Lattice Structures

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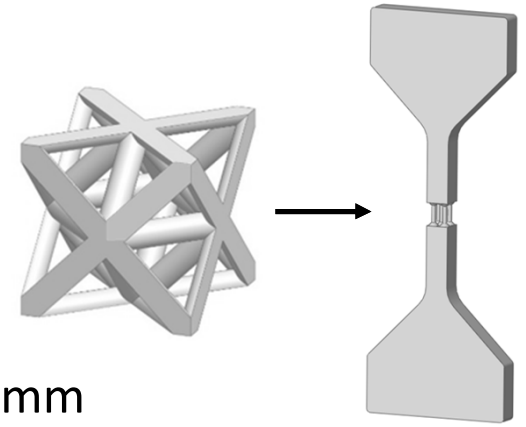
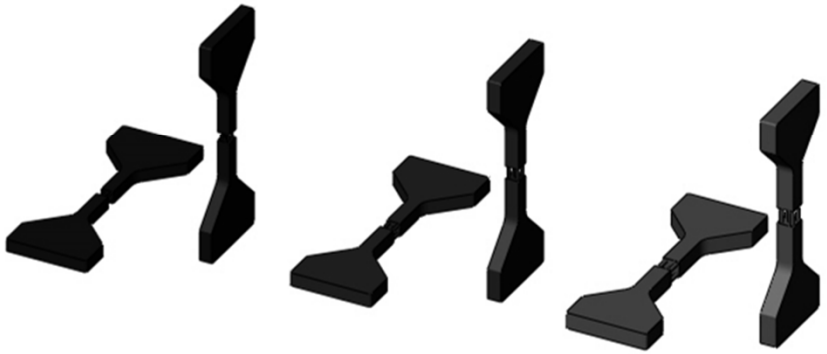
GOAL

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

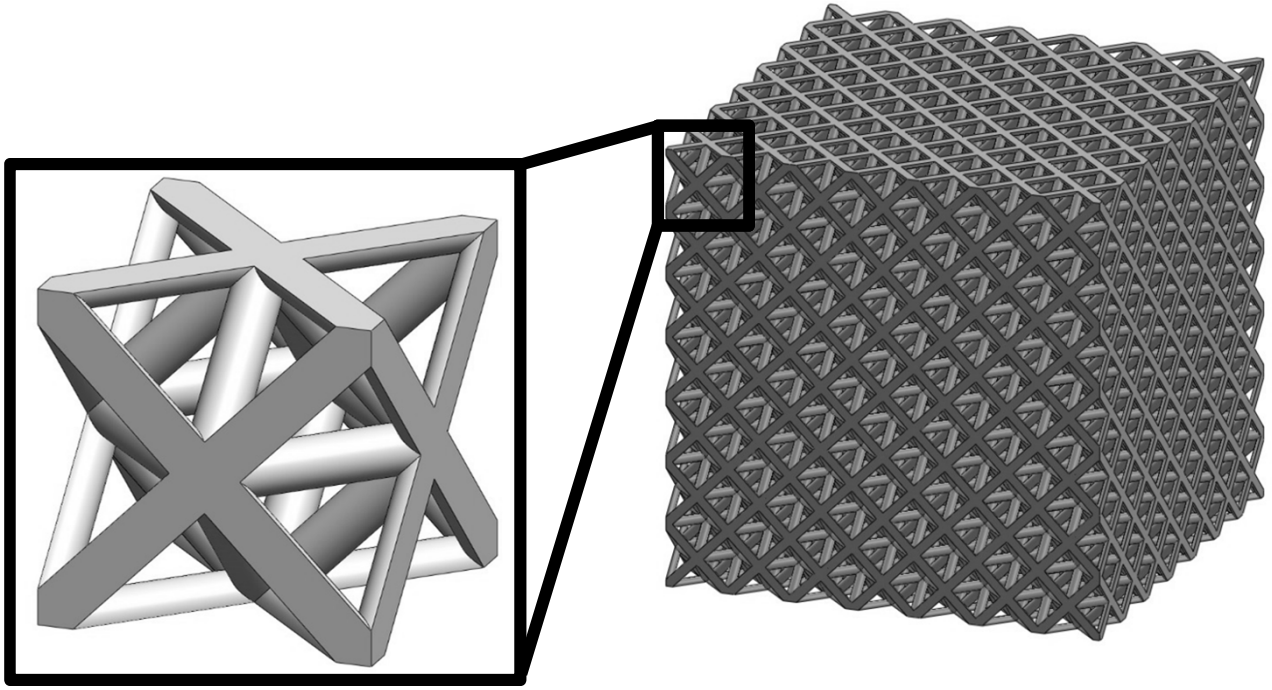
Overview

- 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



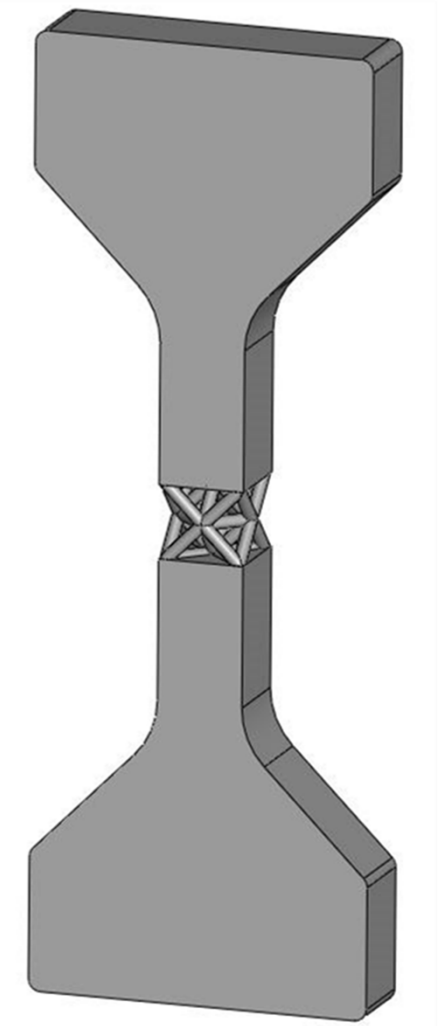


Octet Truss Lattice



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

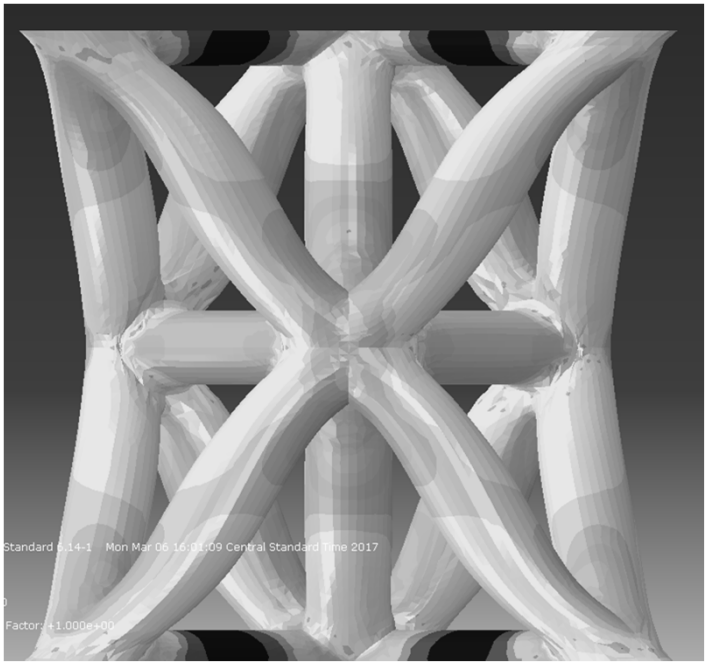
Single Unit Cell Builds



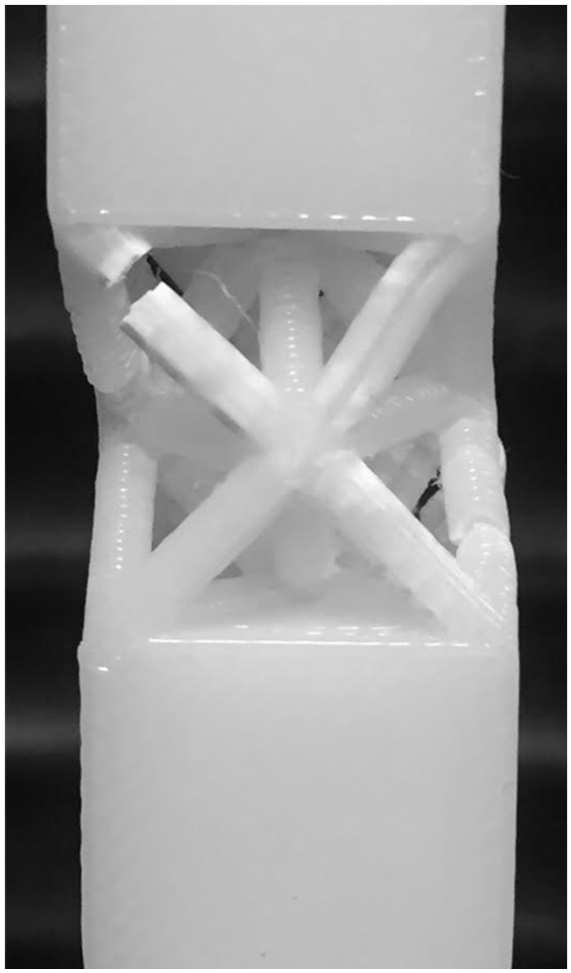
- Individual strut behavior is difficult to analyze in the full lattice structure
- Data depicting how defects impact these small features is important in understanding lattice behavior
- Concerned about struts bending due to limited boundary conditions

Deformation Studies

Abaqus Simulation

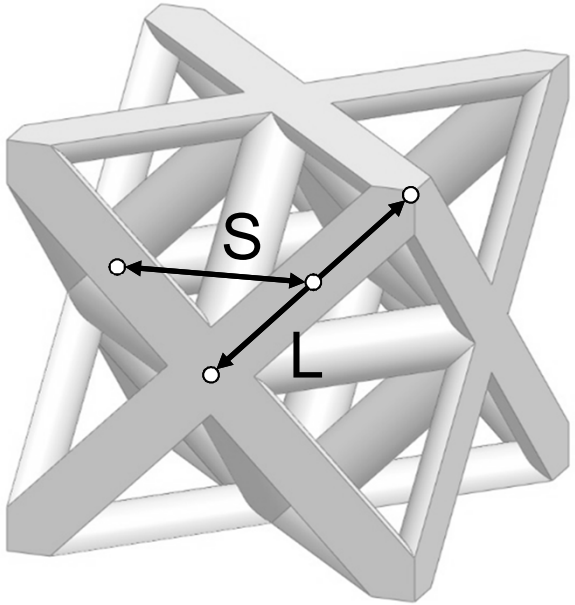


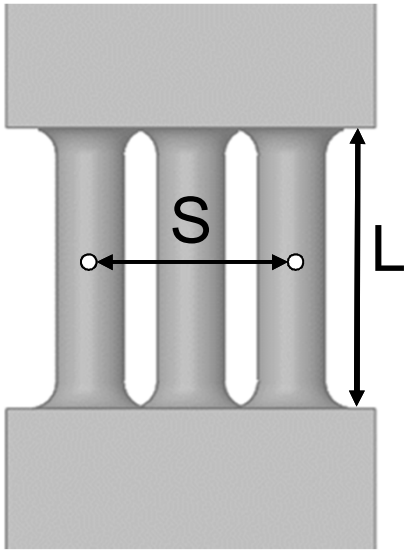
Plastic Test

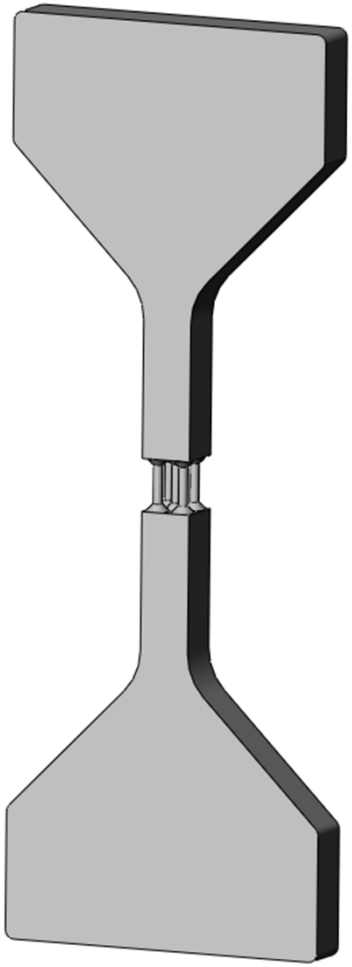


Vertical Strut Builds

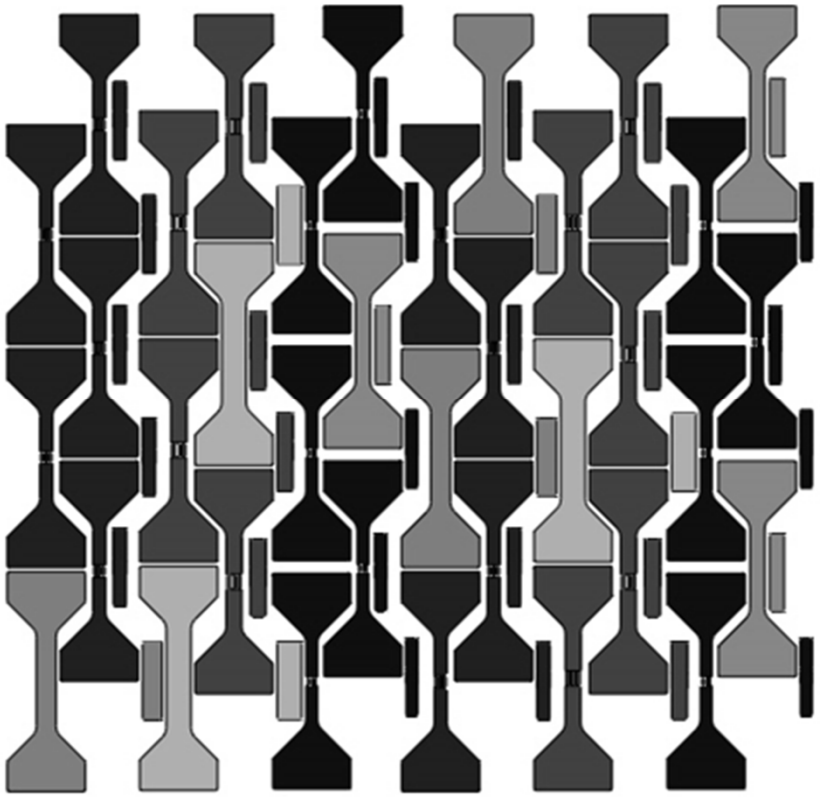
- Spacing based on the octet truss design
- Horizontal and vertical copies
- Three different sizes (representing 3, 4, and 5 mm unit cells)

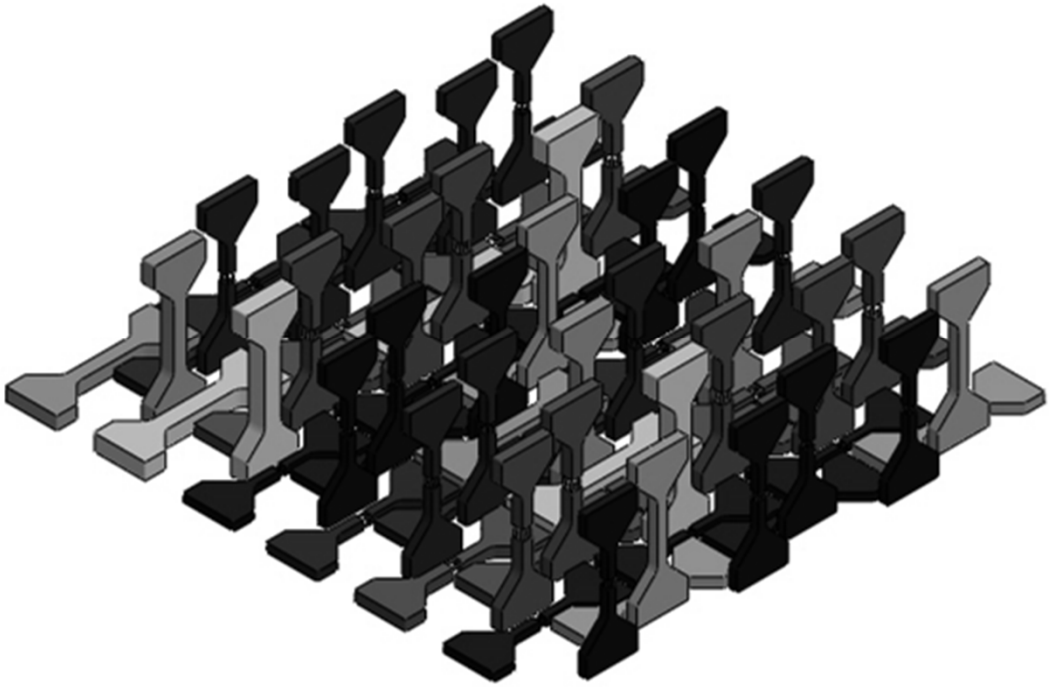






Build Layout

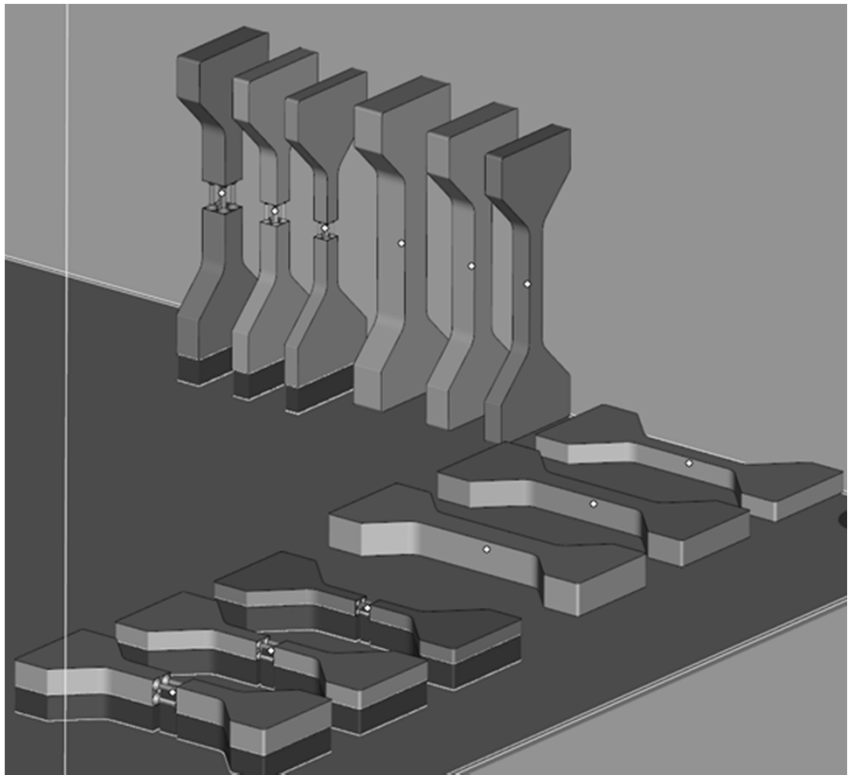




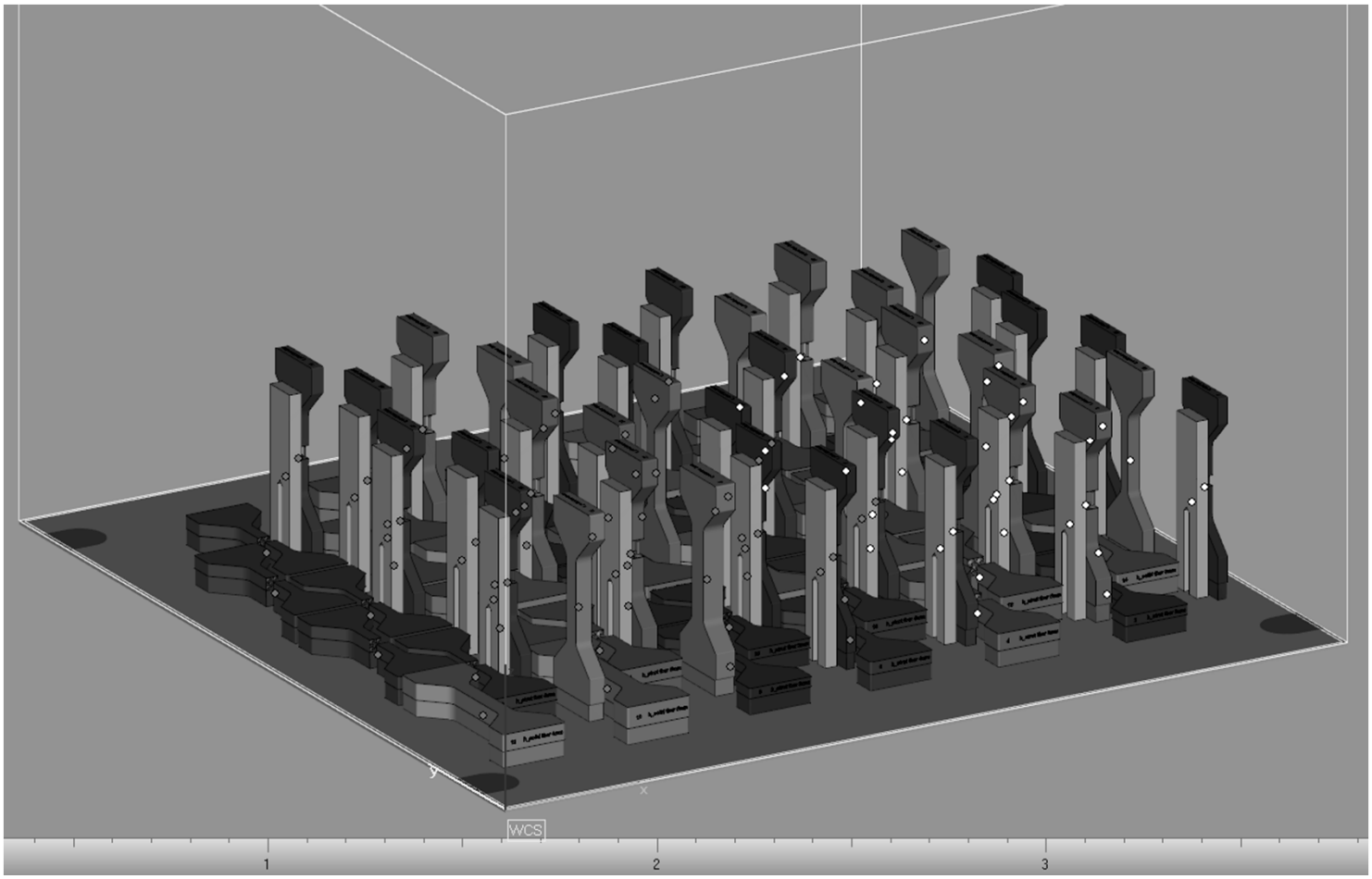
Build Process

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.

Learning About Manufacturability



Rebuild with Recoater Brush and Barriers

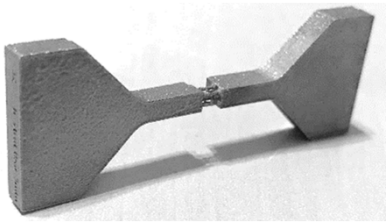
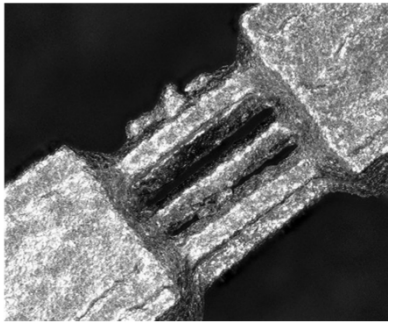
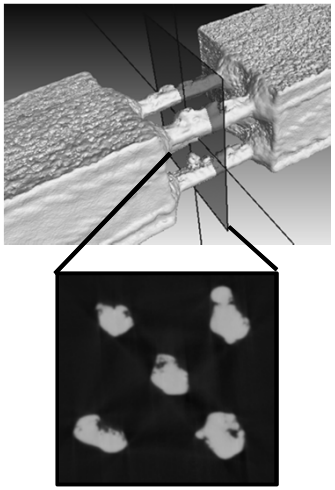
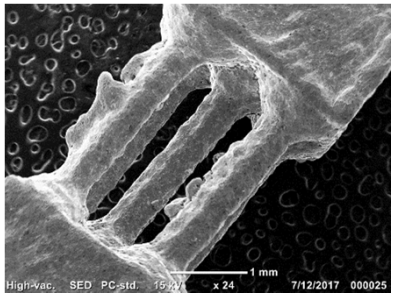
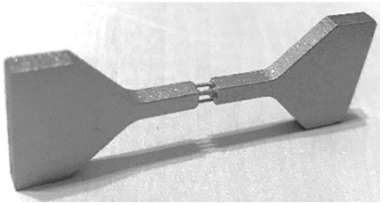
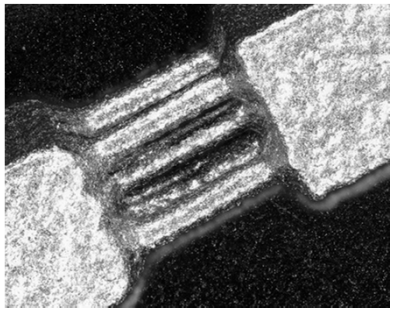
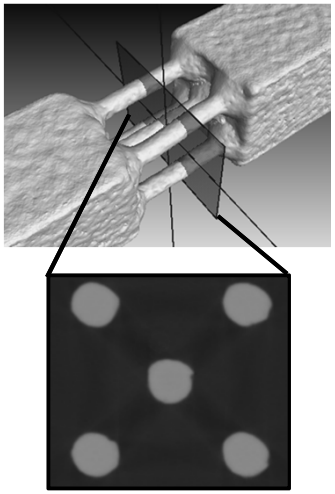
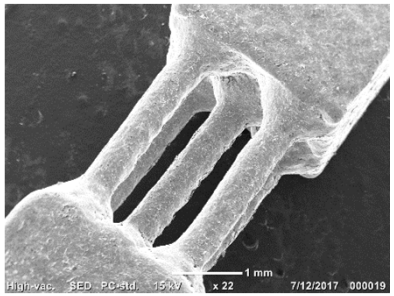


Rebuild Results

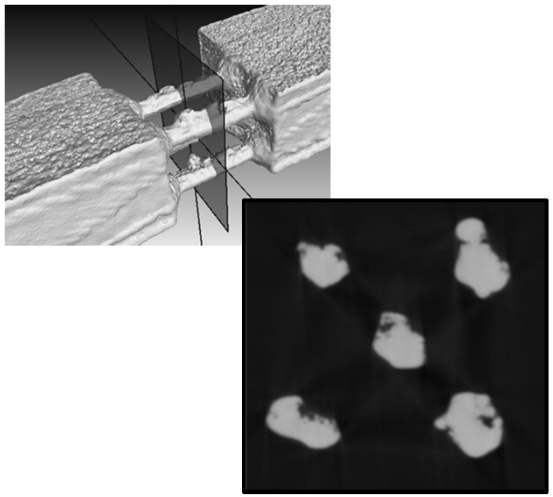
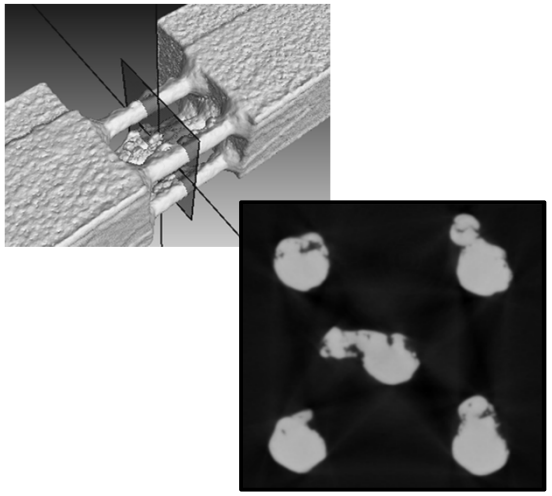
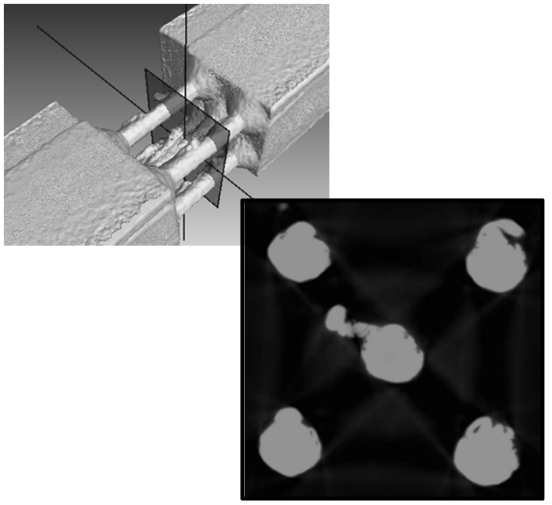
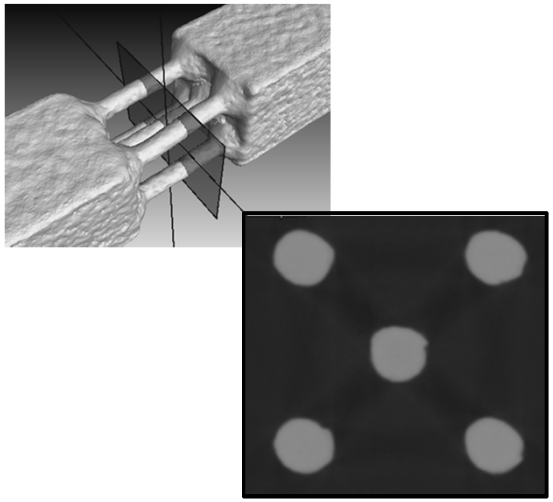
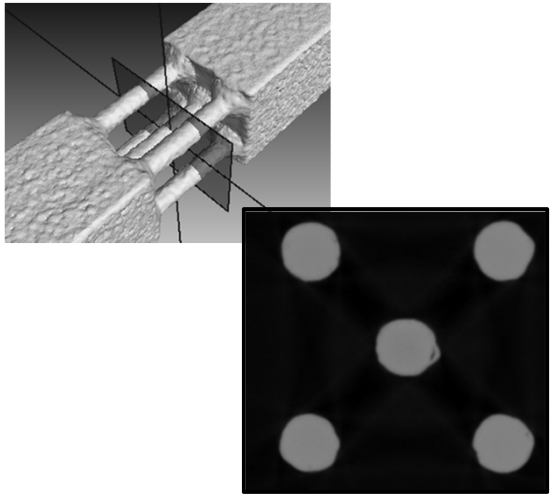
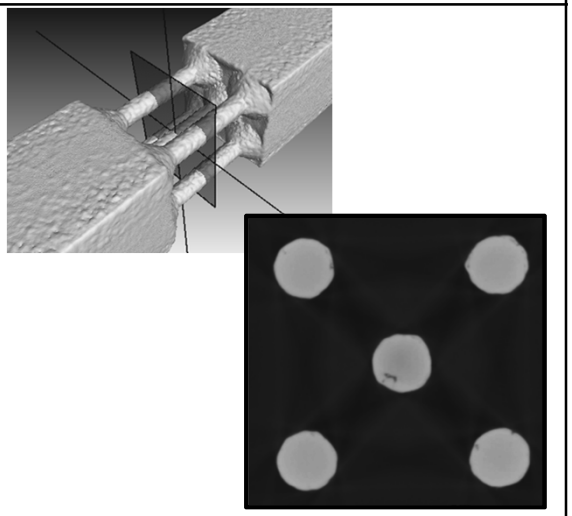
Unfortunately, horizontal bars were broken during removal from the build platform.

NON-DESTRUCTIVE EVALUATION

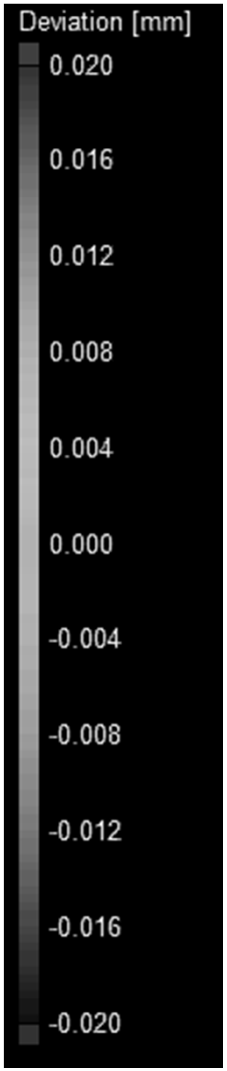
Strut Inspection-Orientation Comparison

	Visual Inspection	Microscope	CT Scan	SEM
3 mm Horizontal Bar				
3 mm Vertical Bar				

CT Results-Configuration Comparison

	‘3 mm Bar’	‘4 mm Bar’	‘5 mm Bar’
Horizontal Bar			
Vertical Bar			

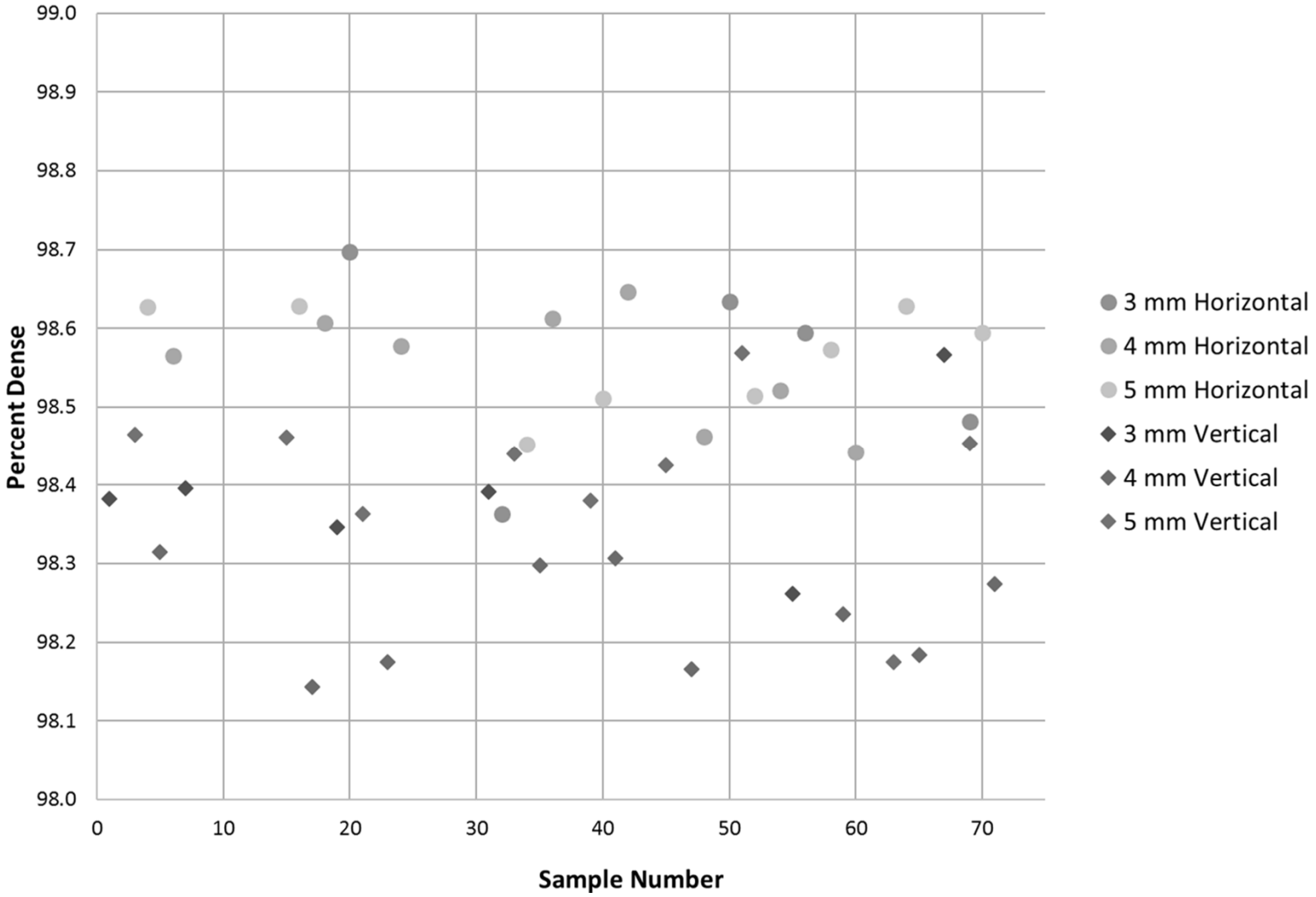
CT Results-Comparison to Nominal



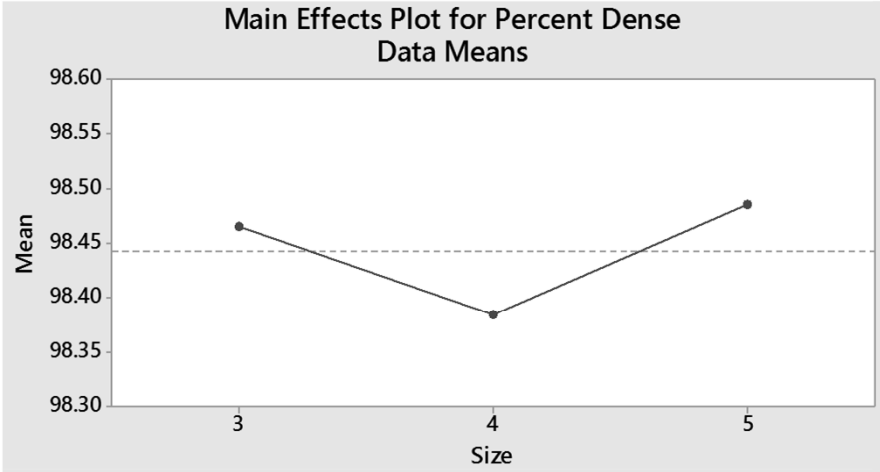
5 mm Vertical

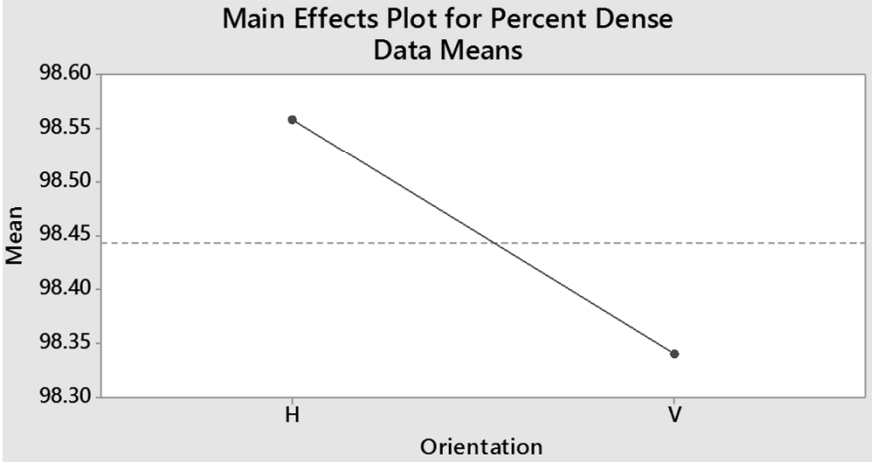
5 mm Horizontal

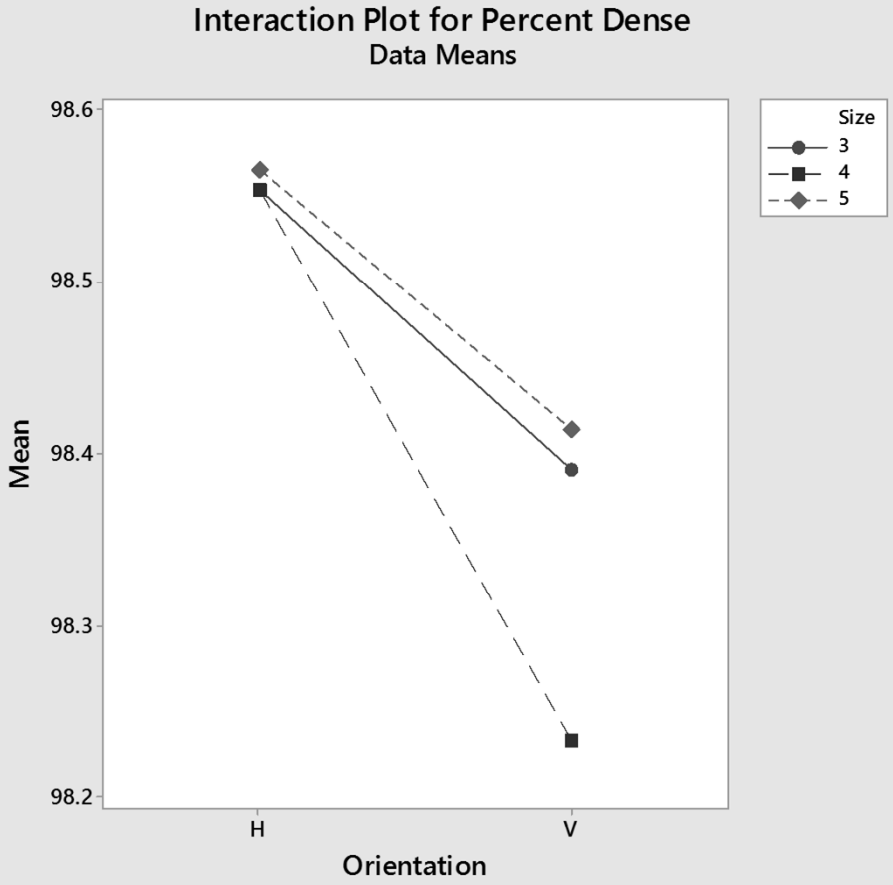
Density Measurements



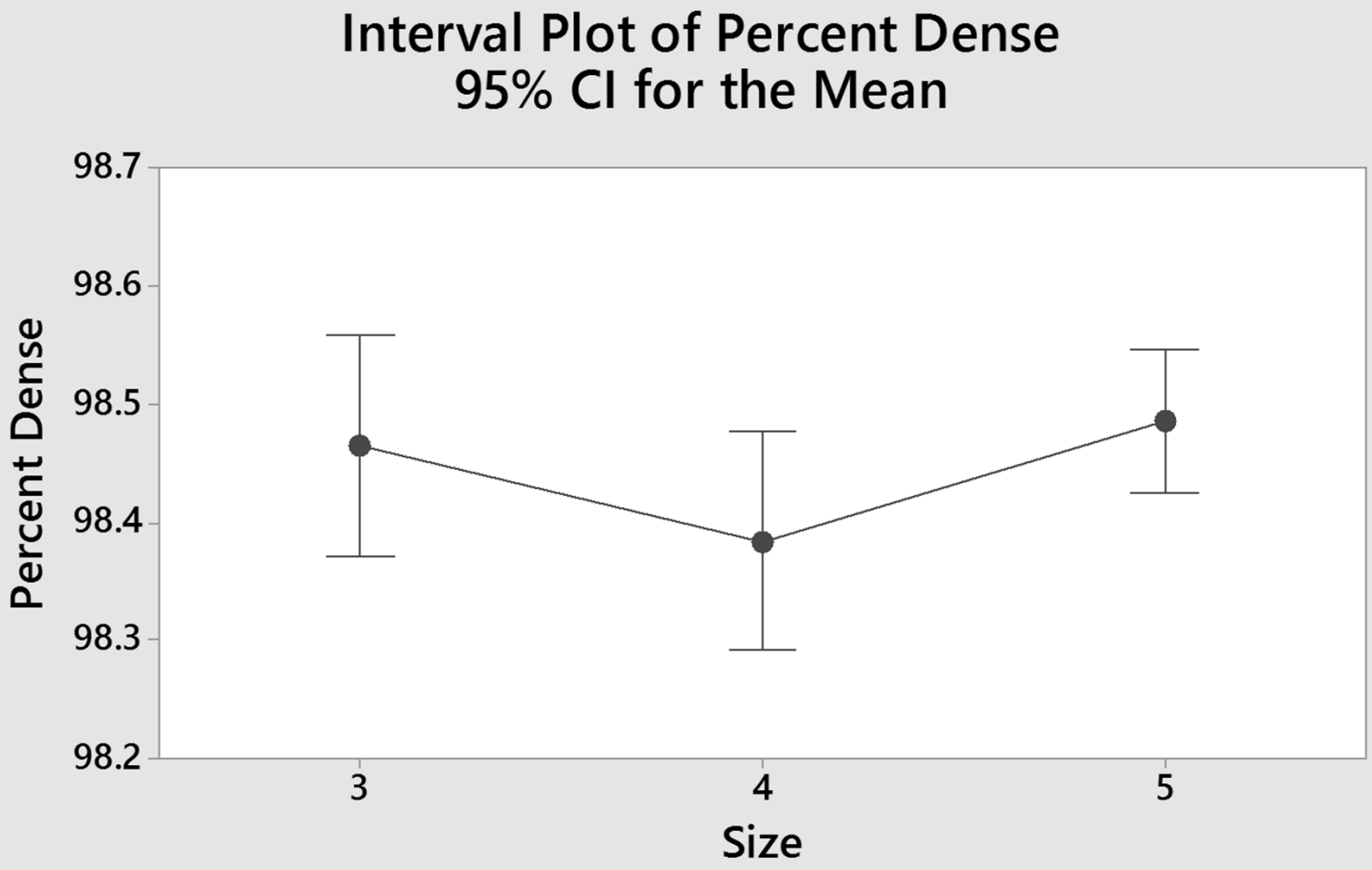
Density Effects



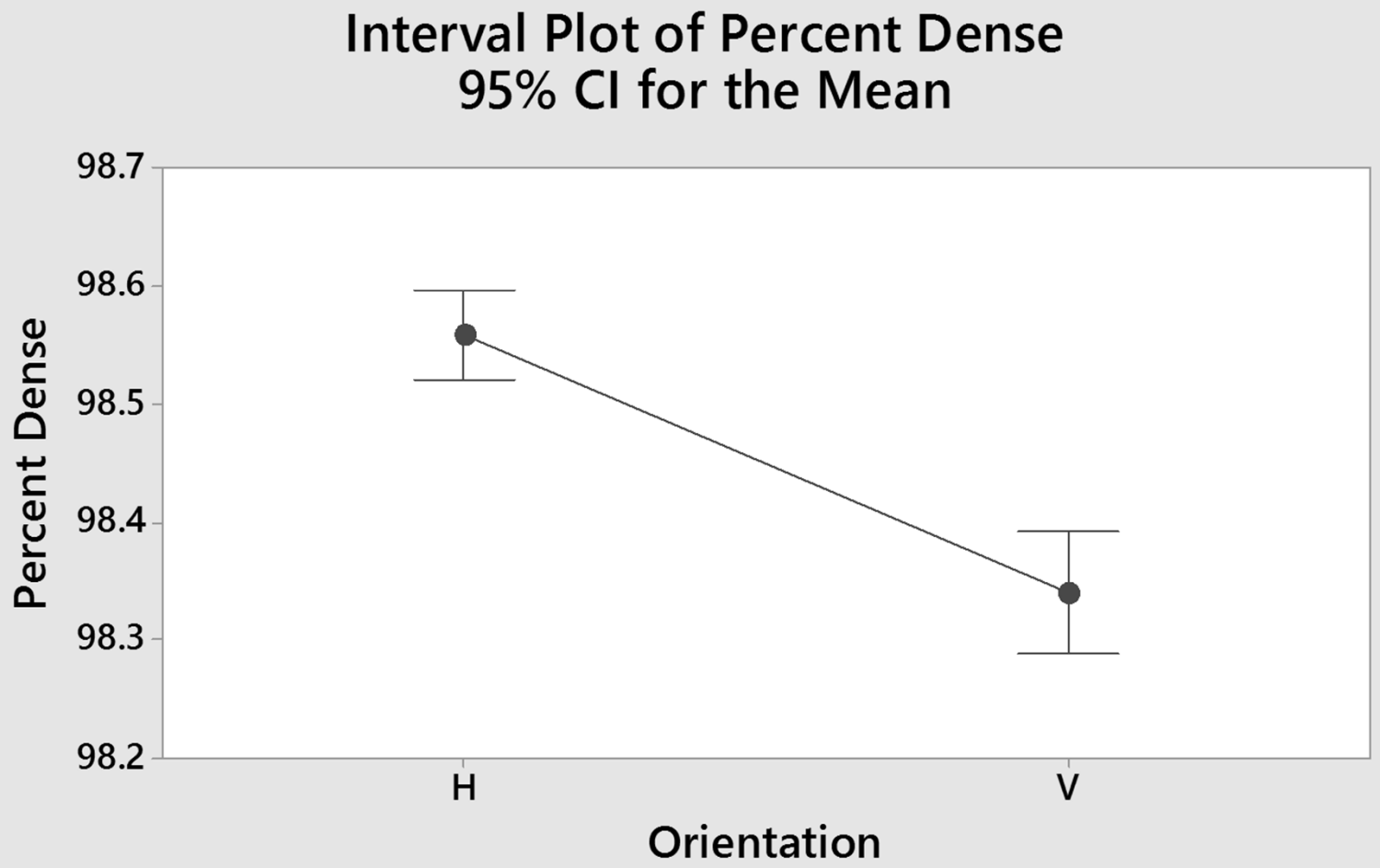




Size Effects on Density



Orientation Effects on Density



Future Work

- Non-Destructive Evaluation
  - Ultrasonic testing and CT scanning of solid samples
  - Density measurement replications
  - Geometric comparison to CAD model
- Destructive Evaluation
  - Tensile tests
  - Failure analysis with SEM
- Look for correlations between NDE and part performance

QUESTIONS?

Acknowledgements

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

Sources

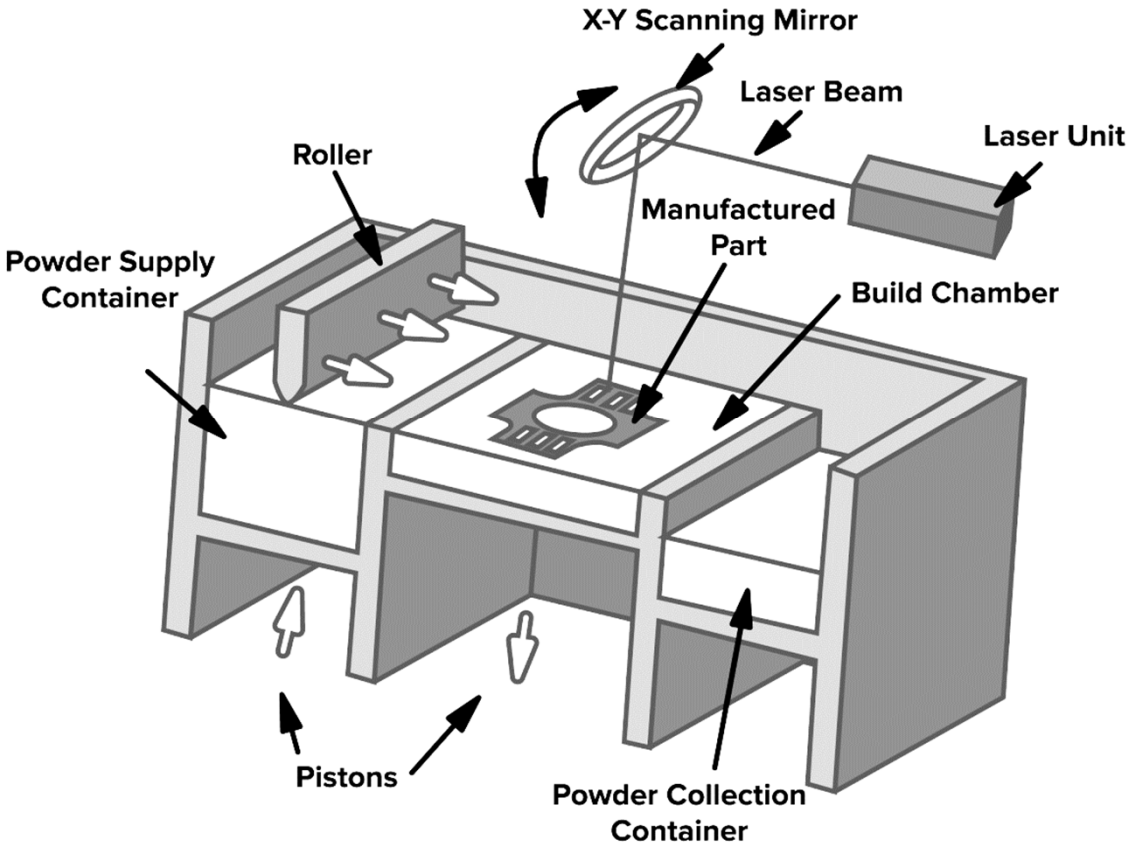
Kalsi M, Hacker K, Lewis K. (1999). A Comprehensive Robust Design Approach for Decision Trade-Offs in Complex Systems Design. ASME. *J. Mech. Des.*

Jared B, Boyce B, Madison J, Ostien J, Rodelas J, Salzbrenner B, Swiler L, Underwood O. (2016). Quantifying Material Performance & Defect Signatures in Laser Powder Bed Fusion.

ACF Group, Inc. (n.d.). Laser Sintering. Retrieved from http://lasersint.com/wordpress/?page_id=195

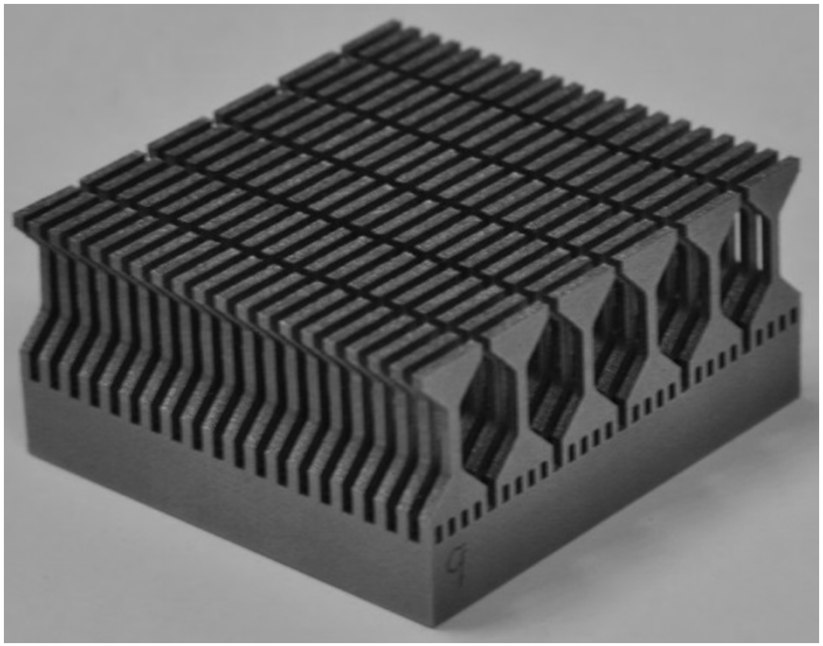
BACKUP SLIDES

Direct Metal Laser Sintering (DMLS)

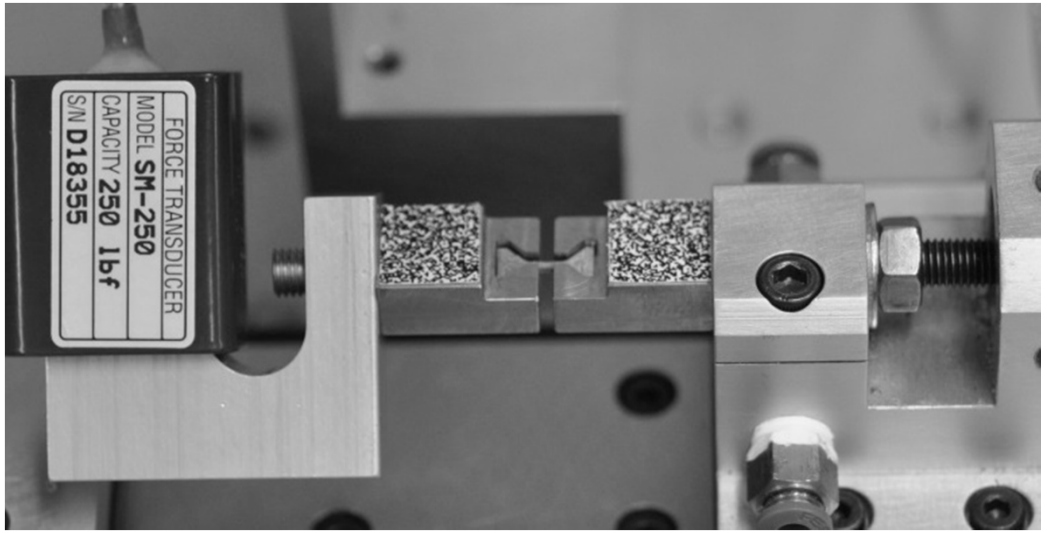


(ACF Group, Inc., n.d.)

High Throughput Testing

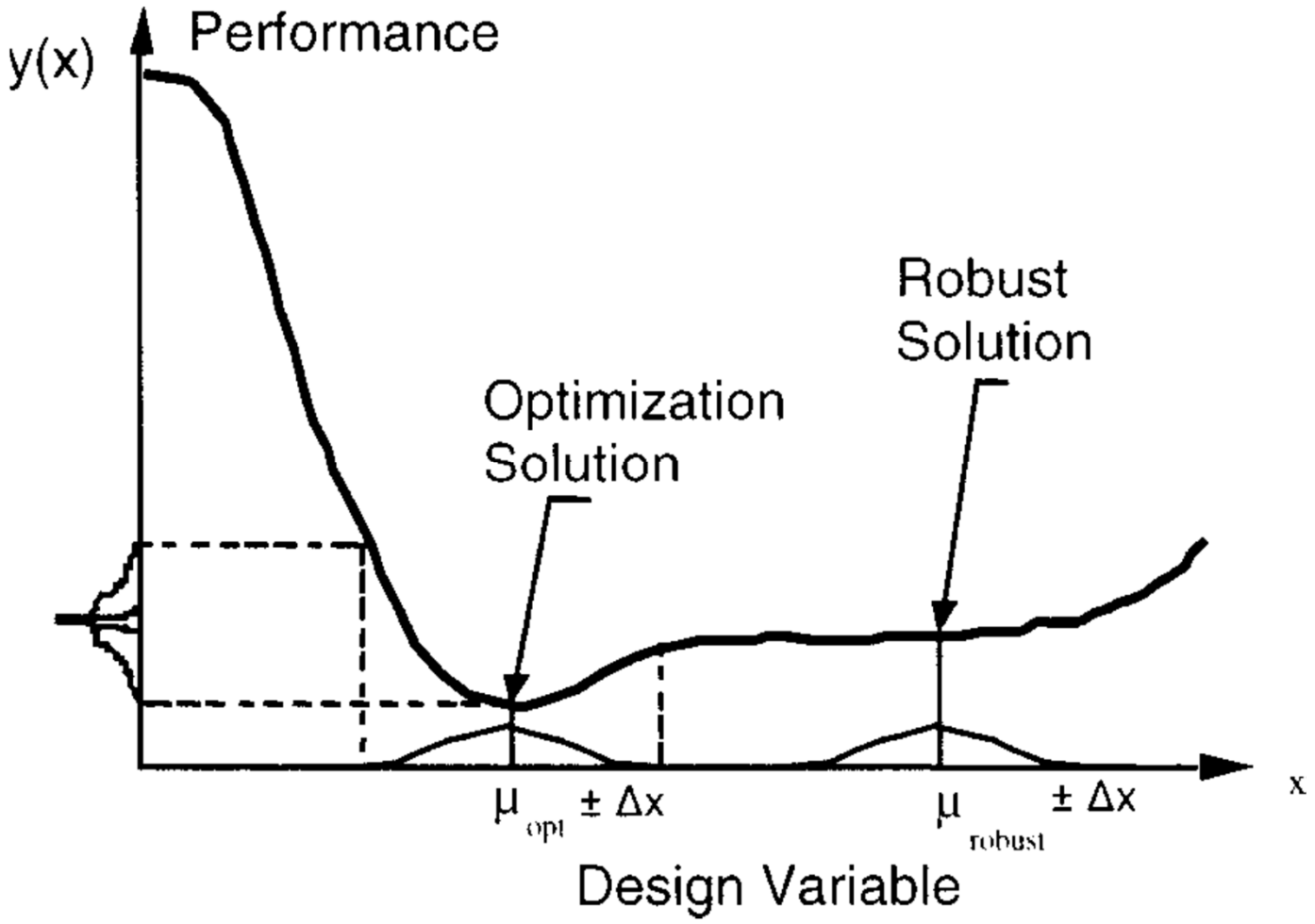


(Jared et al, 2016)



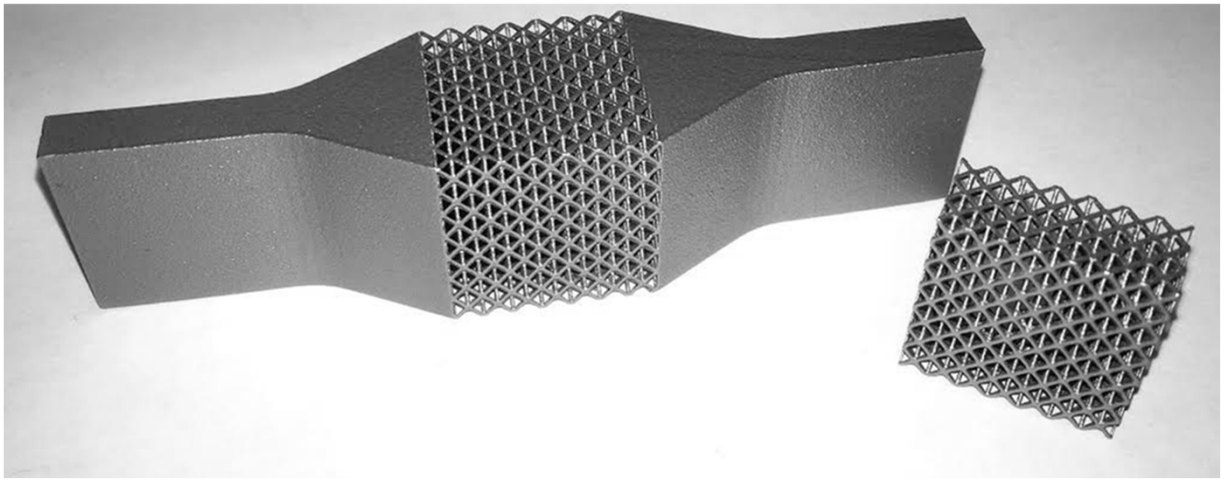
(Jared et al, 2016)

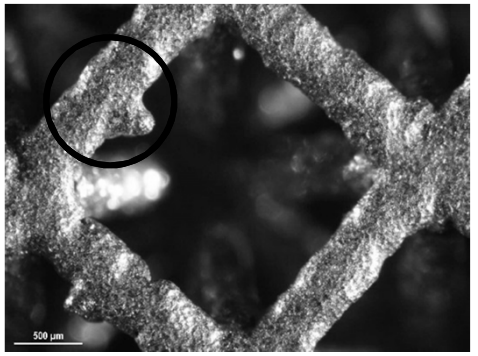
Robust Design

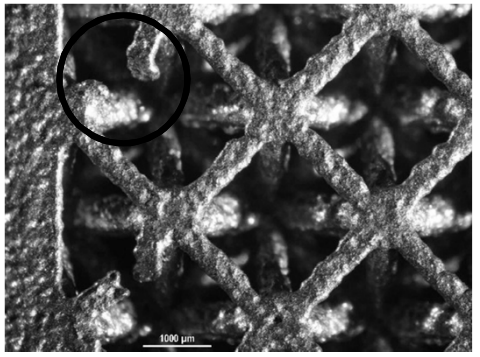


(Kalsi, Hacker, & Lewis, 1999)

Initial Test Parts

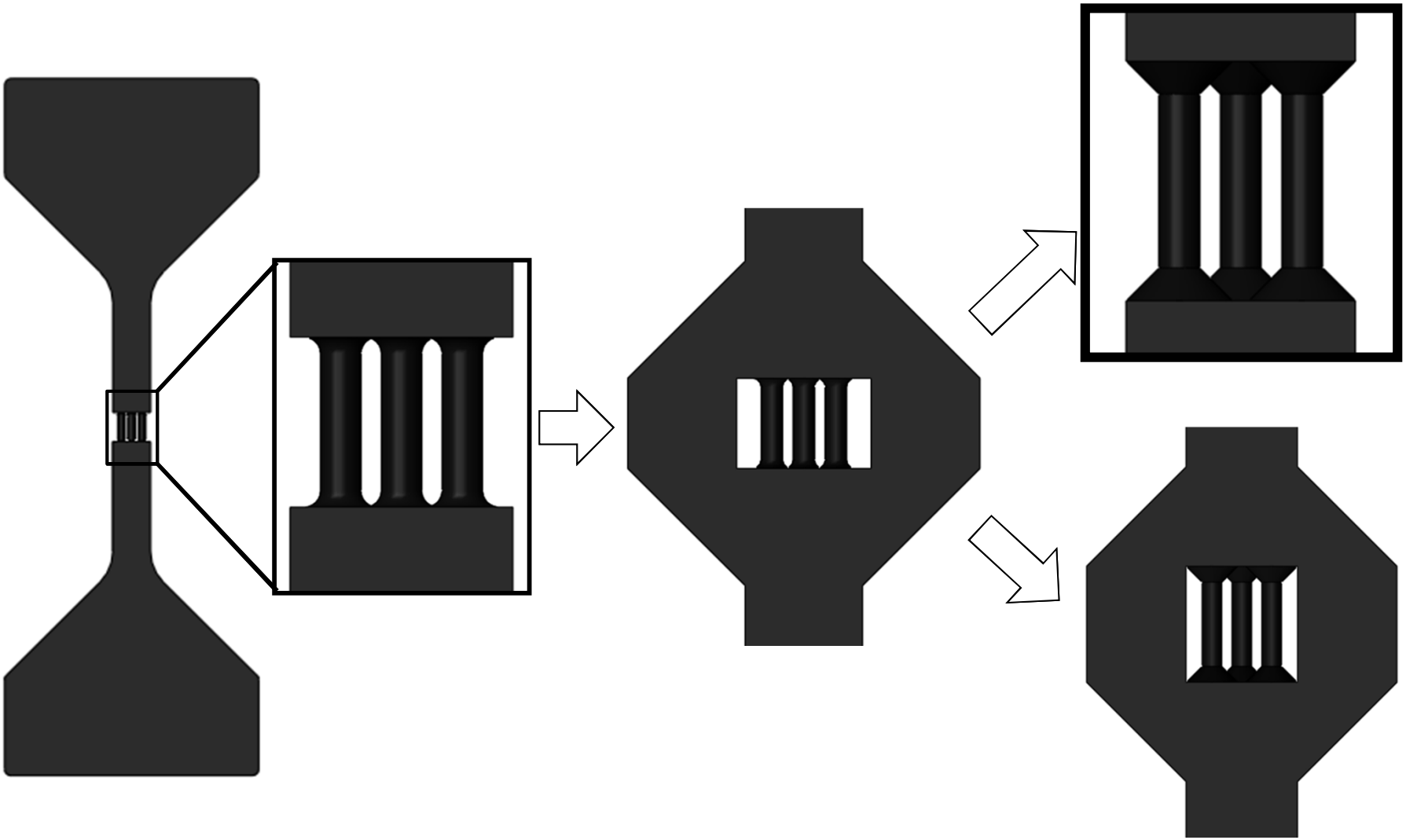






- Small amount of powder remained in the bar
  - Removed with a needle
- Struts were not completely round
- A few struts were missing

Design for Manufacturability



Full Lattice Builds