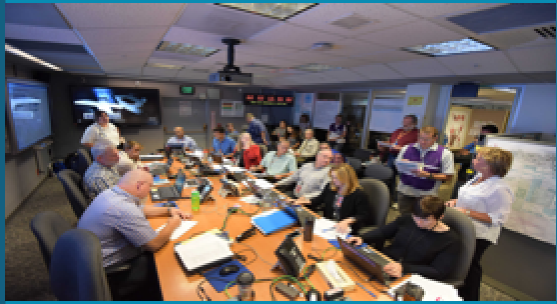
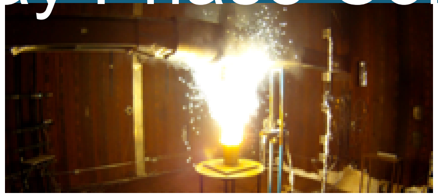
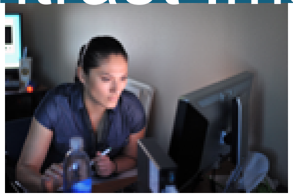
SAND2022-8929C

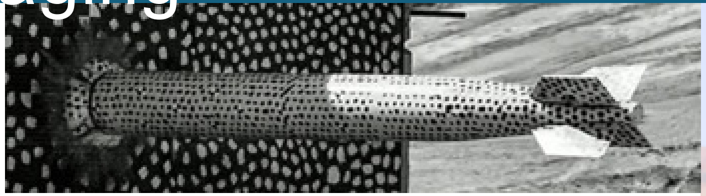
Sandia National Laboratories

Meso-Scale Simulations of the Transient Deformation in Additively Manufactured 316L Stainless Steel Lattices Characterized with in-situ X-ray Phase Contrast Imaging









Group on Shock Compression of Condensed Matter 22nd Biennial Conference

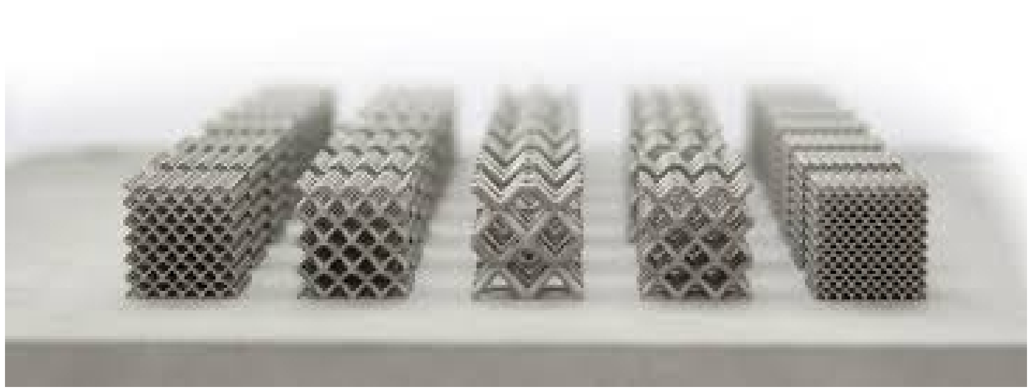
July 14, 2022

Brittany Branch, Paul Specht, David Moore, Tim Ruggles, Scott Jensen, and Bradley Jared

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Background & Motivation



AM has enabled the interconnection of solid struts from edges and faces of cells in order to decrease the relative density (ρ^*/ρ_s) permitting the design of components that are:

- lightweight
- increased stiffness
- other unique mechanical properties

→ **Energy Dissipation**

Lattices are being developed as an engineering solution for vibration and shock mitigation in transportation, aerospace and military applications.

➢ How does microstructure control deformation mechanisms in AM lattices?

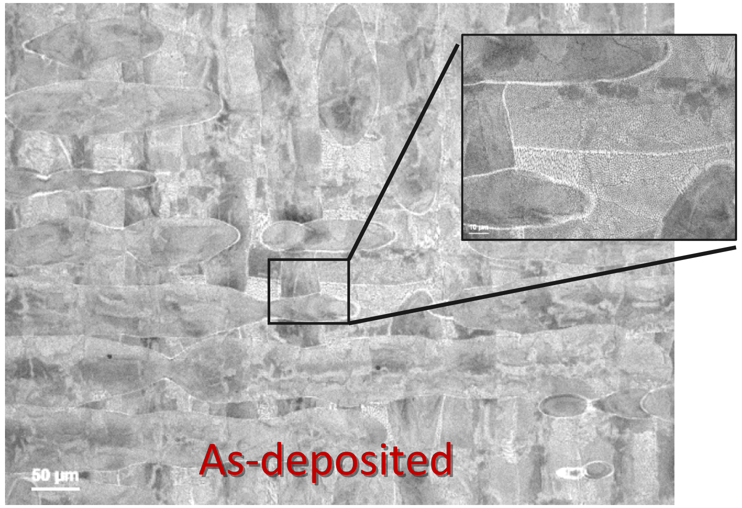
➢ What role does grain structure, filament porosity, processing defects, etc. have on performance of lattice metamaterials?

➢ How does topology dominate performance characteristics in AM lattice metamaterials under shock loading?

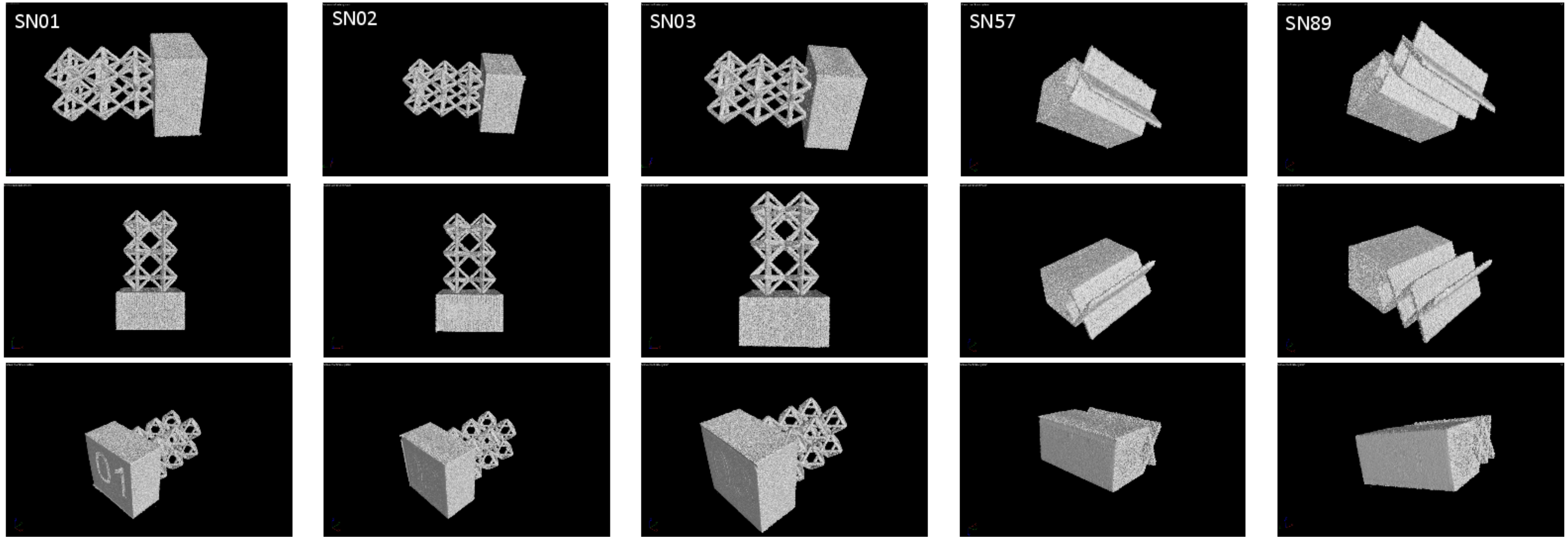
Studies probing lattice performance at high strain rates limited to polymers, limited understanding of metal lattices at high impact pressure.

AM of 316L Stainless Steel

Bradley Jared, University of Tennessee
David Saiz and Scott Jensen, SNL



- Laser Powder Bed Fusion System:
- 25-50µm best accuracy
- surface finish: >5-10µm Sa (~ casting)
- wall thickness: > 100 µm, overhangs < 45°
- single material > 99% density



Computed Tomography Characterization

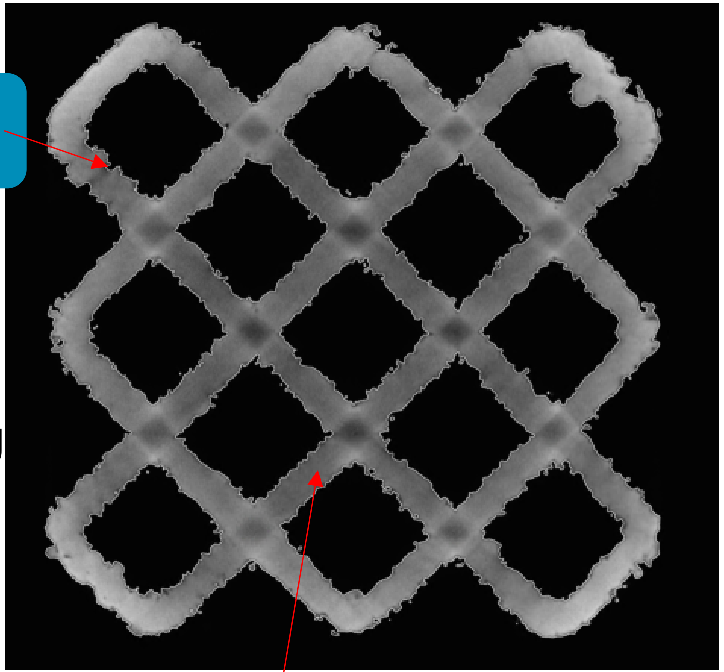
David Moore, SNL

Analysis performed using VGDefX
Standard settings were used for analysis, except:
- Probability Threshold: 0.85
- Minimum edge distance: 13 µm (2 voxels)

Pores down to ~20 µm were detected with confidence, however it is likely that misidentifications are made for pores of this size.

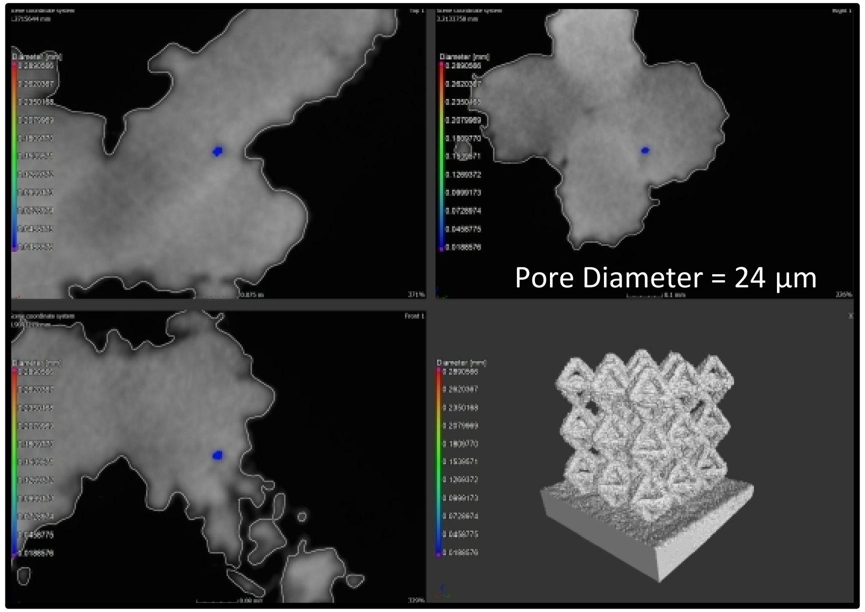
Most difficult part of porosity analysis for lattices with struts of this size is ensuring that the tortuous surface is not misidentified as a pore. Surface effects become more significant with smaller struts [1].

Grayer "pores" near lattice edge

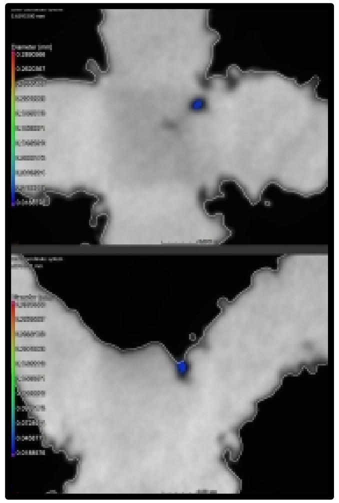


Dark "indications" at lattice nodes. This appears to be an CT image artifact from beam hardening

Porosity Analysis



Edge-crossing Defect



The "pore" is open to surface and therefore is not an internal defect.

Pore Location to Edge: mean 0.035 mm

Pore Diameter: mean 0.0379 mm

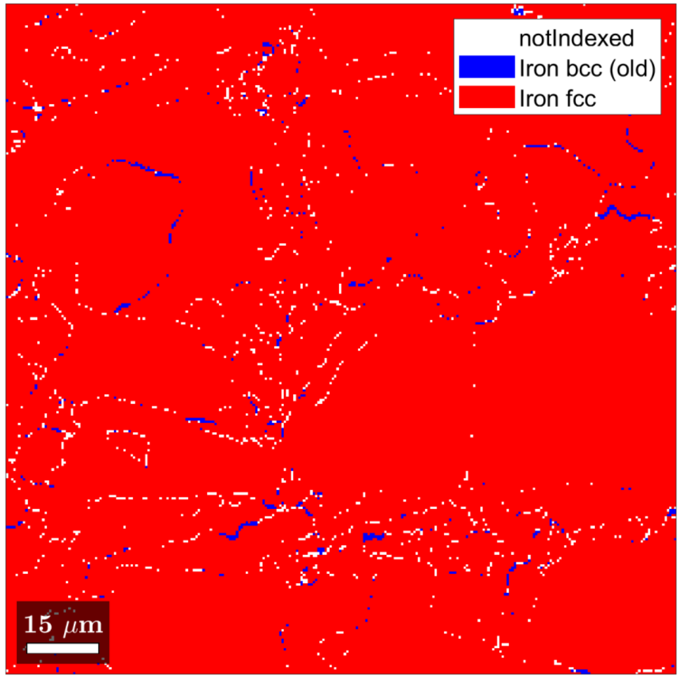
[1] Dressler, A. D., Jost, E. W., Miers, J. C., Moore, D. G., Seepersad, C. C., and Boyce, B. L., 2019, "Heterogeneities Dominate Mechanical Performance of Additively Manufactured Metal Lattice Struts," Additive Manufacturing, **28**, pp.

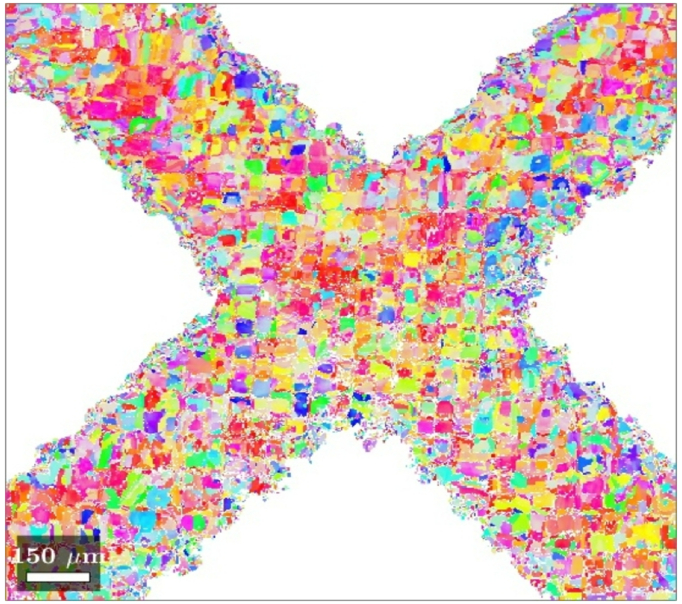
Microstructural Characterization

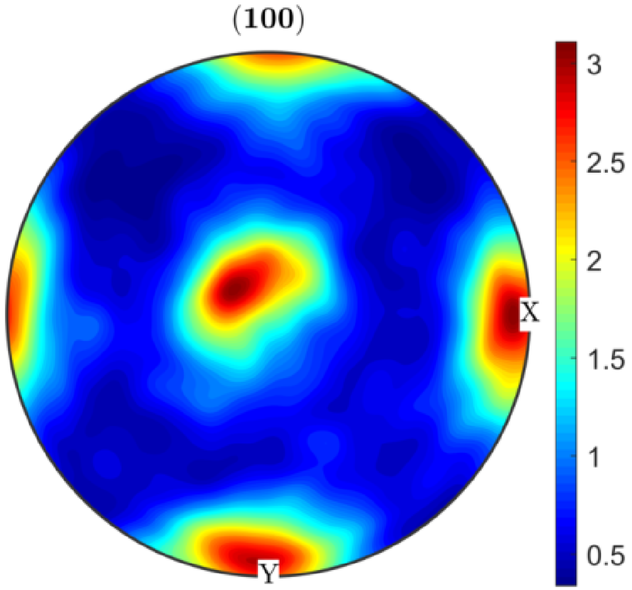
Electron Backscatter Diffraction

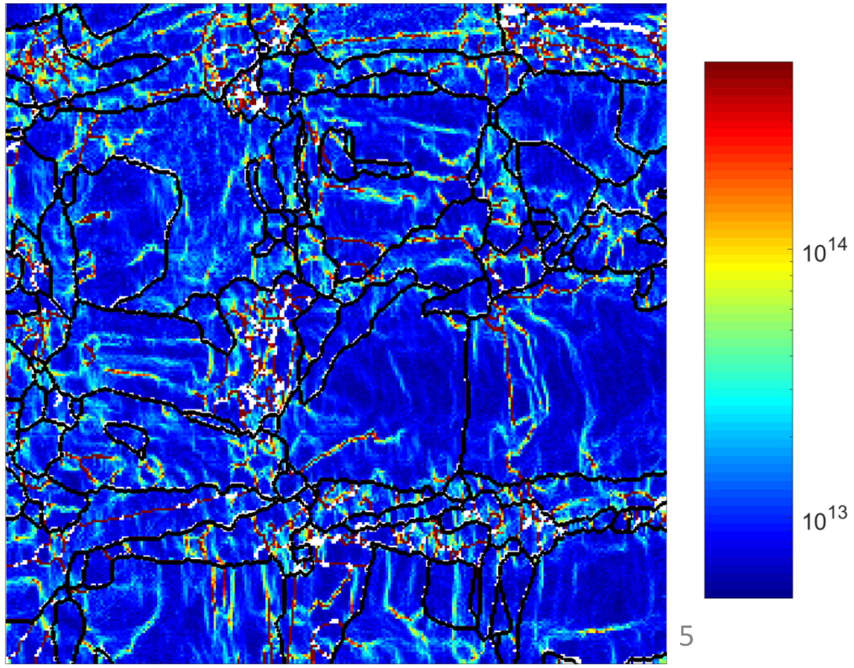
Tim Ruggles, SNL

- As-built microstructures show a cuboidal grain morphology related to the path of laser during additive manufacturing.
- Strong cubic texture: the {100} family of planes tends to align with the x, y and/or z directions.
- All samples are primarily austenitic, with small amounts of ferrite at the grain boundaries.
- Geometrically necessary dislocation (GND) content dispersed throughout microstructure.

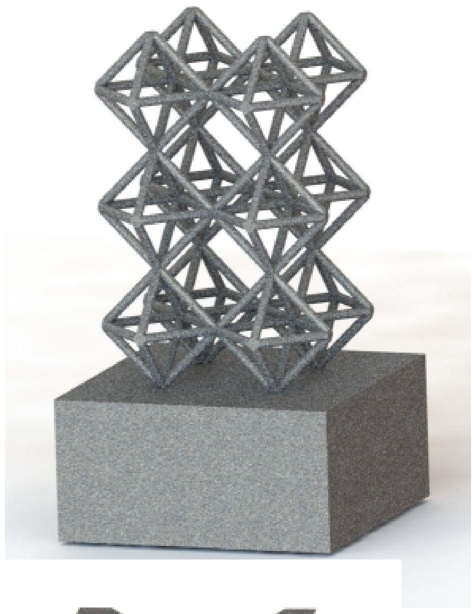


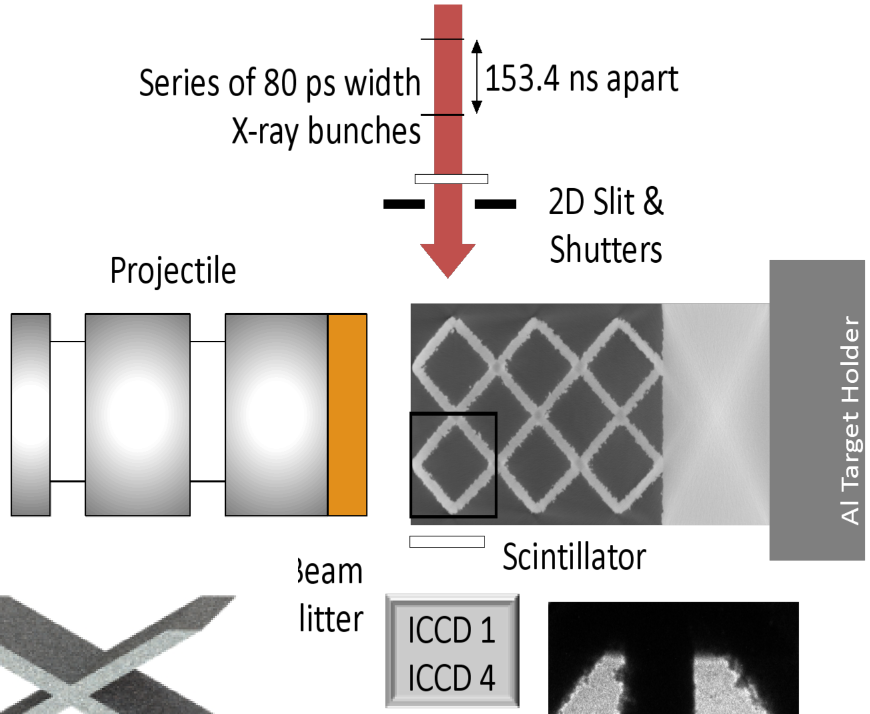


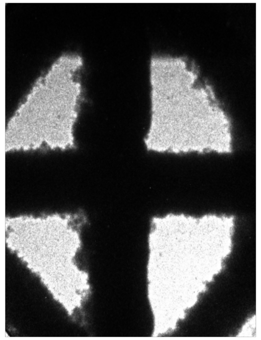




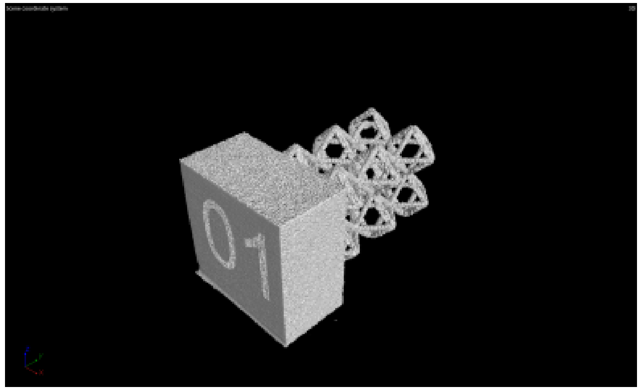
Constrained PCI Studies on Lattices @ DCS



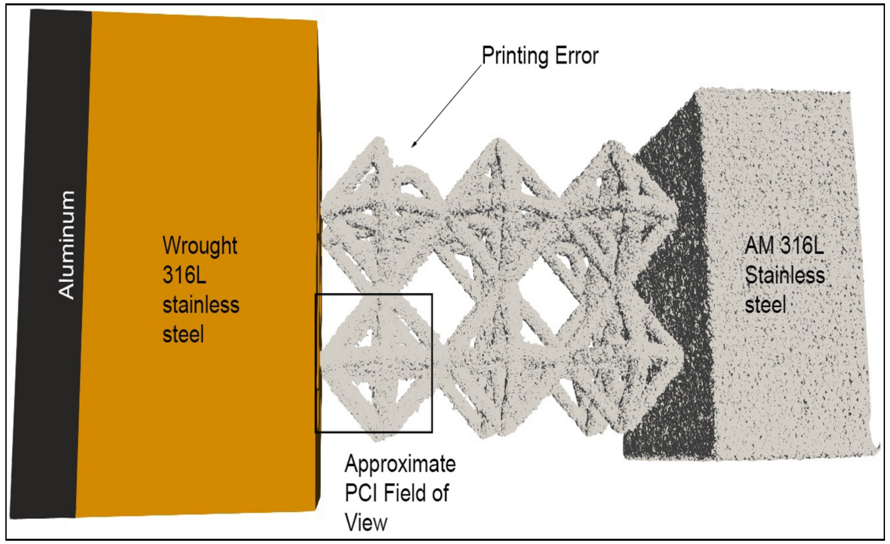




PCI Static Image



CTH Simulation



Mesoscale Modeling

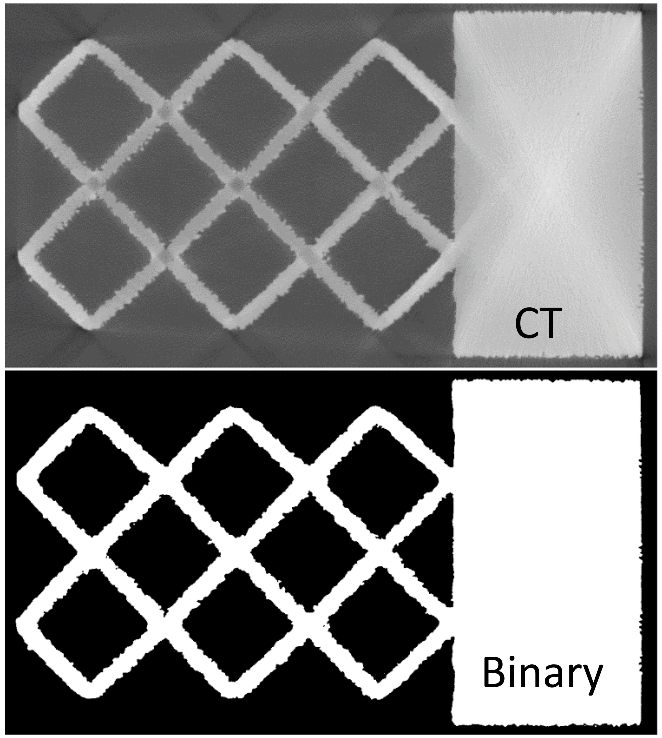
Paul Specht, SNL

CTH Rendering of the As-built Lattice

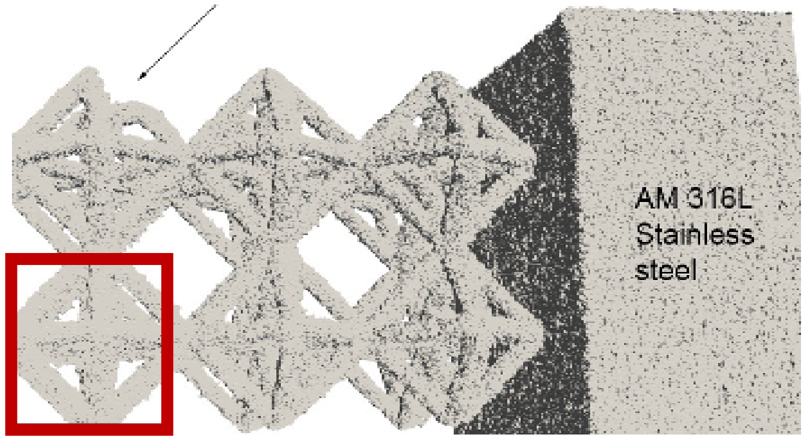
- From CT characterization, 2D slices were generated and converted into binary image using Image Class in SMASH toolbox.
- 3D geometry rendered in CTH
  - ➢ Trace edges of lattice
  - ➢ Store coordinates of each point on the edge in pixels
  - ➢ Convert x and y dimensions using voxel size of CT scan.

Modeling Compaction Response in CTH

- Measured thickness of the Al6061 impactor (3700 SESAME and SG) and impact velocity.
- Semi-infinite BCs were used along the X and Y boundaries along with the negative Z direction.
  - ❖ wave reflection from the edges of the projectile will not influence the results during TOI
- Void BC in positive Z direction
  - ❖ compaction wave never reaches positive Z boundary during the length of the experiment
- 316L SS was modeled using the SESAME 4270 table and Steinberg-Guinan (SG) strength model parameters for 304L SS
  - ❖ 304L and 316L stainless steel are austenitic and have similar composition
- Initial yield point for the SG strength model was increased to 0.55 GPa to match quasi-static compression measurements for SS.
- Simple void insertion based on a tensile pressure threshold was used to approximate the failure response of all materials and interfaces. The impact plane was given an extremely low failure pressure to ensure that it would separate upon any tensile load.



Printing Defect



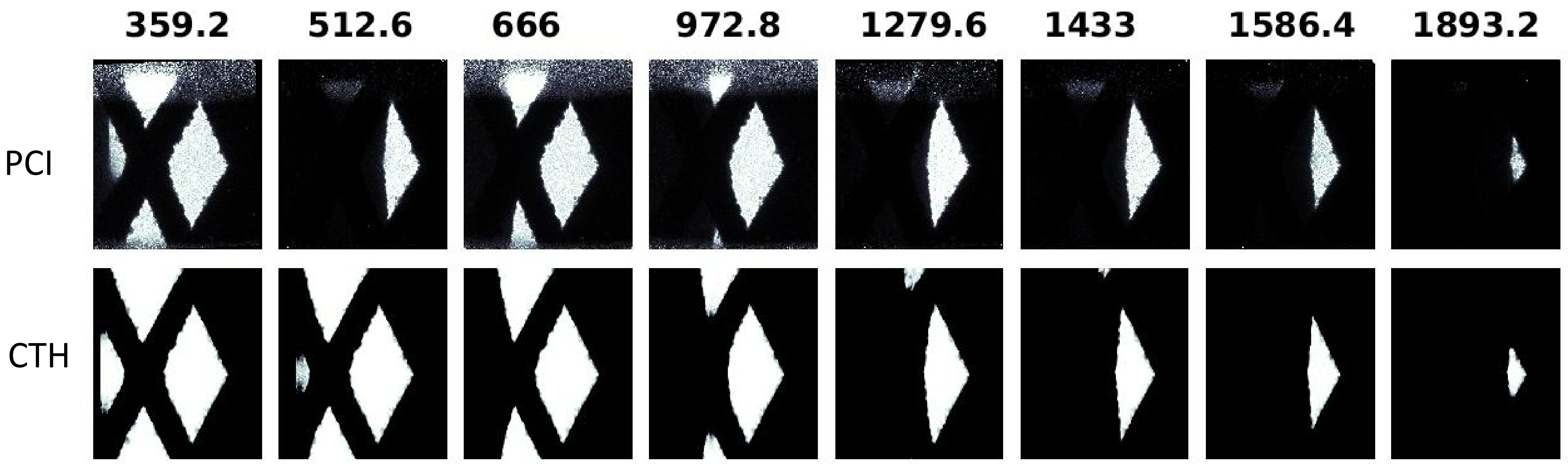
Field of View of PCI

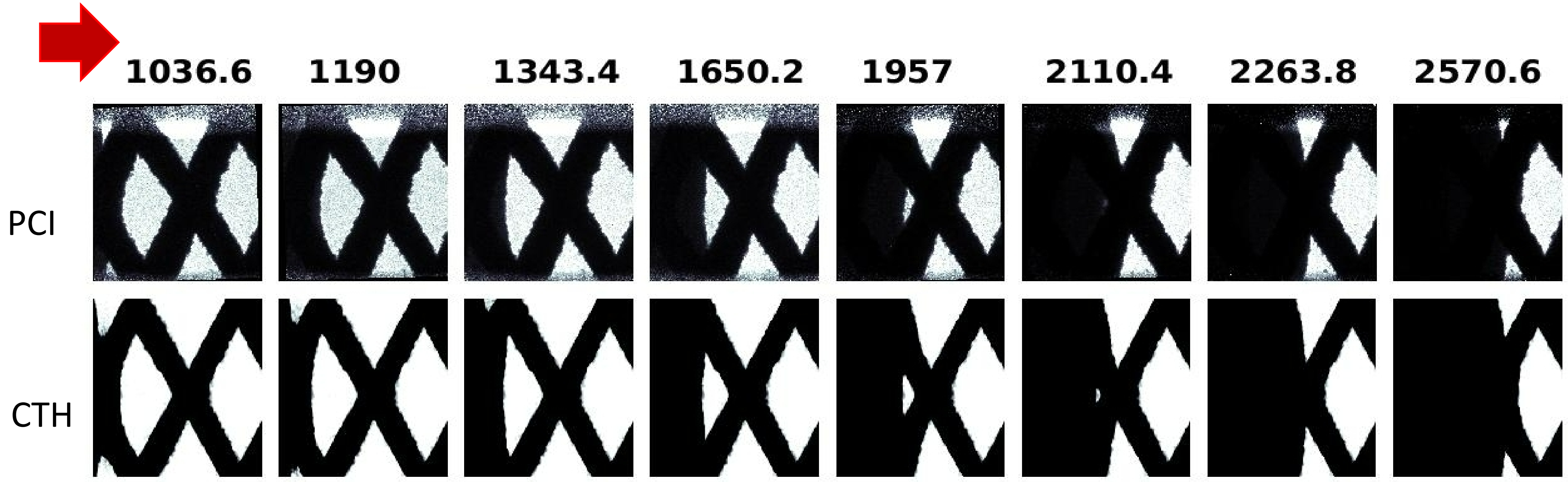
3D CTH Object

D. H. Dolan, T. Ao, and S. C. Grant, "The Sandia Matlab AnalysiS Hierarchy (SMASH) Toolbox," (2016).

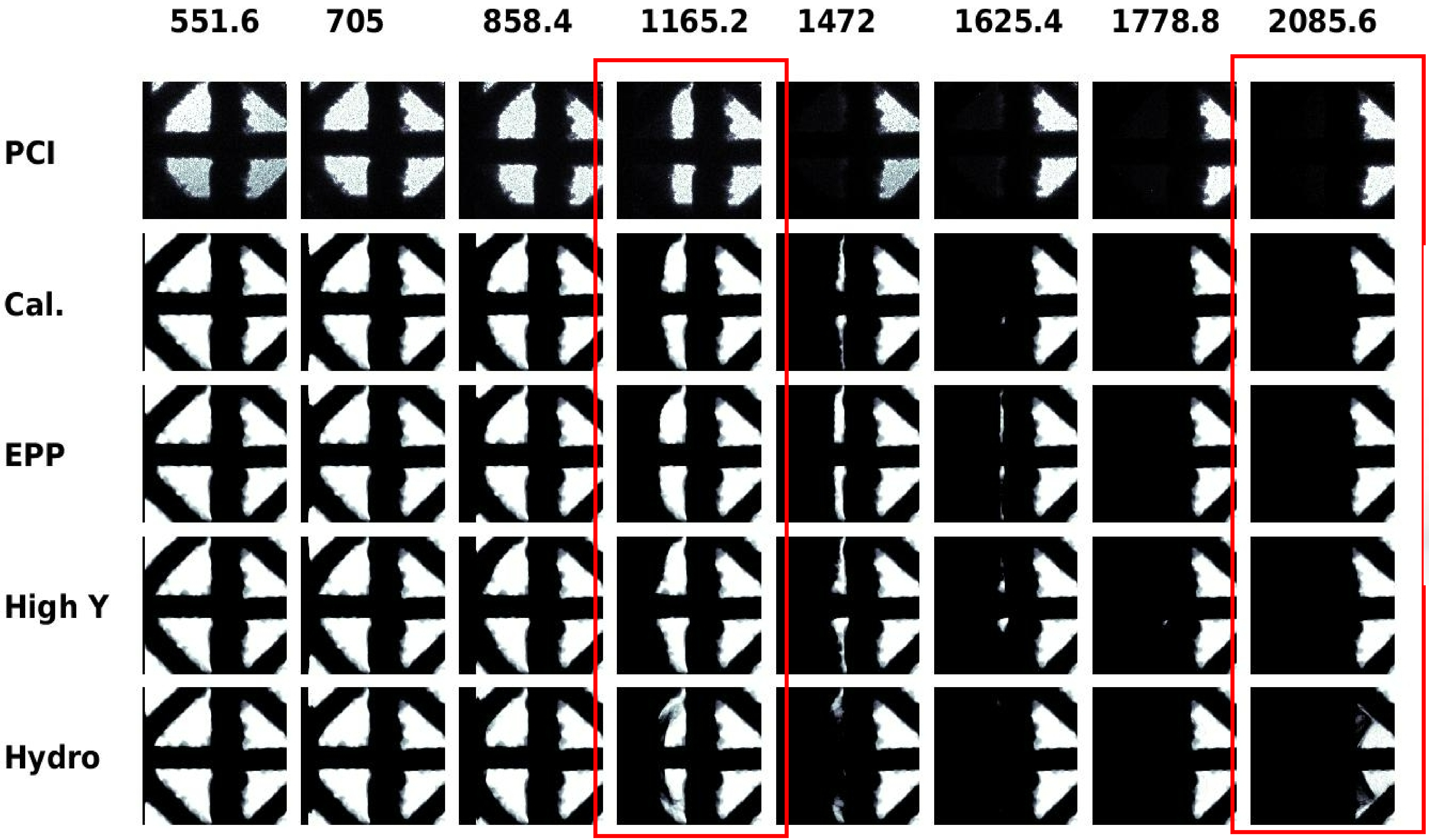
CTH v12.0, Sandia National Laboratories (2017).

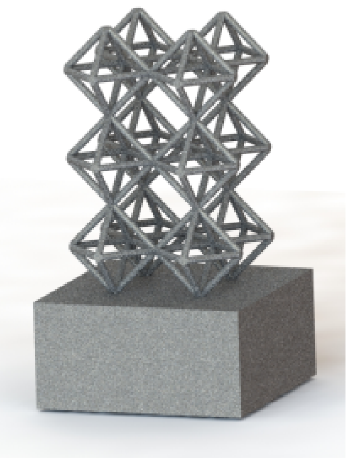
PCI Results Compared to Simulations





Strength Calibration for 316L Lattices



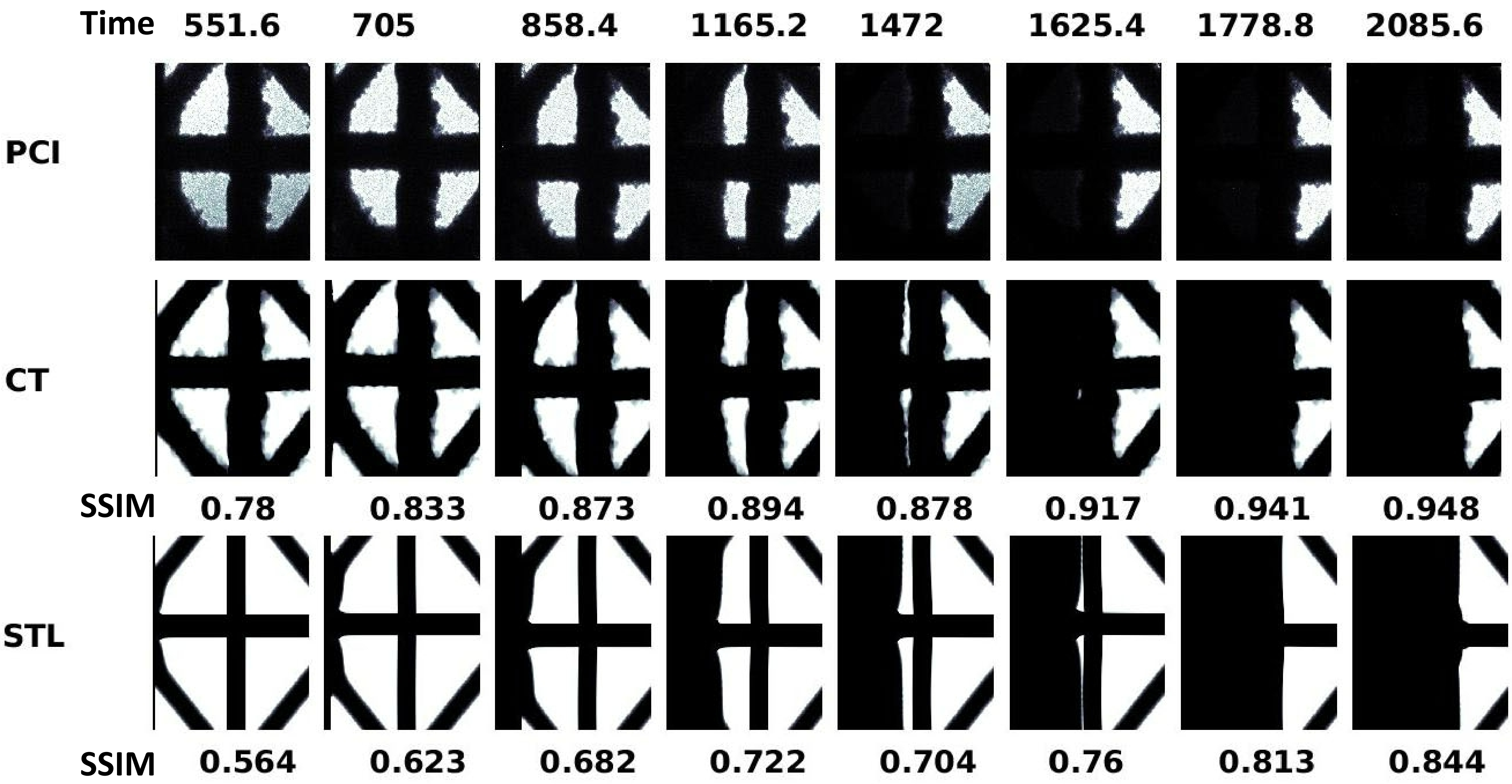


Modified Structural Similarity Index (SSIM)

Quantify Agreement between PCI and Simulated Radiographs

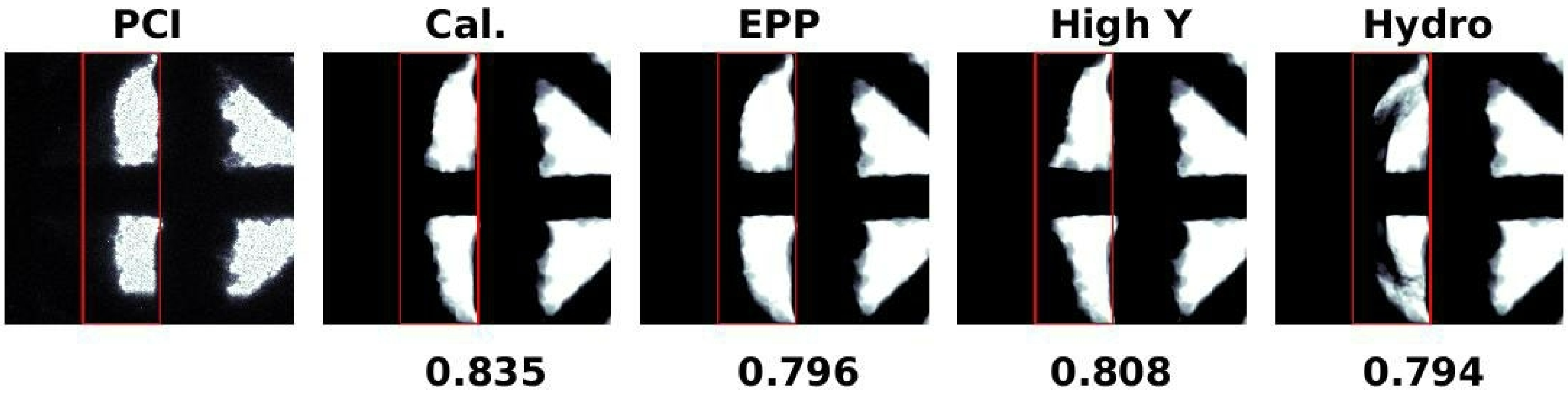
W. Zhou, A. C. Bovik, H. R. Sheikh and E. P. Simoncelli, IEEE Transactions on Image Processing **13** (4), 600-612 (2004).

- Uses luminance, contrast and structure terms to assess similarity.

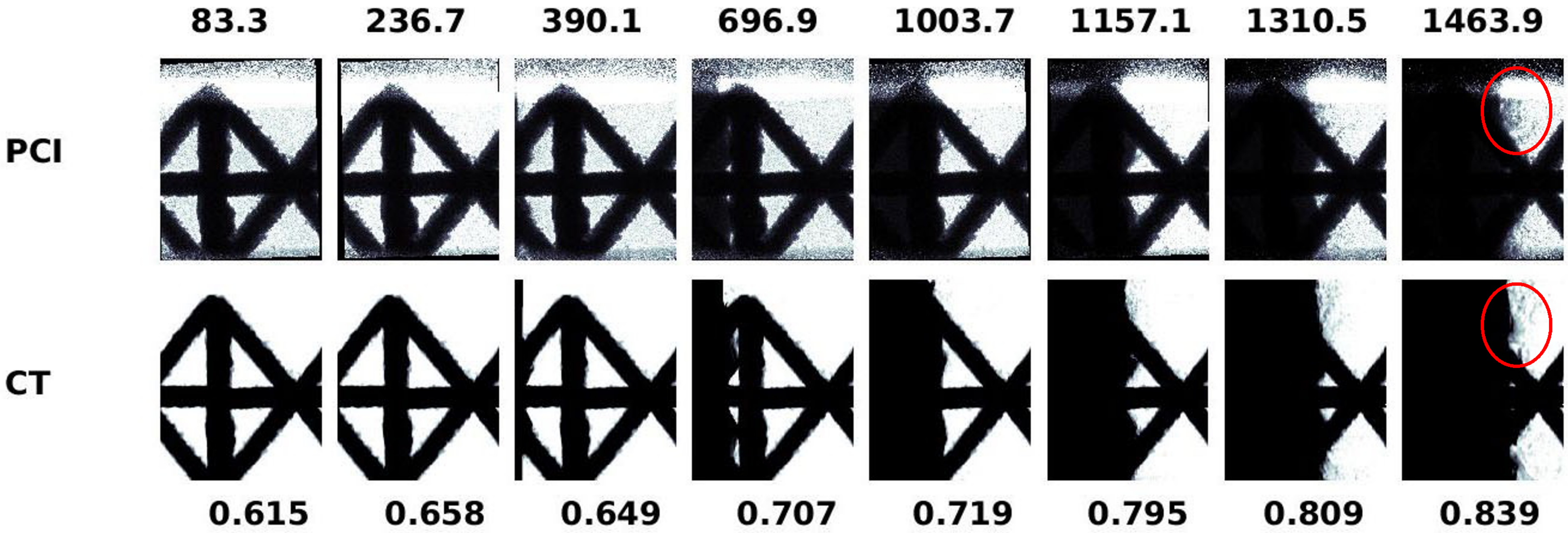


Demonstrate Importance of Utilizing As-built Geometries!

Strength Calibration using SSIM



Predicting Failure



Conclusions

- ✓ Realized lattice architectures with high spatial resolution (200 μm) for imaging experiments at DCS with a limited FOV (2.2 mm).
- ✓ Characterized SS 316 lattice using ex-situ computed tomography (CT) inspection and incorporated the as-built lattice into CTH.
- ✓ Conducted CTH modeling incorporating material strength distributions in order to predict and accurately model deformation characteristics through simulated radiographs for direct comparison to X-ray phase contrast imaging (PCI).

Direct comparison of PCI and CTH simulations offers robust validation for constitutive properties to further our understanding of lattice compaction!

B. A. Branch, P. E. Specht, S. Jensen and B. Jared, International Journal of Impact Engineering **161** (2022).

Acknowledgements

People

DCS Staff at APS

Funding Sources

Department of Energy:

Advanced Certification and Qualification