

Tailorable Energy-Absorbing Beam Lattices for Advanced Air Mobility Structures

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Executive Summary

This project investigates the design and performance of reinforced I-beam lattice structures to improve energy absorption capabilities. Beam lattices are lightweight structures commonly used in aerospace and mechanical applications due to their high strength-to-weight ratio. In this project, we proposed a modified beam lattice that can further improve the energy absorption compared with the conventional designs. The study evaluates how structural variations influence mechanical behavior, particularly in terms of stiffness, strength, and energy absorption. Results from simulations and experimental testing demonstrate that reinforced lattice configurations significantly enhance energy absorption while maintaining structural integrity. These findings contribute to the development of more efficient lightweight structures for impact-resistant applications in aerospace and related industries.

Background

- Reinforced I-beam lattices offer over 200% more energy absorption than a traditional circular cross section lattice.
- Previously, the reinforcements of I-beam lattices have only been utilized at the joints where the I-beams meet. However, this project displays how additional reinforcements along the length of the I-beam may be added and modified to create unique geometries resulting in different mechanical performance.
- Designers can adjust the shape, frequency, and material used for the sectional reinforcements to produce the type of mechanical responses needed per the application.
- Simple reinforcements were added along the beam with materials differing in stiffness used in separate models of the lattice to explore how material changes affect the mechanical performance of the lattice

Experimental Setup

- Muti-material lattices were designed:
 - Design 1: FLX9895 (I-beam) + RGDA8530 (Reinforcements)
 - Design 2: FLX9895 (I-beam) + RGDA8520 (Reinforcements)
 - Design 3: FLX9895 (I-beam) + FLX9895 (Reinforcements)
- Dogbone samples were printed using Stratasys J35 Pro printer. The tensile tests were performed to characterize the printing material properties.
- The reinforced I-beam lattices were printed using Stratasys J35 Pro printer. The compression tests were performed to study the crushing behaviors



Figure 1. Stratasys J35 Pro printer

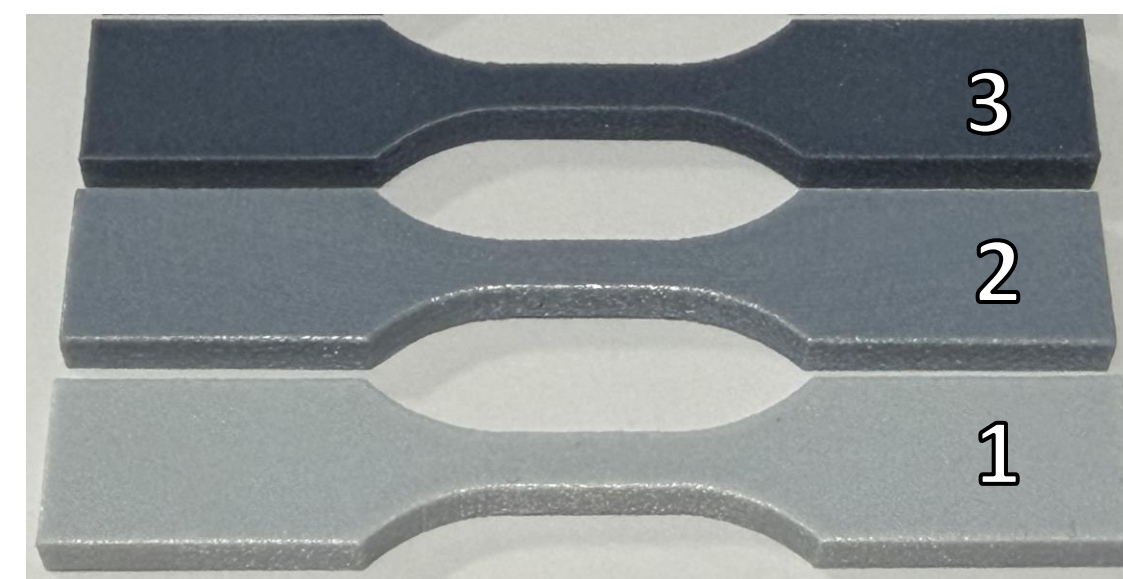


Figure 2. Dogbone Samples

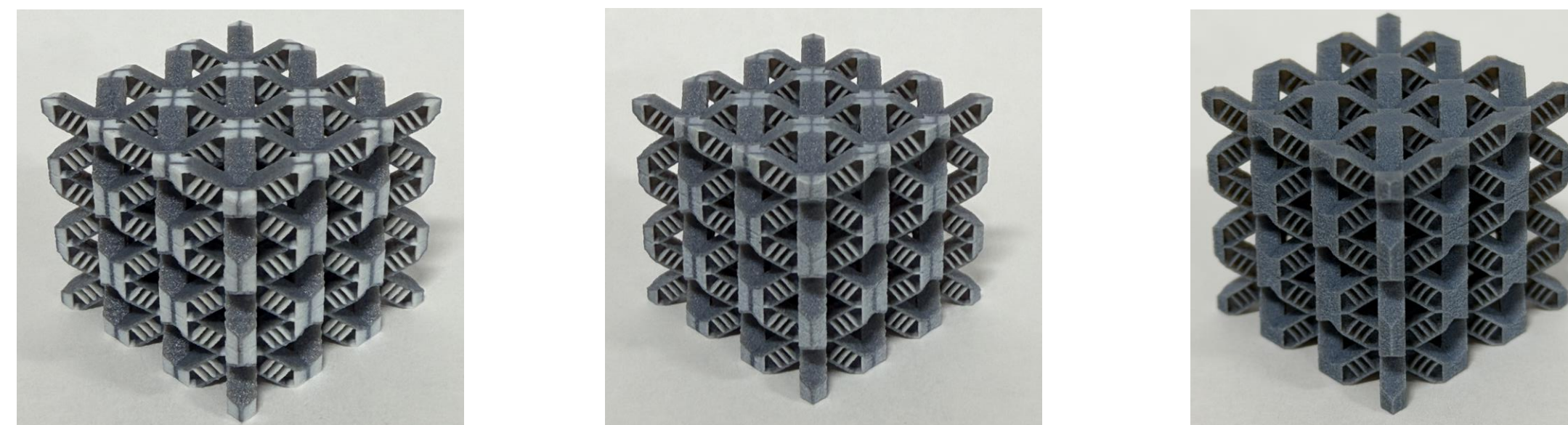


Figure 3. Multi-Material Lattice Specimens (shown from left to right: 3-1, 3-2, and 3-3)

Finite Element Simulations

- Quasi-static compression of different lattice designs were simulated in finite element software Abaqus.
- Shell elements and a quarter model were used to improve the computational efficiency.

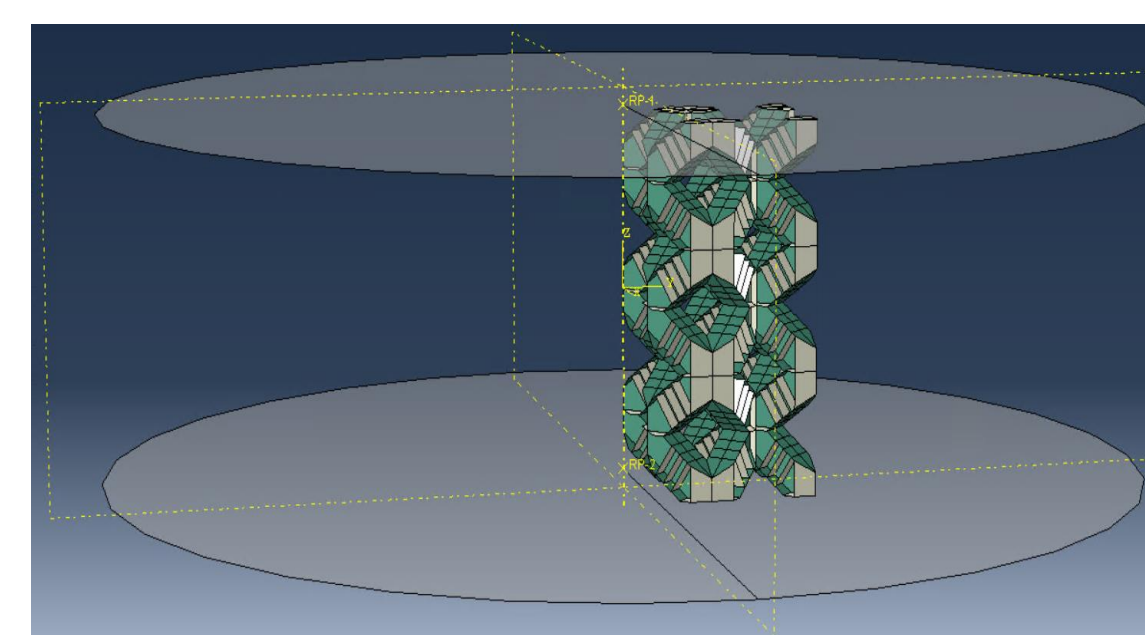


Figure 4. Quarter FE Model Assembly

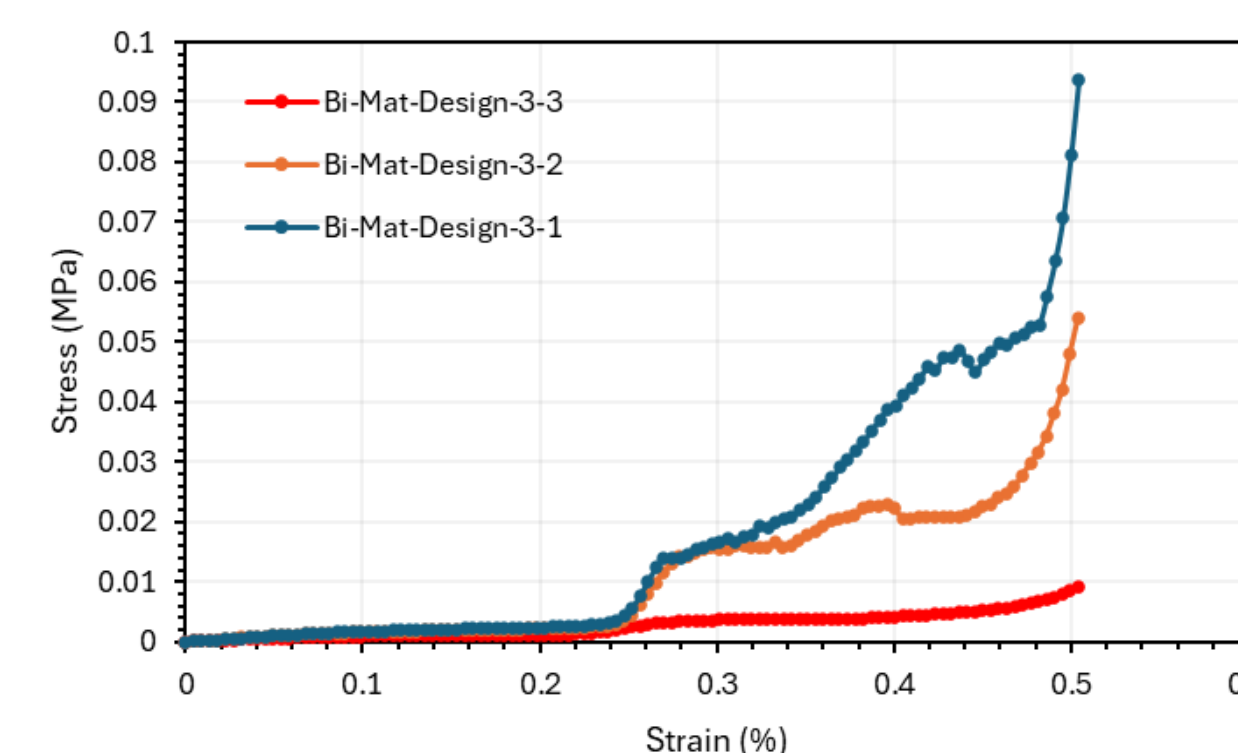


Figure 5. Stress-Strain Curves of FE Models

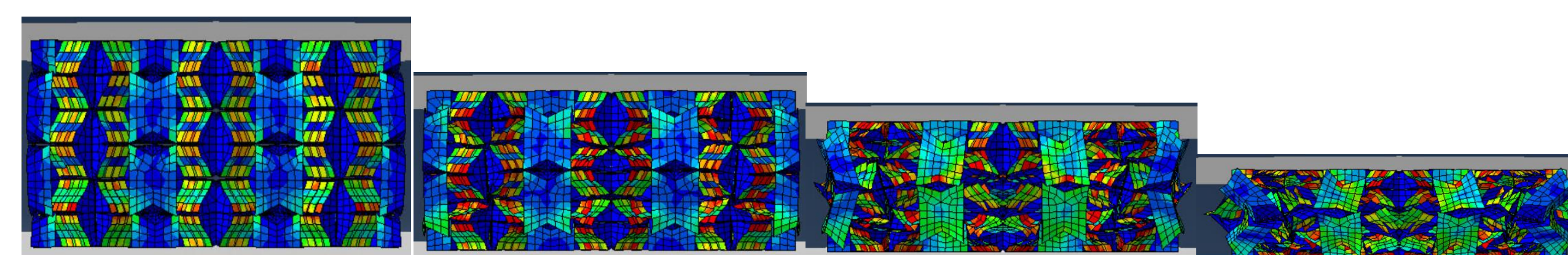


Figure 6. Compression Simulation of the FE Model

Results and Discussion

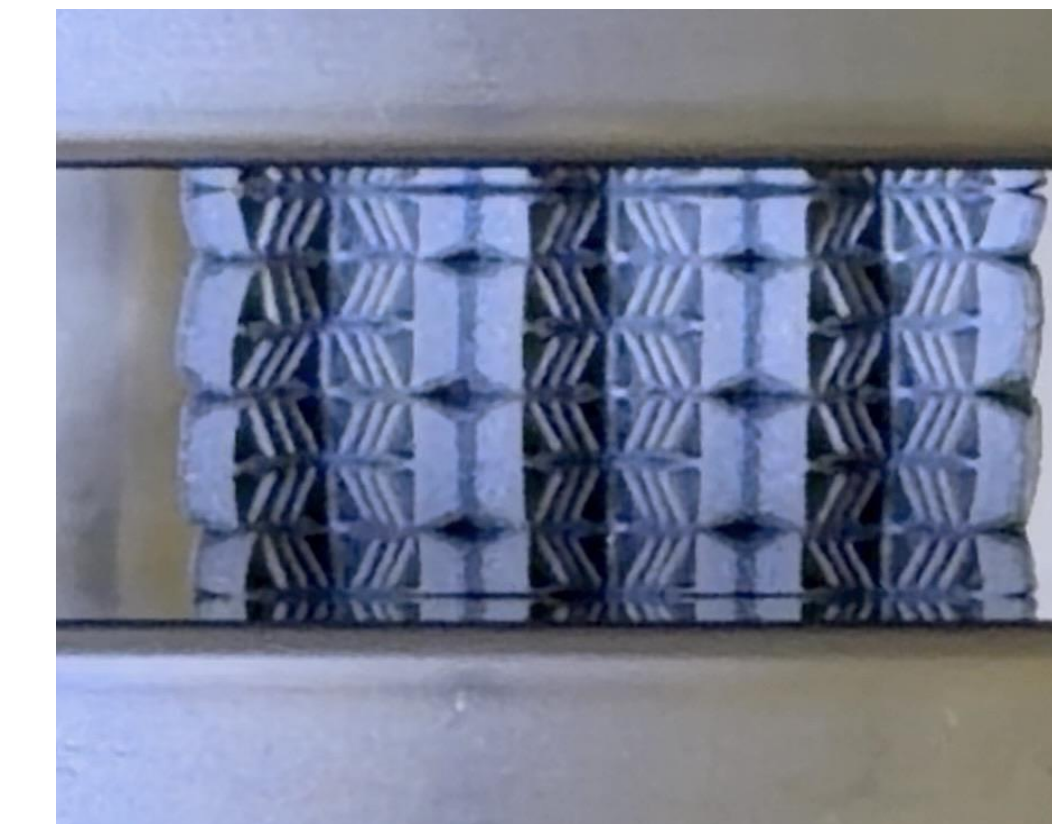


Figure 7. Compression test setup

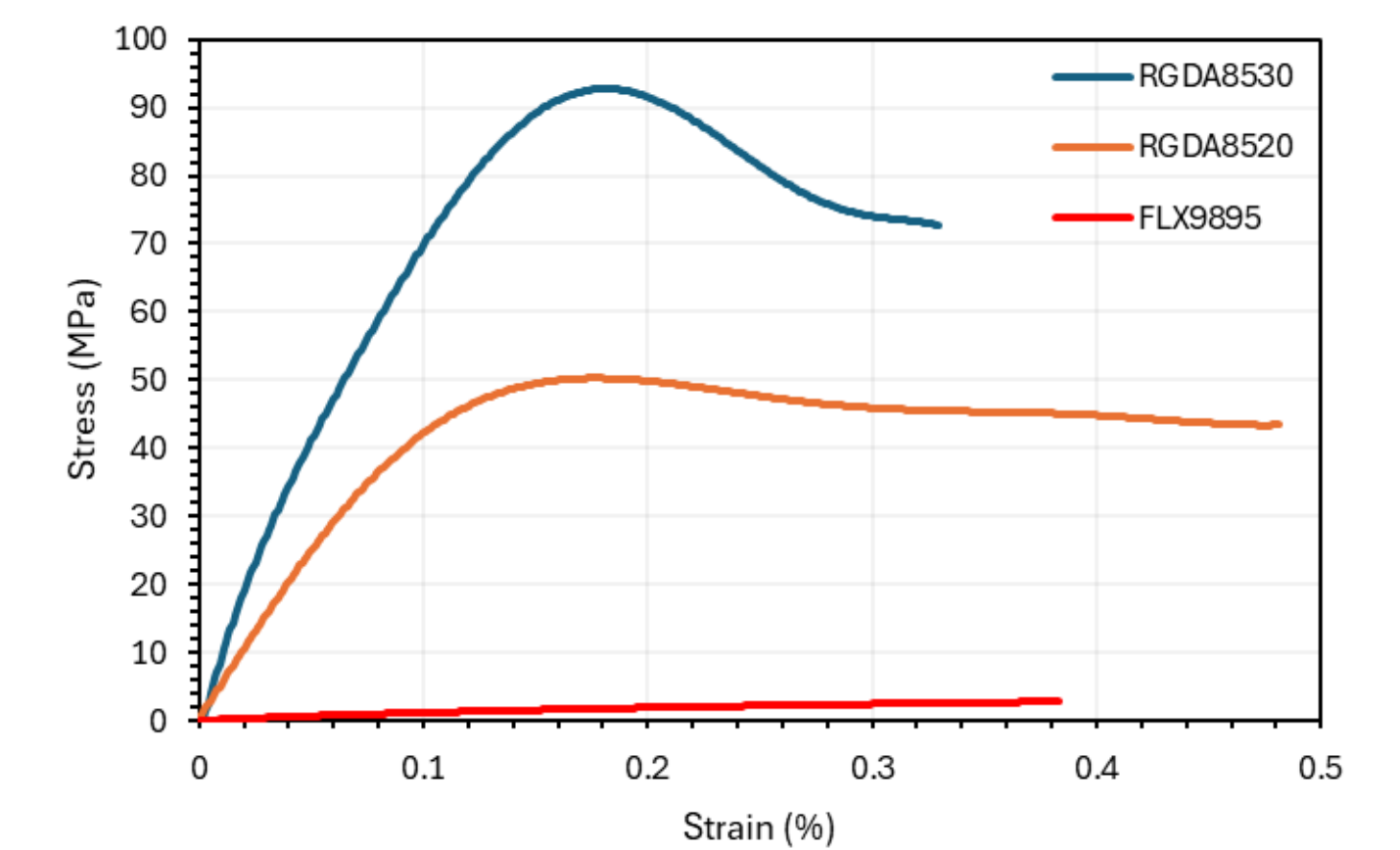


Figure 8. Dogbone Specimen Tensile Analysis

- The lattices with stiffer material reinforcements demonstrated significantly improved energy absorption capacity.
- The high stiffness lattices bulged out at the sides more during the compression tests.
- This could explain the large peaks in the Stress-Strain curves for the lattices composed of stiffer reinforcements.

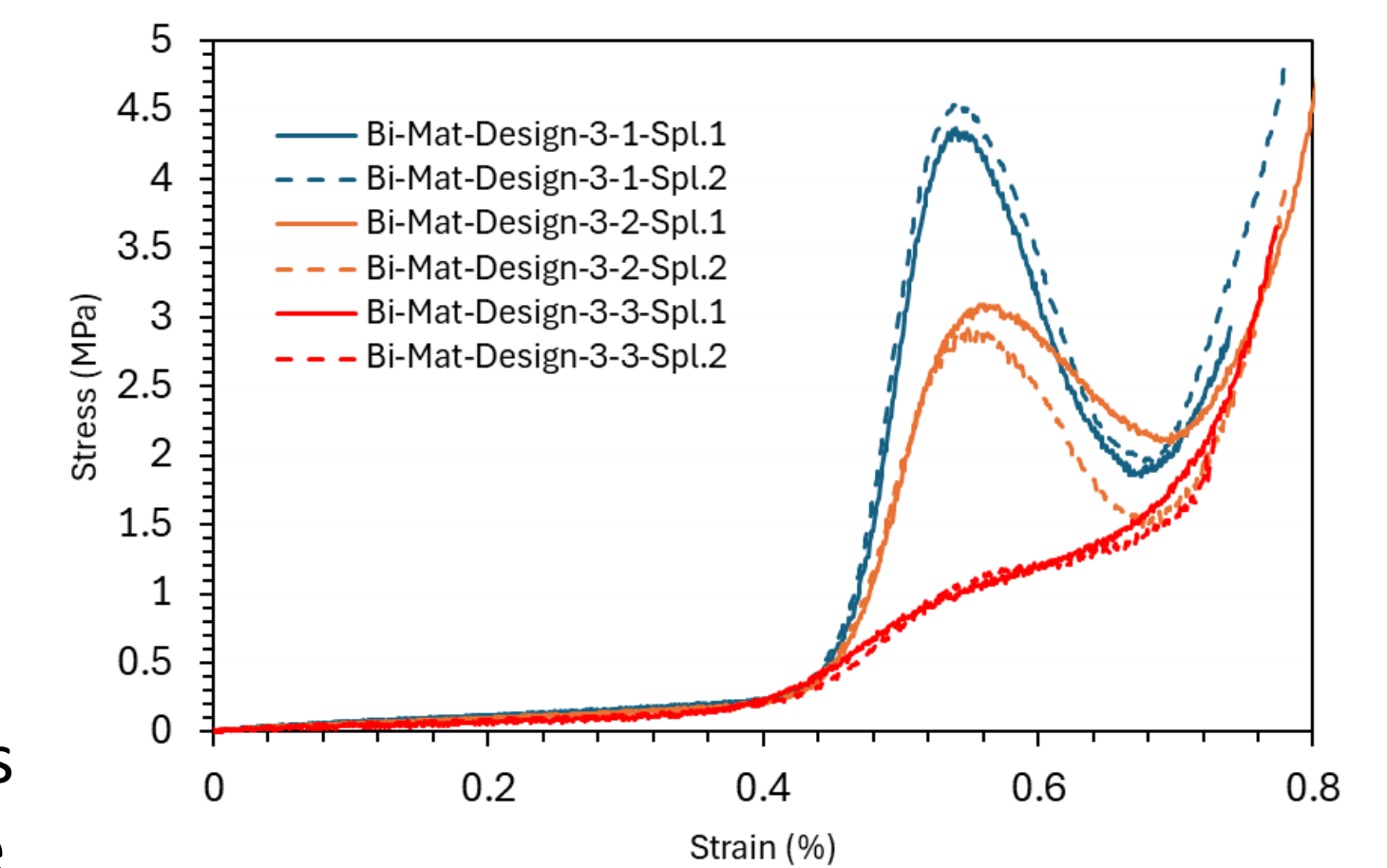


Figure 9. Experimental Stress-Strain Response of Bi-Material I-Beam Lattice Structures

Conclusions

- Sectional reinforcement and material combinations strongly influence stiffness, peak stress, and crushing response of multi-material I-beam lattices.
- Experimental results show that reinforced I-beam lattices exhibit distinct mechanical behaviors and energy absorption capabilities depending on material combinations.
- Shell-based finite element models effectively capture overall trends and deformation modes.
- Discrepancies between simulations and experiments are expected due to the simplified shell representation of the printed structures.
- Reinforced lattice designs demonstrate strong potential as lightweight solutions for enhanced structural energy absorption.

References

- Kothari, T., Liu, X., Kobir, M.H., Yang, Y. and Tao, F., 2025. Design and analysis of reinforced I-beam body-centered cubic lattices for enhanced energy absorption. *Composite Structures*, 355, p.118841.
- Kobir, M.H., Liu, X. and Yang, Y., 2023. Additive manufacturing of Body-Centered cubic metamaterials with novel I-Shaped beam lattice towards enhanced mechanical properties. *Manufacturing Letters*, 35, pp.509-515.
- Liu, X., Kobir, M.H., Yang, Y., Jiang, F. and Kothari, T., 2023. Improving stiffness and strength of body-centered cubic lattices with an I-shape beam cross-section. *Mechanics of Materials*, 182, p.104665.