Design and Analysis of Reinforced I-Beam Lattice with Enhanced Energy Absorption

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Executive Summary

This research aims to enhance the stiffness, yield strength, and energy absorption capabilities of beam lattices. The potential improvements achieved by incorporating **I-beam** and **Reinforced I-beam** designs are provided. Computational simulations and experiments were used to evaluate the effectiveness of design enhancements in improving the mechanical properties and energy absorption of the beam lattices. The research findings offer valuable insights for the development of innovative lightweight lattice structures with enhanced durability and performance. They find applications ranging from automotive chassis, and wing ribs to sandwich structure cores.

Background

- Beam lattice is the repetition of 3D patterns made of beam unit cells.
- Bending-dominated beam lattices have excellent energy absorption and impact resistance.

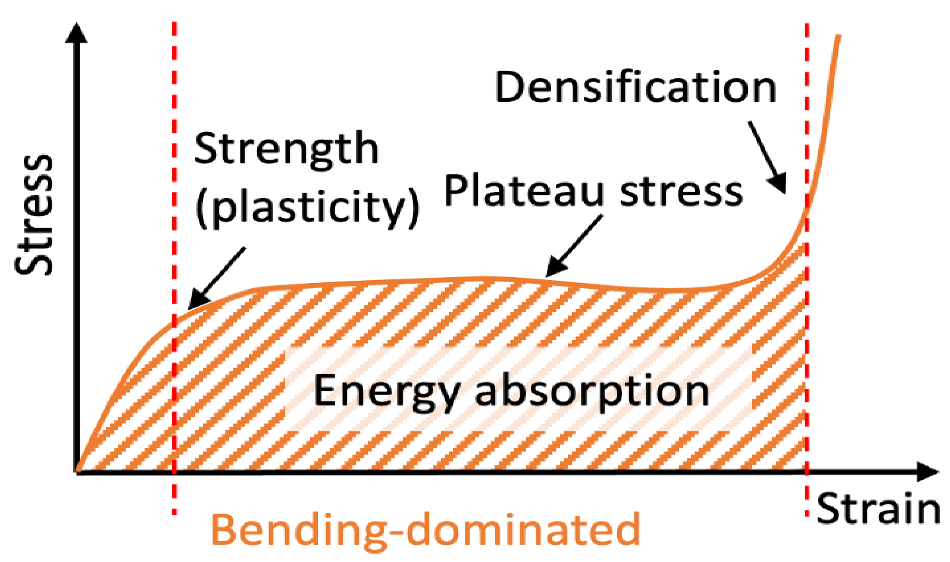

Figure 1: Typical stress-strain curve of beam lattice

- I-beams offer improved bending behavior than conventional circular beams.

Motivation:

I-cross-section beams with reinforcements are used to improve stiffness, yield strength, and energy absorption of beam lattice simultaneously.

Experiment

- Three prototypes- (a) circular conventional beam lattice, (b) I-beam lattice, and (c) Reinforced I-beam lattice are printed using *Stereolithography* (SLA) 3D printer.
- Quasi-static tests are conducted on three beam lattices using MTS machine.

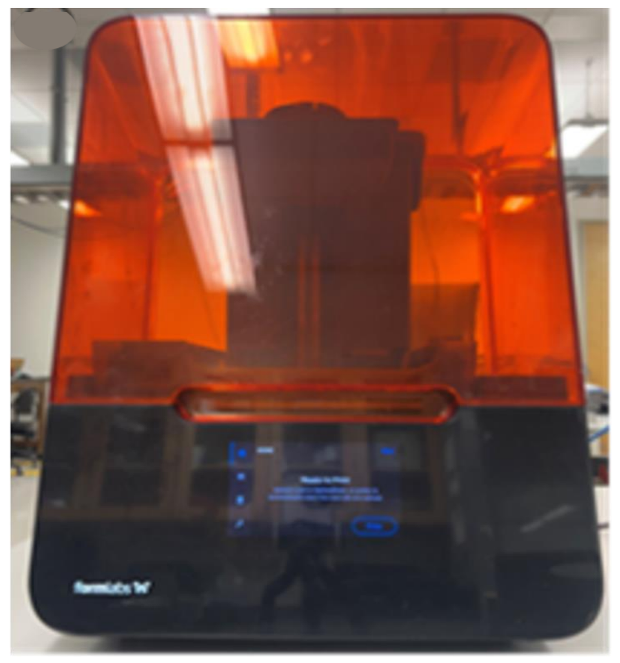

Figure 2: SLA 3D Printer

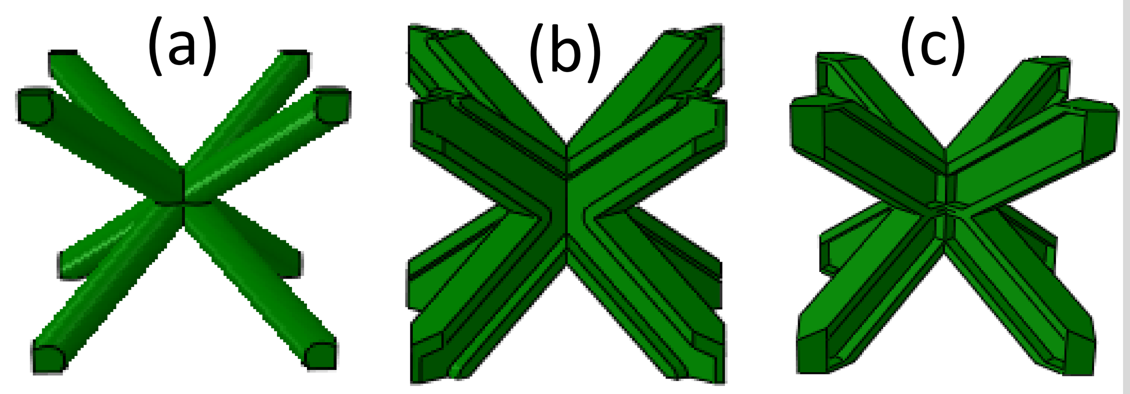

Figure 3: Three considered unit cells

Figure 4: MTS Compression Testing Machine

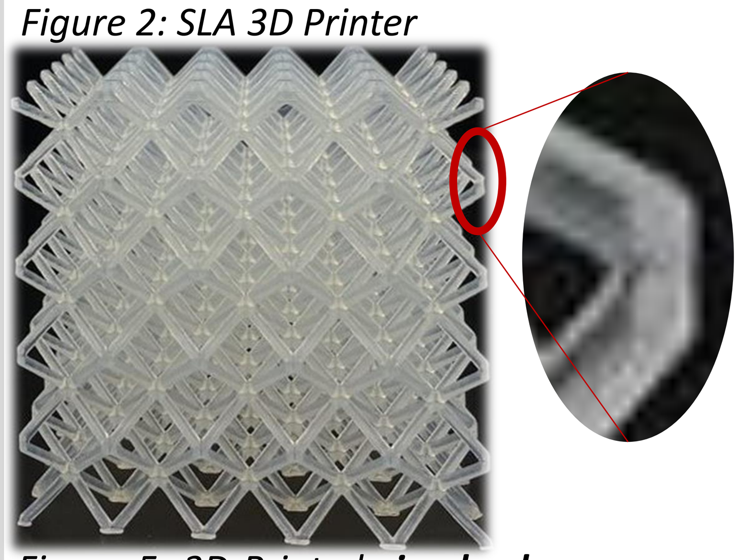

*Figure 5: 3D Printed **circular beam** 50mm x 50mm x 50mm lattice*

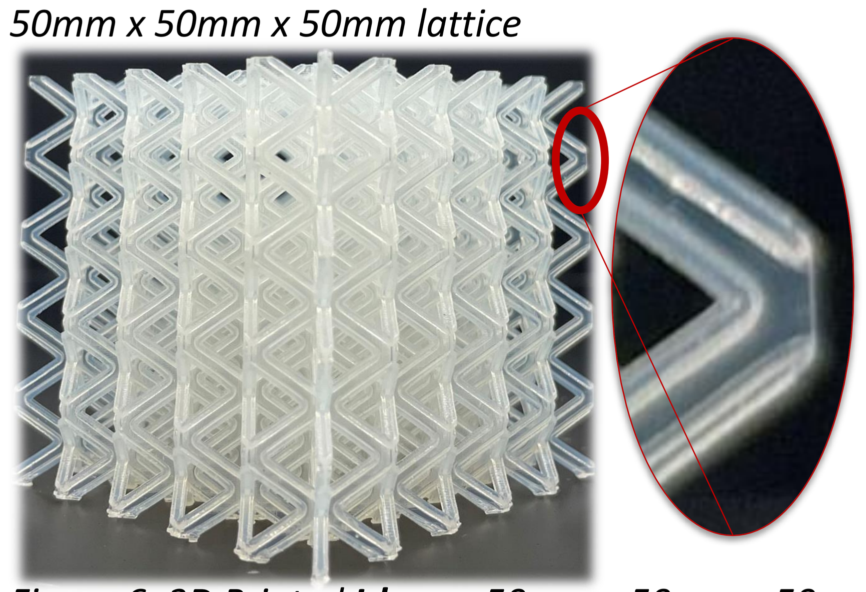

*Figure 6: 3D Printed **I-beam** 50mm x 50mm x 50mm lattice*

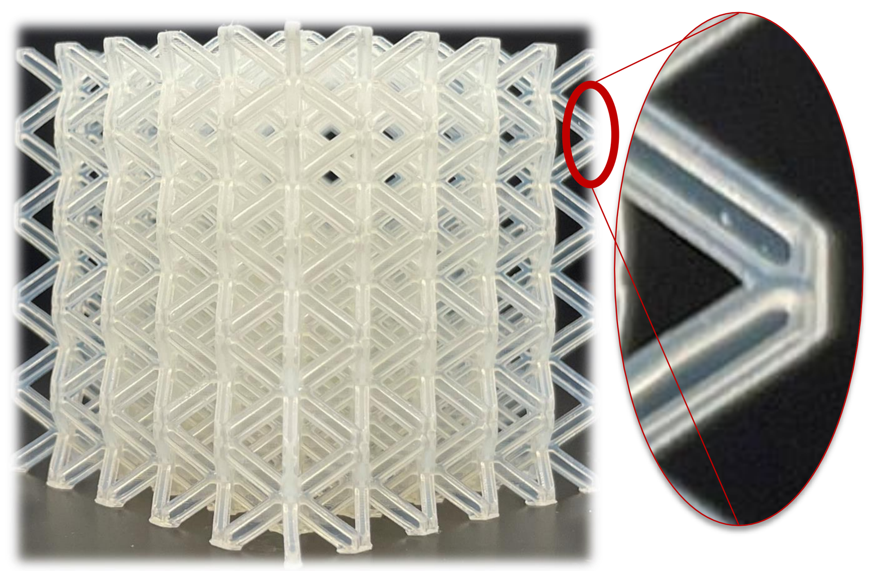

*Figure 7: 3D Printed **Reinforced I-beam** 50mm x 50mm x 50mm lattice*

Finite Element Simulation

- The beam lattice model is placed between two rigid plates.
- A quasi-static load is applied on top of the upper rigid plate, creating a crushing effect on the lattice.
- Shell elements are used in these simulations.

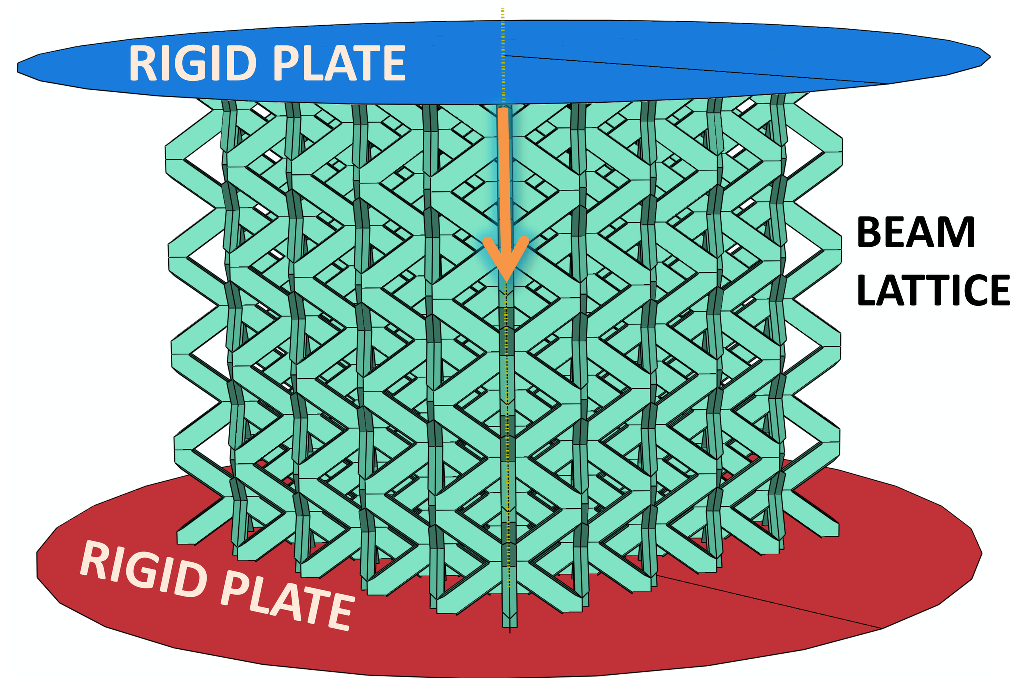

Figure 8: I-beam 5-by-5-by-5 lattice

Experimental Results

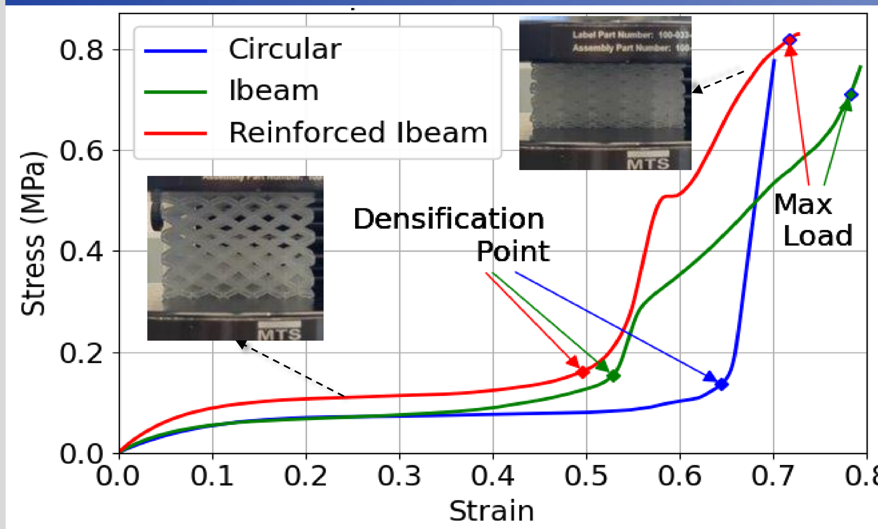

Figure 9: Stress-strain curves of the quasi-static tests

Table 1: Remarkable performance enhancements for lattices over circular conventional lattice

	I-beam	Reinforced I-beam
Stiffness	23.3%	80.0%
Strength	12.1%	81.8%
Energy Absorption	230.6%	247.2%

Simulation Results

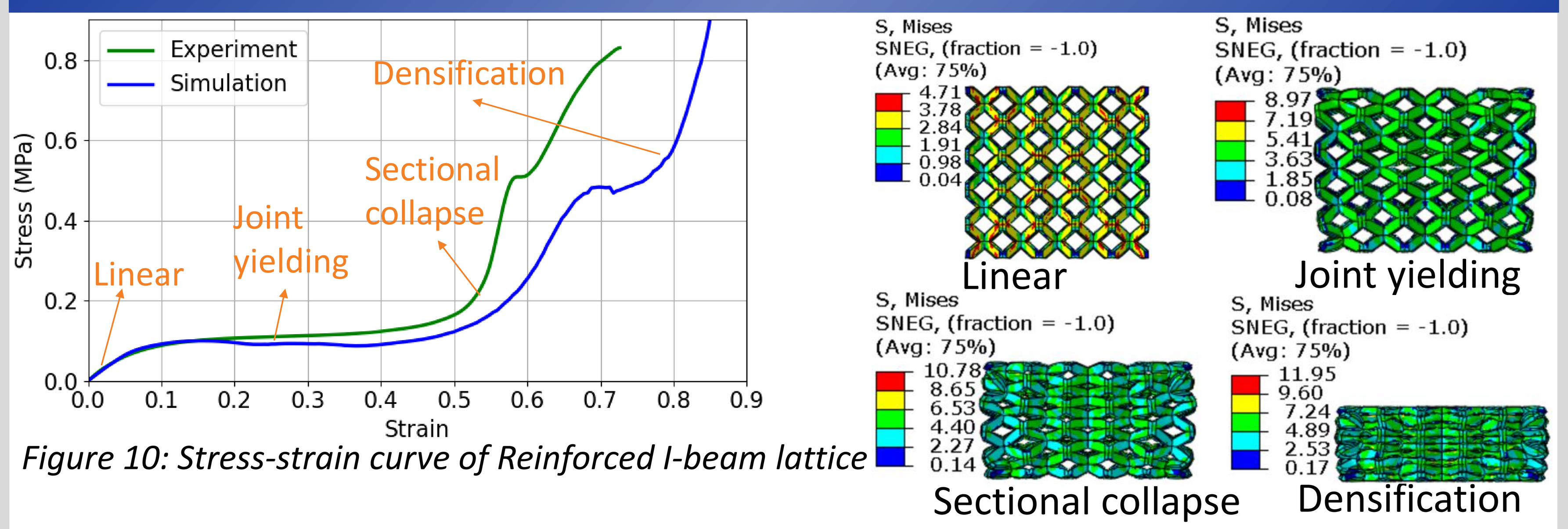

Figure 10: Stress-strain curve of Reinforced I-beam lattice

- Simulation results agree well with the experimental stress-strain curves.
- Progress of compressive deformation can be divided into four stages-
  1. Linear- Beam lattice undergoes linear elastic deformation,
  2. Joint Yielding- As the joints yield, the plastic plateau region is formed,
  3. Sectional collapse- the web of the I-section collapses, one after another
  4. Densification- After all webs collapse, material deformation continues.

Conclusions

- Stress distribution in the flanges and web of I-section beams reduces stress concentration at the joints of the beam lattice and, therefore, exhibits higher yield strength over a circular conventional beam lattice.
- A novel multi-stage energy absorption mechanism, i.e., the sectional collapse of the web of the I-section, is introduced.
- Reinforced I-beam lattices have approx. 250% improved energy absorption than conventional circular beam lattices.

References

1. Liu, X., Kothari, T., Tao, F., Kobir, M. H., and Yang, Y., "Multiscale modeling of quasi-static crushing behavior of body-centered cubic lattices with I-shape beams and reinforced joints," AIAA SCITECH 2024. doi:10.2514/6.2024-2290.
2. Liu, X., Kobir, M. H., Yang, Y., Jiang, F., and Kothari, T., "Improving stiffness and strength of body-centered cubic lattices with an I-shape beam cross-section," Mechanics of Materials, 2023, p. 104665.