Development of Lightweight Structural Materials with Improved Properties for Fission Batteries

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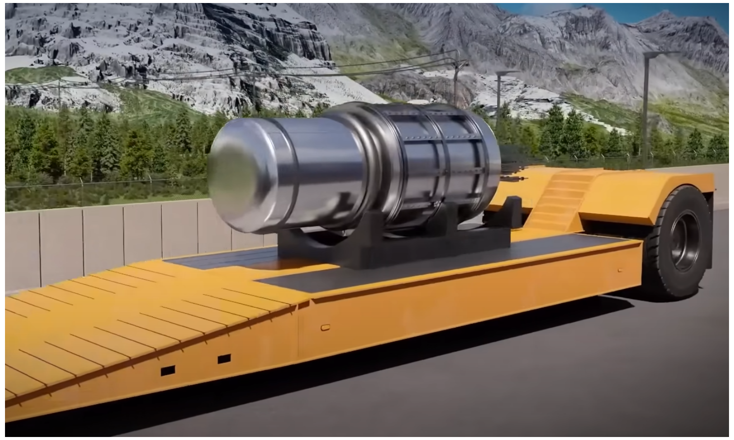
Motivation: Fission Battery Concept

- Fission batteries are a “plug-and-play” take on microreactors
- Self-contained, off-grid, expandable, factory-made
- Enables rapid deployment of power to remote areas with minimal infrastructure requirements

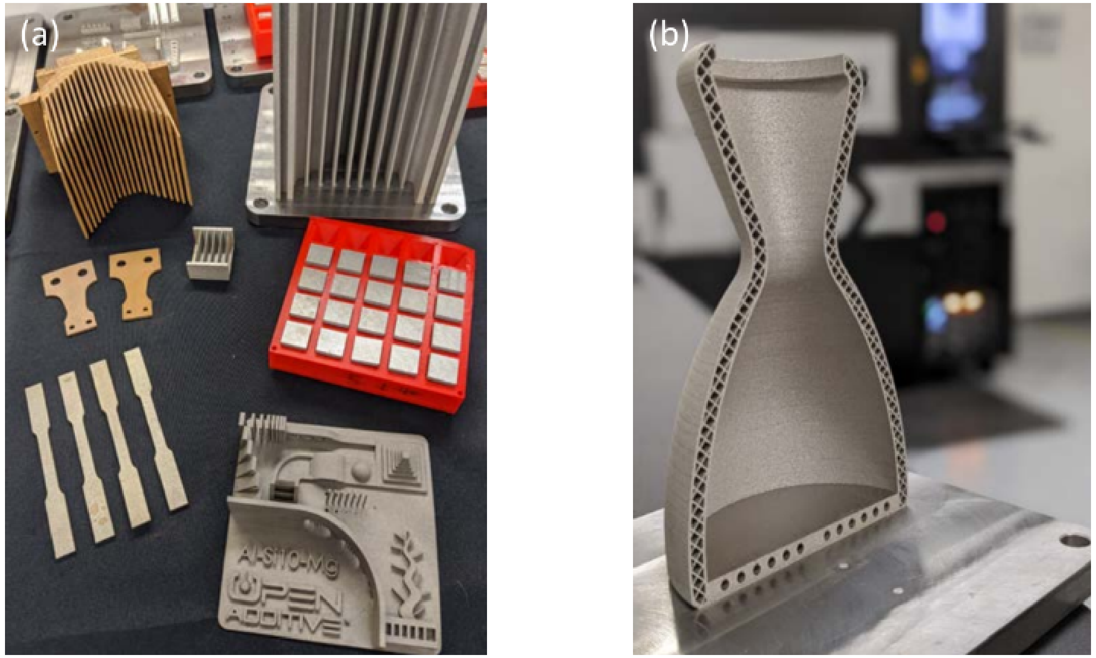
The transportability requirement of fission batteries requires integration of lightweight materials wherever possible in the reactor system.

X-energy Xe-Mobile form factor


Westinghouse eVinci micro reactor rendering

Additive Manufacturing of Lightweight Materials

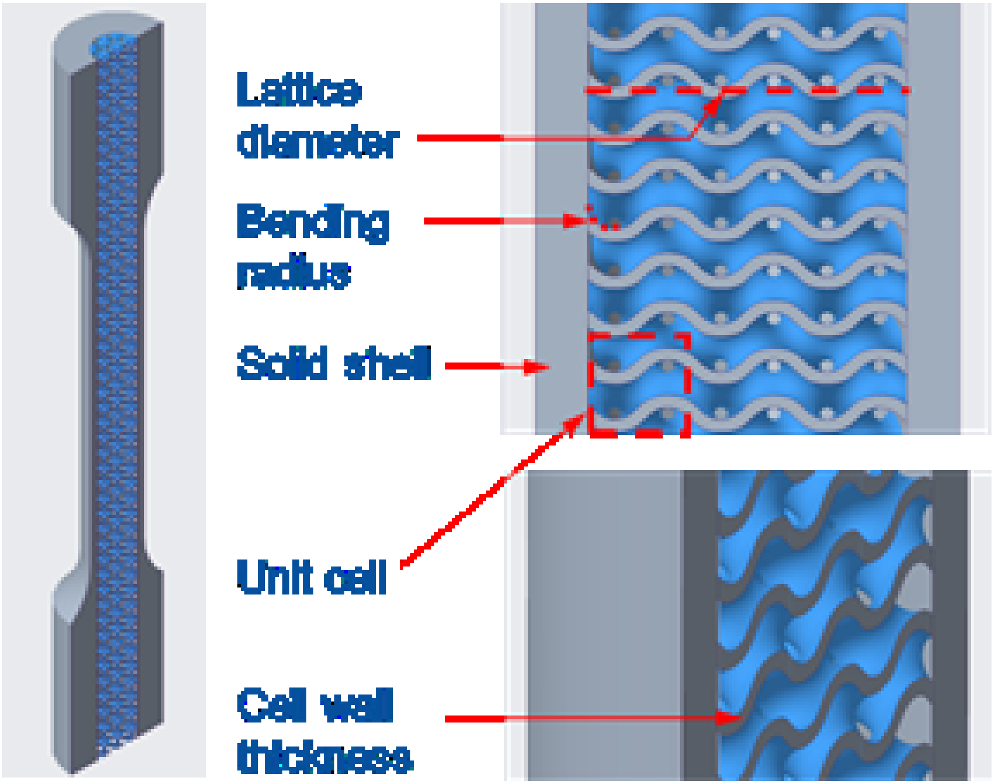
- Component weight can be reduced by use of lower-density materials or by optimizing component geometry
- Additive manufacturing (AM) enables material geometries not producible by traditional means
- Owing to the high-temperature, high-strength requirements of nuclear applications, lightweighting of structural steels via AM was pursued rather than substitution with low density alloys (e.g., aluminum, titanium)



Promotional photos of parts produced using an Open Additive PANDA^{TM}, the same laser powderbed fusion (LPBF) printer available at the Center for Advanced Energy Studies (CAES) at Idaho National Laboratory

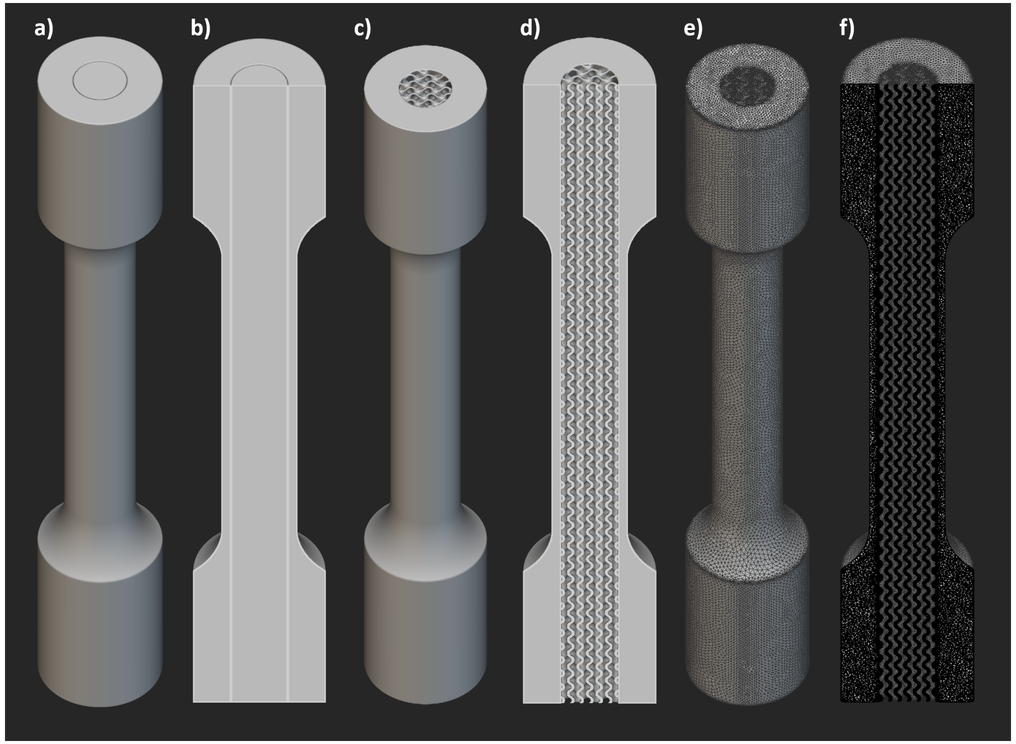
Tensile Bar Design Approach

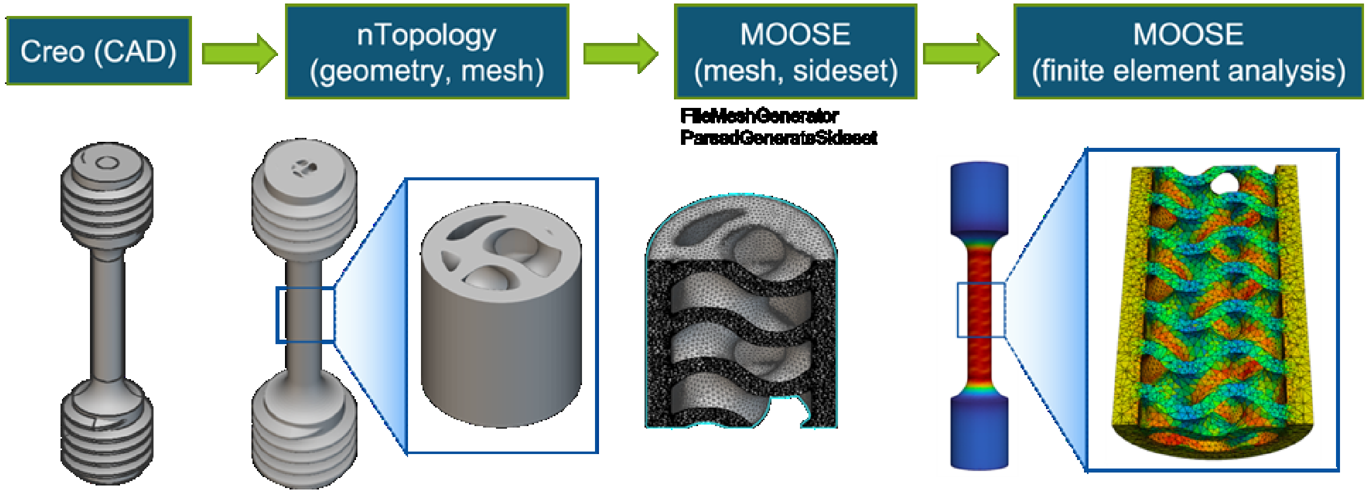
- With both tensile and fatigue testing planned, a cylindrical geometry was adopted
- A solid shell is used throughout the gauge section to:
  - Provides easily machinable gauge section to maintain tolerances
  - Reduces effects of truncating cubic lattice to fit cylindrical geometry
- Lattice region extends through the grips to provide pathway for powder removal



Modeling Pipeline

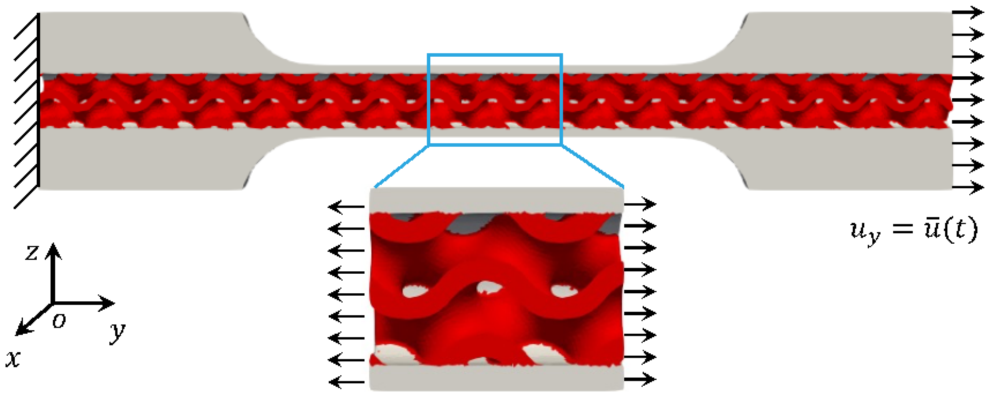
- a-b) base tensile bar is generated using Creo
- c-d) using nTopology, base tensile bar is converted to an implicit body and the core is replaced with a lattice structure
- e-f) implicit body is converted to volumetric mesh used for both printing and FEM via MOOSE

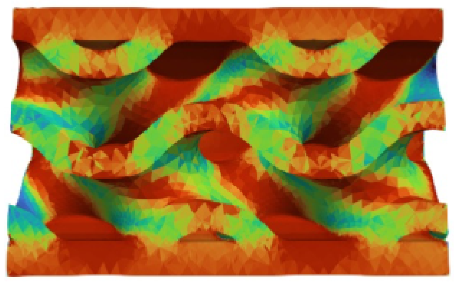




FEM via MOOSE

- A subsection of each tensile bar is imported into MOOSE
- FEM is performed using a power-law hardening model and SS316 mechanical properties from literature
- Each FEM model includes ~2M number of elements and solving for ~1.2M independent variables.

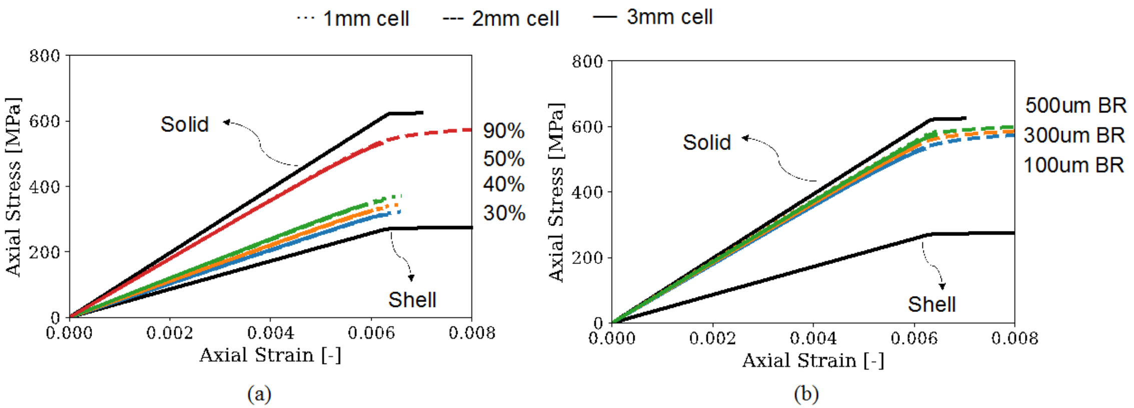


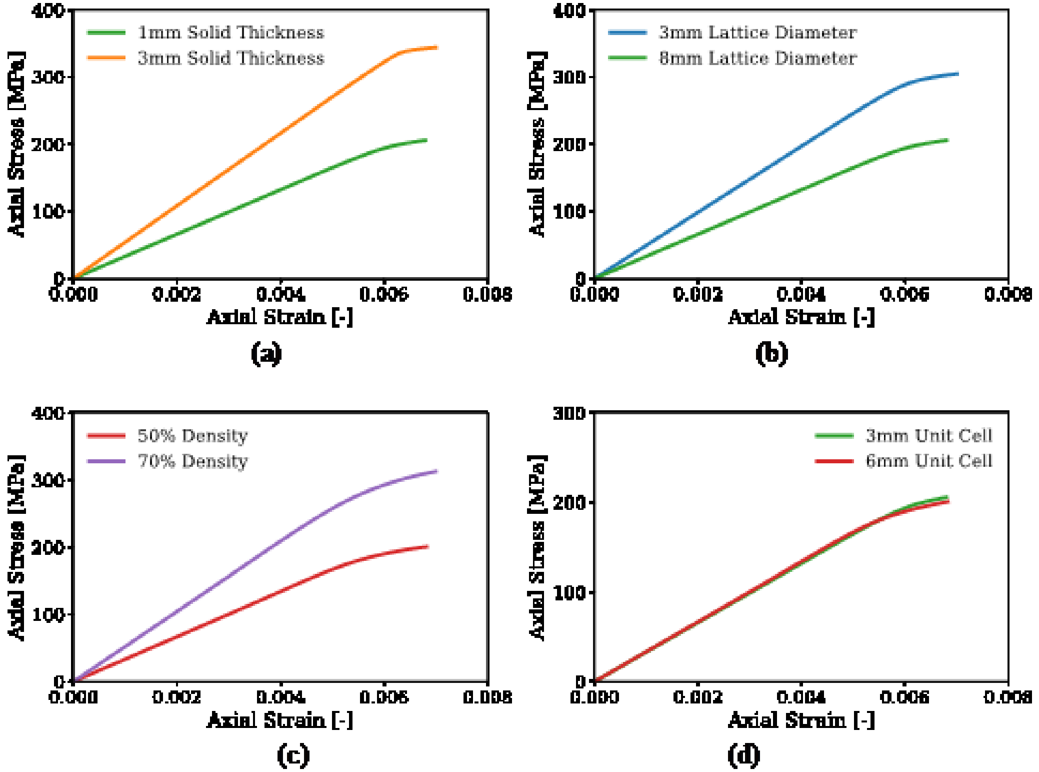


(a) 3mm

FEM Results

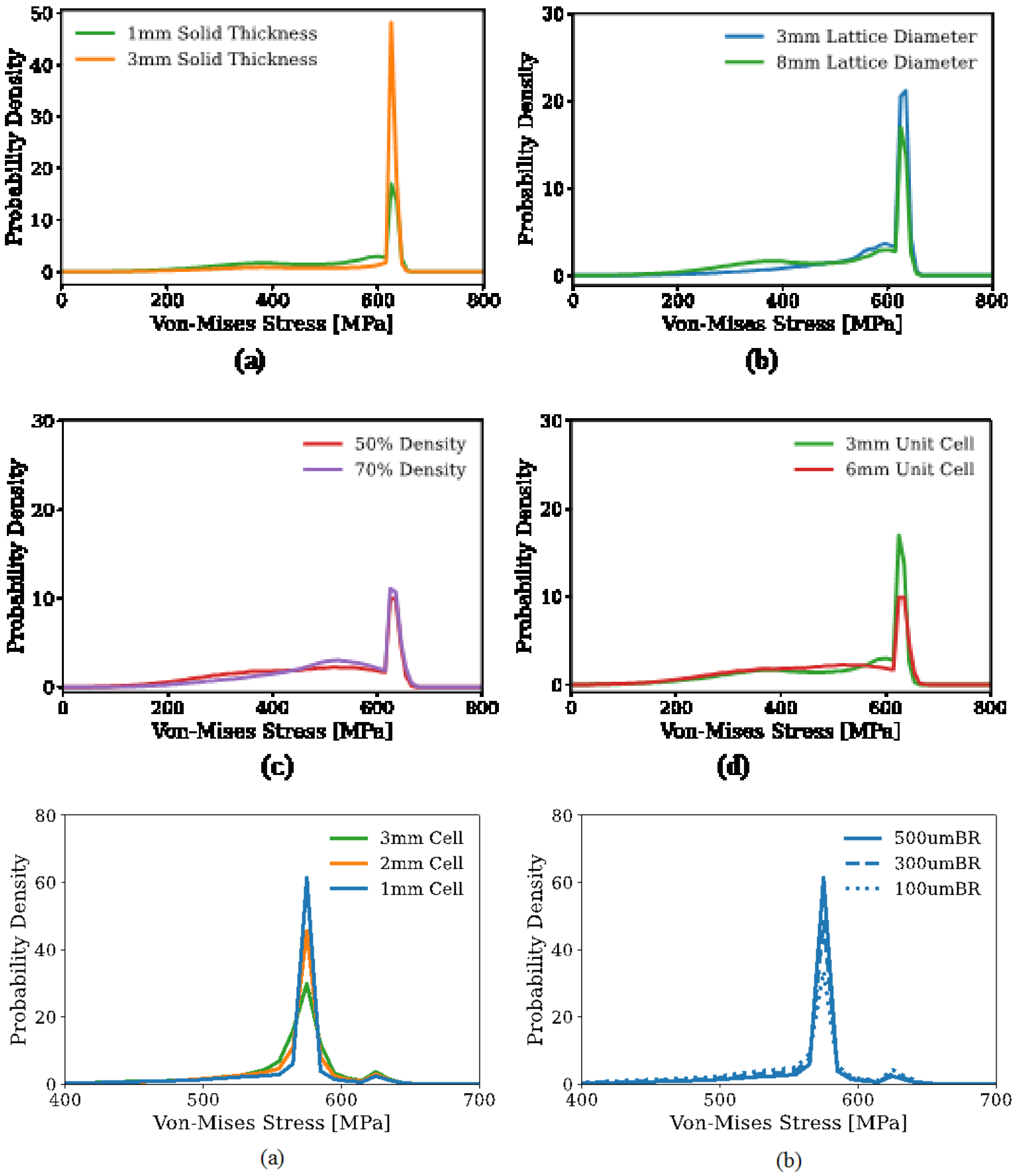
- The elastic modulus was calculated from the FEM results from tensile bars with different lattice design parameters:
  - Lattice unit cell size has negligible effect
  - Modulus decreases dramatically with decreasing lattice densities
  - Blending radius plays minor role, where a larger blend radius marginally increases elastic modulus





FEM Results

- The stress distribution was also examined for several lattice design parameters:
  - A thicker shell in the gauge section promotes a tighter stress distribution
  - Size of the lattice region within the tensile bar and lattice density do not greatly impact stress distribution
  - While unit cell size does not impact elastic modulus, a smaller unit cell size promotes a more uniform stress distribution



Printing of Tensile Bars

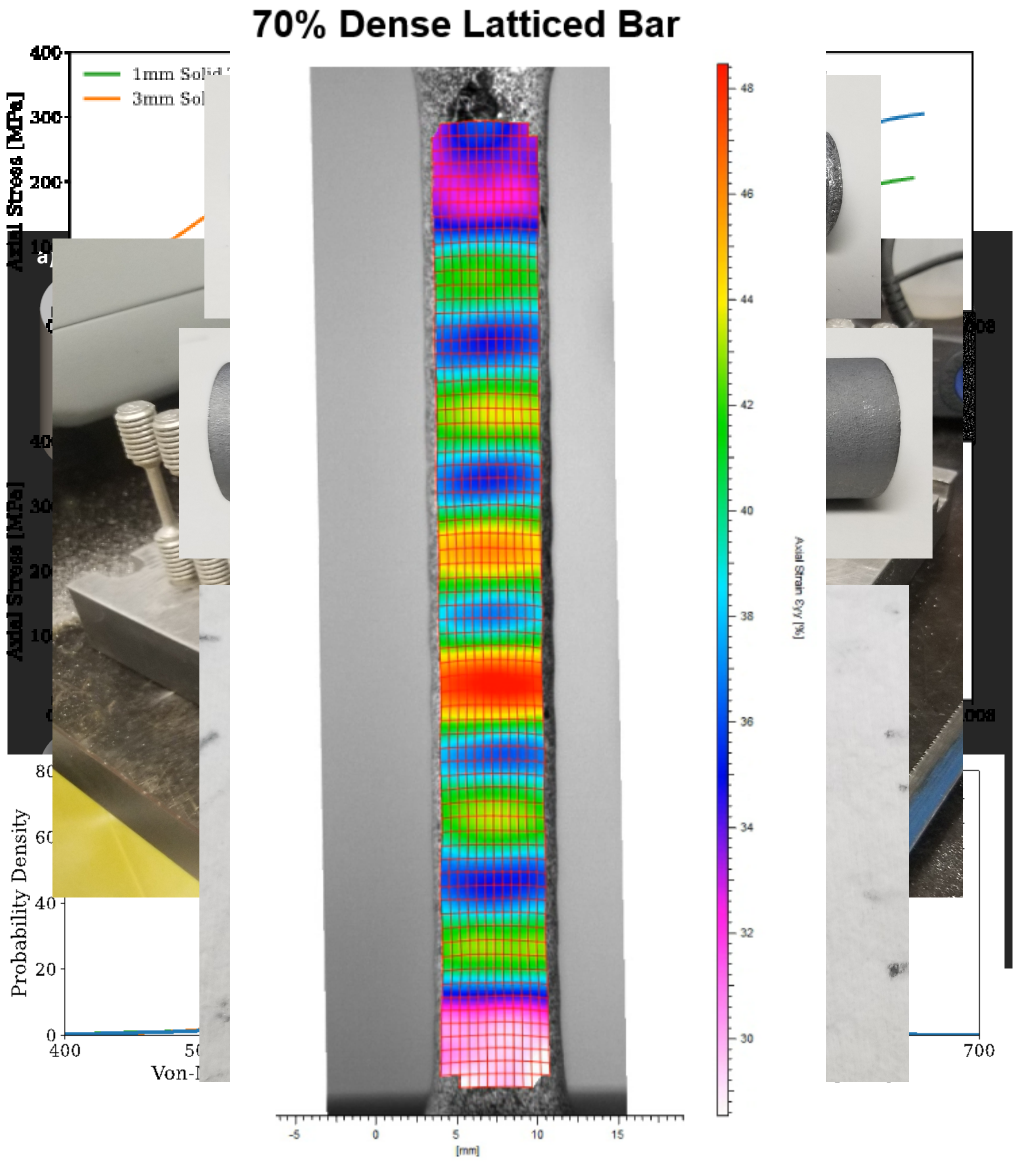
- First round of printing using an EOS M290
  - 4-mm gauge width
  - Printed ½”-13 UNC threads
  - Hand engraved numbers
- Second round of printing
  - 9-mm gauge width
  - 2-mm thick print over printed shell over entire bar
  - Sample index number printed on each grip
- All tensile bars heat treated @ 1050 °C for 1 hour

Mechanical Testing

- Digital imaging correlation (DIC) was used to map strain across gauge section
  - Both latticed and solid tensile bars retain yield strength with exceptional ductility (>50%)
  - Latticed samples exhibit period strain patterns with periodicities matching the lattice unit cell size
- Some of the latticed tensile bars had retained powder which reduced the total elongation

Summary and Outlook

- A modeling and simulation pipeline was developed to produce latticed tensile bars for FEM (MOOSE) and printing
- Salient lattice design parameters were examined via FEM
- SS316 latticed tensile bars were produced via laser powder-bed fusion and an adequate heat treatment was determined
- Lessons learned
  - Don't try printing threads, remove <u>all</u> powder before heat treating
- Validation tensile tests ongoing



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