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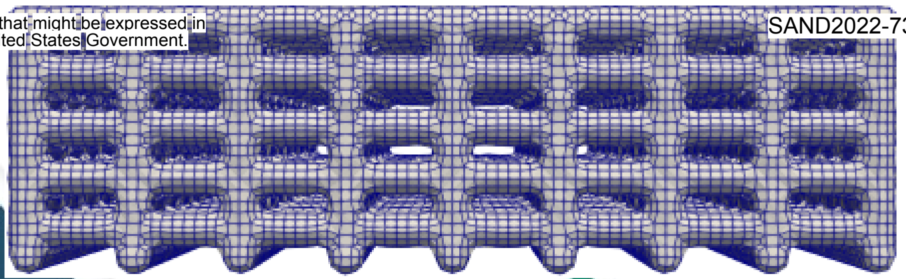
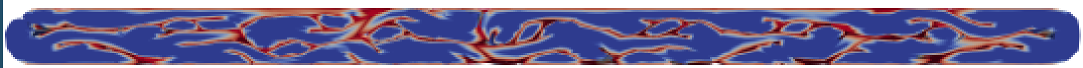
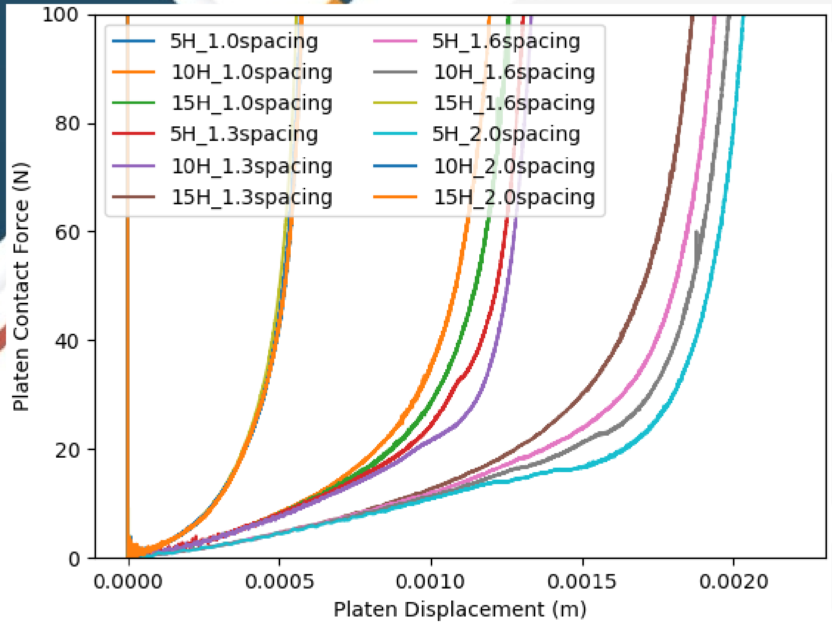




Modeling The Influence of Printing Defects in Additively Manufactured Silicone Lattice Structures

Craig M. Hamel, Kevin N. Long, Devin Roach, and Adam Cook

With Key Input from Mo Khan, **Sharlotte Kramer, Christine Roberts, Rekha Rao, and Jonathan Leonard**



ECCOMAS 2022, Paper 1823

MS121: MODEL-BASED APPROACHES AND DATA-CENTRIC MODELS FOR DIGITAL MANUFACTURING

June 2022, Oslo, Norway

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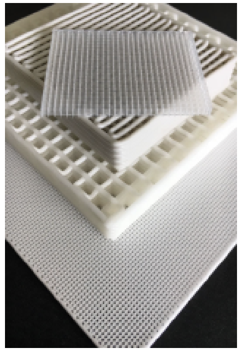
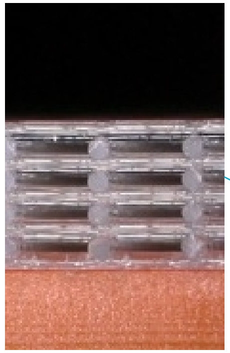
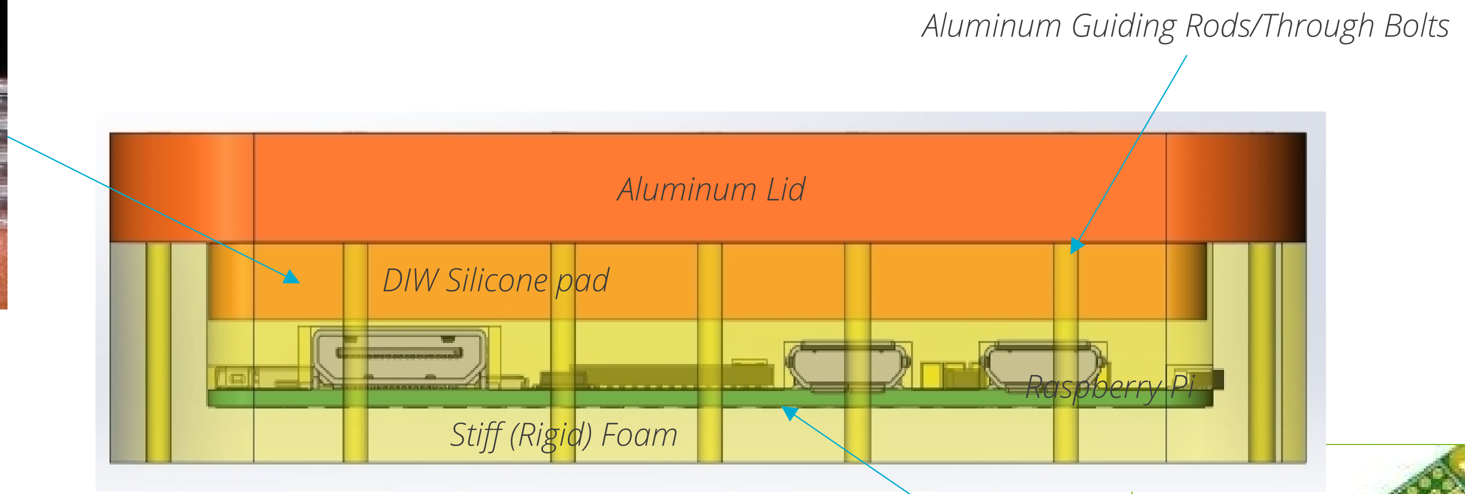
Motivation:
Direct Ink Write (DIW) Silicone Lattice Structures Are Promising for Modular Electronics Packaging







Protect Electronics in Harsh or Diverse Mechanical Environments:

- Wide range of preloads due to tolerance stack up errors
- A key part to modular rigid foam packaging
- Reduce vibration and shock behavior to the electronics

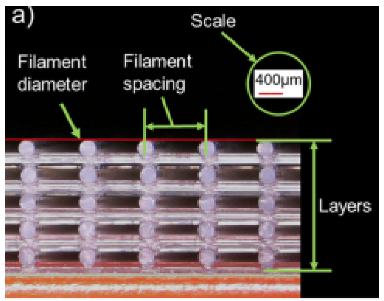
Are we taking *Full* advantage of additive manufacturing with silicone polymer lattice structures?

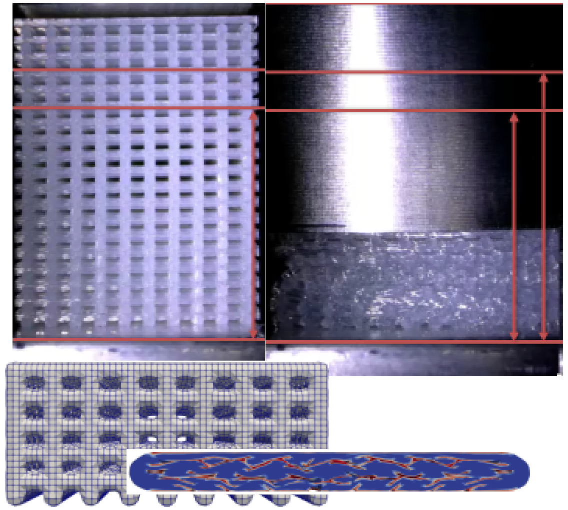
Two important Questions?

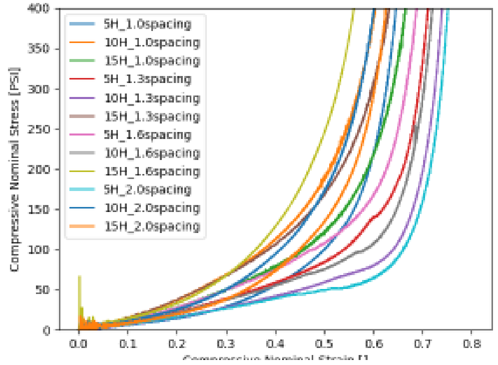
- Can we <u>*Design*</u> the DIW lattice structures to be optimal in multiple mechanical environments?
- How <u>*Robust*</u> are the DIW designs to printing defects and/or variations in tolerance stack up?

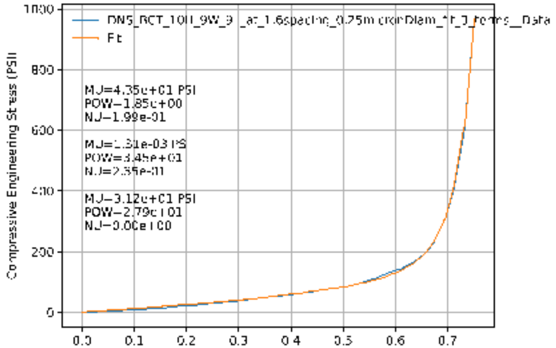
5-Stage Workflow to Connect DIW Printing Parameters to a Component Assembly Structural Mechanics and Dynamics Response

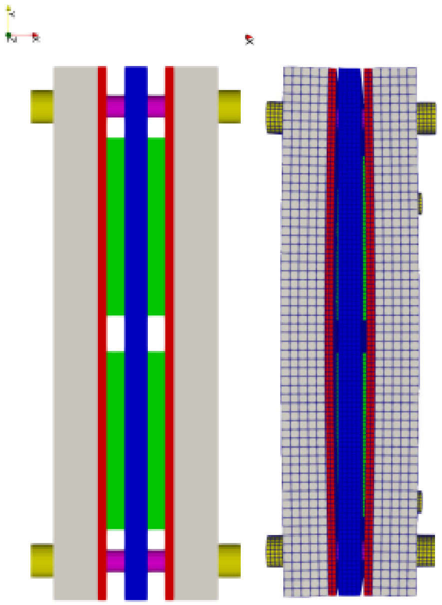
Lattice (Printing) Parameter Inputs → DNS or Experimental Compression of Lattice Structures → Homogenizing the Stress-Strain Behavior with Hyperfoam → Preload / Structural Assembly → Modal and Frequency Response Analyses

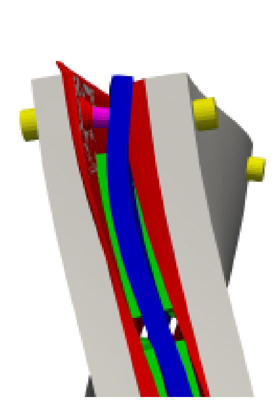


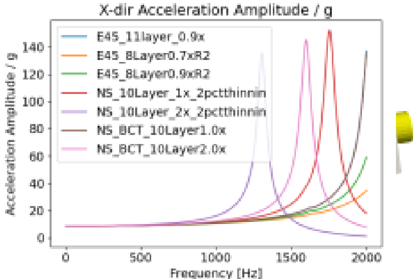






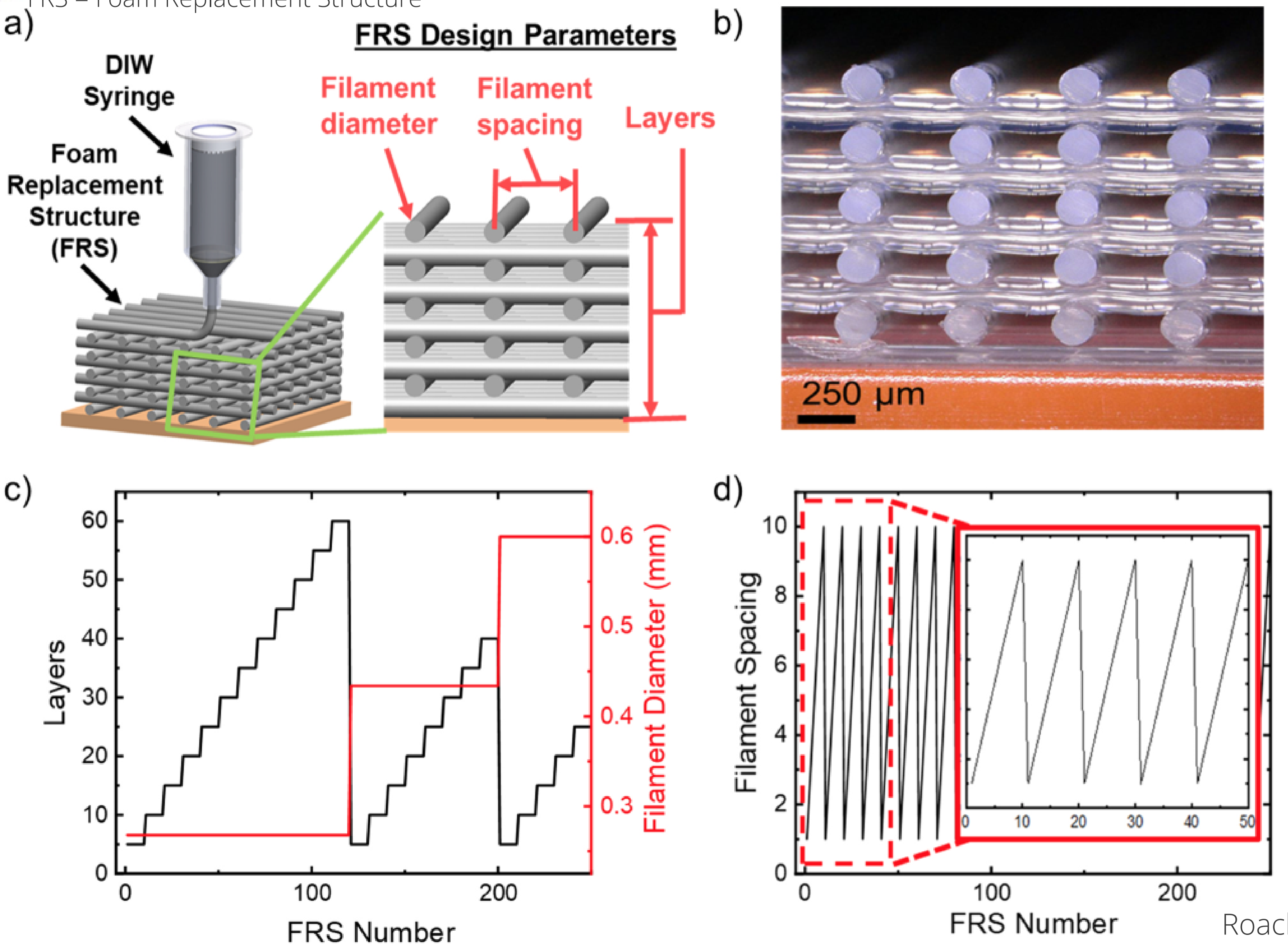






Body Centered Tetragonal (BCT) Lattice Layout and Direct Ink Write (DIW) Printing Design Space with SE1700® Siloxane

FRS = Foam Replacement Structure



Large Printing Design Space

- Nozzle (filament) Diameter
- Filament Spacing
- Number of Layers in Height

Design Space Can Be Much Larger

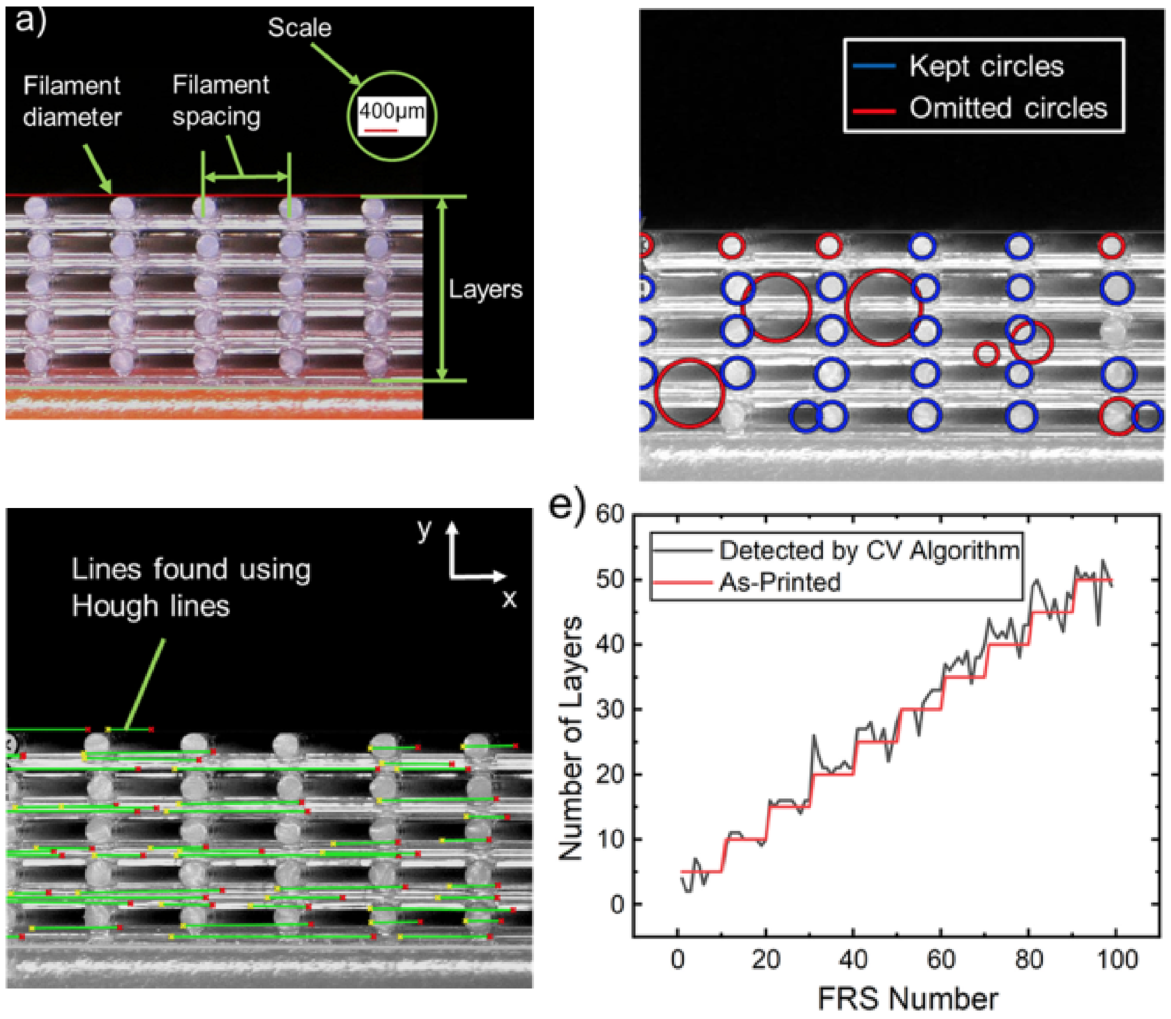
- Different symmetry lattices
- Spatially dependent structure
- Different Inks

Such a large design space is difficult to probe experimentally by trial and error

Roach, *et al.* Additive Manufacturing, 2021

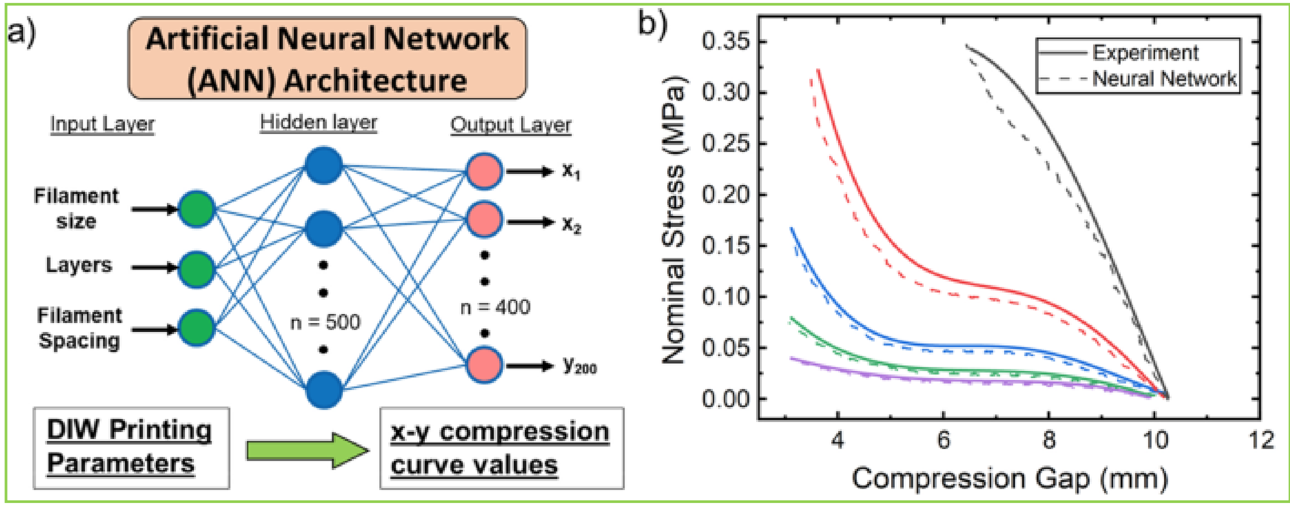
DIW Lattices: An Experimental and ML Driven Mapping from Structure to a "Homogenized" Mechanical Response

Computer Vision—Recognize The FRS As-printed



Machine Learned Regression

Map Printing Parameters to Compressive Stress-Strain Response



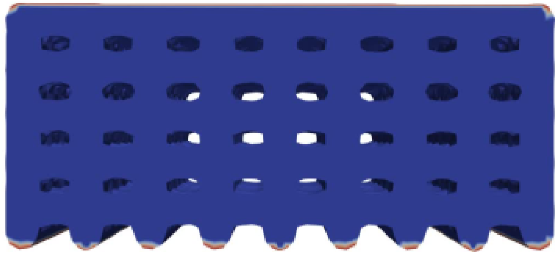
A subset of the printing parameter space can be successfully mapped to the mechanical compression response of interest via fully experimental support and machine learned regression

This approach works when the design space is limited

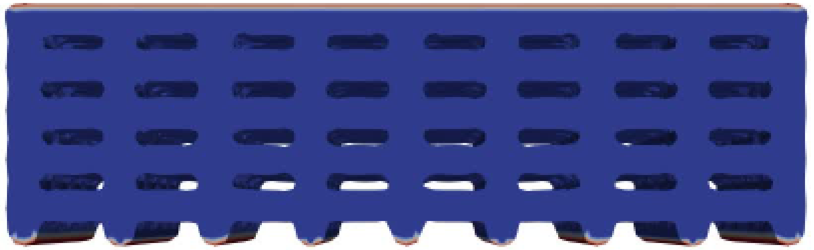
Roach, *et al.* Additive Manufacturing, 2021

DNS DIW Body-Centered Tetragonal (BCT) Lattice Structures Under Uniaxial Compression

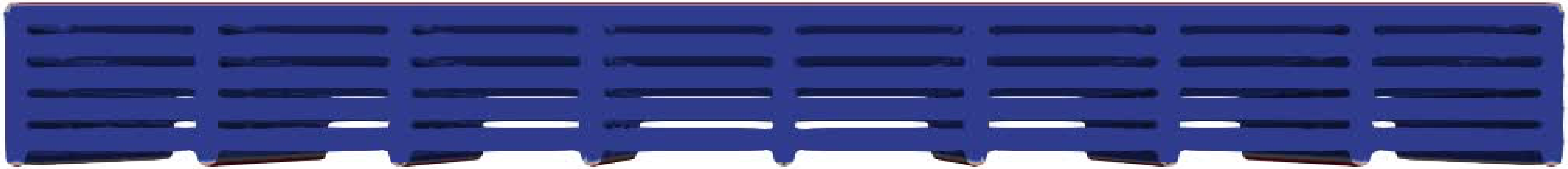
10H x 9W x 9L x 1Spacing



10H x 9W x 9L x 2Spacing



10H x 9W x 9L x 8Spacing

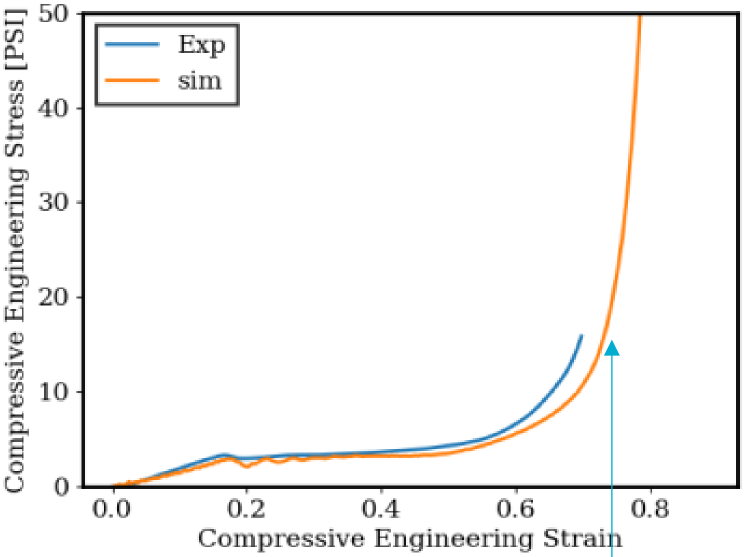


The matrix phase was modeled with a Gent model calibrated to Sylgard 184

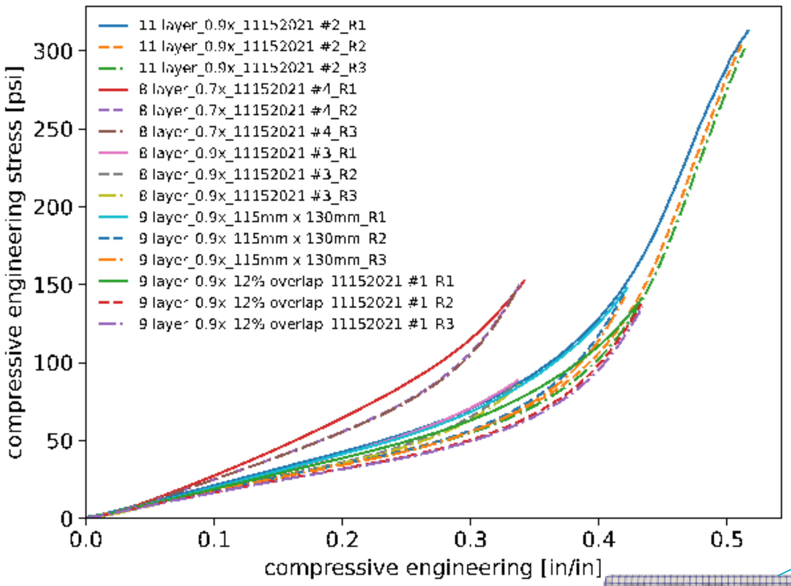
No material tuning was performed despite the DIW ink being a different silicone

DNS DIW Lattice Structures Under Compression

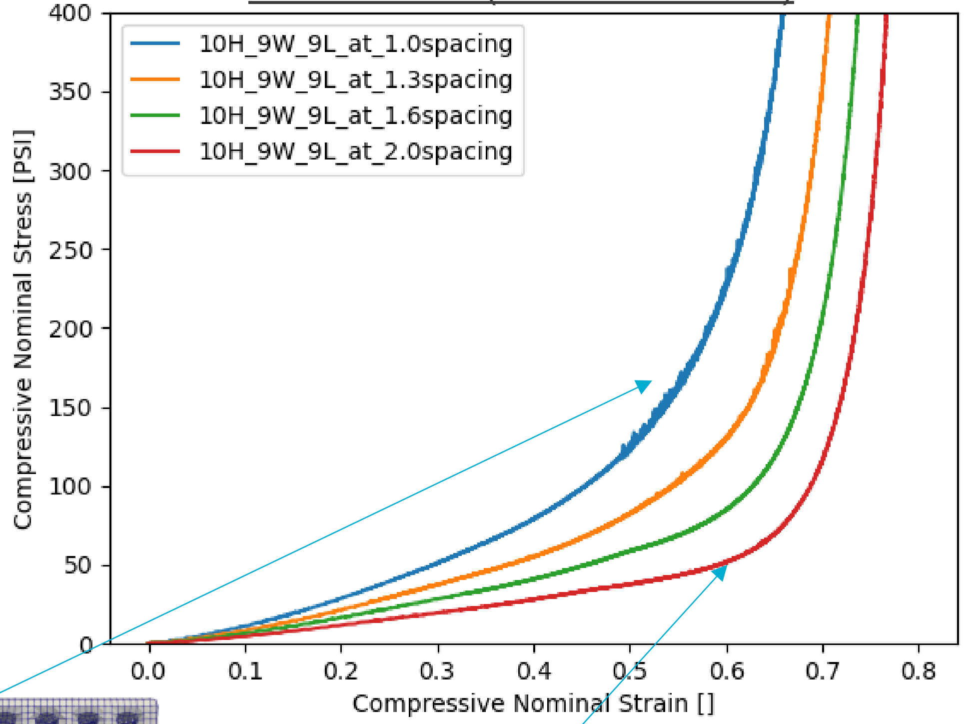
Blind Validation
10 Layer at 8x Spacing (BCT)

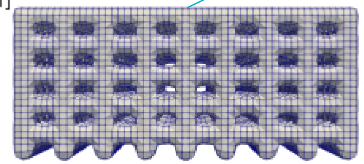


0-45-90-135-180
Experimental Layups

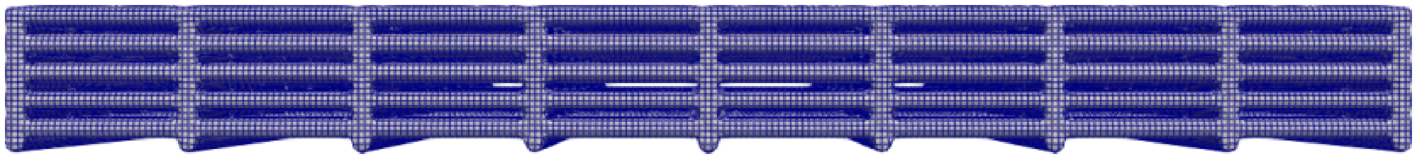


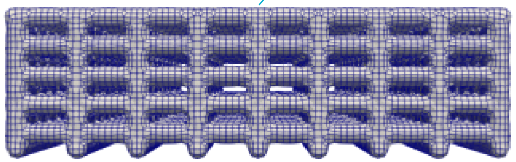
0-90 (BCT) Simulated
Structures (all at 9W x 9L)





Note that Sylgard 184 was used in the matrix phase as a stand in for the SE1700 silicone DIW printed

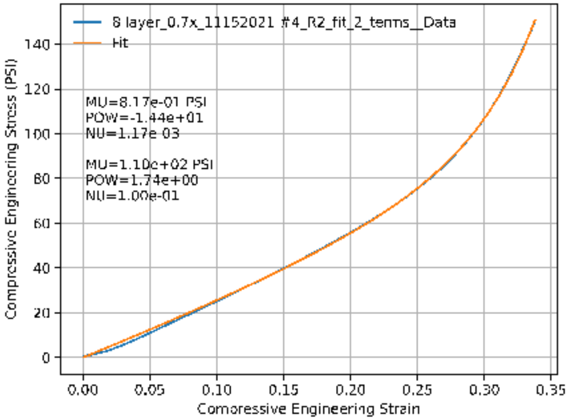


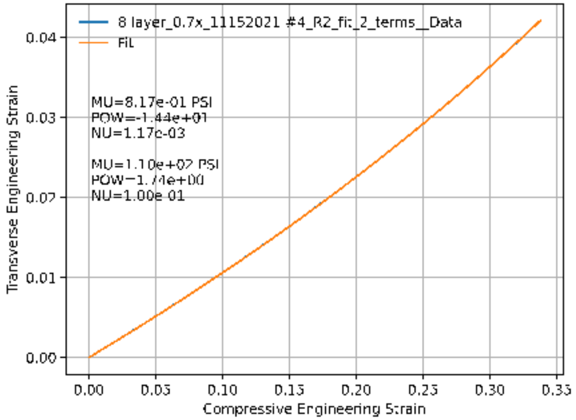


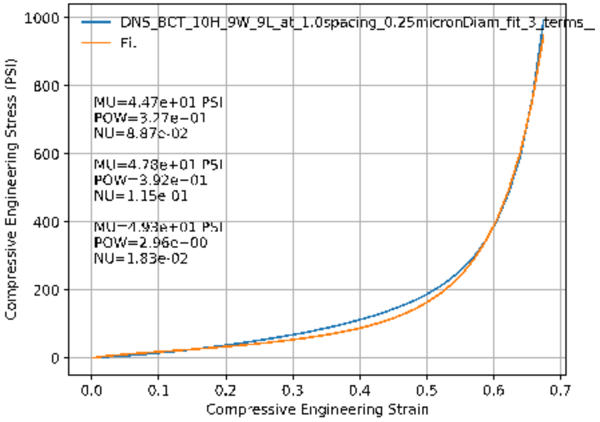
Homogenizing the DNS Pad Or Experimental Measurements for Component/Assembly Simulations via a Stabilized Hyperfoam Fitting Procedure

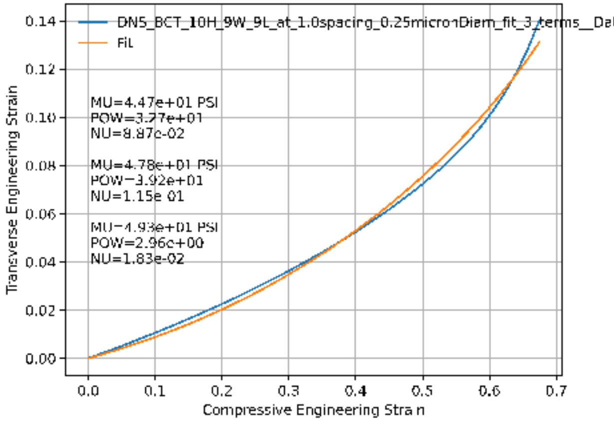
Select 0-45-90-135-180 Experimental Layups

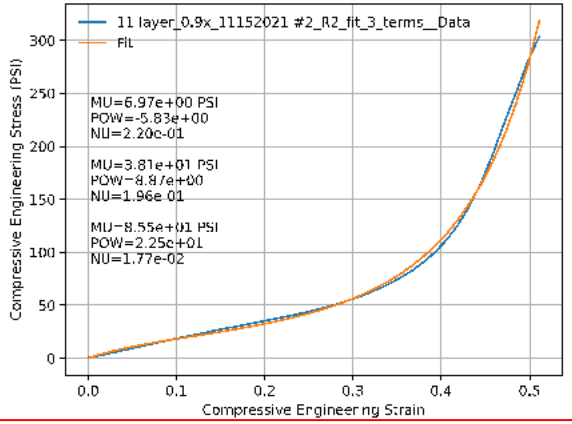
0-90 (BCT) Simulated Structures (all at 9W x 9L)

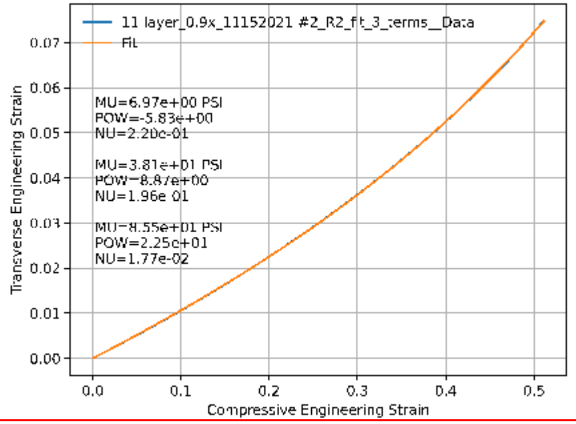


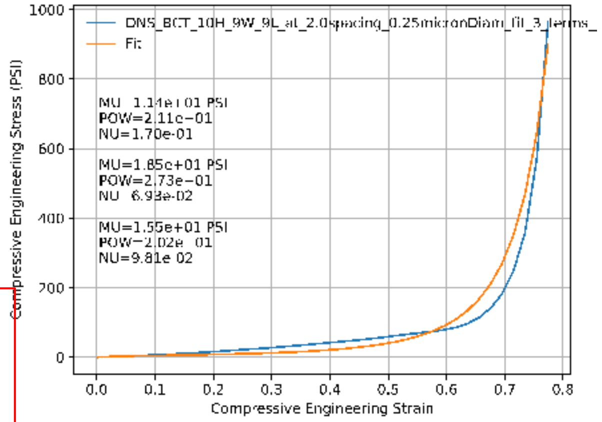


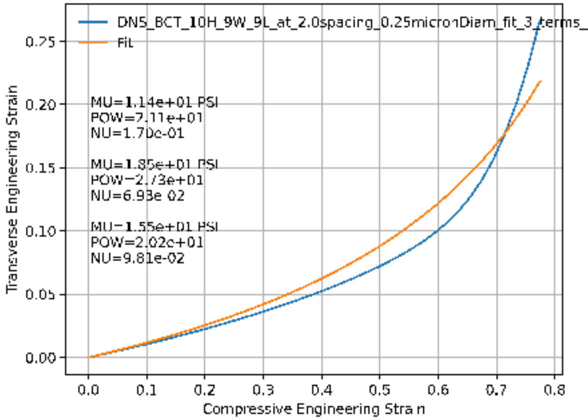








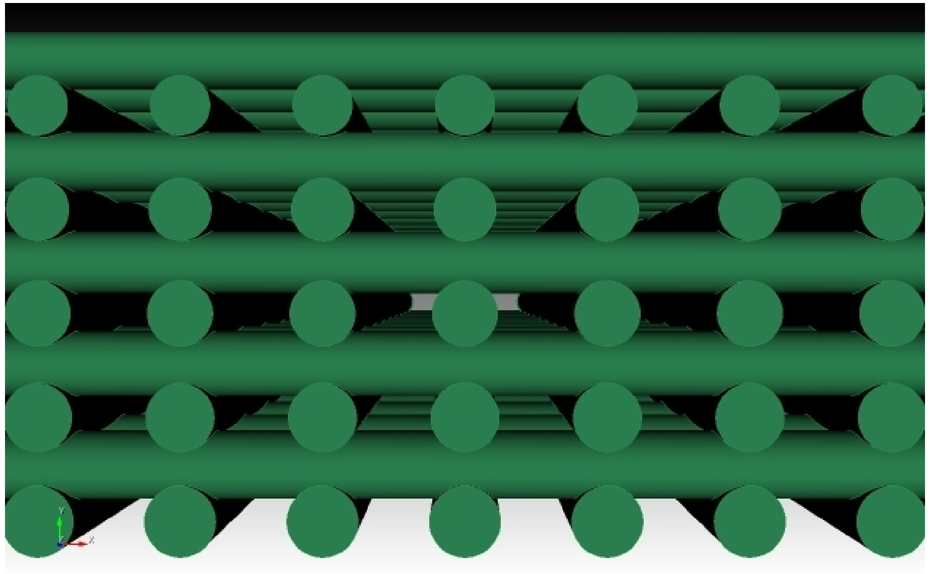


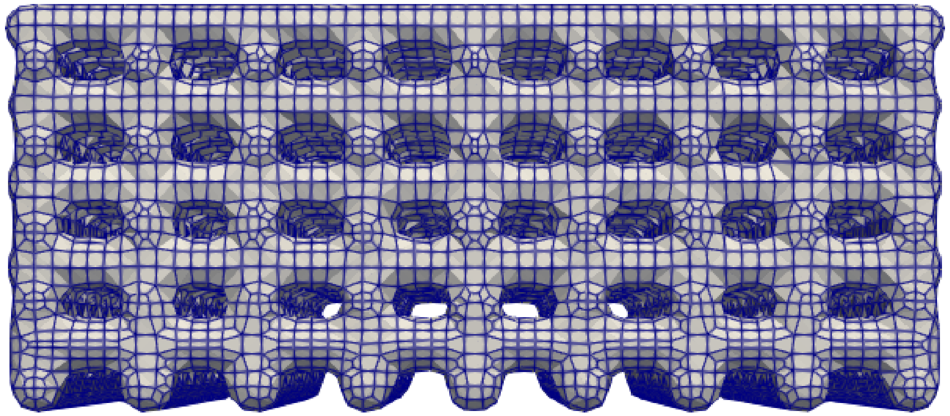


The same material-stability* checked optimization procedure is used to fit experimental and simulated compression curves from individual lattice structures.

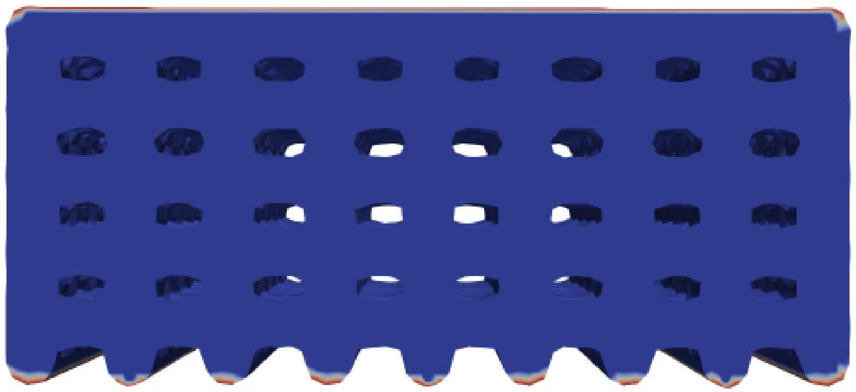
*At each objective function evaluation, the suite of deformations are sampled, and at each state, the material tangent is computed, and many acoustic tensors are formed. If any acoustic tensor is found to have a zero or negative eigenvalue, a substantial penalty is added to the objective function

Modeling a Defective AM Lattice Structure—Consider Thinning of the filaments by 2% with each subsequent printed layer (in height)

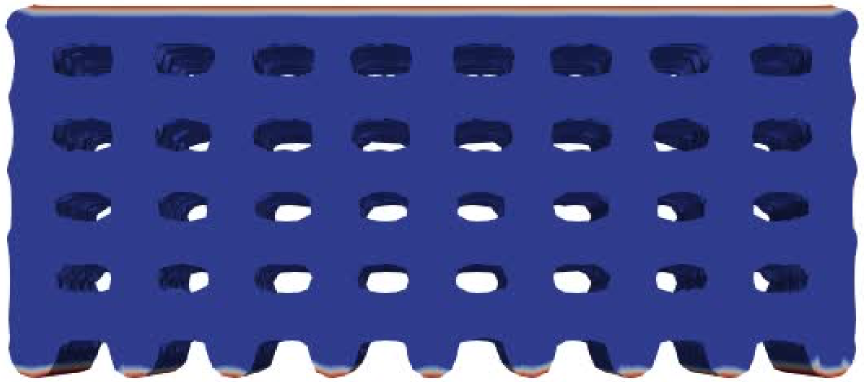




Uniform Layers



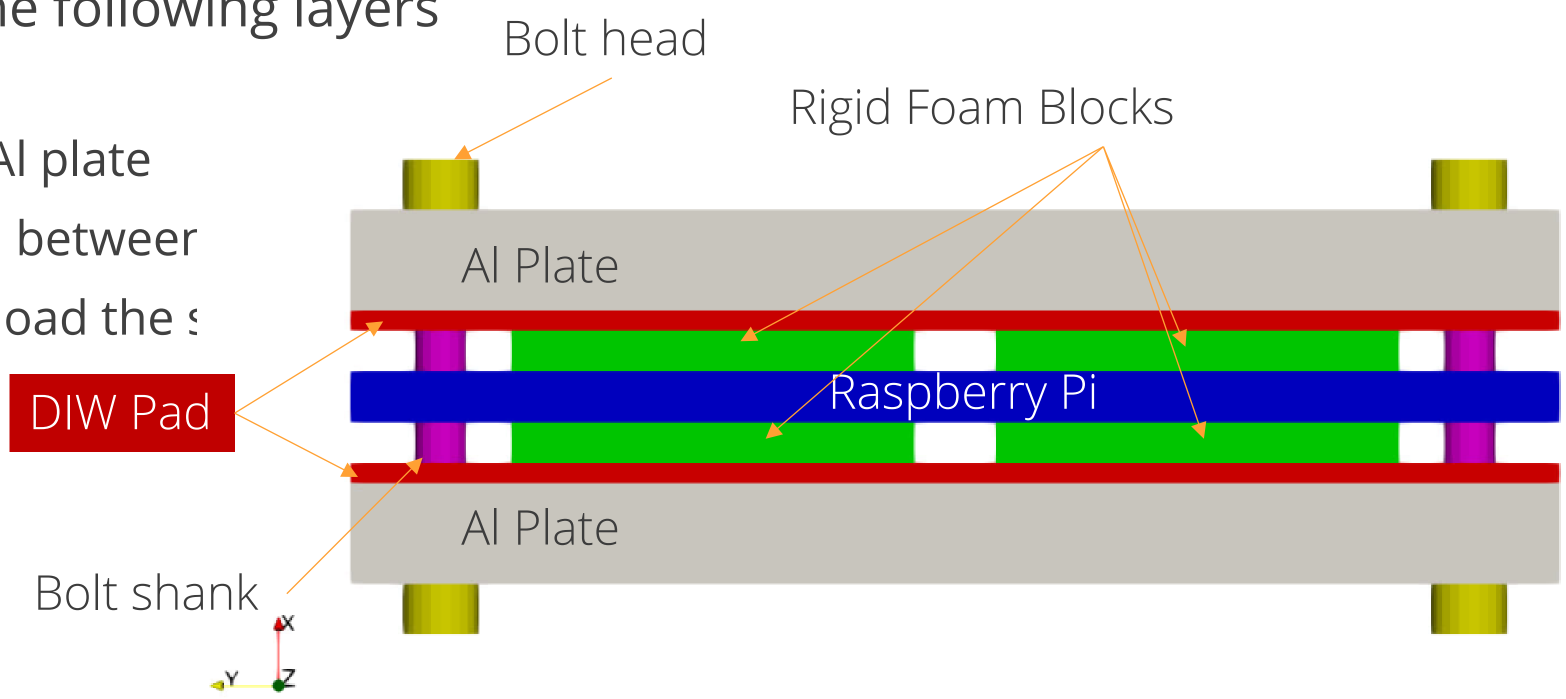
Tapered 2%/layer



Mechanics and Structural Dynamics of a Typical Preloaded Assemblies

Consider a Model Structure with an essential DIW pad

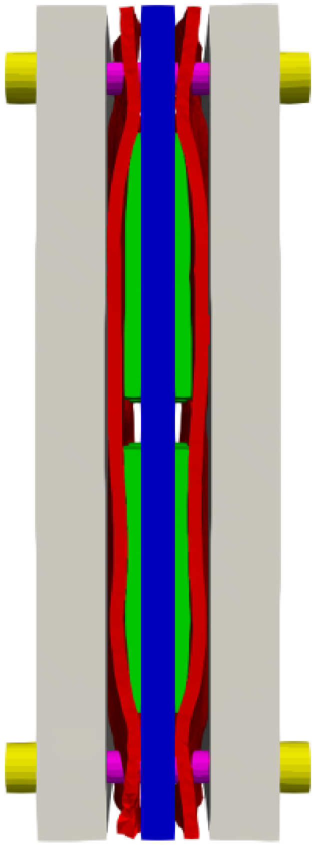
- Double sandwich consists of the following layers
  - Aluminum plates on outside
  - DIW pad on inner side of each Al plate
  - 8 square modular foam pads in betweer
  - 4 bolts near each corner to preload the s
- Geometry details:
  - 6" square Al plates
  - 1.85" total thickness
    - 0.5" Al Plate
    - 0.1" DIW Pad
    - 0.2" Modular Foam
    - 0.25" Raspberry Pi



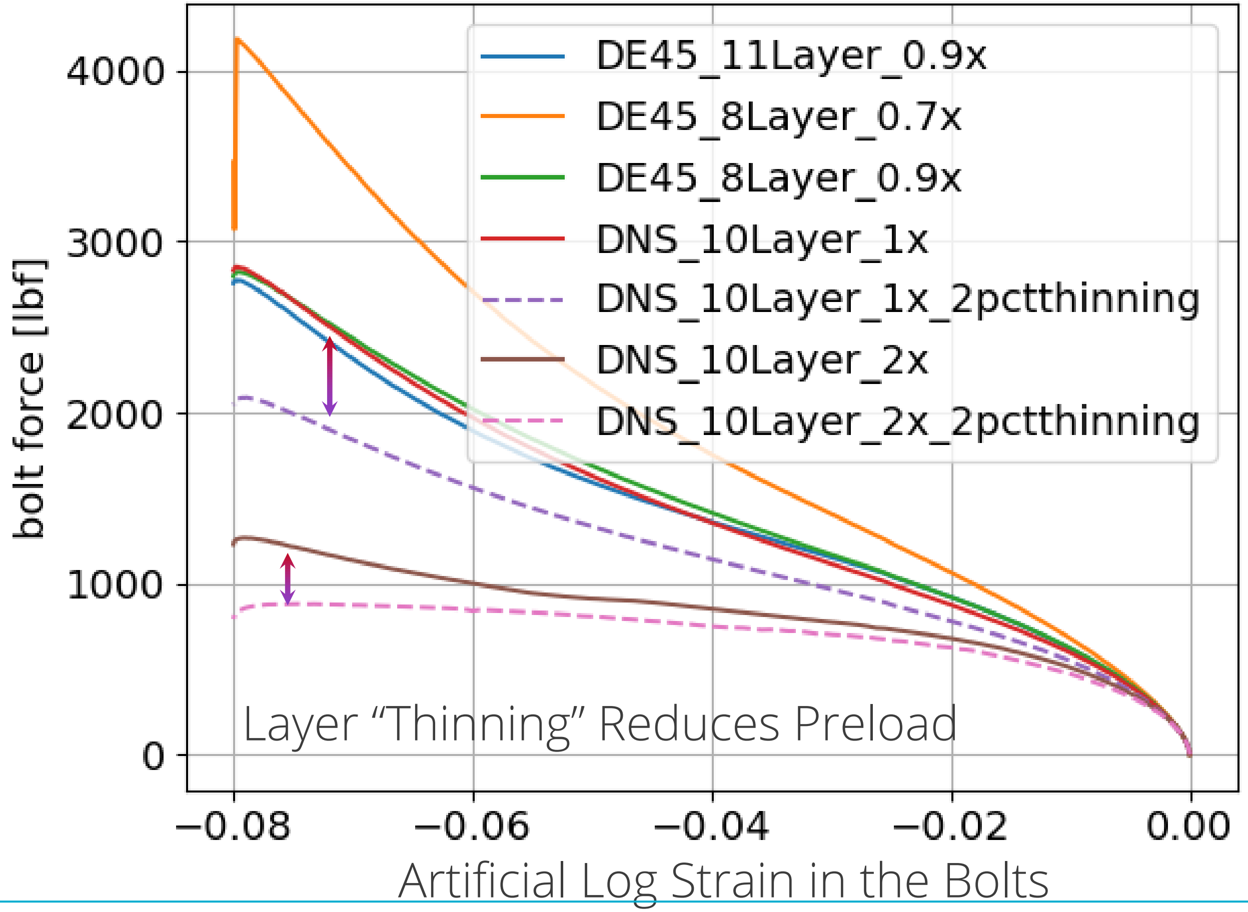
Goal:
Understand how our choice of DIW silicone lattices affects the preloading and steady state vibration response of the assembly and in particular on specific locations of the Rasberry Pi

Structural Assembly/Preload

What is the role of the lattice structure response with the same preload displacement



The DIW lattice at 53% Nom.



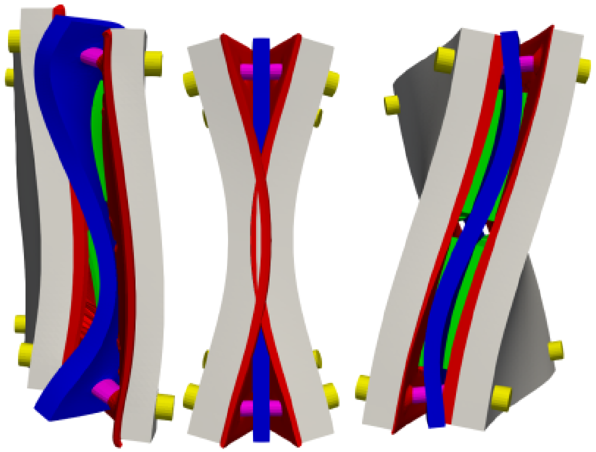
Final State at a Gap Closure of 0.012 inches.

- Notice the Red DIW Lattice Material "pulling away" from the Aluminum Plates
- Notice the significant preload response between the DNS and the defective DNS (with thinning) Cases

Modal Response of the Structure About the Undeformed State

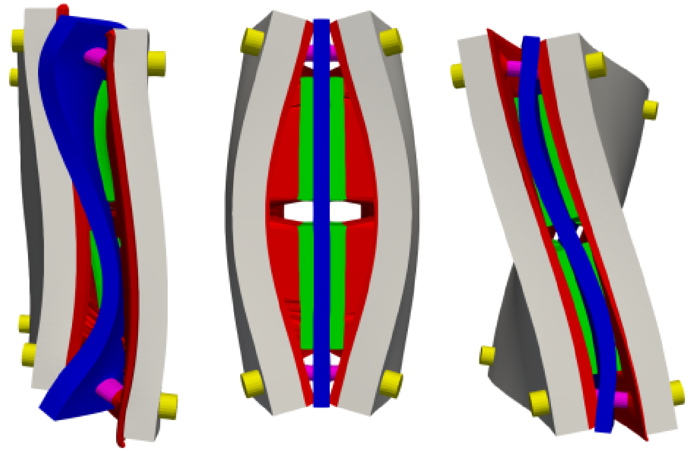
DE 11 Layer 0.9X

requency: 1607.3 Hz
Frequency: 1623.3 H
Frequency: 1625.2 Hz



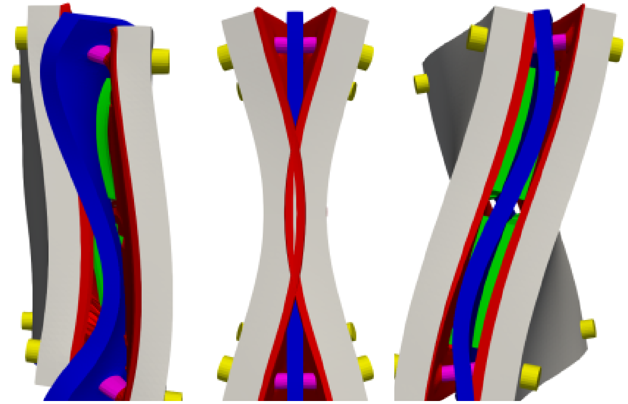
DE 8 Layer 0.9X

Frequency: 1607.3 Hz
Frequency: 1625.1 Hz
Frequency: 1655.2 Hz

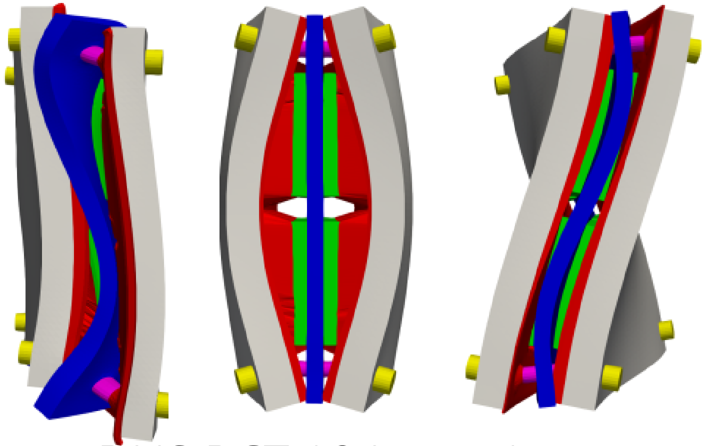


DE 8 Layer 0.7X

Frequency: 1625.1 Hz
Frequency: 1655.2 Hz
Frequency: 1734.4 Hz

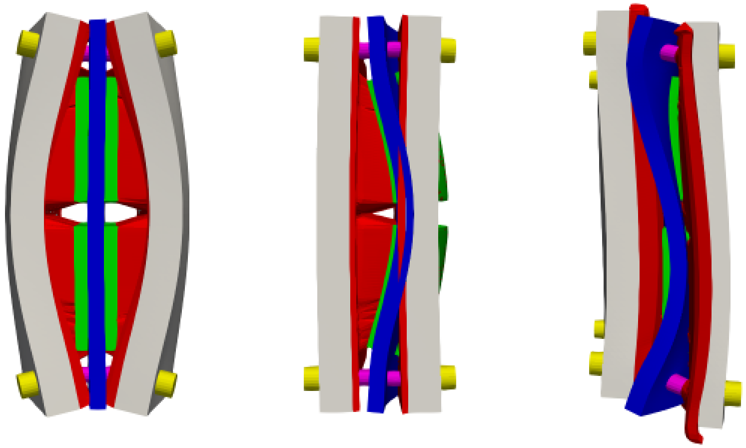


requency: 1607.4 Hz
Frequency: 1623.3 Hz
Frequency: 1625.1 Hz

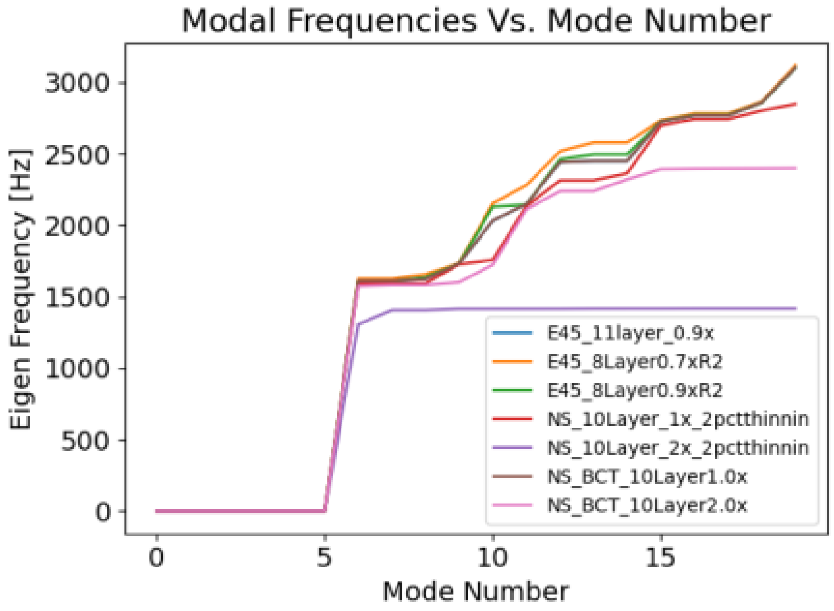


DNS BCT 10 Layer 1x

Frequency: 1575.5 Hz
Frequency: 1600.9 Hz
Frequency: 1582.2

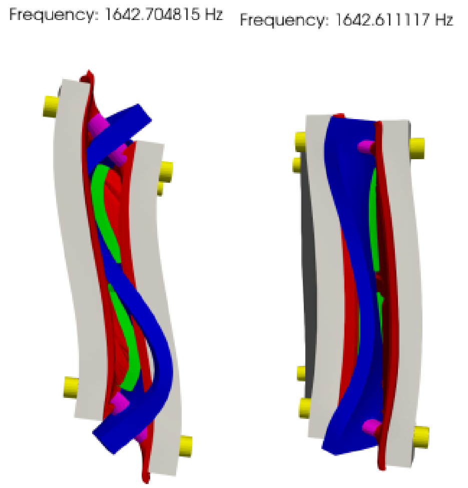


DNS BCT 10 Layer 2X

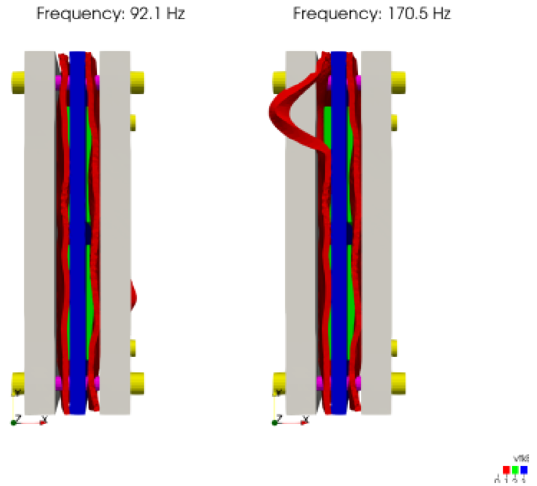


Modal Response of the Structure About the Deformed (about 53% Nominal Compression) State

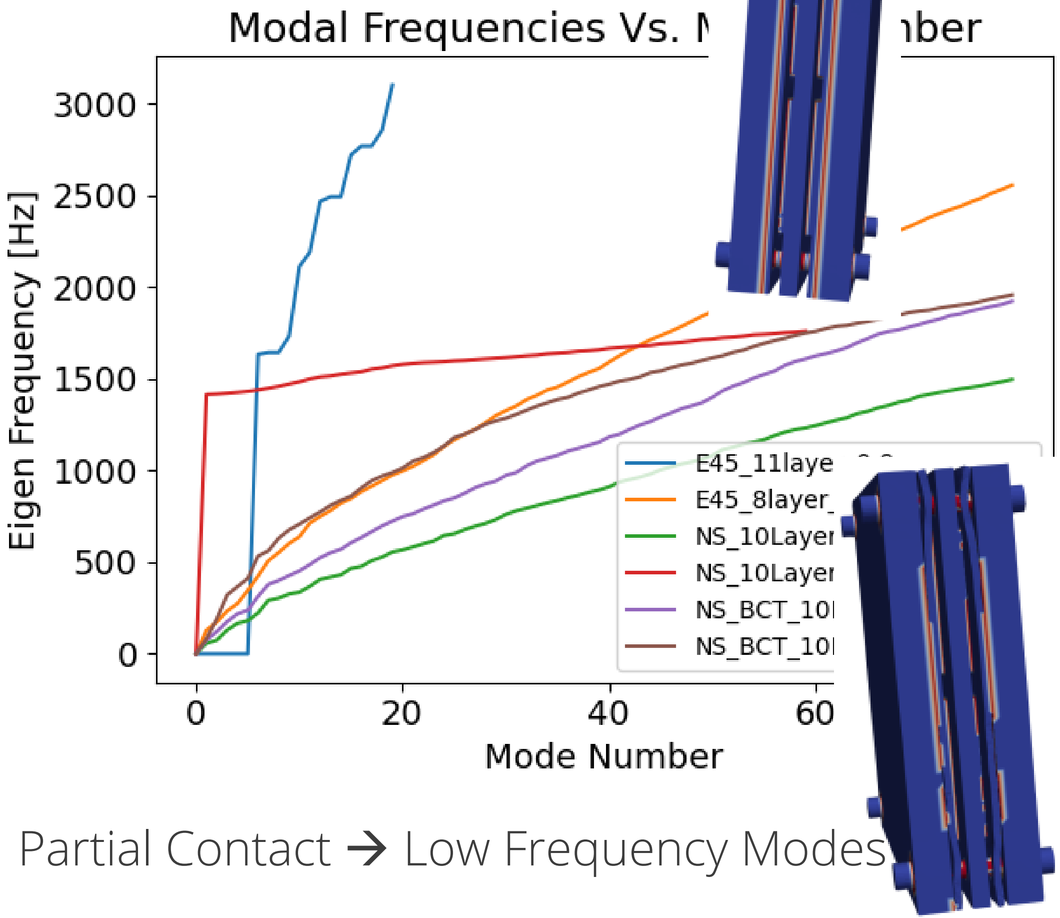
DE 11 Layer 0.9X (Full Contact)



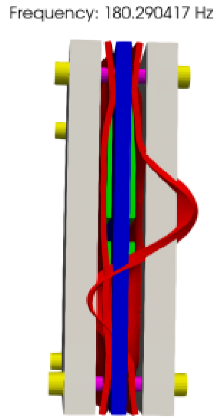
DE 8 Layer 0.9X (Partial Contact)

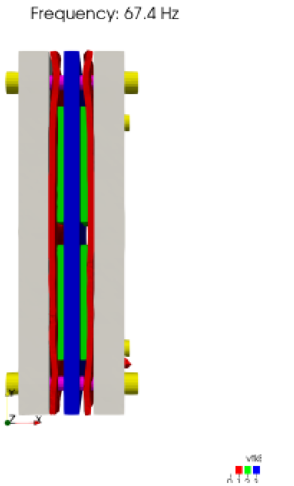


Full Contact
→ Higher Frequency Modes



Partial Contact → Low Frequency Modes



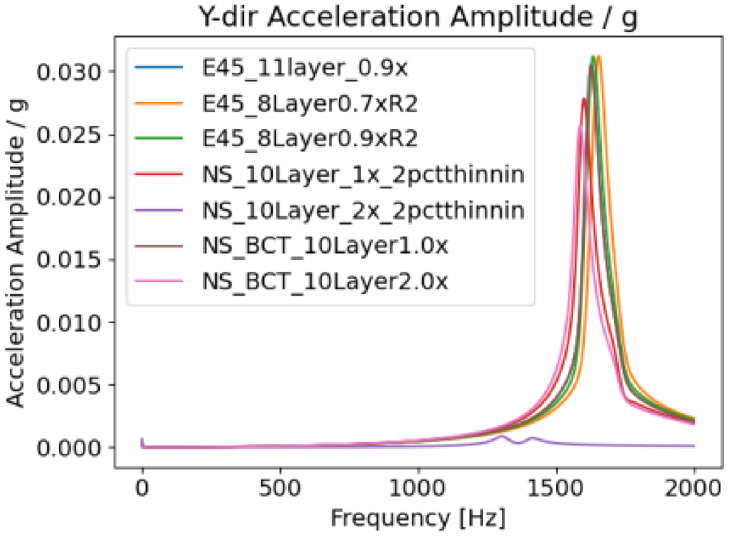


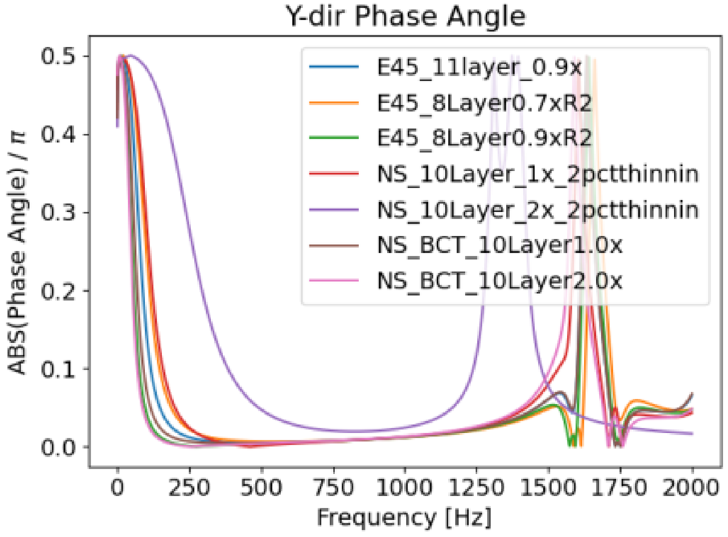
DNS BCT 10 Layer 1x (Partial Contact)

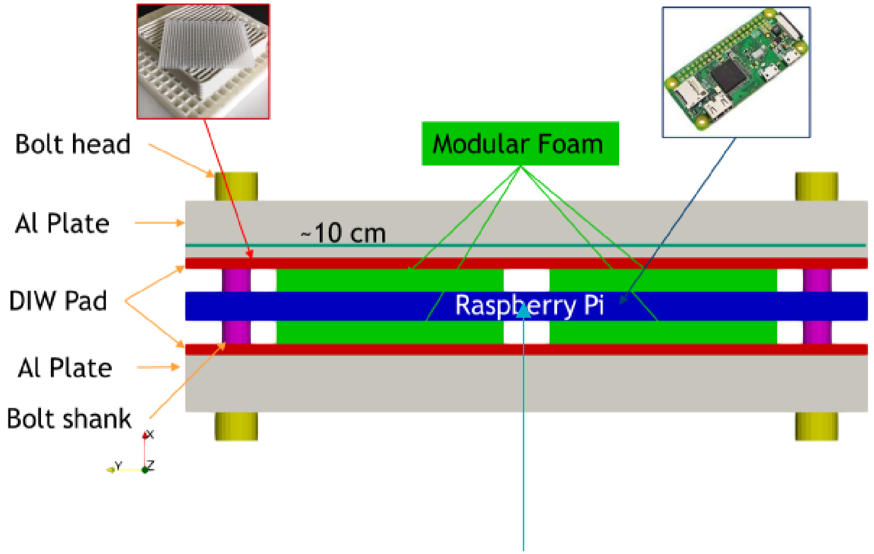
DNS BCT 10 Layer 2X (Partial Contact)

Frequency Response Comparison at the Top-Center of the Rasberry Pi

Undeformed



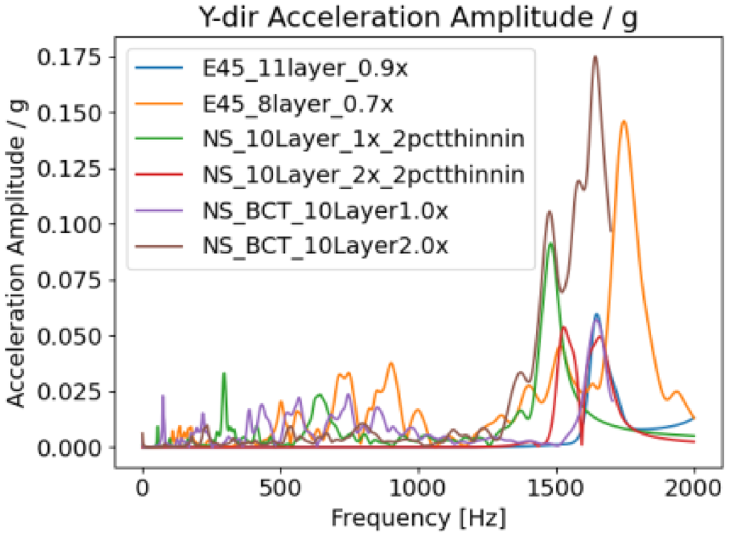


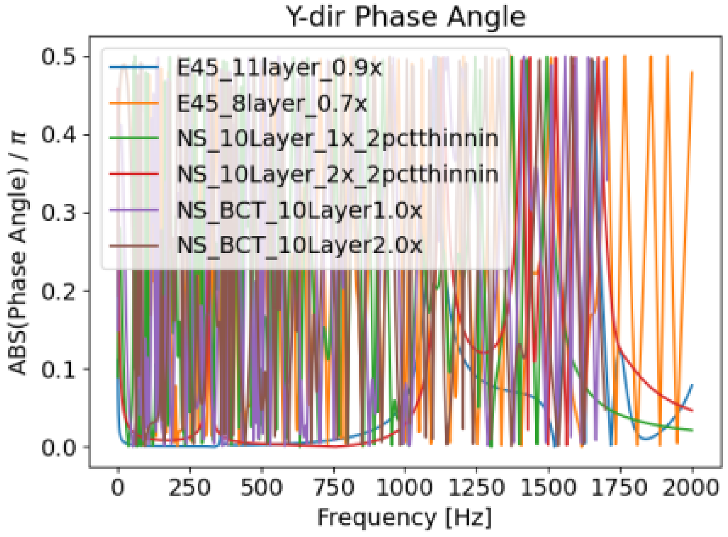


Virtual Accelerometer Location

Vibration only in the “x” (vertical) direction

53% Deformed DIW Lattices





Frequency Response Comparison at the Top-Center of the Rasberry Pi

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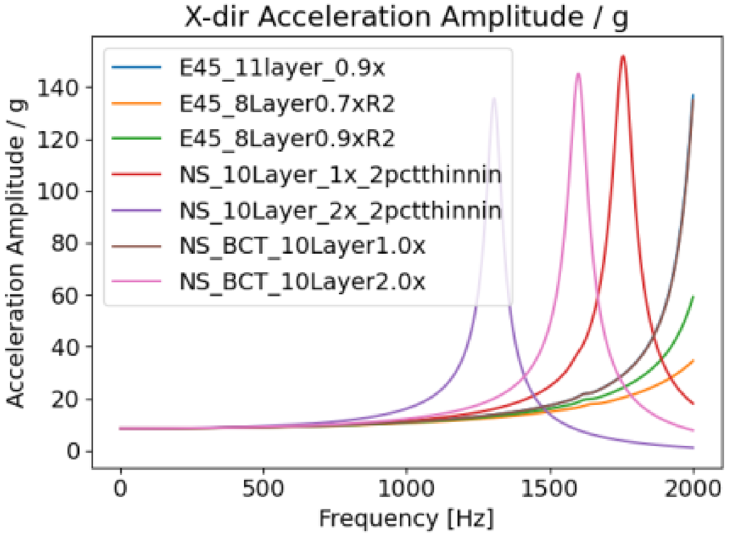

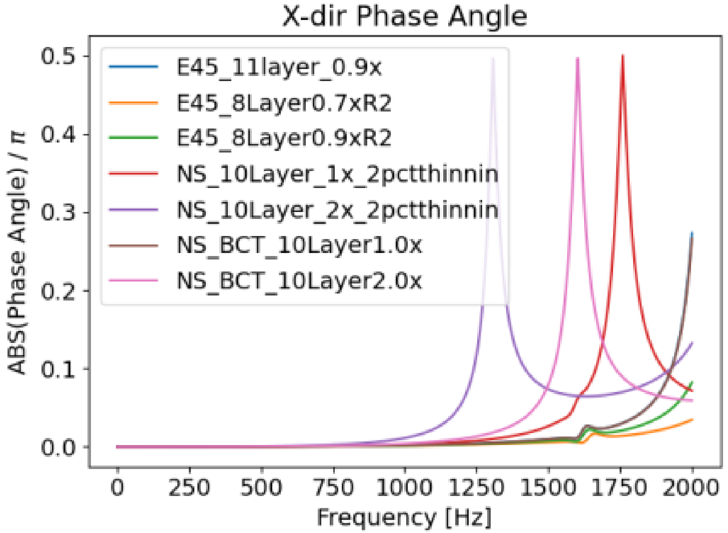

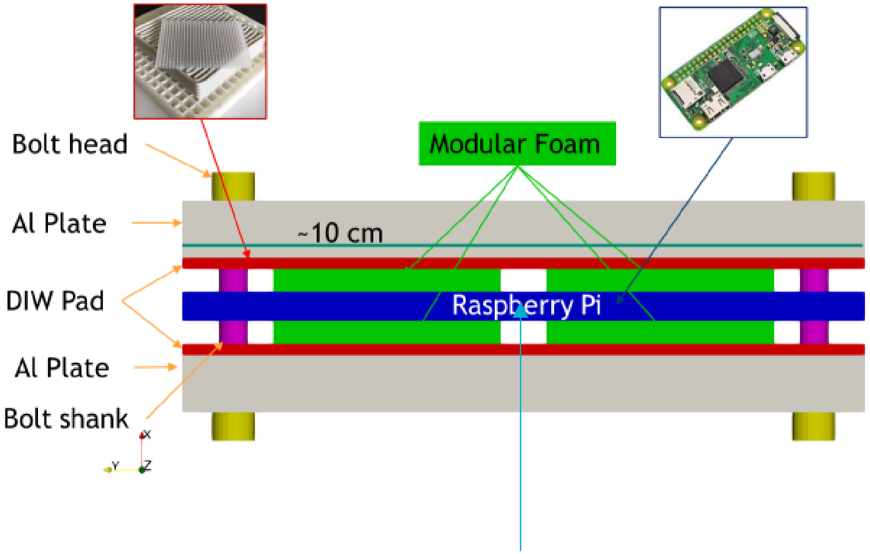

Virtual Accelerometer Location

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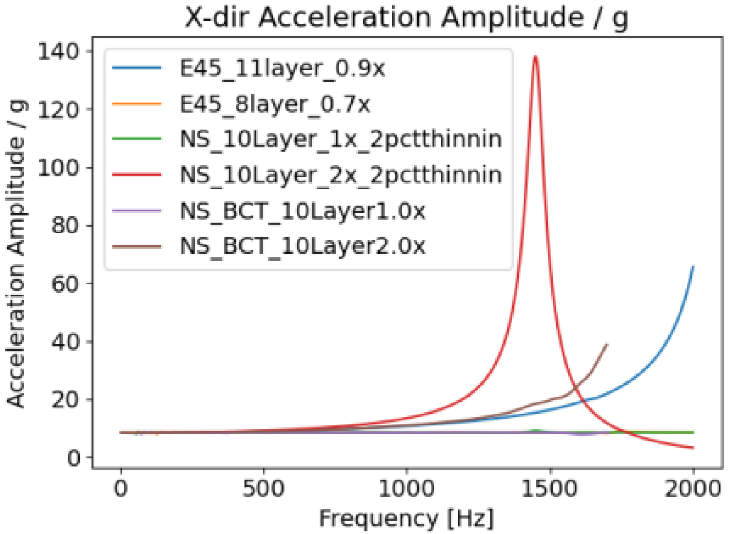
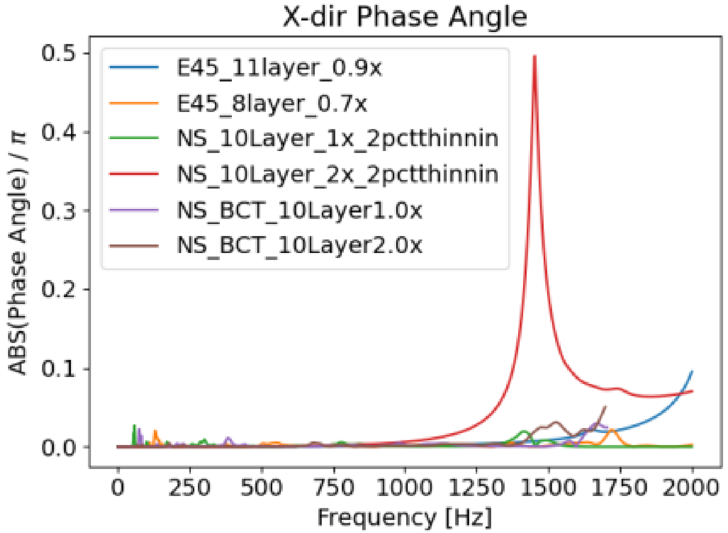
53% Deformed DIW Lattices





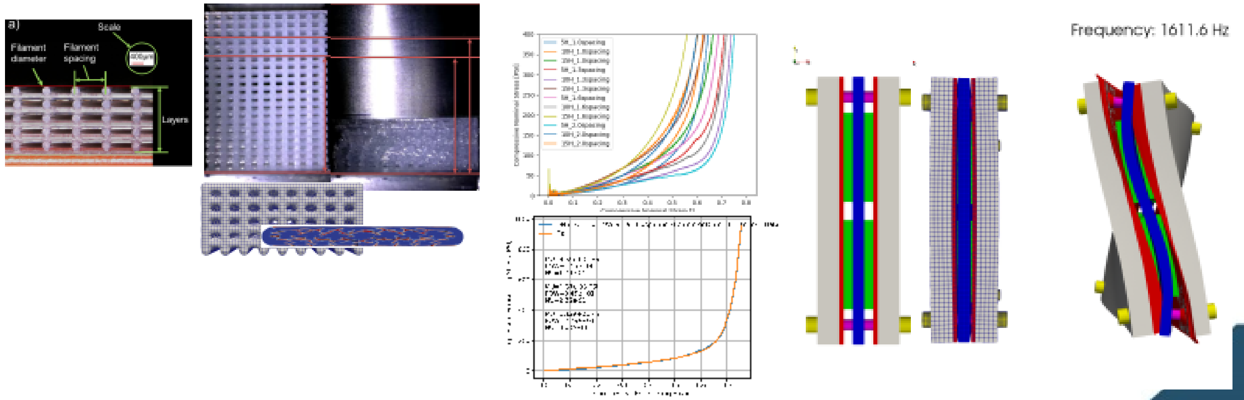
Summary and Closing Remarks

Summary

1. A 5-stage multi-scale workflow compatible with simulated or experimental characterization of DIW Lattice Structures used in electronics packaging mechanical environments was developed
2. Preload, Modal, and FRF behavior was found to strongly depend on pad parameters
3. Defects in pad printing significantly affected the preload and modal response of the structure
4. Contact is very important and must be carefully monitored as it substantially changed the model content of the preloaded structures

Outlook

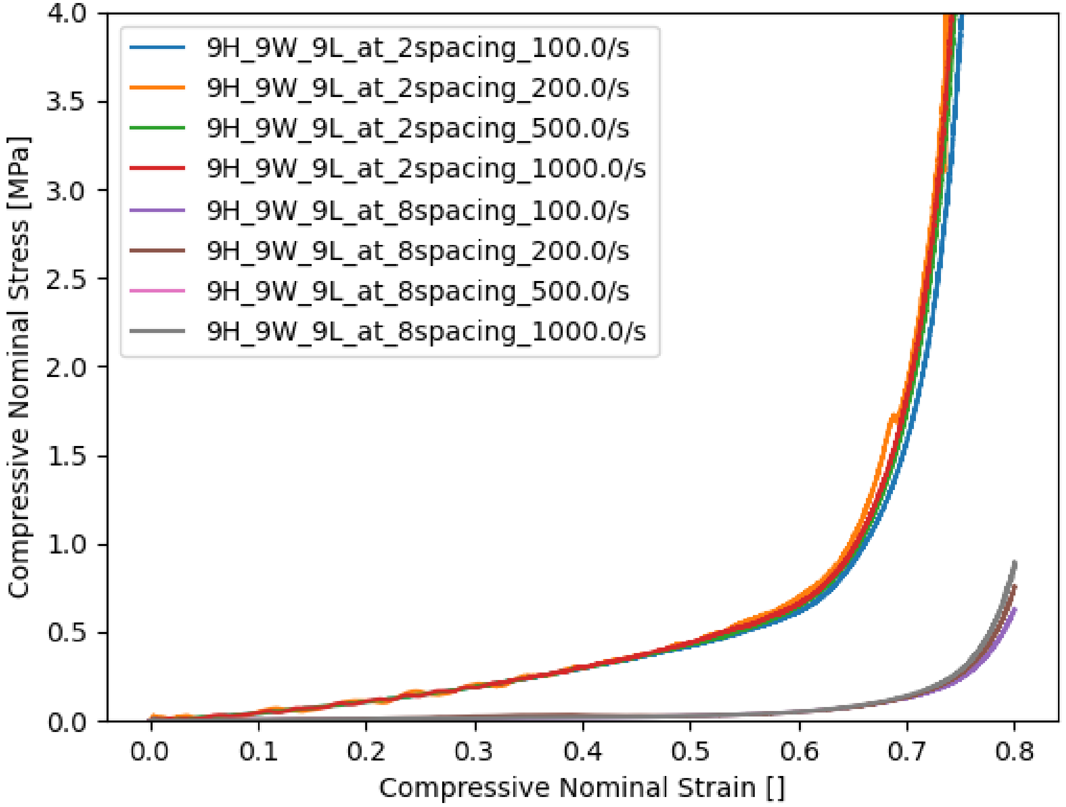
1. Results suggest we can design pads to design the preload, vibration, and transient impulse responses of pads
2. Viscoelasticity should be included



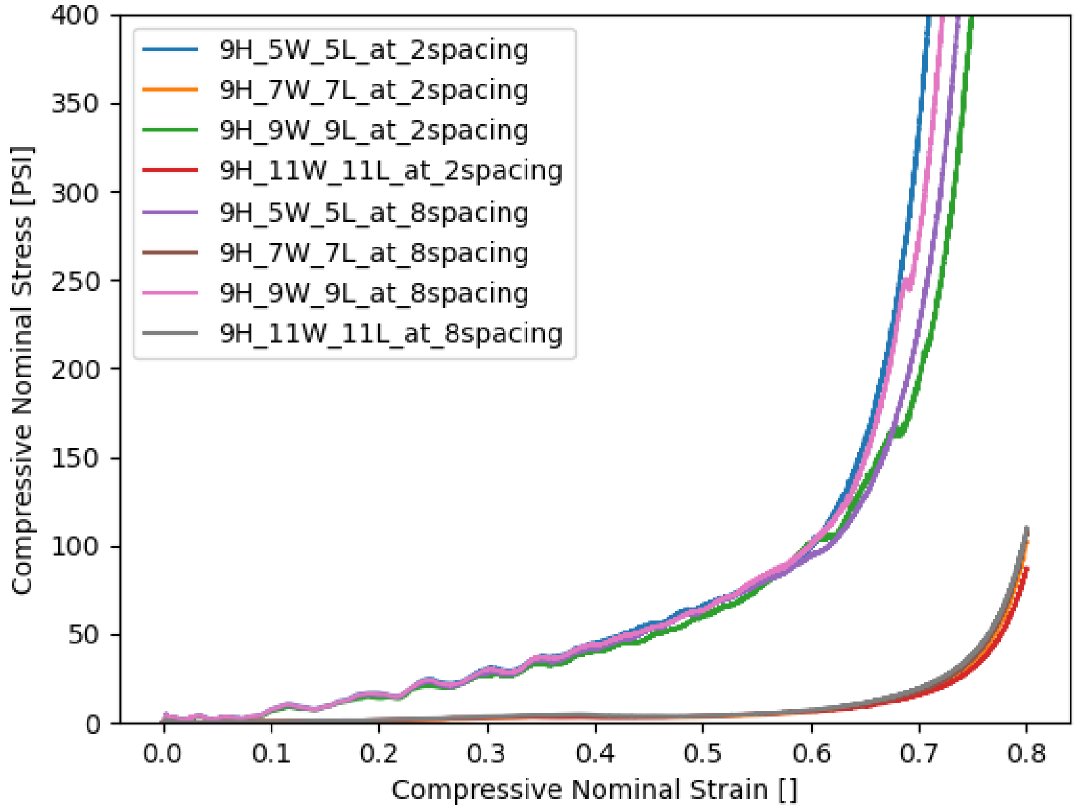
Questions

Kevin Long
knlong@sandia.gov

Explicit Dynamics Strain Rate Study



Lattice Size (Number of Cells In Each Lateral Direction)



Explicit Dynamics Strain Rate Study