Lattice Structures for Extreme Events: A Unique Opportunity in Metal Additive Manufacturing

Simar Bassi, Son Luong, Sameer Meshram, Samuel Sexton, Jagbir Singh, Marwin Tarusna, J. Wang, D. Arola and M. Ramulu

Overview

Background and Motivation

- Crush cartridge is a device located in the airplane tail skid which is responsible for absorbing impact energy in event of a tail strike.
- It acts as a sacrificial structure which can be replaced and is intended to eliminate costly body damage repairs.

Event of a tail strike

Tail skid

Current Concerns

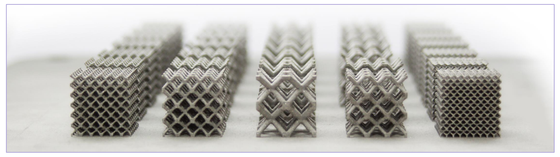
- Presently used traditional aluminum foil crush cartridge is both time consuming and expensive to manufacture.

Goals

- To develop a lattice structure crush cartridge to meet current performance requirements.
- Employ additive manufacturing to eliminate manufacturing difficulties associated with traditional structures.

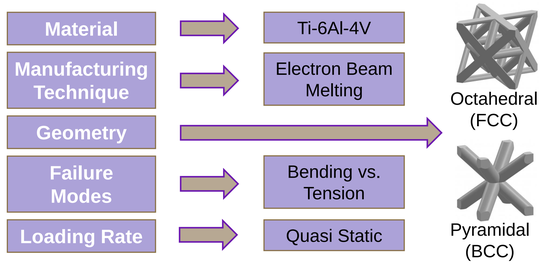
Lattice Structures

- A lattice structure can be defined as a connected network of struts with high strength to weight ratio.

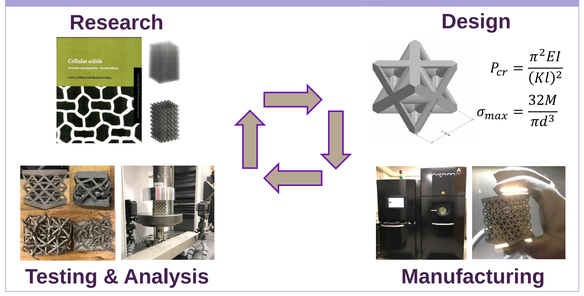


Examples of lattice structures

Property Dependence

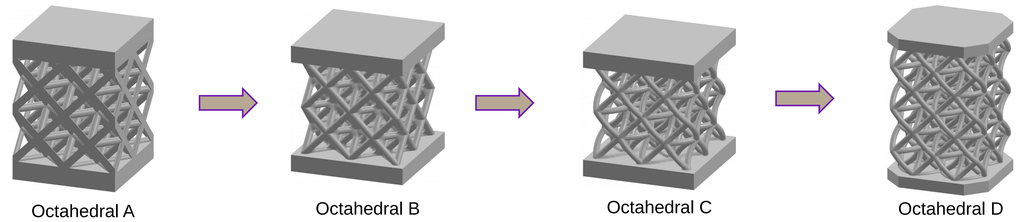


Methodology



Design Iterations

Octahedral Lattice Structures



Octahedral A

- Initial design, boundary defined by preserving unit cell

Octahedral B

- Wider base plates, filleted nodes, complete struts

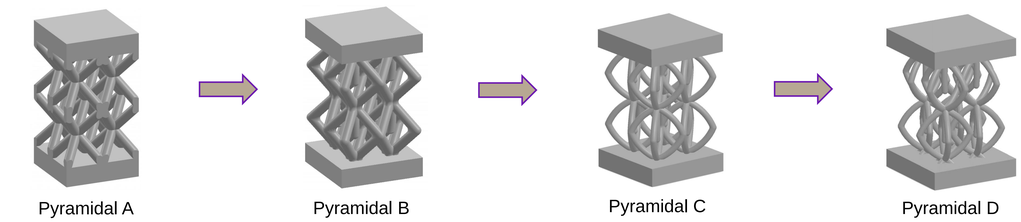
Octahedral C

- Curved struts, smaller strut diameter and fillet

Octahedral D

- Adjusted unit cell definition, additional vertical layer

Pyramidal Lattice Structures



Pyramidal A

- Initial design, boundary defined by preserving unit cell

Pyramidal B

- Adjusted unit cell, reduced fillet radius & vertical struts

Pyramidal C

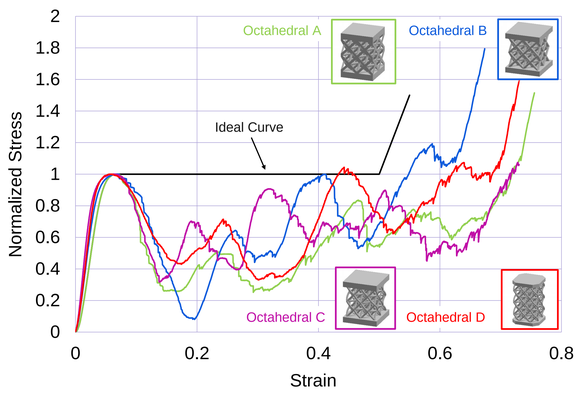
- Curved struts, smaller strut diameter and fillet

Pyramidal D

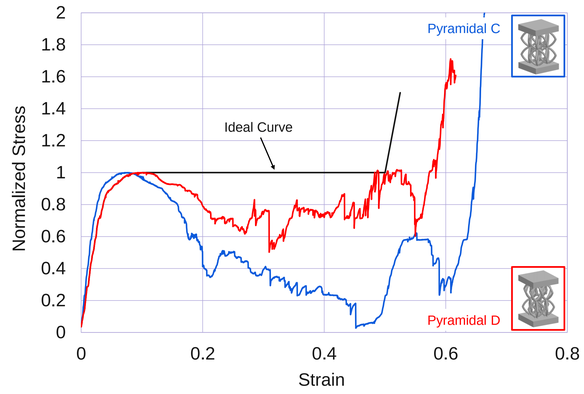
- Unit cells offset by rotation about vertical axis

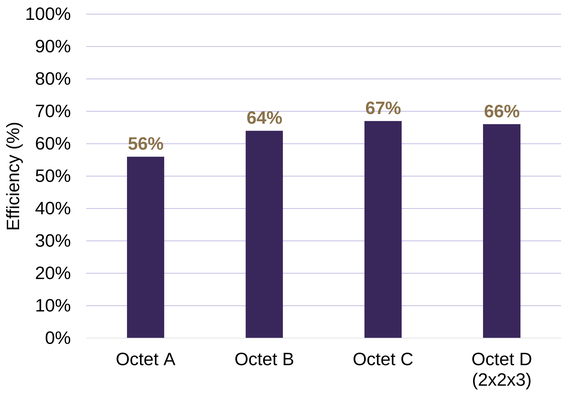
Experimental Results

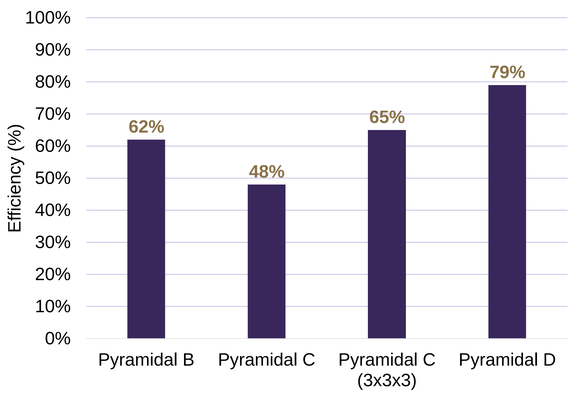
Compression Test on Octahedral Lattice



Compression Test on Pyramidal Lattice





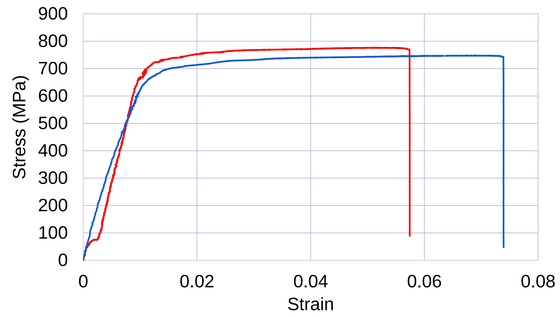


Material Properties

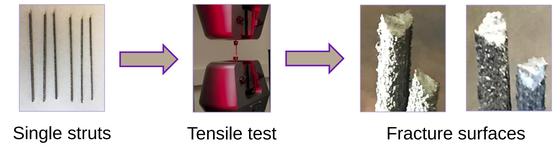
Property Characterization

- To benchmark printed alloy properties with handbook values, tension tests were conducted on single struts of ø 2 mm.

Ti-6Al-4V Tension Test



Alloy Type	Young's Modulus	Yield Strength	Elongation at failure
Arcam Ti-6Al-4V Typical	120 MPa	950 MPa	15.0%
Arcam Ti-6Al-4V Printed	64 MPa	674 MPa	6.5%



Single struts | Tensile test | Fracture surfaces

Conclusions

Proof of Concept

- Approach to design, build and test lattice structures for high energy absorption was demonstrated successfully.

Comparison of Structures

- The pyramidal lattice structure with offset unit cells, curved primary struts and suspended vertical struts demonstrated most favorable energy absorption characteristics.
- However, stiffness and ultimate compressive strength values for pyramidal structures were lower than octahedral lattices.
- The structures can be scaled to satisfy different loading conditions.

Printed Materials

- Young's Modulus, Yield Strength and elongation at failure for printed material was significantly lower than handbook values.
- Fracture surfaces post tensile failure indicated brittle nature of the printed alloy which entails scope for annealing.

Acknowledgments

- The authors would like to thank mentors and sponsors Mr. M. Mellor, S. Chisholm and P. Kim at The Boeing Company.
- University of Washington staff and students Mr. W. Kuykendall, S. Ghods, R. Pahuja, R. Pathak and R. Patel.
- Mechanical Engineering Department at University of Washington, Seattle for providing test equipment needed in fulfillment of this work.