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Energy-Absorbing Lattice Structures: Design, Simulation and Manufacturing Evaluation

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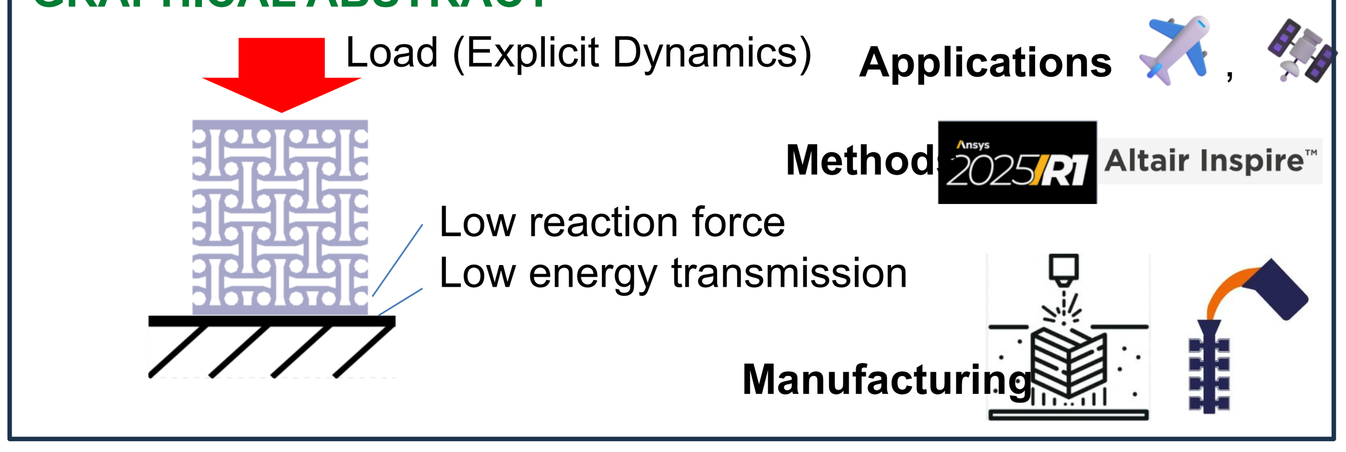
INTRODUCTION & AIM

- Design and analyze 2D lattice structures tailored for aerospace applications.
- Focus on achieving high energy absorption for impact mitigation and low force reaction for efficient damping.
- Prioritize feasibility in manufacturing processes and scalability for industrial applications.

GRAPHICAL ABSTRACT

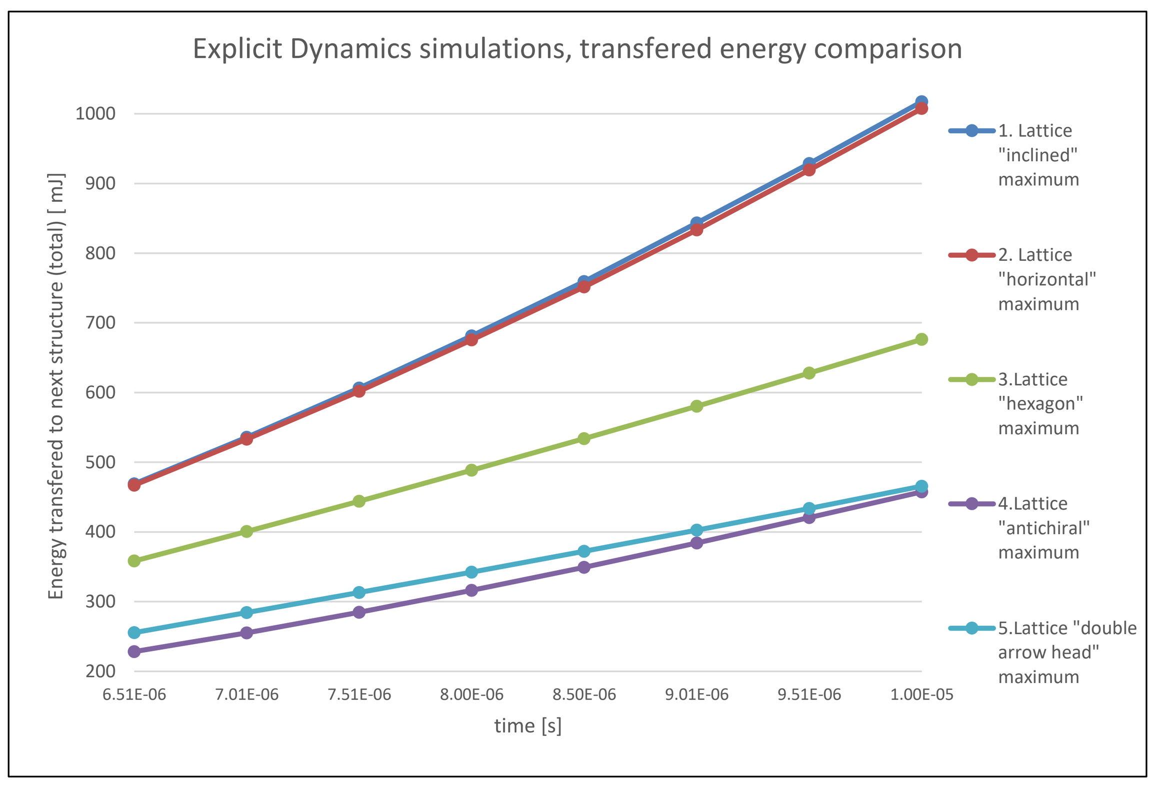


METHOD

1. **Design and Modeling**:
- Developed innovative geometries such as double arrow-headed and anti-tetrachiral patterns using CATIA V5.
- Hexagonal honeycomb served as the benchmark design for performance comparison.

2. **Simulation and Testing:**
- Conducted Explicit Dynamics simulations in Ansys Mechanical to evaluate elastic-plastic deformation and energy absorption during compression.
- Force and Energy Measurement Setup: Integrated probes between the lattice's bottom plate and the support to measure energy dissipation and force reaction after deformation.

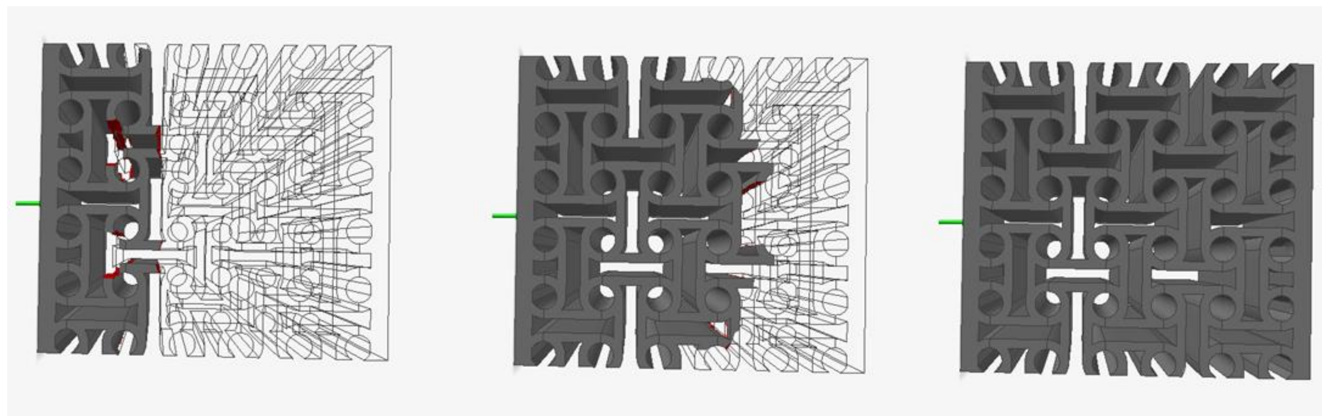
3. **Prototyping and Validation:**
- Produced polymer prototypes for visualization and testing. Metallic coupons to validate mechanical properties during advanced testing.
- Custom Design Investigation: Utilize experimental data to innovate and test custom lattice geometries.
- Established a benchmarking framework to evaluate designs against honeycomb and literature-based geometries.



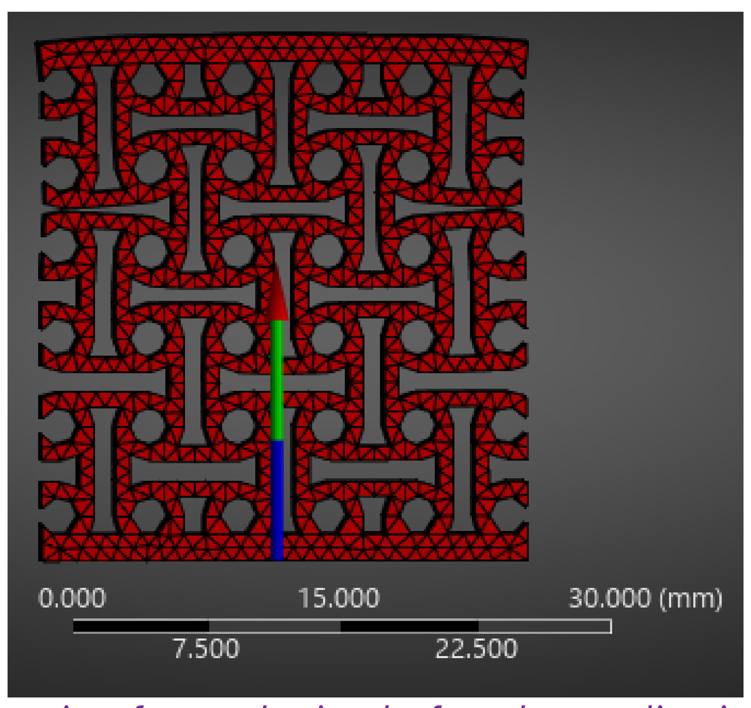
Total energy measured downstream of the grid following the application of a 10 kN compressive load with t_{end}= 10^{-5} s in the Ansys 2025 R1 Mechanical Explicit Dynamics simulation environment.

RESULTS & DISCUSSION

- The “antitetrachiral” lattice demonstrated low values of both energy and force reaction, suggesting limited energy absorption but high suitability for applications requiring minimal force transmission to support structures.
- Manufacturing simulations highlighted critical influences of temperature gradients and material flow patterns on component quality during SLM and Investment Casting.



Simulation of the investment casting process for the anti-tetrachiral lattice. Behavior of the filling front at t=33% (a), t=66% (b), t=100% (c). Altair Inspire Cast simulation environment.



The resulting reaction force obtained after the application of the 10 kN compressive load with a duration of 10^{-5} s in the Ansys 2025 R1 Mechanical Explicit Dynamics simulation environment for the anti-tetrachiral lattice. $F_{reaction}$=72 N at t= 10^{-5} s.

CONCLUSION

This research contributes to advancements in engineering by delivering optimized designs and manufacturing processes for energy-absorbing lattice structures. Beyond aerospace, the findings hold potential for applications in industries requiring lightweight, high-performance structural solutions.

FUTURE WORK

- Manufacture metal prototypes using optimized parameters for SLM and Investment Casting processes.
- Validate results through advanced mechanical testing, benchmarking new lattice designs against honeycomb structures and references from the literature.
- Enhance scalability and dimensional consistency to meet industrial standards.