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ADVANCED FUZING TECHNOLOGY

Multifunctional Metamaterials for Environmental and Structural Health Sensing

Presented By:

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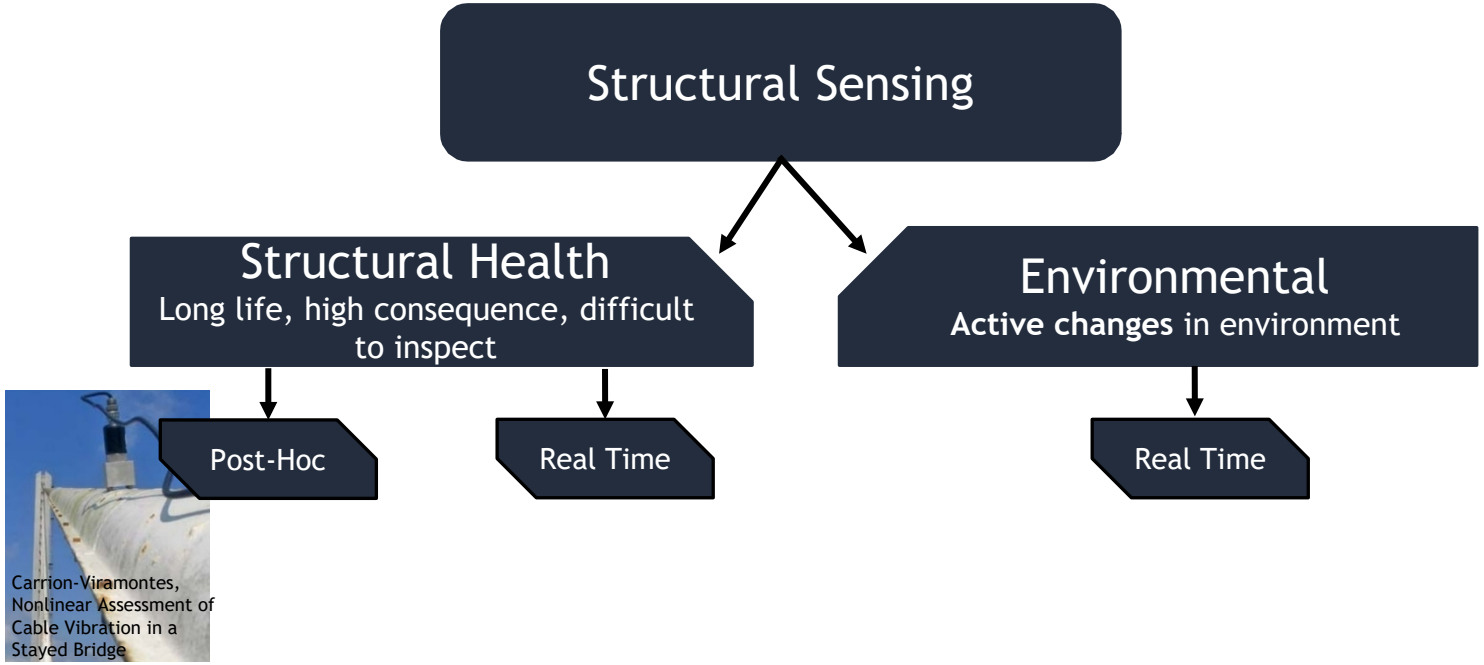
  - Michael Davies
  - Dr. Jacob Dodson
  - ARA Team
    - Dr. Alain Beliveau
    - Dr. Adriane Moura

Sensing Materials

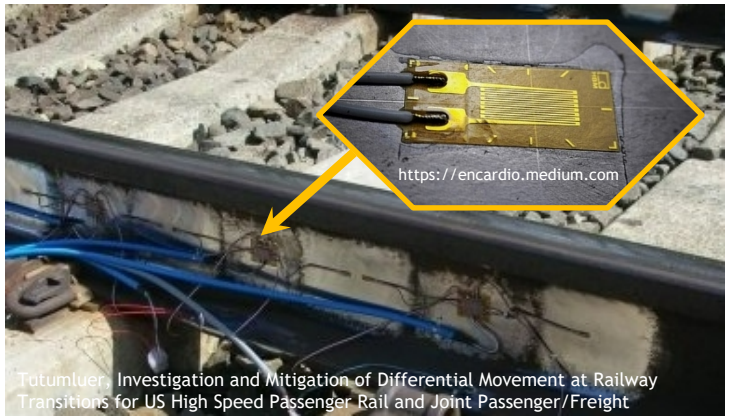
Sensors are everywhere
- As of 2017 the average car has 60-100 sensors[1]

Sensing materials give more information than sensors
- Poor structural performers



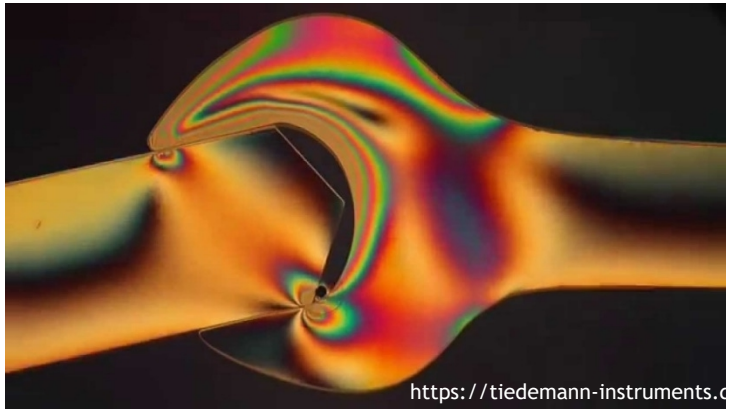
Sensor

-Placed onto structure
-Point Information



Sensing Materials

-Can ***be*** the structure
-Volumetric information

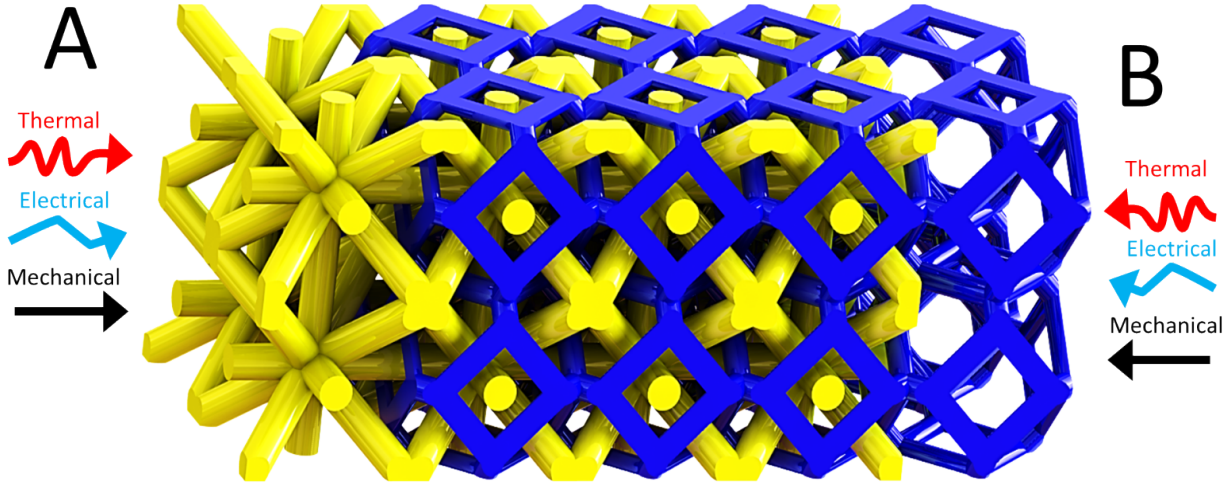


[1]http://www.automotivesensors2017.com

Sensing Metamaterials

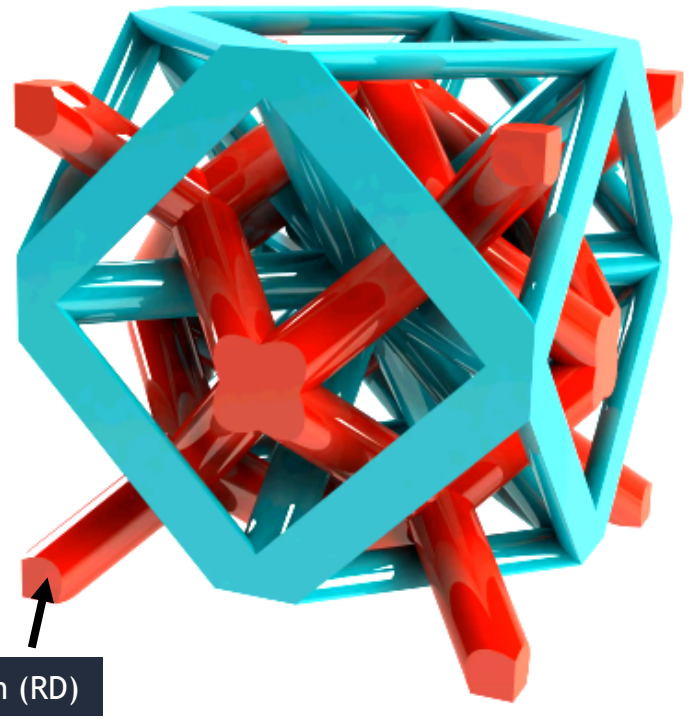
Directly architected metamaterials can better optimize strength and sensitivity
- Direct control over: Base Material, Solid geometry, Interface interactions

Interpenetrating lattice is a case example
- Two separate lattices interweave in the same volume
- Loads can be forced to travel across the interface



White, 2021, Interpenetrating lattices with enhanced mechanical functionality
https://www.sciencedirect.com/science/article/pii/S2214860420311131

Face Centered Cubic (FCC) or Octet



Rhombic Dodecahedron (RD)

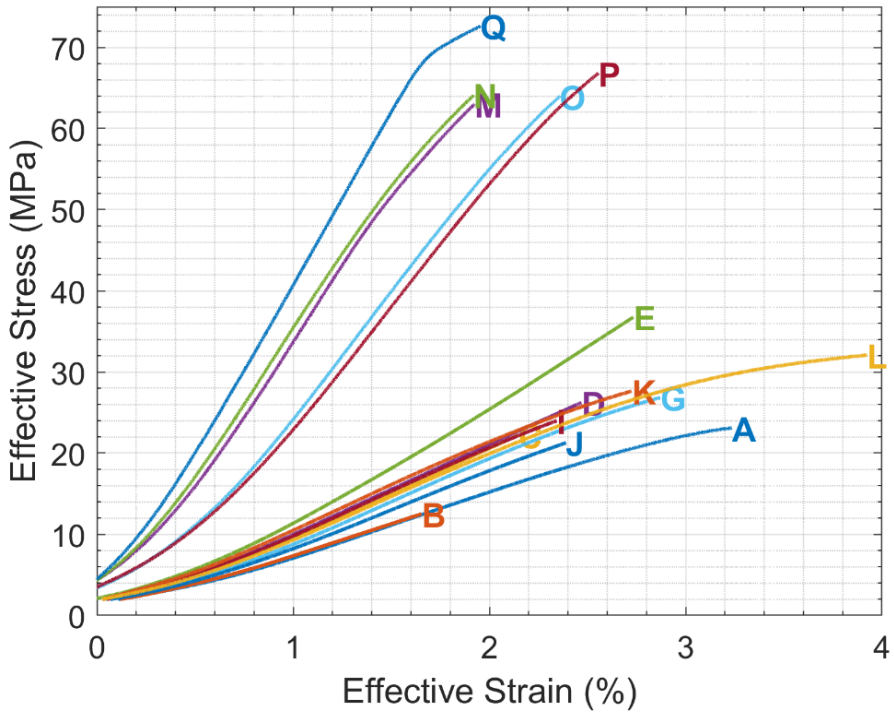
Boyce, 2020, US Provisional Patent 62989288

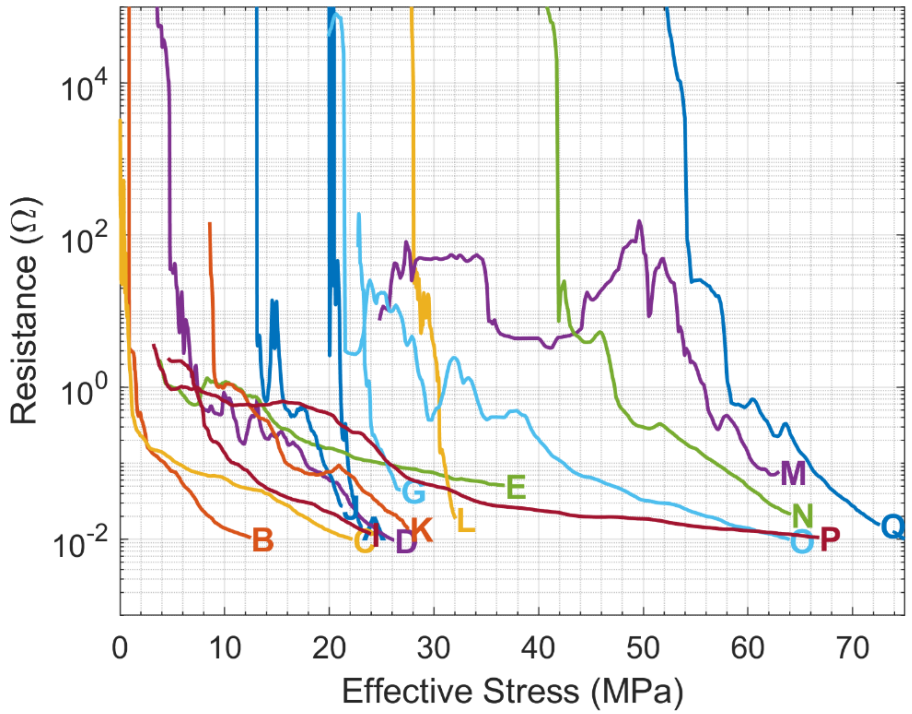
Phase I, Elastic Load Sensing

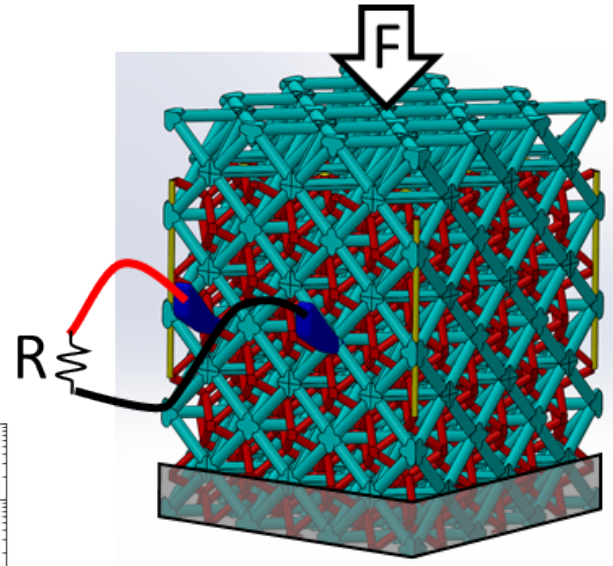
Lattices are initially separate $R \approx \infty$

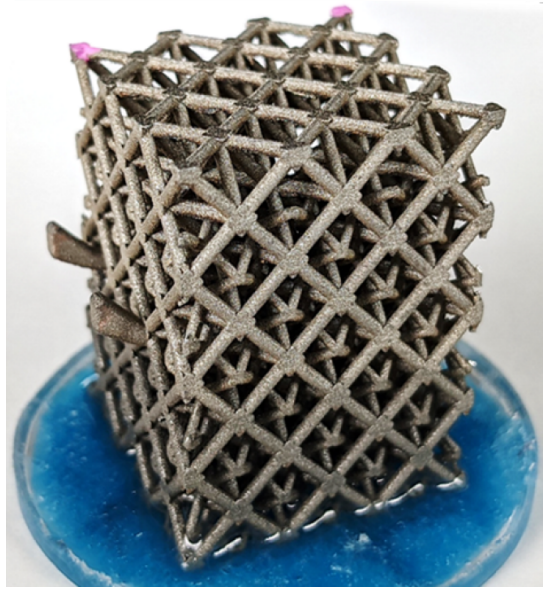
- Elastically deform one lattice into the other $R \propto$ applied load

Contact between lattices is monitored via resistivity and corelated to load







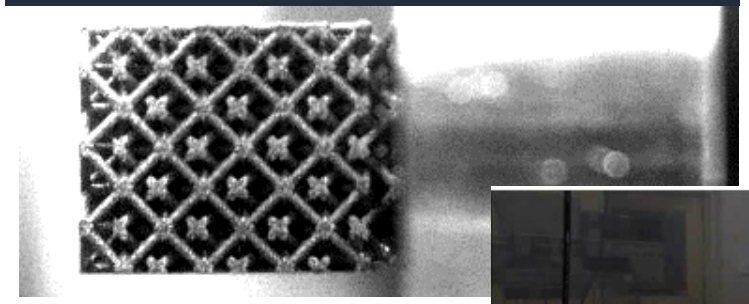


Phase II, Case Integrated Design

Task 1: Lab-scale design and testing

- Correlate dynamic impact to resistivity change
- Assess / improve sensor performance & repeatability

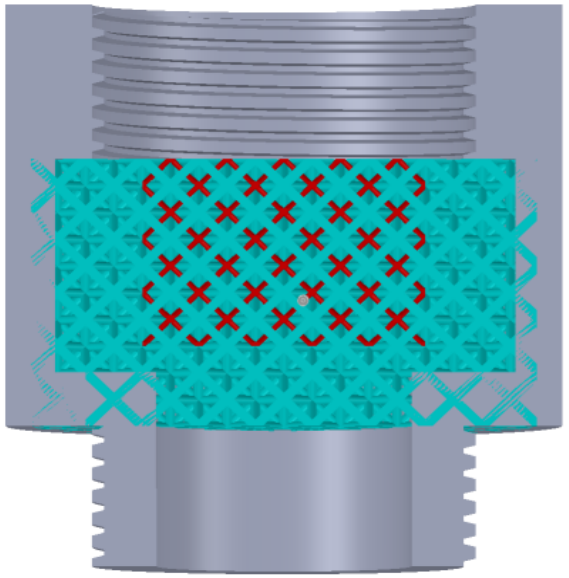
220 m/s impact (gas gun) RD+FCC IPL



3” Hopkinson Bar

Task 2: Case integrated design and testing

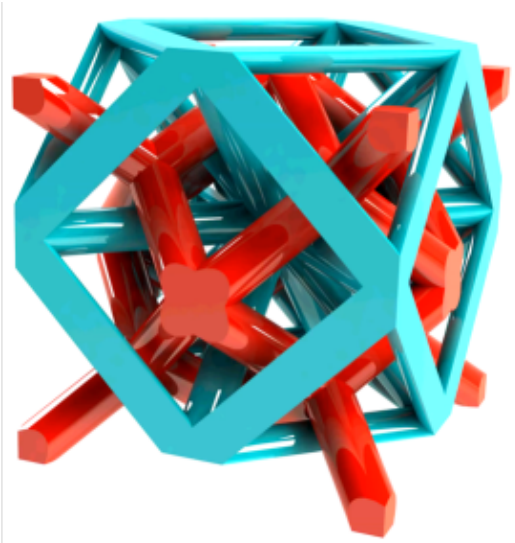
- Demonstrate predictive modeling and design capability
- Design modular sensors
- Design fully integrated AM lattice section



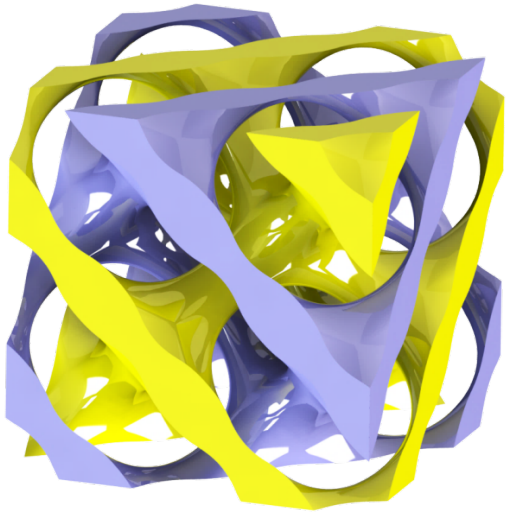
Assessing and Improving Reliability

Quasi-static cycling, print-to-print repeatability

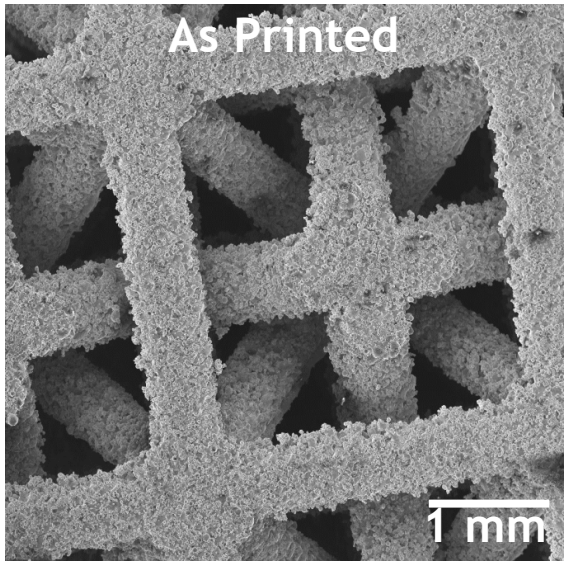
New topologies, miniaturization, surface modifications

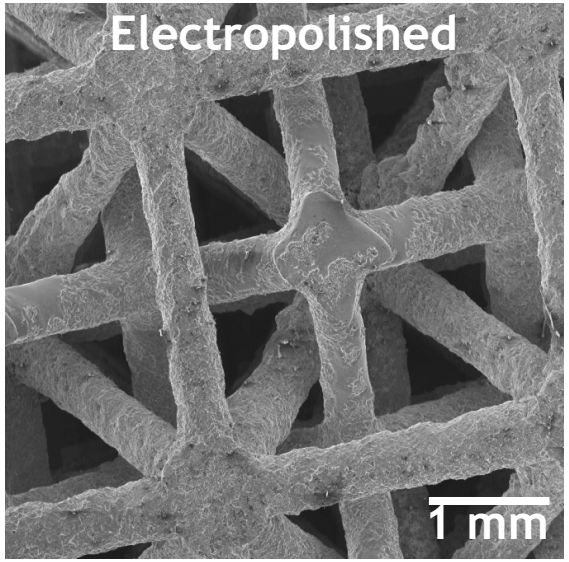


Face Centered Cubic (FCC)



Skeletal Schwarz D IPL





Modeling and Simulation

Modeling and Simulation capabilities needed to facilitate lattice development and adoption

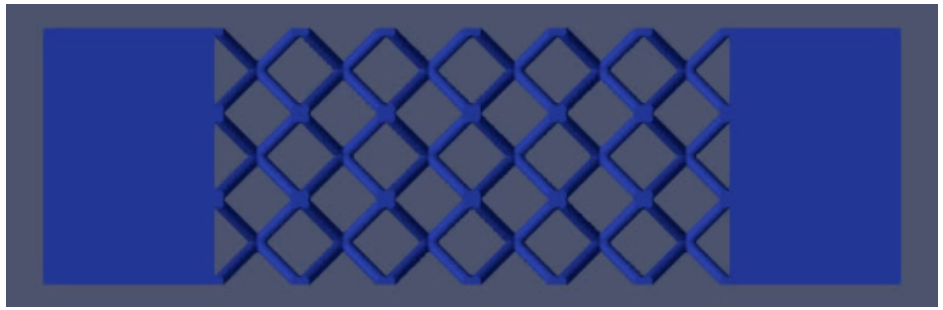
- Reducing development time
- Rapid exploration of different design concepts
- Quantifying performance in scenarios that are expensive/difficult to experimentally test

Lattices have inherent challenges

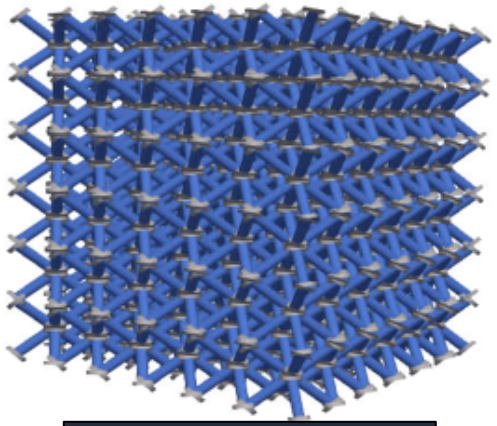
- Large number of geometric features need to be represented (e.g. 5x5x5 FCC lattice has 3600 struts)

Different modeling approaches are needed for different scenarios

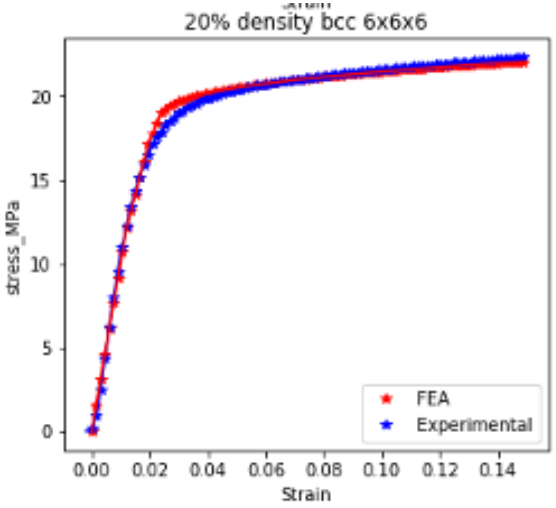
- Balance predictive capability and computational cost
- Direct Numerical Simulation (FEA on mesh of entire lattice structure)
- Engineering-scale models (Homogenized continuum, beam element representation)



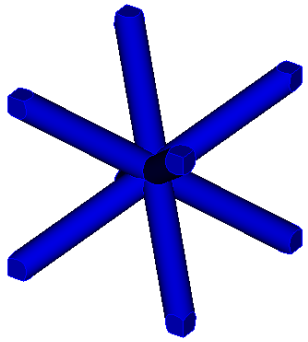
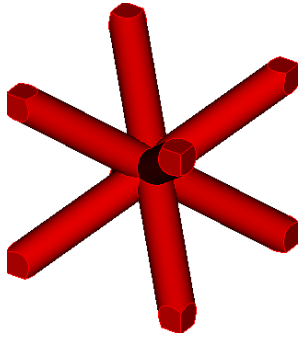
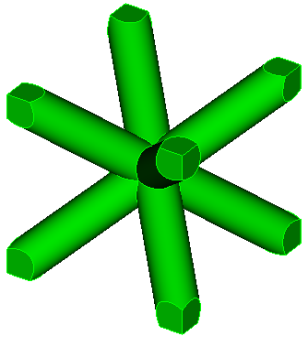
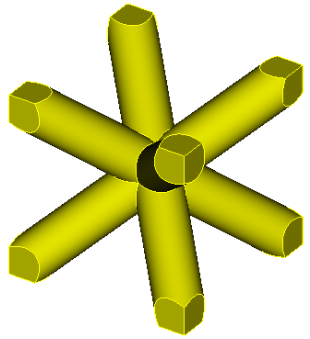
3D elements

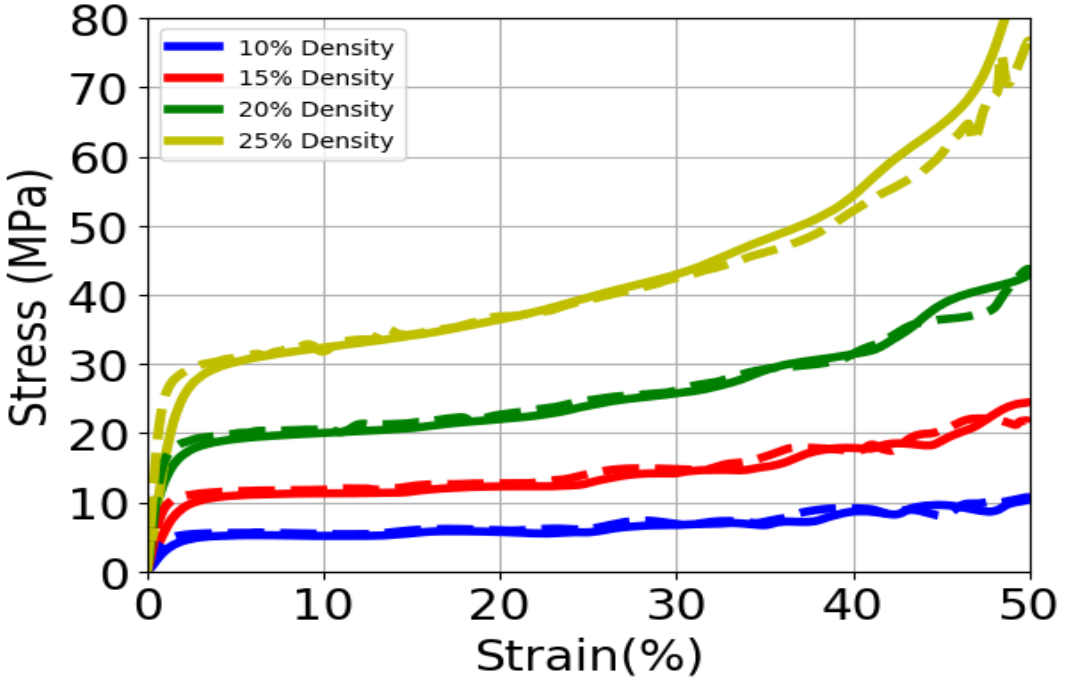


Beam Elements



3D Element FEA to Explore Design Space

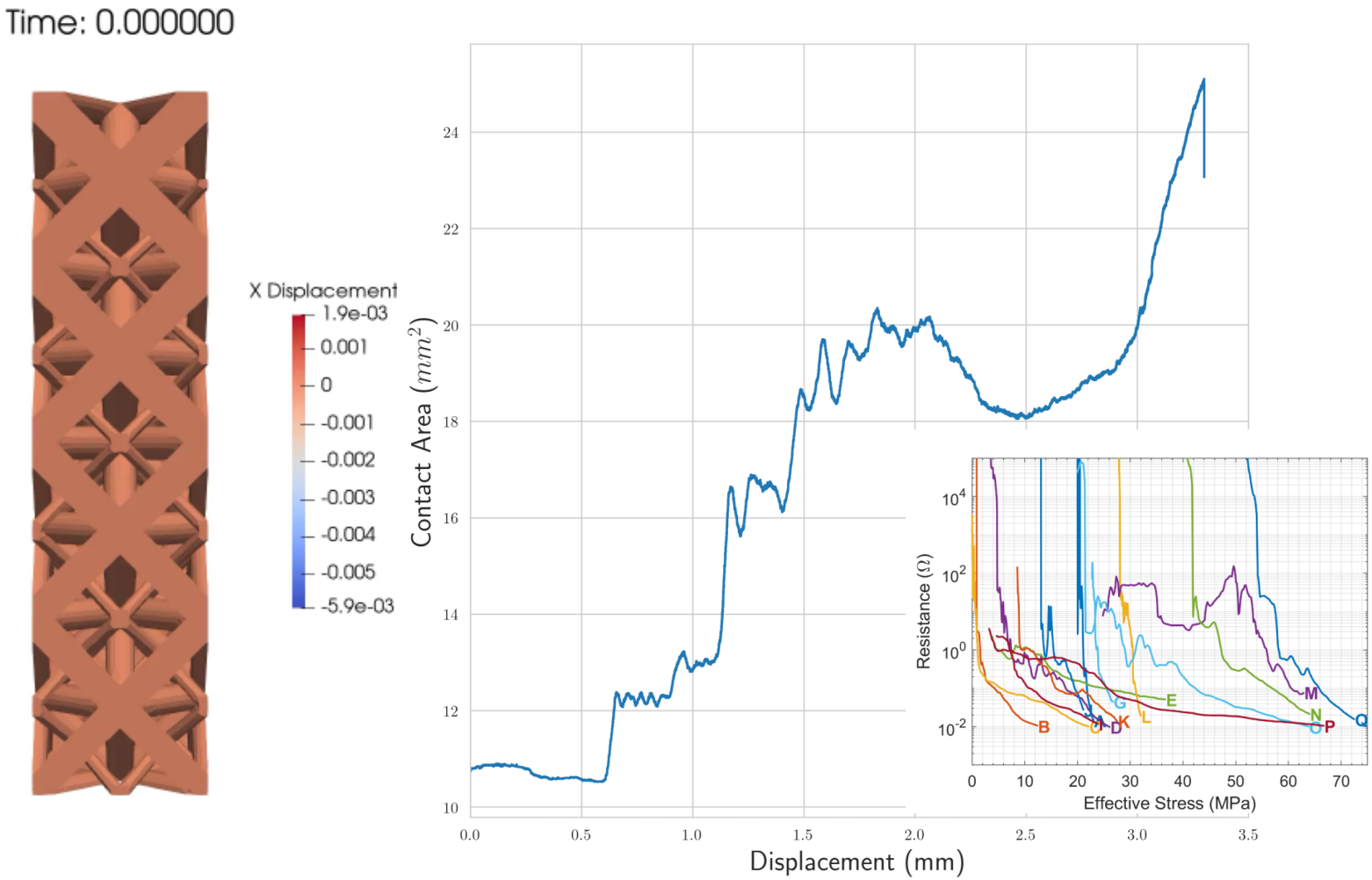


Experimental

Simulated

Tracking Contact Area

- Contact area may serve as a surrogate for resistance
- Contact area needs to be validated against experimental resistance changes
- Homogenization of contact area will be explored

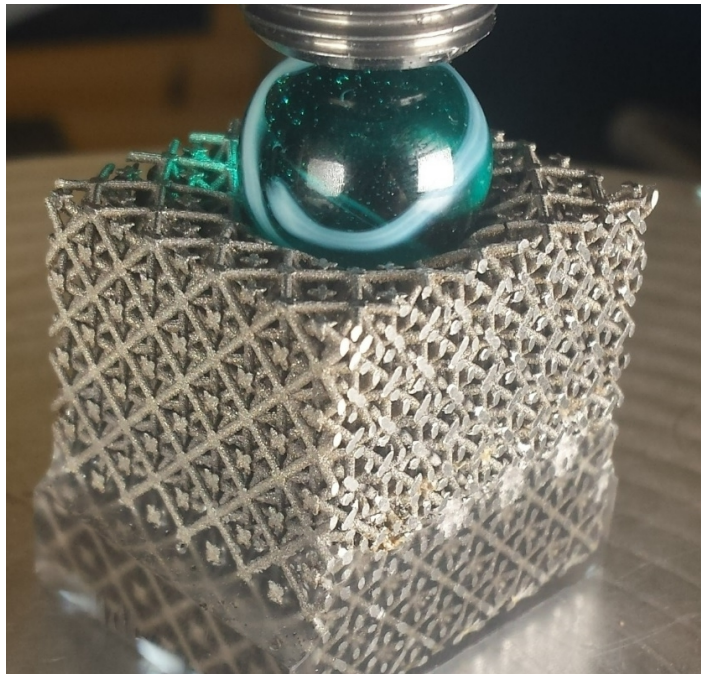


Related Work, Plastic Damage Sensing / Concepts

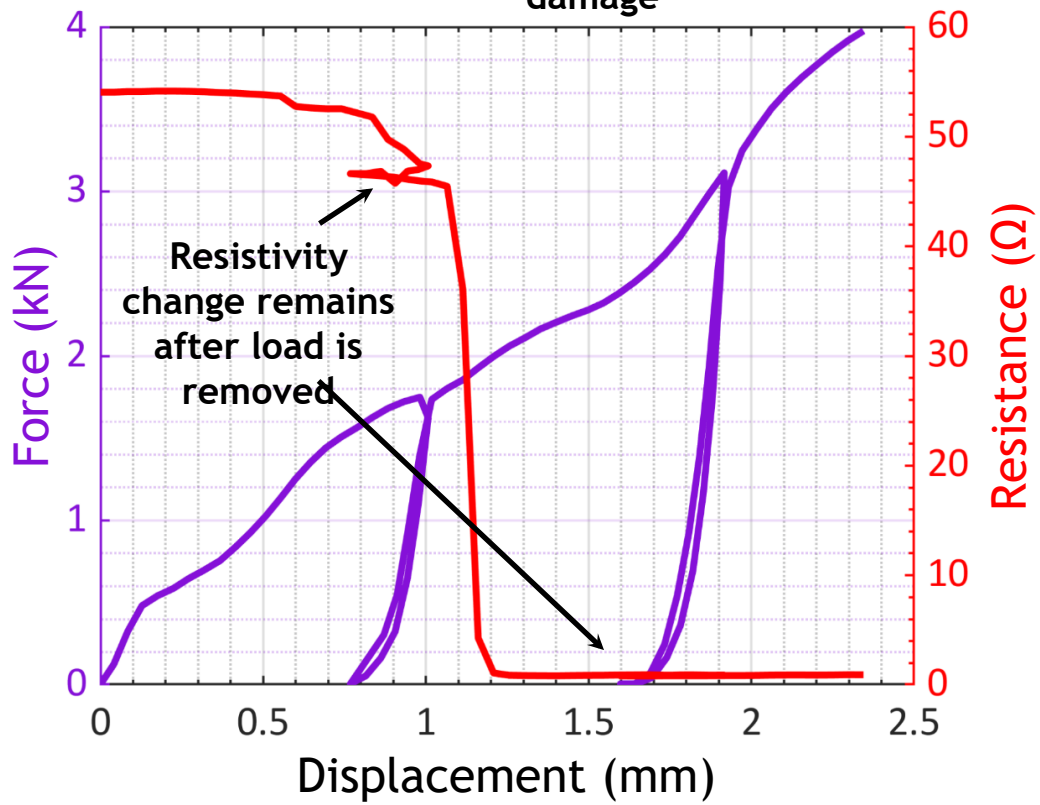
Lattices initially separate: $R \approx \infty \rightarrow$ damage causes contact: $R \propto damage$

Plastic deformation stores information permanently

- Damage can be **easily, cheaply** assessed in real time or after the fact



Not just a switch, some sensitivity to amount of damage

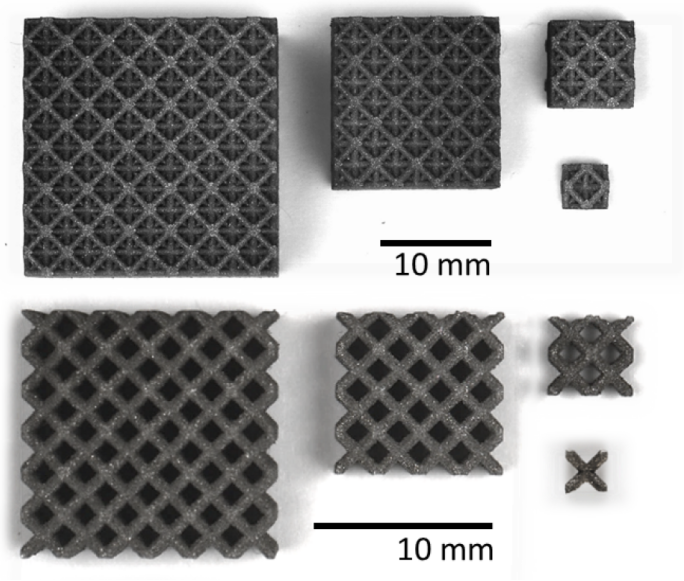


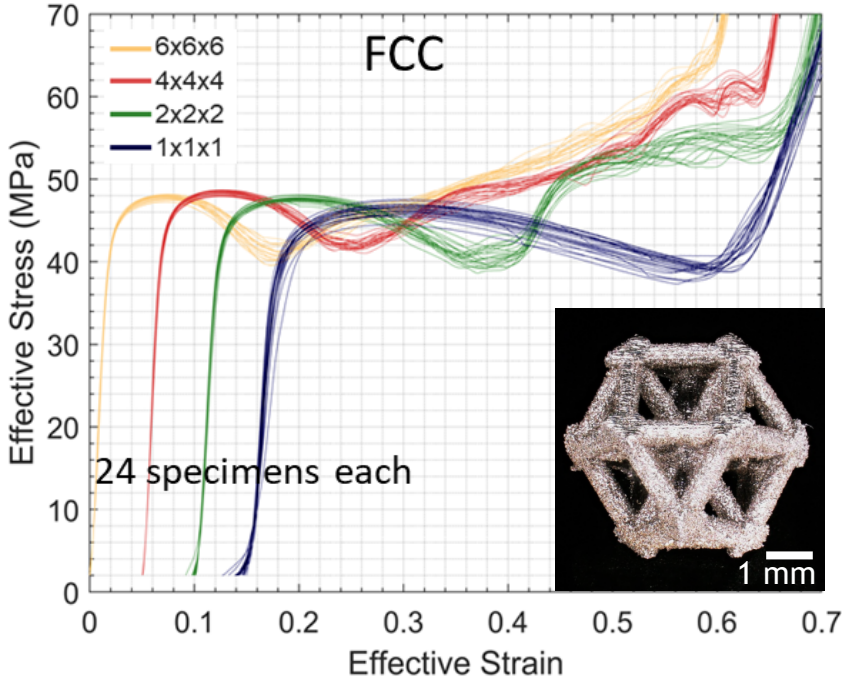
Related Work, Lattice Repeatability

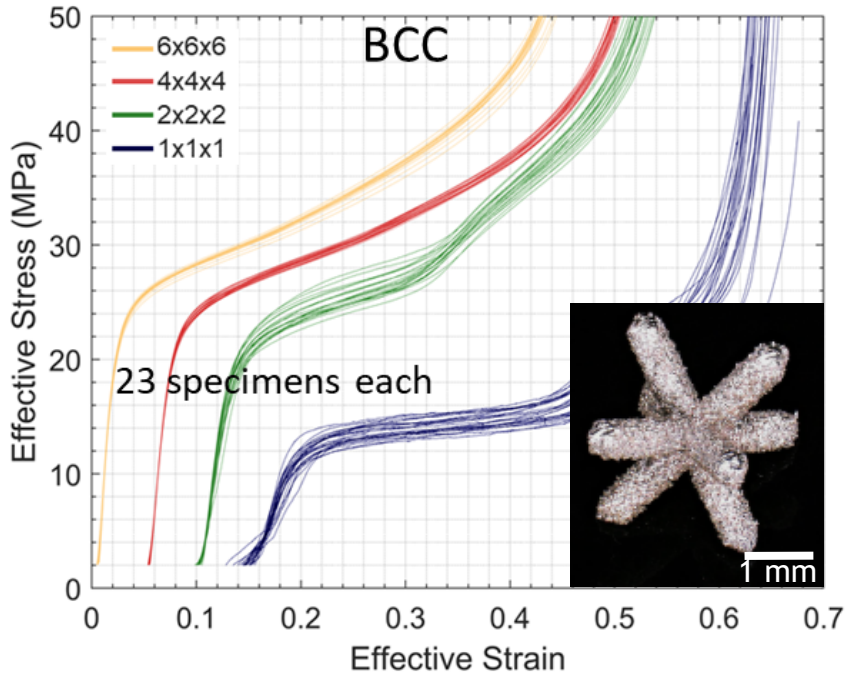
Lattices are reasonably repeatable
- Variability decreases with increased lattice size
- Material chosen (316) lends itself to repeatability due to ductility

Topology changes performance, but does not affect variability

Additional cells reduces variations

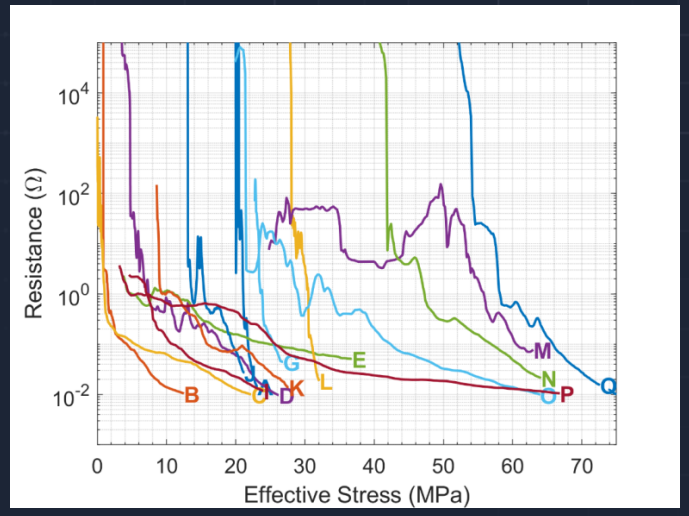


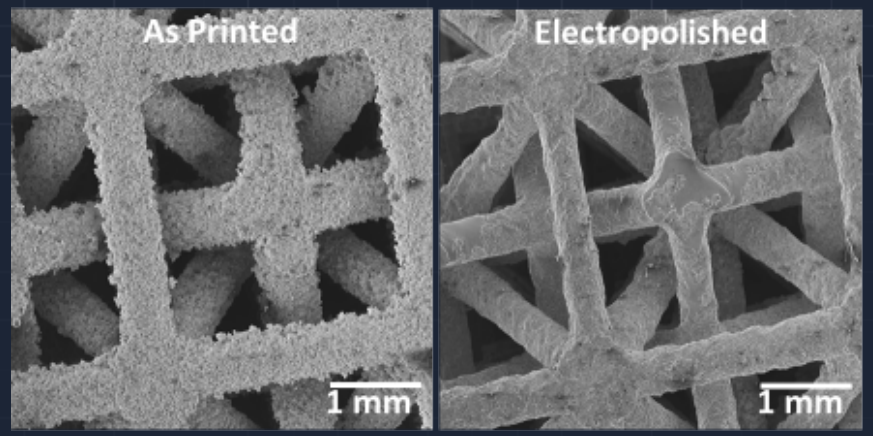


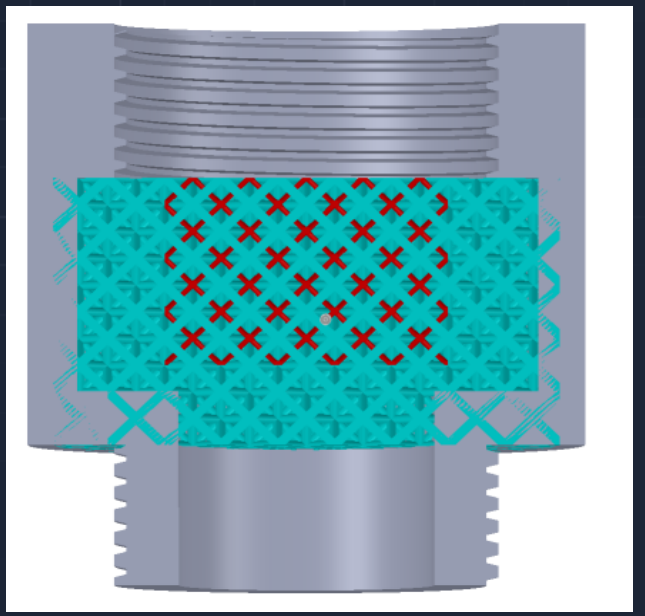


Conclusions

- Known:
  - Lattices can offer elastic strain sensing
  - Electropolishing can smooth both lattices throughout their interior volume
  - Direct numerical simulation is accurate
- Unknown:
  - Is the dynamic impact behavior the same as quasi-static
  - How can we design and model a lattice integrated into DoD applications







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