



Finite Element Analysis of Re-entrant Auxetic Honeycomb Structures for Impact Resistance and Energy Absorption Using ANSYS Explicit Dynamics

Mohd. Azam¹, Birendra Singh Karki^{1*}, Mohit Kumar¹, Rakesh¹, Deepa Singh¹

¹Department of Mechanical Engineering, College of Technology, GBPUAT, Pantnagar, India

*Corresponding author, Email address: bskarki57@jmes.com

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Abstract: This study investigates the mechanical behavior of re-entrant auxetic honeycomb structures using finite element analysis (FEA) in ANSYS Explicit Dynamics. A detailed methodology involving CAD modeling, meshing, material property assignment, and dynamic impact simulations was employed to analyze the deformation, stress distribution, and energy absorption characteristics of auxetic structures made from Polylactic Acid (PLA). Core thicknesses of 0.8 mm, 1.0 mm, and 1.2 mm were evaluated under varying impact velocities (6 m/s, 50 m/s, 100 m/s) to assess their influence on mechanical performance. The simulation results confirmed the negative Poisson's ratio effect, with structures exhibiting lateral expansion under tensile loading, thereby enhancing energy distribution and minimizing stress concentrations. Thicker auxetic cores demonstrated superior impact resistance and energy absorption capacity, while optimized geometrical configurations facilitated lightweight design without compromising structural integrity. The findings validate the efficacy of auxetic honeycomb structures for applications demanding high impact mitigation and energy absorption, offering significant potential for aerospace, defense, and protective systems.

1. Introduction

Materials that defy conventional mechanical logic often captivate the imagination of engineers and scientists alike. Among these, auxetic honeycomb structures—materials that expand laterally when stretched—stand out as a fascinating anomaly (Montgomery-Liljeroth *et al.*, 2023; Tripathi *et al.*, 2013). Unlike traditional materials that thin out when pulled, auxetic structures behave counterintuitively by becoming wider, exhibiting what is known as a negative Poisson's ratio (Grima *et al.*, 2006; Tripathi *et al.*, 2013; Wollner *et al.*, 2018). This rare characteristic is not merely a scientific curiosity; it fundamentally alters how these materials interact with external forces, opening new frontiers in energy absorption, impact resistance, and structural robustness.

The extraordinary deformation mechanism of auxetic honeycombs offers a suite of mechanical advantages that are highly desirable in critical applications such as aerospace components, biomedical implants, protective systems, and advanced automotive structures (Sun *et al.*, 2013; Sengul *et al.*, 2025). By expanding simultaneously in multiple directions under load, these materials

achieve superior stiffness, enhanced indentation resistance, and more uniform stress distribution, traits that are difficult to achieve with conventional materials.

However, the journey from laboratory prototypes to real-world applications has been hindered by a limited understanding of their complex mechanical behavior under practical loading scenarios (Hu *et al.*, 2024). In dynamic conditions, such as impact events or blast loads, accurately predicting how auxetic honeycombs deform, absorb energy, and withstand failure becomes a formidable challenge (Wu *et al.*, 2024). The interplay between geometrical configurations, material properties, and loading conditions introduces a level of complexity that demands deeper scientific inquiry.

To overcome these challenges, researchers must delve into the intricate deformation mechanisms, analyze stress concentration patterns, and evaluate the structural performance of auxetic honeycombs across varying geometrical and loading parameters. Of particular importance is understanding how the negative Poisson's ratio influences energy dissipation and mechanical integrity during high-strain-rate events—an area that remains insufficiently explored (Hu *et al.*, 2024).

A substantial body of research has examined the mechanical performance of auxetic honeycombs, particularly under dynamic and multi-axial loading conditions. Structural configurations such as re-entrant, chiral, and rotating unit-cell honeycombs have been studied extensively for their direction-dependent deformation behaviors and energy dissipation capabilities. For instance, (Alomarah *et al.*, 2020; Zhou *et al.*, 2022; Byiringiro *et al.*, 2025a) highlighted that the loading orientation significantly affects both deformation mechanisms and energy absorption efficiency, emphasizing the importance of design orientation in practical applications. These findings underline the necessity for tailored geometric configurations that align with specific loading scenarios to maximize performance outcomes.

Moreover, innovations in unit-cell design have been pivotal in enhancing the mechanical attributes of auxetic honeycombs. Advanced geometries, such as the re-entrant combined-wall (RCW) honeycomb and doubly re-entrant auxetic unit-cell, have been introduced to improve tunability, orthogonality, and stiffness characteristics (Zhou *et al.*, 2022). These designs have successfully achieved a further reduction in Poisson's ratio while concurrently increasing Young's modulus, allowing for customizable mechanical performance profiles that cater to specialized engineering applications (Zhou *et al.*, 2022; Széles *et al.*, 2024; Byiringiro *et al.*, 2024). Such geometric innovations have opened new pathways for the design of auxetic structures with optimized load-bearing capabilities and resilience against failure.

The application scope of auxetic honeycomb structures continues to expand across various engineering domains. In aerospace and automotive industries, their superior impact energy absorption capacity offers significant advantages for lightweight and crash-resilient structures. Recent studies by (Shuaibu *et al.* 2024; Wu *et al.*, 2024; Byiringiro *et al.*, 2025b) demonstrated the efficacy of auxetic configurations in dissipating kinetic energy during collision and vibration scenarios, showcasing their potential for next-generation impact-resistant systems. Additionally, the unique deformation characteristics of auxetic materials have been explored in filtration systems, where they exhibit enhanced selectivity and resistance to clogging. Early research by (Alderson *et al.*, 2000) provided insights into how the dynamic reconfiguration of auxetic pores can improve filtration efficiency, thus broadening the multifunctional utility of these structures.

Another critical enabler for the advancement of auxetic honeycombs is the role of computational modeling and simulation. Techniques such as FEA and parametric design optimization have been instrumental in elucidating how geometrical modifications influence mechanical behavior (Justin *et al.*, 2018). (Rad *et al.*, 2015) emphasized that through detailed simulation frameworks, it becomes

possible to predict structural performance with high accuracy, facilitating the practical implementation of auxetic designs in complex systems. Computational approaches not only accelerate the design iteration process but also offer predictive insights into failure modes, stress distributions, and energy absorption patterns, thereby supporting the development of optimized auxetic architectures tailored for specific operational conditions.

In engineering fields where weight efficiency is a critical constraint—such as aerospace, automotive, and biomedical applications—there is a pressing need to develop structures that offer high strength-to-weight ratios. Auxetic materials, due to their unique properties, present opportunities for weight-optimized designs that do not compromise on performance (Catar *et al.*, 2025). Therefore, the final focus of this research is to assess the role of material properties—such as Young’s modulus, Poisson’s ratio, and density—in optimizing auxetic structures for lightweight applications. The interplay between material selection and geometric design is examined to develop strategies for structural efficiency, energy absorption, and mechanical robustness under minimal weight conditions.

Building upon the current understanding, the first aim of this study is to comprehensively investigate the mechanical performance of re-entrant auxetic honeycomb structures under various quasi-static and dynamic loading conditions. Special emphasis is placed on elucidating how design parameters, such as core thickness and applied velocity, influence the stress distribution, deformation modes, and failure mechanisms. This investigation will involve finite element modeling (FEM) and stress analysis techniques to quantify mechanical responses and identify critical factors that differentiate auxetic structures from conventional (non-auxetic) honeycombs in terms of structural integrity and energy absorption efficiency.

In addition to mechanical performance assessment, the study will explore how the geometrical configuration of honeycomb unit cells governs their impact resistance and energy absorption characteristics (Bustihan *et al.*, 2025). Parameters such as cell shape, wall thickness, and cell distribution patterns play a decisive role in determining how energy is absorbed and redistributed throughout the structure during dynamic loading. Owing to their inherent deformation adaptability, auxetic geometries exhibit superior energy dissipation behaviors, which are yet to be fully quantified across varying geometrical scales. Therefore, this study aims to perform a parametric analysis to evaluate the influence of these geometrical parameters on the impact behavior of auxetic structures, with the objective of identifying optimized configurations that enhance structural resilience and minimize localized stress concentrations during high-strain-rate events.

Ultimately, this research endeavors to bridge the existing gaps in the predictive understanding of auxetic honeycomb structures by integrating advanced computational modeling techniques with detailed geometrical optimization studies, thereby contributing to their broader adoption in impact-critical applications.

This work aims to contribute a deeper understanding of auxetic honeycomb mechanics and to provide a basis for advanced engineering applications where both mechanical efficiency and lightweight performance are critical.

2. Methodology

2.1 Sourcing and preparation of

Researching re-entrant auxetic structures using ANSYS involves simulating their mechanical behavior. Begin with a literature review to understand their properties and applications. Create a 3D CAD model in SOLIDWORKS and then import the geometry in ANSYS Design Modeler or import one. Mesh the model using ANSYS Meshing and then simulation in ANSYS Explicit dynamics

analysis refining it in key areas. Define material properties and proceed with simulations to analyze the structure's behavior (Ouazzan *et al.*, 2024).

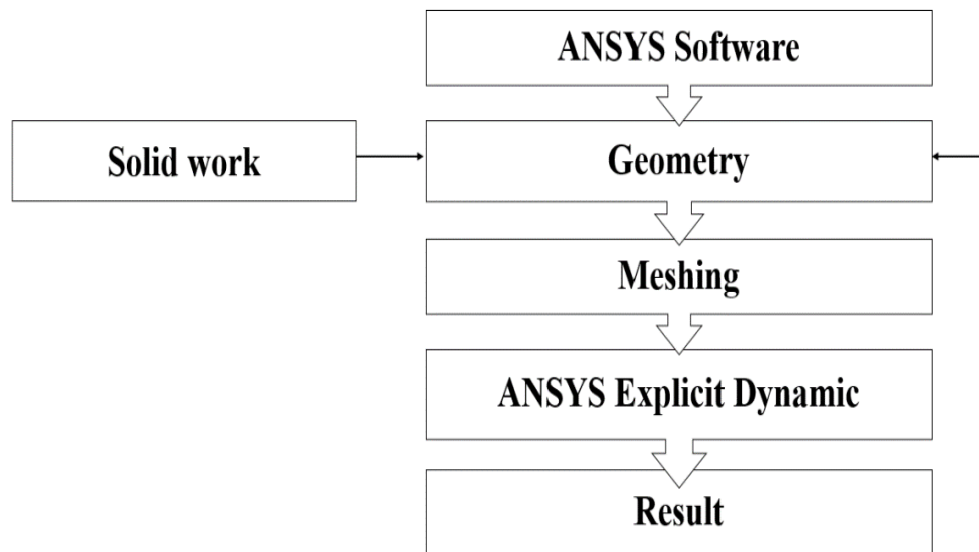


Figure 1: Flow chart of Research Methodology

Figure 1 represents the flow chart of the research methodology adopted for numerical analysis using ANSYS software. The process begins with the SolidWorks stage, where the 3D model of the lattice structure is designed with specified geometric parameters such as cell dimensions, wall thickness, and overall configuration. This CAD model is then imported into ANSYS Software for further computational analysis.

In the Geometry step, the model is refined and prepared for simulation by defining the structural domain and boundaries. Subsequently, Meshing is performed to discretize the geometry into smaller finite elements, ensuring accurate stress and deformation predictions under applied loads. The ANSYS Explicit Dynamic module is then employed to simulate the transient dynamic behavior of the structure under impact and loading conditions, capturing real-time stress propagation and deformation responses.

Finally, the Result stage involves post-processing, where outputs such as stress distribution, strain energy, and deformation contours are analyzed. This systematic workflow ensures accurate modeling, efficient simulation, and reliable interpretation of the mechanical behavior of the designed lattice structures under various loading conditions.

2.2 Experiments

For the auxetic structure, loading plate, fixed Plate in the meshing of the whole Sandwich auxetic panel model, there are thickness 0.8mm, 1.0mm and 1.2mm (Novac *et al.*, 2022) nodes and elements are 148662 and 137150. The mesh density of 2mm was found to be sufficient to ensure the numerical accuracy based on studies on mesh sensitivity.

Figure 2 shows the meshing of the re-entrant auxetic panel created in ANSYS. The mesh represents the discretization of the 3D geometry into smaller finite elements, which is a crucial step in the finite element method (FEM). This process allows accurate simulation of stress, strain, and

deformation throughout the structure. A refined and uniform mesh ensures better convergence and more reliable numerical results, particularly in regions experiencing high stress concentration.

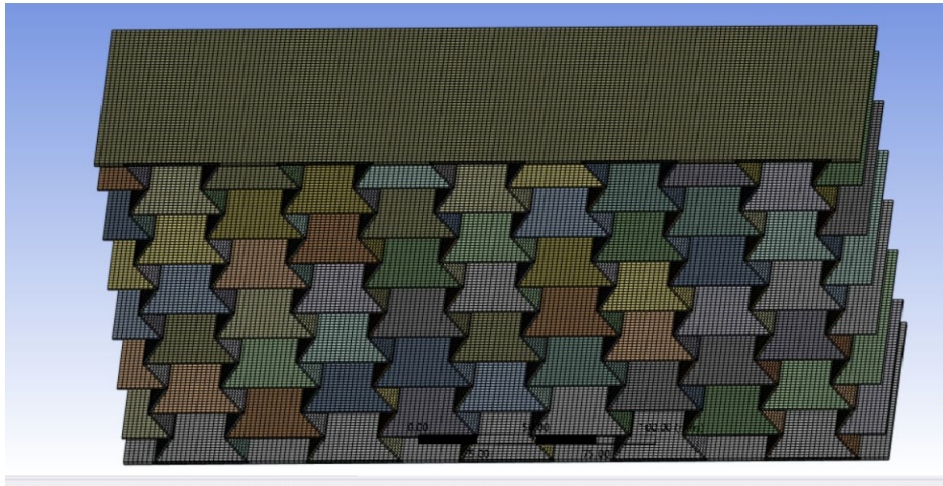


Figure 2: Meshing of Re-entrant Auxetic Panel

2.3 Product characterisation

The base for the numerical solution of the created new geometry is ANSYS- 2022 R1 Here is a description in the design modeler (it is a design modeler inbuilt with the ANSYS) of ANSYS-2022 R1. After material assignment, the new geometry imported into the Explicit Dynamics Module.

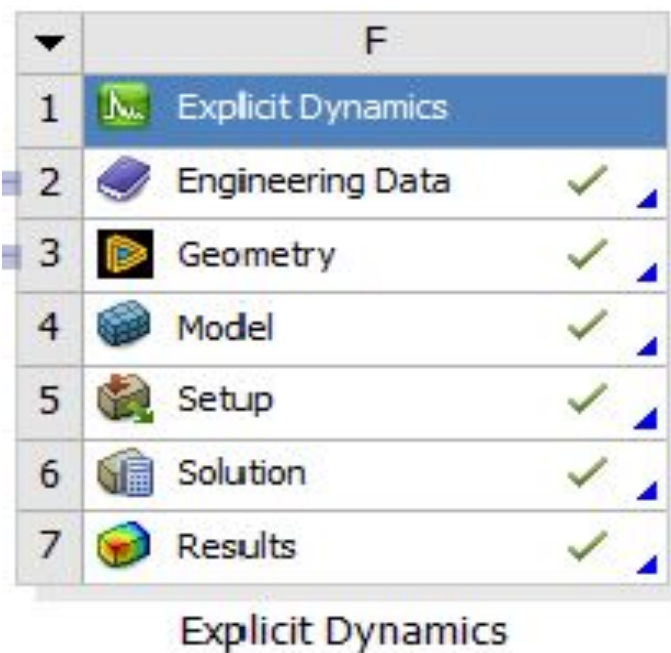


Figure 3: Brief Interface of Explicit Dynamics Module Schematic in ANSYS

Figure 3 illustrates the brief interface of the Explicit Dynamics module schematic in ANSYS. It highlights the key stages of the simulation workflow—Engineering Data, Geometry, Model, Setup, Solution, and Results. Each stage represents a systematic step: assigning material properties, defining boundary and loading conditions, setting up the dynamic analysis parameters, solving the simulation, and finally visualizing results such as deformation and stress distribution. This structured sequence ensures consistency and accuracy throughout the modeling process.

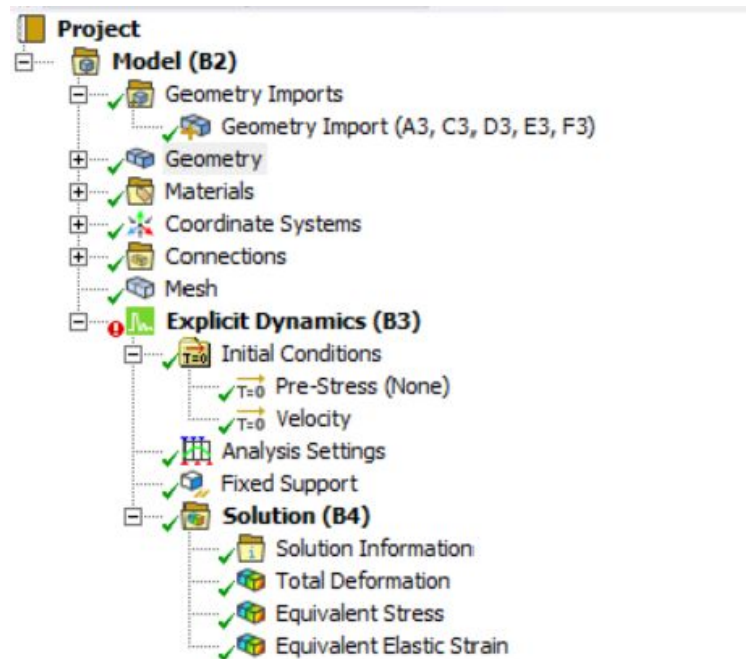


Figure 4: Interface of Project schematic in simulation window in ANSYS

Figure 4 presents the interface of the project schematic in the simulation window of ANSYS. It provides an overview of how different modules—geometry imports, materials, coordinate systems, mesh, and explicit dynamics setup—are interconnected within the project. The highlighted sections, such as velocity, boundary supports, and solution outputs (e.g., total deformation and equivalent stress), indicate the parameters and results monitored during simulation. This interface serves as the central workspace where all elements of the finite element analysis (FEA) are integrated and executed effectively.

The study employs two primary materials for the numerical analysis of the re-entrant auxetic structure:

- **Auxetic Core Material (PLA- PLA, MAT-024):** This material is selected for its negative Poisson's ratio and favorable mechanical properties such as lightweight and impact resistance.
- **Young's Modulus:** 1.743 GPa
- **Density:** 1300 kg/m³
- **Poisson's Ratio:** 0.36
- **Loading and Fixed Plates (Structural Steel, MAT-09):** Used to apply load and fixation in the simulation, ensuring proper boundary conditions.
- **Young's Modulus:** 210 GPa
- **Density:** 7800 kg/m³
- **Poisson's Ratio:** 0.30

The properties are derived from standard material data and are essential inputs for finite element modeling in ANSYS. The auxetic core structures are modeled with varying thicknesses to analyze their effects on mechanical response. The specific core thicknesses considered are:

- 0.8 mm
- 1.0 mm
- 1.2 mm

The geometrical configuration follows the re-entrant auxetic honeycomb design, which exhibits negative Poisson's ratio behavior under deformation.

- **Geometry Creation:** The 3D CAD model of the re-entrant auxetic structure is created in SOLIDWORKS, capturing the intricate cell geometry necessary for accurate simulation.
- **Import and Meshing:** The CAD model is imported into ANSYS DesignModeler. A high-quality mesh is generated, with refinements in critical areas to capture stress concentrations accurately.
- **Material Property Assignment:** Material properties as specified are assigned to respective parts in ANSYS.
- **Boundary Conditions:** The fixed plate is constrained to prevent movement, simulating attachment to a rigid substrate.
- **Loading Conditions:** The structure is subjected to impact loading at different velocities:
 - **Low velocity:** 6 m/s
 - **Medium velocity:** 50 m/s
 - **High velocity:** 100 m/s

The loading is applied as a dynamic impact force, and the simulation uses ANSYS Explicit Dynamics to analyze the behavior under these conditions.

2.4 Simulation Approach

- **Finite Element Analysis (FEA):** The numerical analysis employs the explicit dynamics method in ANSYS, suitable for high-velocity impact problems.
- **Procedure:**
 - Create the finite element model based on the geometrical design.
 - Assign material properties.
 - Apply boundary conditions and impact loading.
 - Run simulations to analyze deformation, stress distribution, and strain response over time.

3. Results and Discussion

3.1 Validation on Finite Element Method Results

The simulation based on the ANSYS MECHANICAL 2022R1 for the validation of the explicit dynamics analysis of re-entrant auxetic structure resulted in the research of (Xiao *et al.*, 2019). ANSYS Mechanical was accepted for evaluation since the mechanical properties meet on the Re-entrant auxetic structure under impulsive loading condition validation for deformation error upto 10%.

Figure 5 illustrates the correlation between deformation and impulse, comparing experimental results reported by (Xiao *et al.*, 2019) with numerical results obtained from ANSYS simulations. The graph shows a nearly linear relationship between impulse (KN·s/m²) and deformation (mm), indicating that deformation increases proportionally with the applied impulse. Both experimental and simulated curves exhibit a close agreement throughout the range, with only minor deviations observed at higher impulse values. This strong correlation validates the accuracy and reliability of the ANSYS model in replicating the experimental behavior, demonstrating that the numerical simulation effectively captures the material's deformation response under dynamic loading conditions.

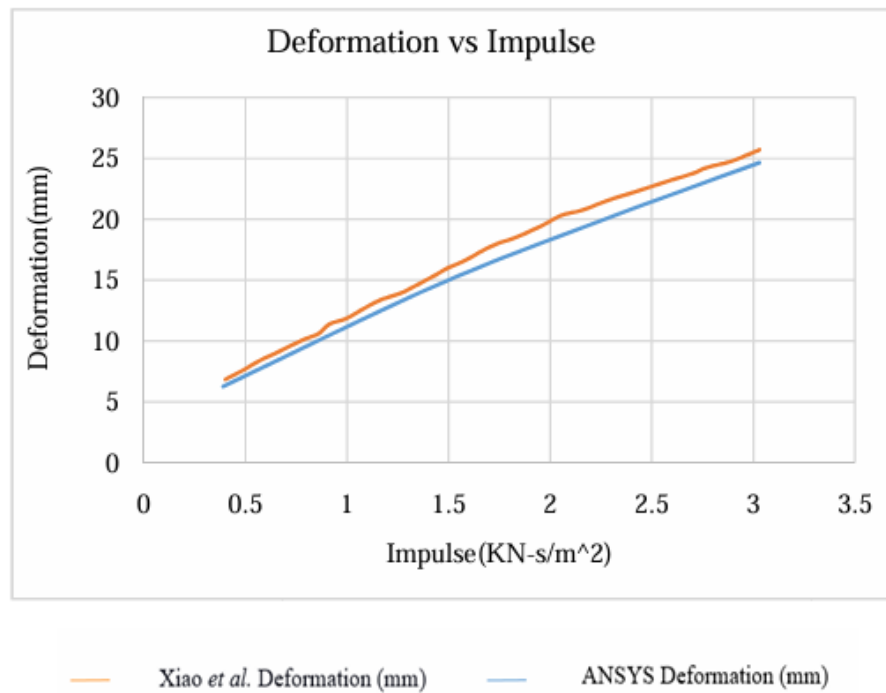


Figure 5: Validation of experimental results with ANSYS results (Xiao et al., 2019)

This entire simulation serves as a strong validation for the ANSYS results to perform the numerical evaluation. After the validation of the previous research, and my work same related to previous research for stress concentration factor for different thickness of auxetic core panel.

3.2 Mechanical Properties Analysis of Re-entrant Auxetic Structure

The Re-entrant auxetic structures are used in the explicit dynamics analysis to determine deformation, stress, and strain during the explicit dynamics analysis. Varying impact velocities and thicknesses provides to auxetic core valuable insights into deformation, stress distribution, and strain patterns, which can be applied to design more effective and resilient materials.

3.2.1 Confronting the Negative Poisson's Ratio and Assessing Mechanical Behavior of Auxetic Honeycomb Structures

The simulation results vividly demonstrate the unique deformation characteristics of the re-entrant auxetic honeycomb structures, confirming their negative Poisson's ratio behavior. Under tensile loading, the structures exhibit lateral expansion when stretched longitudinally, a hallmark of auxetic materials.

The auxetic structures show controlled and predictable deformation, with lateral expansion becoming more pronounced at higher strains. For example, at a core thickness of 1.0 mm subjected to impact velocities of 6 m/s, the lateral deformation ranged from minimal at low strain to substantial at higher impact, indicating effective auxetic performance. Figure 6 displays the deformation vs time at low velocity. Total deformation of auxetic core near upper end is 3.2958mm.

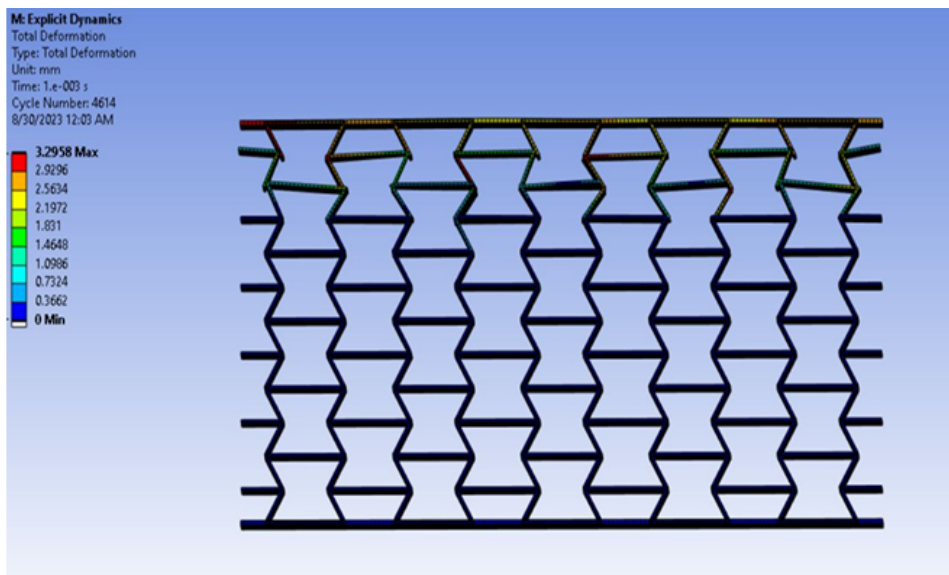


Figure 6: Deformation vs time at Low velocity ANSYS Image

FEA revealed uniform stress distribution during impact, with reduced stress concentrations compared to conventional honeycomb structures. Stress concentration factors (SCF) decreased with increasing auxetic behavior, implying enhanced capacity to manage dynamic loads positively.

The negative Poisson's ratio promotes more uniform energy redistribution throughout the structure during impact, thereby enhancing structural stability and reducing the likelihood of localized failure under high strain conditions.

3.2.2 Analyzing Geometrical Parameters for Impact Resistance and Energy Absorption Capacity

The influence of geometrical parameters—particularly core thickness—on impact resistance and energy absorption was systematically evaluated:

Thicker cores (1.2 mm) demonstrated greater impact resistance, absorbing higher energy and exhibiting smaller deformations compared to thinner cores (0.8 mm). For instance, at 100 m/s impact velocity, the maximum deformation was approximately 43.39 mm for 1.2 mm thickness vs. 53.95 mm for 0.8 mm thickness.

The newly proposed lattice structure, optimized for volume and surface-to-volume ratio, exhibits superior strength, stability, and progressive hardening under compression, outperforming conventional lattice designs (El *et al.*, 2021).

The area under the stress-strain curve increased with core thickness, indicating enhanced energy absorption capacity. Thicker auxetic cores effectively dissipated impact energy, reducing peak stress values and minimizing localized failure.

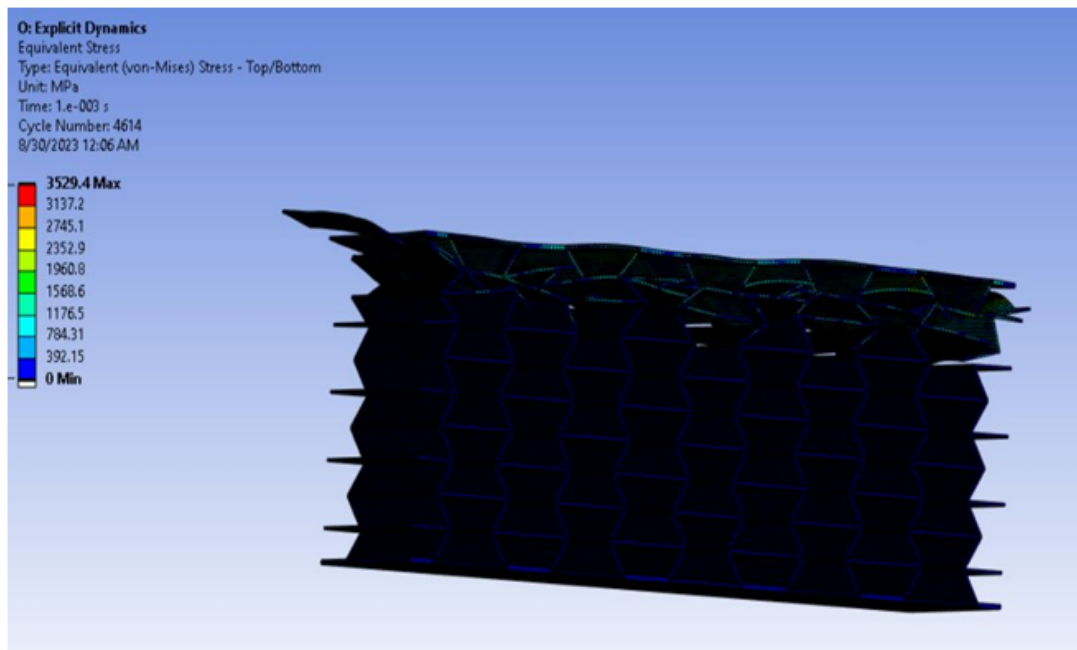


Figure 7: Deformation vs time at Low velocity ANSYS Image

Figure 7 illustrates the deformation behavior of the lattice structure under low-velocity impact as simulated using ANSYS. The deformation contour indicates that the stress distribution is uniform across the structure, highlighting its ability to maintain geometric stability under load. Thicker and geometrically optimized designs exhibited delayed failure and better energy dissipation, indicating superior resistance to localized buckling and impact-induced deformation. This confirms that fine-tuning geometrical parameters such as cell size and wall thickness directly influences the structure's robustness against impact forces, making it ideal for protective and aerospace applications.

Structures with optimized geometrical parameters displayed delayed failure modes and maintained integrity under high-impact velocities. The uniform distribution of stress and deformation was more evident in thicker and geometrically optimized designs, showcasing their robustness against impact loads.

Fine-tuning geometrical parameters such as cell size and wall thickness can significantly improve impact resistance and energy absorption, vital for applications like protective gear and aerospace structures.

3.2.3 Checking Material Properties through Lightweight Optimization

Material properties, combined with geometrical design, influence the lightweight nature of the structures:

- **Material Utilization:** PLA as the auxetic core provides a low-density alternative, contributing to overall lightweight advantages. When combined with optimized geometrical configurations, it enables structures that are both lightweight and mechanically resilient.

- **Optimization Outcomes:** The simulations reveal that reducing core thickness from 1.2 mm to 0.8 mm decreases weight but increases deformation and stress concentrations. Conversely, moderate thicknesses balance weight savings with impact resistance.

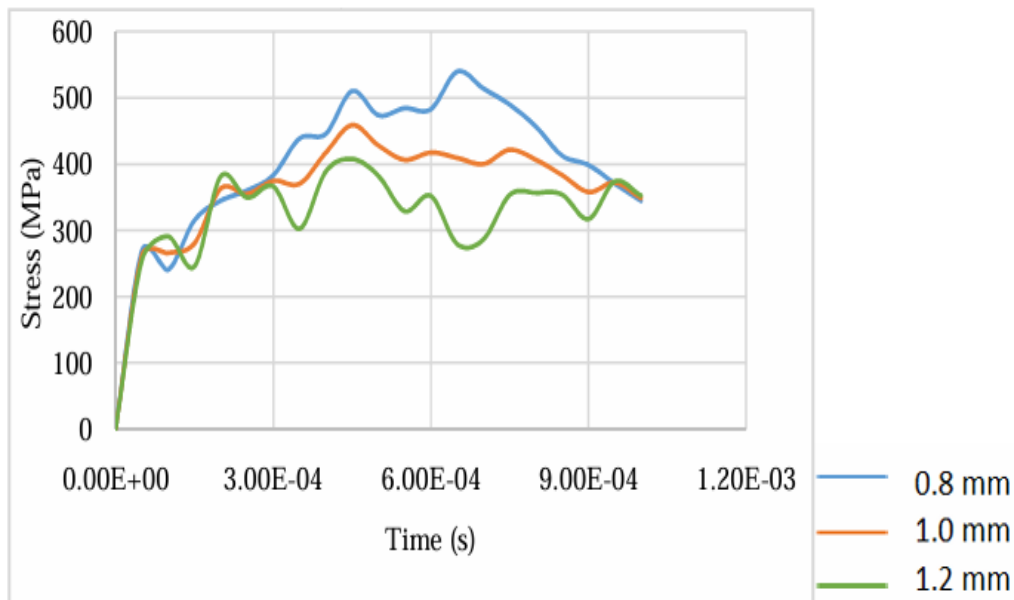


Figure 8: Deformation vs time at Low velocity

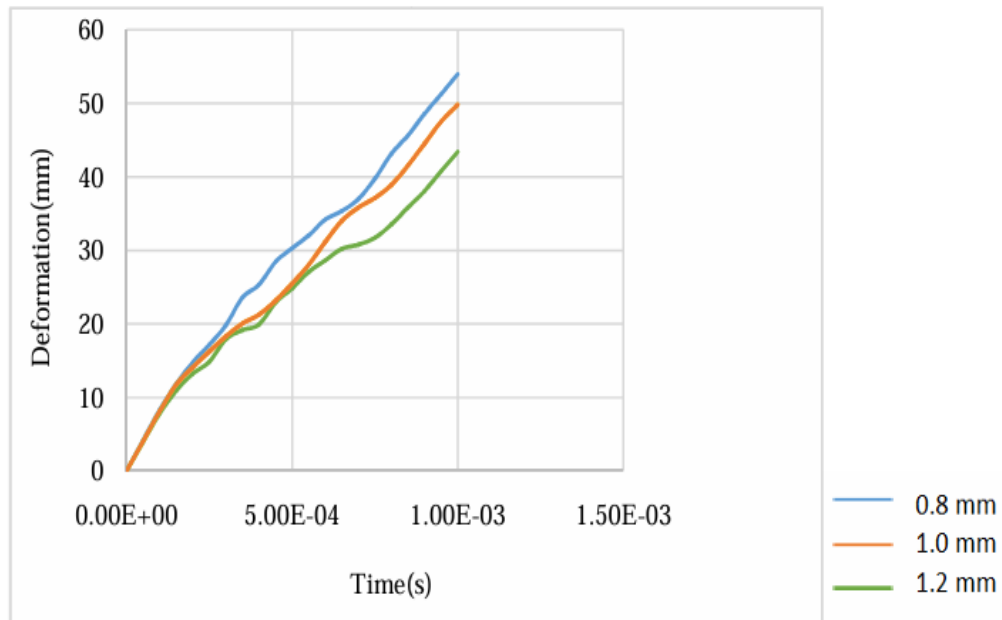


Figure 9: Deformation vs time at High velocity

Figure 8 presents the stress versus time relationship at low impact velocity for three different core thicknesses—0.8 mm, 1.0 mm, and 1.2 mm. The graph reveals that the 1.0 mm and 1.2 mm structures sustain higher stress levels, reaching up to approximately 500–600 MPa, before showing signs of relaxation. In contrast, the 0.8 mm sample demonstrates lower stress-bearing capacity, indicating reduced strength under low-velocity conditions. This behavior emphasizes that increasing wall thickness enhances impact resistance and distributes stress more uniformly throughout the structure.

Figure 9 shows the deformation versus time at high impact velocity for the same range of core thicknesses. The deformation response indicates that thinner cores (0.8 mm) experience significantly higher displacement—up to nearly 60 mm—compared to thicker counterparts, which deform less

under identical loading conditions. This trend suggests that while reducing core thickness decreases the overall weight, it compromises structural rigidity and increases deformation under dynamic loading. Conversely, moderate thickness (around 1.0 mm) achieves a balanced performance between lightweight efficiency and mechanical strength.

Integrating the findings from [Figures 7–9](#), it is evident that geometric optimization and material selection are critical in tailoring the mechanical performance of lightweight lattice structures. Thicker cores improve energy absorption and stress resistance, while thinner geometries enhance weight reduction but at the expense of higher deformation. The negative Poisson's ratio of the auxetic design further enhances energy absorption without significant mass increase, promoting efficient lightweight design strategies that maintain structural integrity under varying impact velocities.

The negative Poisson's ratio amplifies impact energy absorption without substantial weight increase, facilitating lightweight design solutions that do not compromise structural integrity as pointed out by [Seyedkazemi et al., \(2024\)](#).

Enhanced lightweight design involves integrating materials with high strength-to-weight ratios and optimizing cell geometries for maximum performance with minimal material use.

Conclusion

This study successfully addressed the three key objectives, demonstrating that:

1. The negative Poisson's ratio characteristic of auxetic honeycomb structures enhances their mechanical behavior by enabling lateral expansion under tensile loading, which contributes to improved energy distribution and reduced stress concentrations, thereby confirming their potential for impact mitigation.
2. The geometrical parameters, particularly core thickness, significantly influence impact resistance and energy absorption capacity. Thicker cores exhibit higher energy dissipation and better structural resilience, indicating that precise geometrical optimization is vital for maximizing impact performance.
3. Material properties, when integrated with lightweight design strategies, enable the development of resilient yet lightweight auxetic structures. By optimizing geometrical configurations alongside suitable materials like PLA, it is possible to achieve structures that balance weight savings with mechanical robustness.

Overall, the findings affirm the efficacy of auxetic honeycomb structures in mechanical applications requiring impact resistance and energy absorption, paving the way for their implementation in sectors such as aerospace, defense, and biomedical engineering.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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