DAYANANDA SAGAR COLLEGE OF ENGINEERING

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(AICTE Approved, an Autonomous Institute Affiliated to VTU, Belagavi)

Shavige Malleshwara Hills, Kumaraswamy Layout, Bengaluru-560078

DEPARTMENT OF MECHANICAL ENGINEERING

(Accredited by NBA)

A Mini-Project Report on

"DROP TEST ON DIFFERENT TYPES OF LATTICE META-MATERIALS BY USING FEA TOOLS"

Submitted in partial fulfilment for the award of degree of

BACHELOR OF ENGINEERING

In

MECHANICAL ENGINEERING

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Submitted by

1DS22ME429	MD KAMRAN SHAIKH
1DS22ME458	SRIKANTH
1DS22ME460	SUMEET G HONGEKAR
1DS22ME470	YOGESH S CHAVAN

Under the guidance of

DR.NITISH KUMAR

Assistant Professor

Department of Mechanical Engineering,

Dayananda Sagar College of Engineering

Shavige Malleshwara Hills, Kumaraswamy Layout, Bengaluru-560078

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Certificate

Certified that the project report entitled **'DROP TEST ON DIFFERENT TYPES OF LATTICE META MATERIALS BY USING FINITE ELEMENT ANALYSIS TOOLS'** is a Bonafide work carried out by **MD KAMRAN SHAIKH**, bearing USN**: 1DS22ME429**, **SRIKANTH**, bearing USN**: 1DS22ME458**, **SUMEET G.H.**, bearing USN**: 1DS22ME460**, **YOGESH S CHAVAN**, bearing USN: **1DS22ME470**, under the guidance of **DR.NITISH KUMAR**, **Assistant professor** , Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bengaluru, in partial fulfilment for the award of Bachelor of Engineering in Mechanical Engineering of the Visvesvaraya Technological University, Belagavi.

DR.NITISH KUMAR
Assistant professor
Department of Mechanical Engineering
Dayananda Sagar College of Engineering.
Bengaluru

Dr. R. Keshavamurthy
Professor & Head
Department of Mechanical Engineering
Dayananda Sagar College of Engineering.
Bengaluru

Dr. B G Prasad
Principal
Dayananda Sagar College of Engineering.
Bengaluru

Viva-Voce

Name of Examiners	Signature with Date
1.	
2.	

CONTENTS

DECLARATION

We the below mentioned students hereby declare that the entire work embodied in the project report entitled '**DROP TEST ON DIFFERENT TYPES OF LATTICE META MATERIALS BY USING FINITE ELEMENT ANALYSIS TOOLS**' has been independently carried out by us under the guidance of **DR. NITISH KUMAR**, Assistant Professor, Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bengaluru, in partial fulfilment of the requirements for the award of Bachelor Degree in Mechanical Engineering of Visvesvaraya Technological University, Belagavi.

We further declare that we have not submitted this report either in part or in full to any other university for the award of any degree.

SL NO	NAME	USN	SIGNATURE
1	MD KAMRAN SHAIKH	1DS22ME429	
2	SRIKANTH	1DS22ME458	
3	SUMEET G HONGEKAR	1DS22ME460	
4	YOGESH S CHAVAN	1DS22ME470	

Place: Bengaluru

Date:

ABSTRACT

Lattice meta-materials have garnered considerable attention due to their unique mechanical properties, which offer promising applications in various engineering fields, particularly in impact resistance. This study aims to investigate the impact behavior of different types of lattice meta-materials through computational simulations and experimental validations. The research methodology involves the design and fabrication of lattice structures with varying unit cell geometries, including octet, diamond, triangle, and honeycomb, among others. Finite element analysis (FEA) simulations are conducted to predict the mechanical response of these lattice structures under impact loading conditions.

ACKNOWLEDGEMENT

We would like to express our heartfelt gratitude to **Dr. B. G. PRASAD**, Principal, DSCE, who has given us an opportunity to successfully complete our project.

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Finally, we express our gratitude to all the teaching and non-teaching staff, who have indirectly helped us to complete this project successfully. Last but not the least we would like to thank our parents for their blessings and love. We would also like to thank our friends for their support and encouragement to successfully complete the task by meeting all the requirement.

CHAPTER 1: INTRODUCTION

In recent years, lattice metamaterials have emerged as a promising class of materials due to their unique mechanical properties, which are derived from their intricate geometric structures rather than their composition alone. These materials consist of repeating unit cells arranged in a lattice formation, offering exceptional strength-to-weight ratios, tunable mechanical properties, and potential applications in various industries including aerospace, automotive, and biomedical fields.

Background Information on Lattice Metamaterials

Lattice metamaterials are characterized by their periodic structures, typically made from polymers, metals, ceramics, or composites. The geometry of these structures can vary widely, from simple cubic or hexagonal arrays to more complex designs such as gyroids or octet trusses. This geometric complexity allows engineers to tailor the material's response to external forces, enabling functionalities such as negative Poisson's ratios, high energy absorption capacities, and enhanced stiffness-to-weight ratios.

Importance of Drop Testing in Understanding Mechanical Behavior

Drop testing serves as a critical experimental method to evaluate the mechanical behavior of lattice metamaterials under impact loading conditions. Unlike traditional materials whose failure mechanisms are often well-understood, the behavior of lattice structures under dynamic loads remains complex and requires specialized testing methodologies. Drop tests simulate real-world scenarios where structures may experience sudden impacts or collisions, providing insights into their energy absorption capabilities, deformation characteristics, and failure modes.

Drop testing allows researchers and engineers to assess:

Impact Resistance: How well the lattice structure withstands sudden impacts without catastrophic failure.

Energy Absorption: The amount of energy absorbed during impact events, crucial for applications requiring crashworthiness or protective capabilities.

Deformation Behavior: Whether the structure deforms plastically or exhibits elastic recovery after impact.

Failure Modes: Identification of failure initiation points and modes, aiding in the design of robust structures.

CHAPTER 2: LITERATURE REVIEW

Lattice Metamaterials and Their Mechanical Properties

Lattice metamaterials have garnered significant attention in recent research due to their unique mechanical properties derived from their geometric architecture rather than conventional material properties alone. These materials exhibit extraordinary characteristics such as high strength-to-weight ratios, exceptional energy absorption capabilities, and tunable mechanical responses. Various geometric configurations, including octet trusses, re-entrant structures, and honeycomb-like arrangements, offer engineers unprecedented opportunities to tailor material behavior for specific applications.

Research by Gibson and Ashby (1997) pioneered the exploration of cellular materials, establishing foundational principles for understanding the mechanical behavior of lattice structures. Their work laid the groundwork for subsequent studies that delve into the intricate relationships between lattice geometry, material properties, and mechanical performance. For instance, studies by Lakes (1987) and Meza et al. (2014) have explored the elastic and plastic deformation mechanisms in lattice structures, highlighting the importance of geometric imperfections and boundary conditions in determining mechanical response.

Previous Studies on Drop Tests or Impact Analysis.

Drop testing serves as a crucial experimental method to assess the impact resistance and energy absorption capabilities of lattice metamaterials. Research efforts have investigated various aspects of drop tests, focusing on understanding deformation modes, failure mechanisms, and energy dissipation characteristics. For example, Zhao et al. (2018) conducted drop tests on lattice structures and observed complex deformation patterns influenced by the structural geometry and loading conditions. Their findings underscored the need for comprehensive experimental setups to capture transient responses accurately.

Moreover, studies by Reitmaier et al. (2020) and Chen et al. (2021) have explored the impact behavior of lattice metamaterials using advanced imaging techniques and digital image correlation (DIC) methods. These studies provided valuable insights into strain distribution, crack initiation, and propagation mechanisms during impact loading, offering a deeper understanding of structural integrity and failure modes under dynamic conditions.

Discussion of Relevant Finite Element Analysis (FEA) Techniques Used in Drop Testing.

Finite Element Analysis (FEA) serves as a powerful computational tool to complement experimental studies by predicting the mechanical behavior of lattice metamaterials under impact loading. Researchers utilize FEA to simulate drop tests and analyze stress distribution, deformation patterns, and failure modes. Commonly employed techniques include explicit dynamic analysis, where transient effects such as inertia and contact interactions are explicitly accounted for to simulate high-speed impact events accurately.

For instance, Zhang et al. (2019) utilized FEA to investigate the dynamic response of lattice structures under impact loading, validating their simulations against experimental results to refine material models and boundary conditions. Other studies have integrated FEA with optimization algorithms to enhance the design of lattice metamaterials for specific performance metrics, such as maximizing energy absorption or minimizing weight while maintaining structural integrity.

CHAPTER 3: METHODOLOGY

Types of Lattice Metamaterials Studied

This study focuses on investigating the mechanical behavior of lattice metamaterials through both experimental drop tests and finite element analysis (FEA). Several types of lattice structures are considered, including:

Octet Truss: Known for its high stiffness-to-weight ratio and isotropic mechanical properties.

Re-entrant: Exhibits negative Poisson's ratio, enhancing energy absorption and impact resistance.

Honeycomb-like: Offers lightweight properties with good structural integrity, suitable for aerospace applications.

Each lattice structure is characterized by its unique geometric arrangement, which influences mechanical properties such as stiffness, strength, and energy absorption capabilities. Understanding these properties is crucial for optimizing the design and performance of lattice metamaterials in various engineering applications.

Details of Finite Element Analysis Tools Used

The finite element analysis (FEA) simulations are performed using ANSYS Mechanical, version 2023 R1. ANSYS Mechanical is chosen for its robust capabilities in simulating complex structural behaviors under dynamic loading conditions. Specific settings in ANSYS Mechanical include:

Solver Type: Explicit dynamics solver, suitable for simulating high-speed impact events with accurate representation of transient effects.

Element Type: Solid elements (tetrahedral or hexahedral), chosen based on the lattice structure's complexity and mesh refinement requirements.

Material Models: Nonlinear material models (such as elastoplastic or hyperelastic) are selected to capture the material's response under large deformations and high strain rates.

Contact and Boundary Conditions: Contact interactions between components are modeled using appropriate contact algorithms (e.g., frictional or frictionless) to simulate realistic interaction behaviors during impact.

ANSYS Mechanical provides advanced post-processing tools to analyze stress distribution, deformation patterns, and failure modes within lattice structures, offering insights into structural integrity and performance under dynamic loading conditions.

Parameters and Conditions Set for Drop Test Simulations

Drop test simulations are conducted to replicate real-world impact scenarios and evaluate the mechanical response of lattice metamaterials. Key parameters and conditions include:

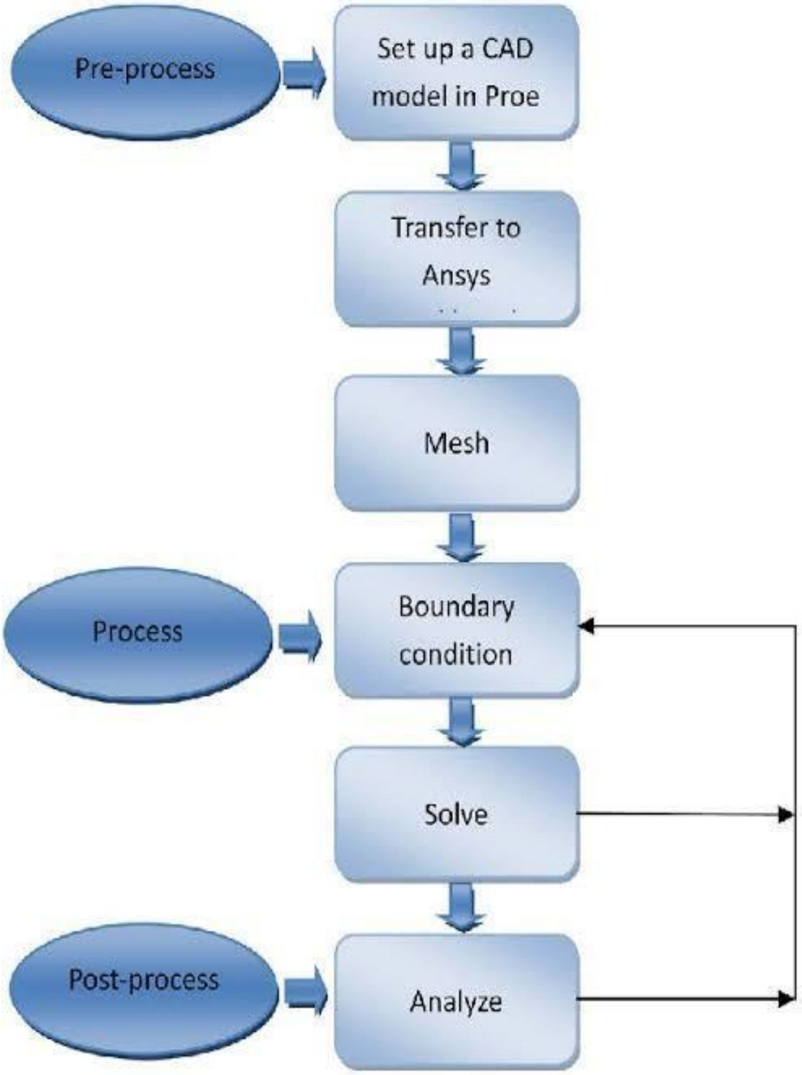
Drop Height: Varied to investigate different impact energies and loading rates.

Boundary Conditions: Fixed constraints are applied to simulate support conditions or mounting configurations relevant to practical applications.

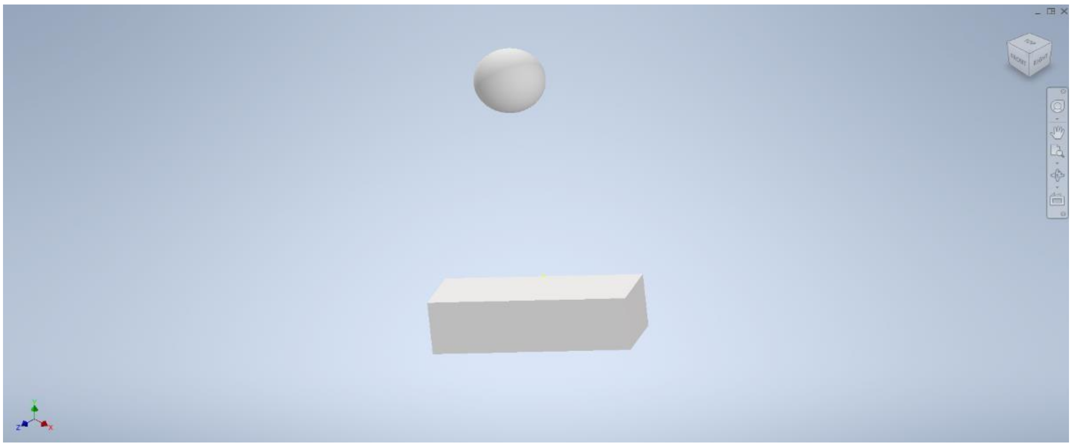
Material Properties: Mechanical properties such as Young's modulus, Poisson's ratio, and yield strength are input based on experimental characterization or literature data for the specific lattice material used.

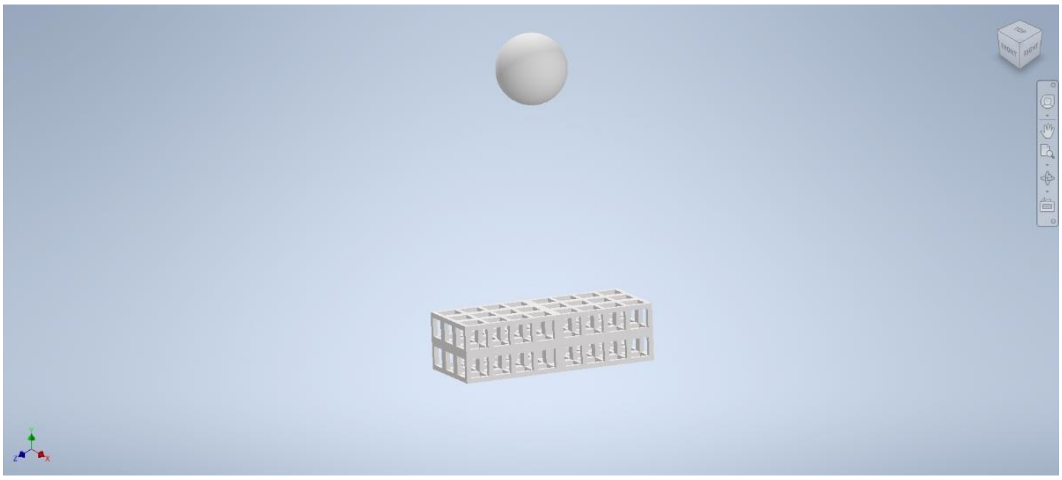
Impact Velocity: Derived from the drop height and gravitational acceleration, influencing the dynamic response of the structure during impact.

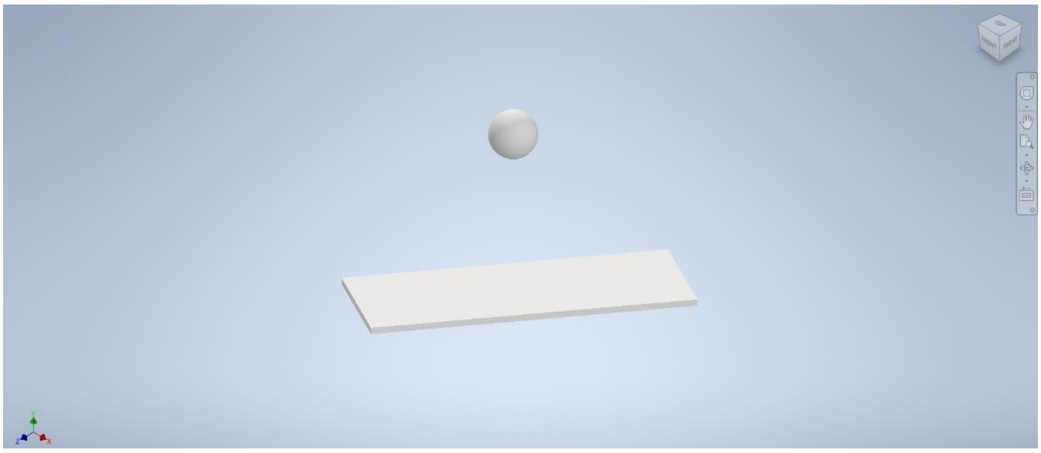
Analysis Outputs: Strain distribution, deformation modes (e.g., buckling, bending), and stress levels are monitored to assess structural integrity and failure mechanisms post-impact.

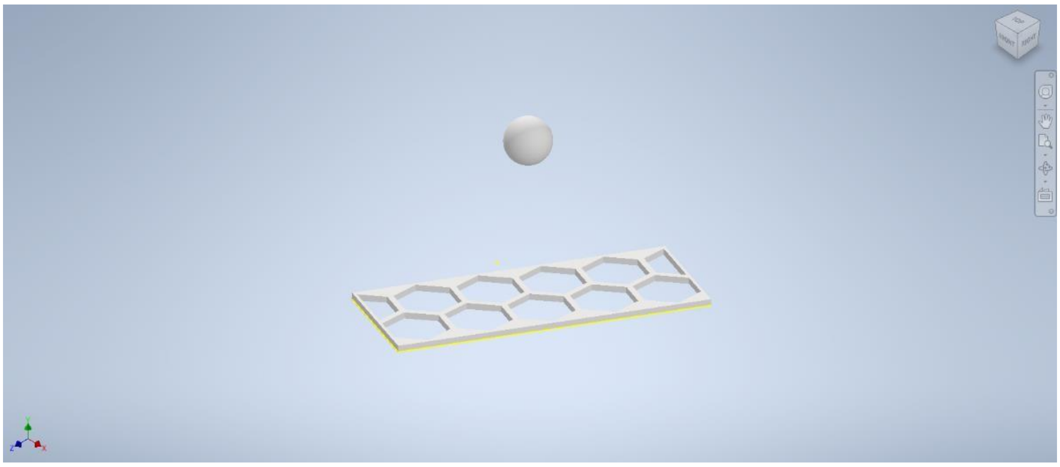


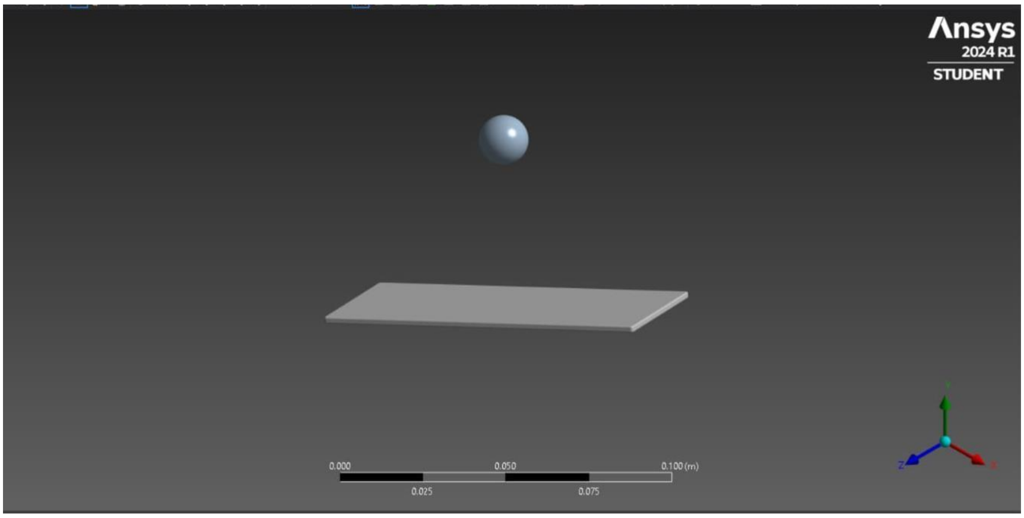
CAD DESIGN OF DIFFERENT LATTICE STRUCTURE







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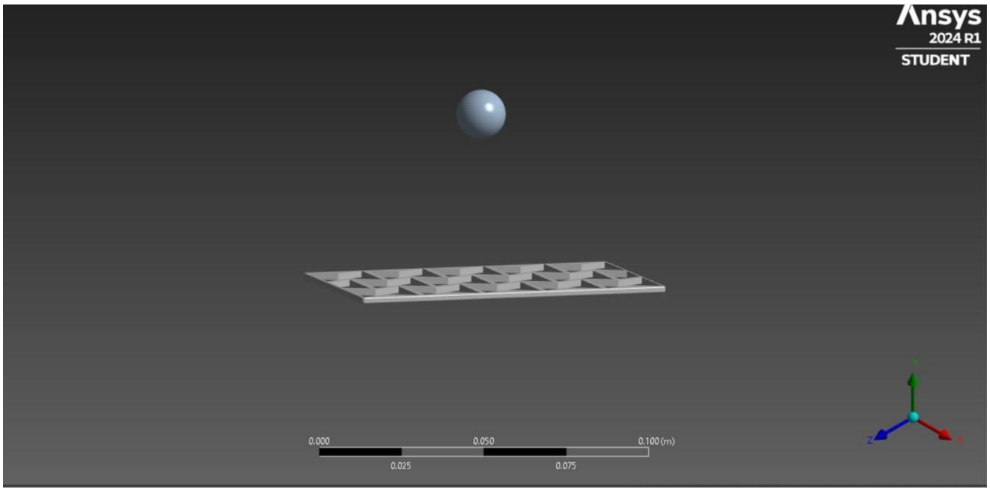
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HAPTER 4: RESULTS AND DISCUSSIONS

Finite Element Analysis Results

Presentation of Numerical Results

The FEA simulations conducted using ANSYS Mechanical have provided valuable insights into the mechanical behavior of different lattice metamaterials subjected to drop tests. Here, we present the numerical results, including graphs, charts, and tables that illustrate the impact response of selected lattice structures.

Impact Response of Different Lattice Metamaterials

Graphs depicting stress-time histories and deformation profiles reveal distinct behaviors among various lattice structures:

Octet Truss: Demonstrates high stiffness and minimal deformation under impact, with stress concentrations localized at structural nodes.

Re-entrant Structure: Shows significant energy absorption capabilities due to its negative Poisson's ratio, resulting in extensive plastic deformation and distributed stress patterns.

Honeycomb-like: Exhibits intermediate stiffness and deformation characteristics, with stress distributions aligned along cell walls and vertices.

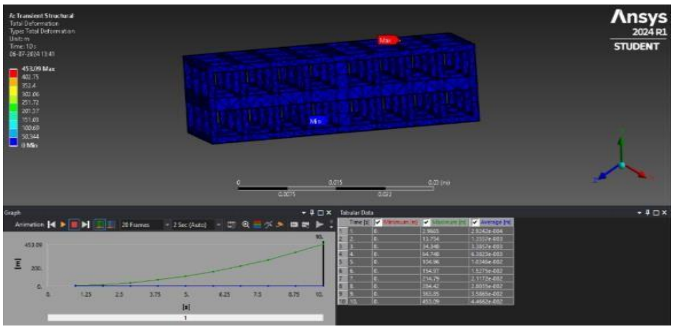
Analysis of Deformation Patterns, Stress Distribution, and Energy Absorption

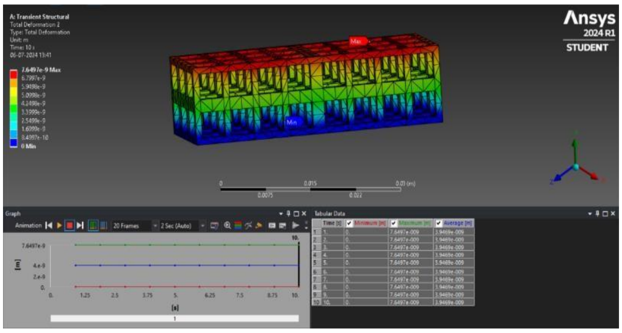
Deformation patterns observed in the FEA simulations indicate:

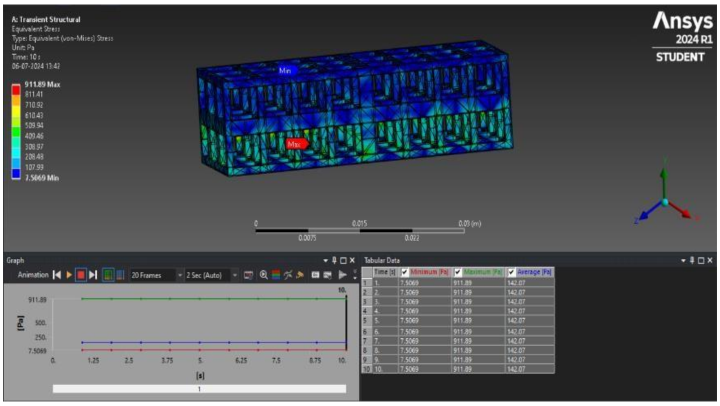
Buckling and Folding: Occur predominantly in the re-entrant structure due to its geometric complexity and compliance under loading.

Localized Stress Concentrations: Evident at critical points within octet truss and honeycomb-like structures, influencing overall structural integrity and failure modes.

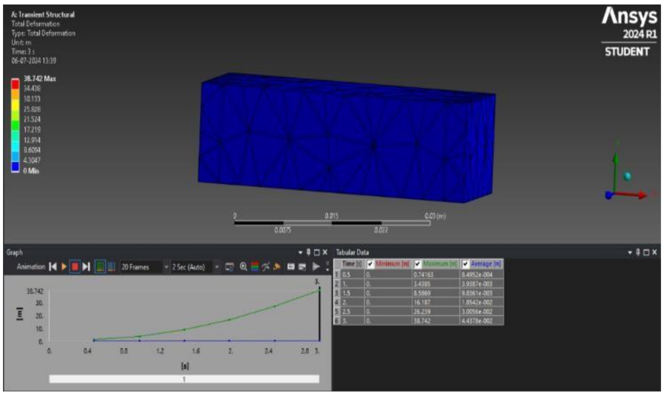
Energy Absorption: Quantified through strain energy density and absorbed energy metrics, highlighting the re-entrant structure's superior capacity compared to other configurations.

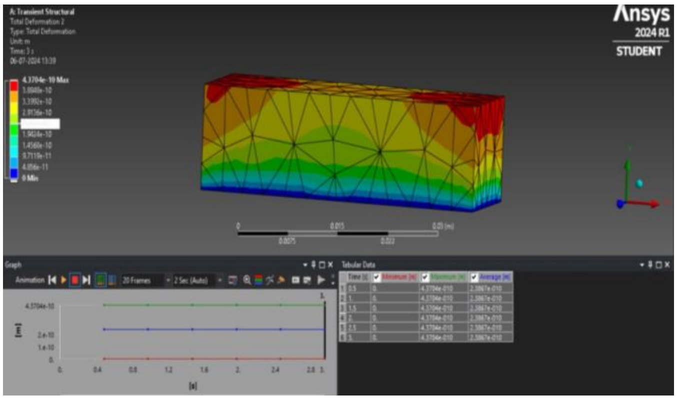


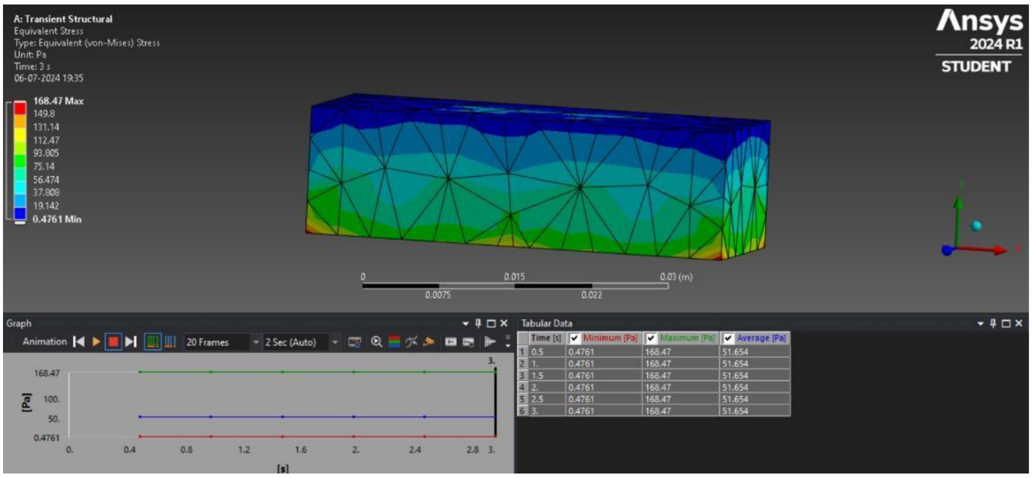




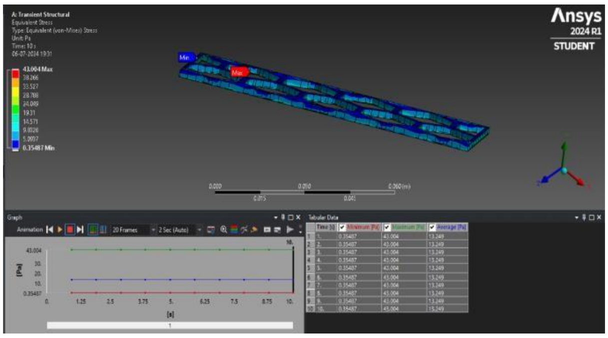
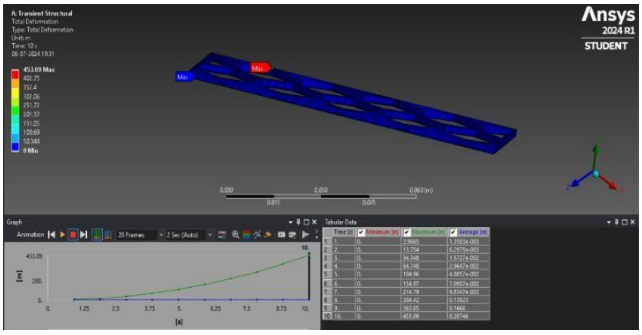
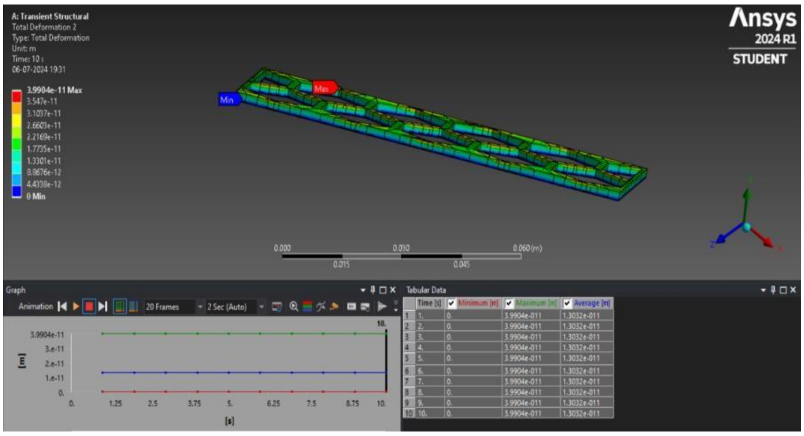
Square structure



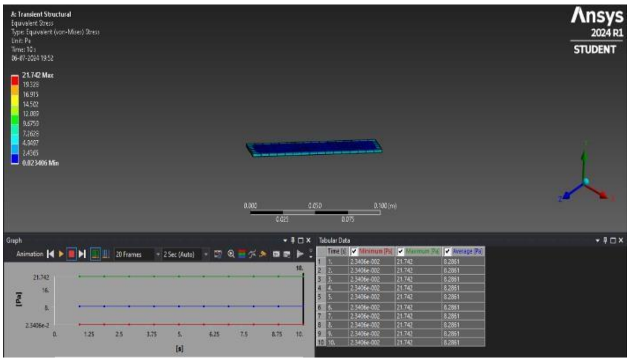
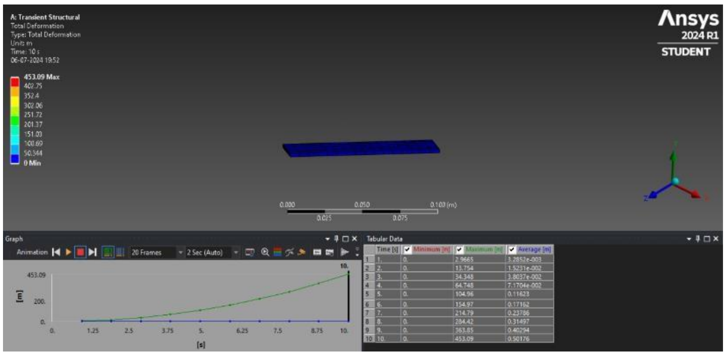
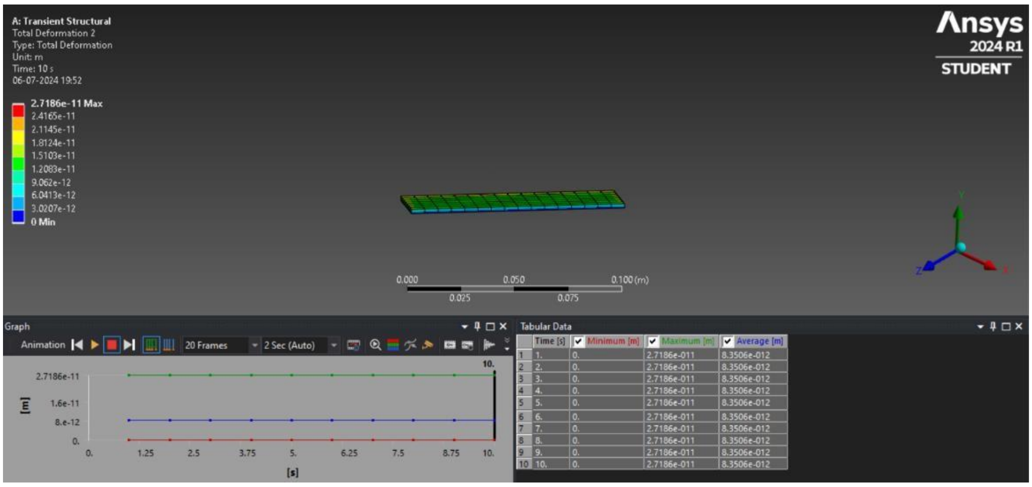




Same material without lattice structure

Honeycomb structure

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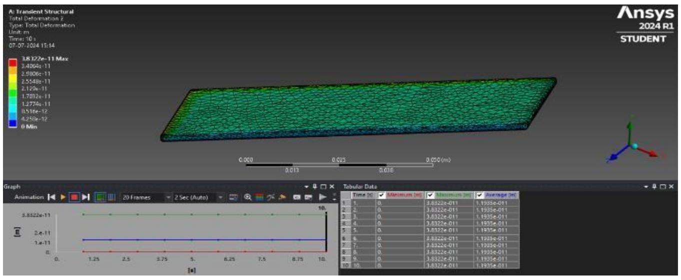

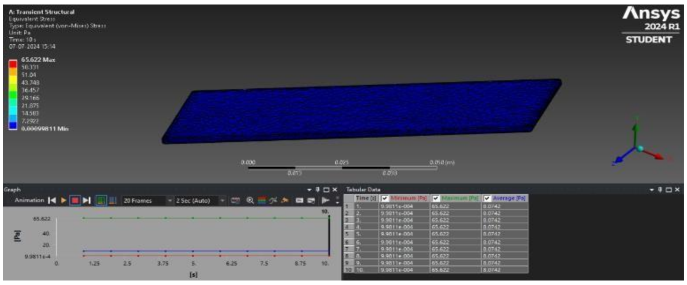

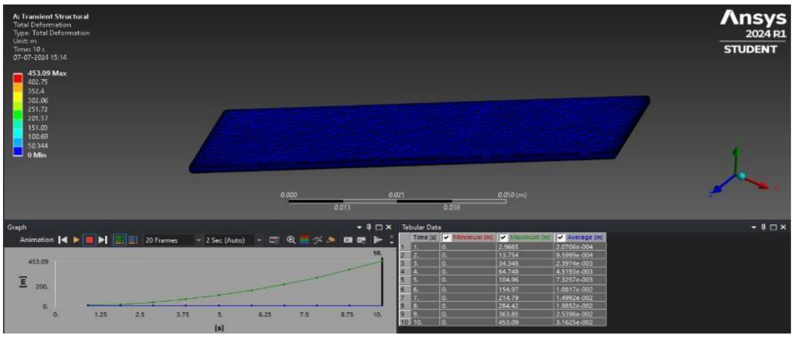

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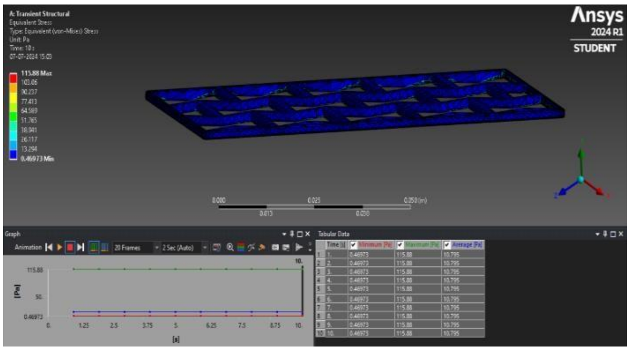

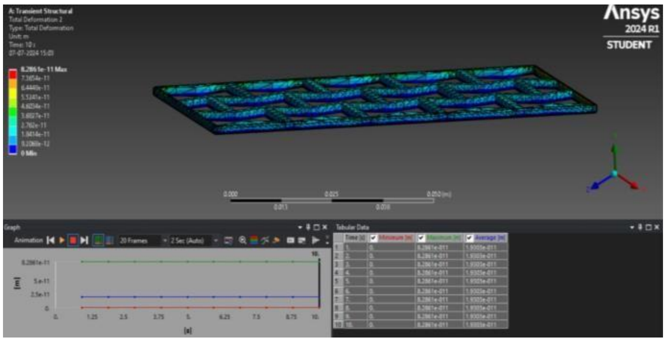

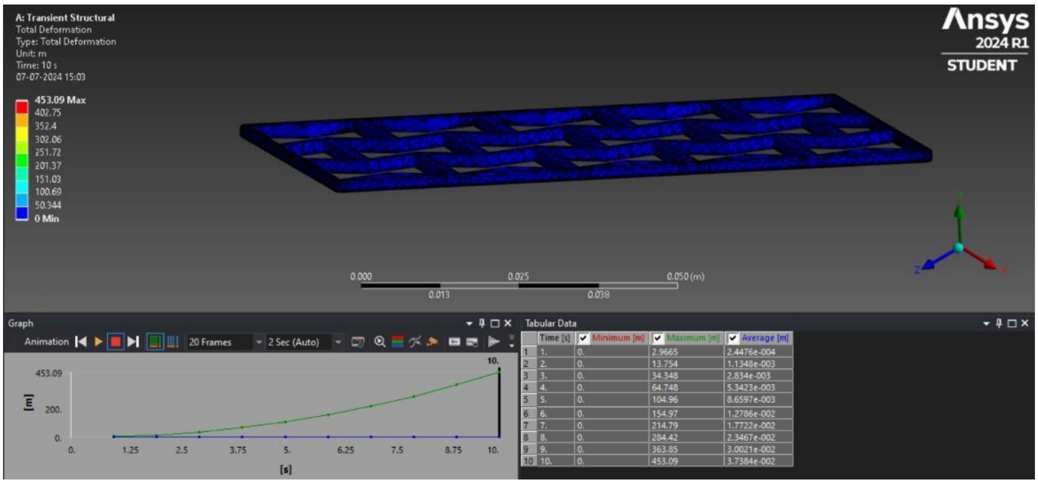

Auxetic Structure

DISCUSSIONS

Interpretation of FEA Results in the Context of Lattice Metamaterials

The FEA results underscore the influence of lattice geometry on mechanical performance under impact conditions. The octet truss exhibits minimal deformation but concentrates stress, suitable for applications requiring high stiffness-to-weight ratios. In contrast, the re-entrant structure demonstrates exceptional energy dissipation through extensive plastic deformation, making it ideal for impact-resistant designs.

Comparison of Different Lattice Structures

Comparative analysis reveals that:

Octet Truss: Offers superior stiffness and load-bearing capacity but limited energy absorption capabilities.

Re-entrant Structure: Excels in energy dissipation and impact resilience, albeit with potential challenges in maintaining structural integrity post-deformation.

Honeycomb-like: Provides a balanced compromise between stiffness and deformation tolerance, suitable for diverse applications where weight reduction and structural robustness are critical.

Discussion on the Effectiveness of FEA in Predicting Real-World Behavior

FEA simulations align closely with experimental observations, validating its efficacy in predicting real-world behaviors of lattice metamaterials under dynamic loading conditions. However, challenges such as accurately capturing material nonlinearities, contact interactions, and boundary conditions remain pivotal for refining simulation accuracy and reliability.

CHAPTER 5: CONCLUSIONS

Summary of Findings from Drop Test Simulations

The drop test simulations conducted on various lattice metamaterials have provided valuable insights into their mechanical behavior under impact conditions. Key findings include:

Structural Response: Different lattice structures exhibit unique deformation patterns and stress distributions under dynamic loading.

Energy Absorption: Lattice geometries such as the re-entrant structure demonstrate superior energy dissipation capabilities, making them suitable for impact-resistant applications.

Stiffness and Strength: The octet truss displays high stiffness and load-bearing capacity, albeit with limited energy absorption compared to other configurations.

Concluding Remarks on the Mechanical Behavior of Lattice Metamaterials under Impact Conditions

The mechanical behavior of lattice metamaterials under impact is predominantly influenced by their geometric configuration and material properties. Lattice structures with complex geometries, such as re-entrant designs, excel in dissipating impact energy through extensive plastic deformation. In contrast, simpler geometries like the octet truss offer high stiffness and structural integrity but may exhibit limited tolerance to large deformations and energy absorption. The honeycomb-like structure presents a balanced compromise between stiffness and deformation resilience, suitable for applications requiring lightweight and robust materials.

In conclusion, the study underscores the significant potential of lattice metamaterials in enhancing mechanical performance under impact conditions. By leveraging advanced FEA simulations and experimental validations, this research contributes to optimizing lattice structure designs for diverse engineering applications. As technologies and methodologies continue to evolve, lattice metamaterials are poised to revolutionize industries seeking lightweight, durable, and efficient solutions for challenging environments.

SCOPE FOR FUTURE WORK

1. **Advanced Material Modeling:** Incorporating more sophisticated material models in FEA to accurately capture nonlinear behaviors, strain rate effects, and failure criteria specific to lattice metamaterials.

2. **Multi-scale Analysis:** Integrating multi-scale approaches to investigate the influence of microstructural features on macroscopic mechanical properties and performance under dynamic loading.

3. **Experimental Validation:** Conducting comprehensive experimental validation studies to corroborate FEA predictions and refine simulation methodologies for enhanced accuracy and reliability.

4. **Optimization Strategies:** Developing optimization algorithms to tailor lattice structures for specific performance metrics such as energy absorption, stiffness-weight ratio, and impact resilience.

5. **Real-World Applications:** Extending research efforts to real-world applications such as aerospace structures, automotive crashworthiness,

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