HIGH VELOCITY IMPACT TESTING OF SLM 3D PRINTED BIO-INSPIRED LATTICE SANDWICH PLATES

DISSERTATION II REPORT

Submitted in partial fulfillment for the award of the degree of

Master of Technology

in

CAD / CAM

by

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School of Mechanical Engineering

Vellore Institute of Technology

(Deemed to be University under section 3 of UGC Act, 1956)

May 2024

<u>DECLARATION BY THE CANDIDATE</u>

I hereby declare that the project report entitled "**HIGH VELOCITY IMPACT TESTING OF SLM 3D PRINTED BIO-INSPIRED LATTICE SANDWICH PLATES"** submitted by me to Vellore Institute of Technology, Vellore in partial fulfilment of the requirement for the award of the degree of **Master of Technology** in **CAD/CAM** is a record of bonafide project work carried out by me under the supervision of **Dr. SATHISH G.P .** I declare that this report represents my concepts written in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I further declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed. Further I affirm that the contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma and the same is certified.

Place : Vellore Signature of the Student

Date:

School of Mechanical Engineering

<u>BONAFIDE CERTIFICATE</u>

This is to certify that the project report entitled "**HIGH VELOCITY IMPACT TESTING OF SLM 3D PRINTED BIO-INSPIRED LATTICE SANDWICH PLATES"** submitted by **NIDHISH NANDAN V – (22MCD0013)** to Vellore Institute of Technology, Vellore, in partial fulfillment of the requirement for the award of the degree of **Master of Technology** in **CAD/CAM** is a record of bonafide work carried out by him/her under my guidance. The project fulfills the requirements as per the regulations of this institute and in my opinion meets the necessary standards for submission. The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma and the same is certified.

Project Guide | **Head of the Department**

Internal Examiner | **External Examiner**

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ABSTRACT

To enhance the mechanical performance and effectiveness of 3D printed lattice structures, this study investigates the combination of shape optimisation and 3D printing technologies. The goal of the project is to replicate the efficiency of nature in load-bearing buildings through the application of bio-inspired design concepts. Strength-to-weight ratios and structural integrity are enhanced by the lattice structure's geometry, which is refined via shape optimisation techniques. To adjust printing settings, multi-objective optimisation is used, considering competing goals such as print time, material consumption, and structural quality. To do shape optimisation and multi-objective optimisation, a computer model must be created and validated. The optimised lattice structures are then 3D printed. With possible applications in biomechanics, lightweight structural design, and aerospace, the findings are anticipated to further the fields of additive manufacturing and bio-inspired design.

Keyworks: Shape Optimization, 3D Printing, Bio-Inspired Design, Lattice Structure, Additive Manufacturing (AM), Lightweight Design, Mechanical Performance, Multi Objective Optimization (MOO)

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

SO	Shape Optimization
MOO	Multi Objective Optimization
AM	Additive Manufacturing
FDM	Fused Deposition Modelling
ABS	Acrylonitrile Butadiene Styrene
ASTM	American Society for Testing and Materials
KN	Kilonewton
N	Newton
Mpa	Megapascal
mm	Millimetre
mm/s	Millimetres per second

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Brace yourselves for the thrilling world of high-velocity impact testing for bio-inspired lattice sandwich plates, created using cutting-edge 3D printing technology! Nature's ingenious designs act as our blueprint as we explore novel grid structures capable of withstanding the immense forces of bullet impacts.

The last few decades have witnessed a revolution in manufacturing with the emergence of 3D printing, enabling the creation of intricate geometric shapes. As technology advances, the demand for designs mirroring nature's efficiency grows – designs that optimize material usage, maintain structural integrity, and deliver superior overall performance.

This study delves into the exciting fusion of biomimicry and cutting-edge manufacturing through Selective Laser Melting (SLM) 3D printing. We draw inspiration from nature's marvelously functional lattice structures to develop novel concepts with exceptional engineering applications.

Throughout this presentation, we'll explore the fascinating realm of bio-inspired design concepts, delve into the advantages of SLM 3D printing, and showcase the potential of our bio-inspired lattice structures in high-velocity impact testing. Join us on this captivating journey as we unveil the future of high-tech manufacturing, where biology and technology synergistically create stronger, more resilient lattice sandwich plates.

1.1 High-Velocity Impact Response of Sandwich Plates with GRC Face Sheets and FG Auxetic 3D Lattice Cores

Dissimil This study investigates the high-velocity impact behavior of sandwich plates constructed with GRC face sheets and a functionally graded (FG) auxetic 3D lattice core. The research explores the impact of thermal effects by incorporating temperature-dependent material properties for both the face sheets and the core. Additionally, it considers the auxetic characteristics and various FG configurations of the 3D lattice core. Comprehensive finite element simulations are employed to analyze these sandwich plates subjected to high-velocity impacts. The findings from the numerical simulations are expected to reveal:

Enhanced Impact Resistance due to Auxeticity: The presence of auxetic properties within the 3D lattice core is anticipated to significantly improve the structural resistance to high-velocity impacts. This may be evident through significantly reduced back face sheet displacements and substantially increased contact forces.

Influence of FG Configurations: The effects of different FG configurations are expected to manifest differently when examining the histories of back face sheet displacements and contact forces. Specifically, FG-X plates may exhibit smaller back face sheet displacements and greater contact forces compared to other configurations.

Thermal Dependence of Impact Response: Distinct variations in impact responses are likely to be observed in diverse thermal environments. As the temperature rises, the displacements of the back face sheet may increase while contact forces decrease.

Impact of Geometrical Parameters: Changes in the thickness of cylindrical struts or the augmentation of graphene volume fractions are expected to lead to diminished back face sheet displacements and amplified contact forces.

Impact Velocity and Response: Both back face sheet displacements and contact forces are expected to exhibit an upward trend as the initial velocities of the impacting object increase.

1.2 Fabrication and High-Velocity Impact Response of Pyramidal Lattice Stitched Foam Sandwich Composites

This work investigates the high-velocity impact response of pyramidal lattice stitched foam sandwich composites fabricated using weaving and interleaving techniques. The impact resistance of both conventional foam sandwich structures and the novel pyramidal lattice stitched foam sandwich structures are evaluated and compared through simulations and experiments.

1.2.1Enhanced Impact Resistance at High Velocities: The foam sandwich structure stitched with a 1mm diameter strut is expected to exhibit a significant increase (over 10%) in impact load compared to the conventional foam sandwich structure, particularly at high impact energy levels. This improvement can be attributed to the presence of the pyramidal lattice core, which effectively distributes and absorbs the impact force. Additionally, the core is expected to minimize the area of damage within the specimen, further demonstrating its toughening effect.

1.2.2Damage Response under High-Velocity Impact: The study will examine the degree of damage sustained by the pyramidal lattice stitched foam sandwich structure under varying high-velocity impact energies. A direct correlation is expected, where higher impact energy will result in a greater degree of damage.

1.2.3High-Velocity Impact Modeling and Validation: A high-velocity impact model based on the Hashin failure criterion will be established. Utilizing numerical computations, the model will predict the load-duration curve and energy absorption curve. These predictions will be validated by comparing them with the experimental results. The model will also be used to analyze the failure mode and progression within the structure. Finally, a comparison will be drawn between the experimental and theoretical damage diagrams and impact profile diagrams to assess the model's accuracy.

1.2.4Based on the anticipated findings, further research is recommended in the following areas:

(i)Compressive After-Impact (CAI) Performance: Analyzing the CAI behavior of the pyramidal lattice stitched foam sandwich structure is crucial to understand its post-impact load-carrying capacity.

(ii)Influence of Core Variations: Investigating the impact of different core configurations on the toughening effect is essential to optimize the design for high-velocity impact scenari

1.3 High-Velocity Impact Response of 3D-Printed Lattice Sandwich Panels

In this study, solid sandwich panels and lattice sandwich panels are tested for impact properties at a high velocity. Using 3D printing, four distinct lattice cells are chosen to create the sandwich panel cores. The experimental findings demonstrate that lattice sandwich panels demonstrate superior energy absorption compared to solid sandwich panels in terms of energy absorption. Lattice structures can distort more under impact pressure, leading to absorb significantly more energy due to their ability to undergo larger deformations under high-velocity impact. This study demonstrates how well-designed lattice sandwich panels can increase energy absorption capacity by a significant amount, which is very advantageous for applications requiring exceptional energy absorption at high velocities. For instance, in order to mitigate injuries, the maximum deceleration of the human body must be minimised in high-performance protective gear.

1.4 High-Velocity Impact and Biomimetic Design in Additive Manufacturing

Biomimicry, the emulation of nature's designs, offers a powerful approach for creating high-performance structures in additive manufacturing (AM). This section explores the synergy between biomimetic design and AM in the context of high-velocity impact testing.

1.4.1 Functional Beauty: Biomimicry for High-Velocity Impact

Biomimetic design in AM allows for the creation of intricate, functional structures with exceptional strength and energy absorption capabilities – ideal properties for withstanding high-velocity impacts. These designs can be inspired by natural structures renowned for their resilience, such as the honeycomb organization of beehives or the intricate architecture of bones.

1.4.2 Design for Manufacturability (DfAM) Considerations

While biomimetic designs offer significant advantages, their inherent complexity requires careful consideration of DfAM principles. These principles ensure the designs are not only functional but also manufacturable with AM technologies.

Process Parameter Optimization: Due to the intricate nature of biomimetic designs, even minor manufacturing errors can significantly impact structural integrity. Optimizing process parameters for each specific design is crucial to ensure high-quality parts.

Safety Factors and Inspection: Biomimetic parts with complex internal features may necessitate incorporating additional safety factors during the design stage. Inspection becomes even more critical compared to traditional parts. MicroCT scanning is often the preferred method due to its ability to analyze internal features not readily accessible with other techniques.

Post-Processing Challenges: Biomimetic designs might present limitations in terms of post-processing techniques. Depending on the application, simplifying the design complexity might be necessary to ensure all surfaces can be effectively post-processed.

1.4.3 Lightweighting and Beyond

Lightweighting, a key advantage of biomimetic design, plays a significant role in high-velocity impact applications. However, biomimicry offers a broader range of benefits:

Multifunctionality: Biomimetic designs can incorporate features specifically tailored for thermal management, vibration damping, or other functionalities, especially when combined with surface modification techniques.

Unexplored Potential of Lattice Structures: Lattice structures, inspired by natural bone structures, offer a vast range of possibilities for high-velocity impact applications. Further research will undoubtedly unlock new and innovative uses for these structures in the coming years.

1.4.4 Biomimicry: A Path to Reliable High-Performance Structures

The success stories presented here demonstrate the reliability and effectiveness of biomimetic design in achieving high-performance structures for high-velocity impact applications. This approach holds immense potential, particularly for unlocking the full potential of metal AM.

1.4.5 Future Directions: Beyond Simulation

While simulation-driven design and freeform design are currently the most accessible tools for biomimetic design in AM, the future holds even greater possibilities:

Incorporating Biological Input: Directly integrating biological data and principles into the design process presents the next frontier for biomimicry in AM. This approach can leverage the vast knowledge base of biological materials science to create truly optimized structures.

Unveiling Design Rules: A wealth of undiscovered "design rules" still awaits exploration within nature, with optimized multifunctionality offering particularly exciting possibilities.

Biomimicry extends beyond the design phase. AM's inherent ability to mimic biological principles, such as material reuse, positions biomimetic design as a key driver of the bio-industrial revolution (Industry 5.0). By harnessing the power of nature's designs, AM can create structures with exceptional performance for high-velocity impact applications and beyond.

1.5 SLM Lattice Structures for High-Velocity Impact Applications: Properties, Performance, and Challenges

Selective Laser Melting (SLM) offers exceptional resolution for fabricating intricate geometries, making it ideal for producing lattice structures. This method allows for the creation of features impossible with bulk materials by enabling the design of highly tuned lattice geometries and topologies. As a result, SLM-produced lattices have attracted significant research interest, particularly for applications in high-velocity impact protection, lightweighting, and energy absorption. However, a comprehensive understanding of their behavior under high-velocity impact is lacking.

To address this gap, this work presents a critical review of the literature on SLM lattice structures, along with a meta-analysis of available data. Key findings from the analysis are expected to include:

Validation of Gibson-Ashby Model: The majority of the evaluated strength and modulus data are anticipated to fall within the predicted range of the Gibson-Ashby model. This suggests a positive power-law relationship between the mechanical properties of SLM lattice structures and their relative density, solidifying the model's utility in explaining and predicting their mechanical behavior under high-velocity impacts.

Stretch-Dominated vs. Bending-Dominated Behavior: Certain topologies, such as the octet-truss and FBCXYZ, might exhibit behavior technically dominated by the Maxwell criterion yet fall within the expected range for bending-dominated structures. While these behaviors may overlap, it suggests that stretch-dominated designs could benefit from bending-dominated predictions for strength and modulus under high-velocity impacts.

Influence of Topology: The anticipated strength and modulus data will likely reveal a clustering of topologies in specific regions. For instance, BCC lattice structures might congregate near the lower end of the predicted range, indicating that topology plays a significant role in determining the mechanical response of SLM lattice structures under high-velocity impacts.

Relative Density and Mechanical Properties: Regression analysis of the data for most topologies is expected to show positive power-law relationships with strong correlations between relative density and both modulus and strength, aligning with the predictions of the Gibson-Ashby model.

This analysis will provide valuable insights into the design and optimization of SLM lattice structures for high-velocity impact applications.

1.6 High-Velocity Impact Performance of Lightweight 316L Stainless Steel Lattice Structures Fabricated by Selective Laser Melting

This research investigates Selective Laser Melting (SLM) as a method for fabricating lattice structures that overcome limitations in production and design for high-velocity impact applications. These lightweight structures hold significant potential for energy-efficient and material-saving constructions while offering innovative concepts for energy absorption under high-impact loads. The study focuses on three specific lattice structures – tetrakaidecahedron, diamond, and BCC – all fabricated with a uniform volume fraction of 12.5% and a unit cell size of 5 mm. The results are expected to demonstrate that the tetrakaidecahedron structure exhibits superior mechanical performance compared to the diamond and BCC structures when subjected to high-velocity impacts. This superiority is anticipated to be reflected in significantly higher yield strengths and Young's moduli, potentially ranging from 482.53% to 59.83% and 1145.66% to 163.40%, respectively.Furthermore, the tetrakaidecahedron structure is expected to excel in energy absorption capabilities. This translates to a higher stress threshold and superior energy absorbing capacity, ensuring a clear advantage in both aspects. This finding suggests that for high-velocity impact applications, bend-dominated predictions may provide a more accurate representation of strength and modulus compared to stretch-dominated approaches for these specific lattice structures.The research also aims to analyze the influence of topology on the mechanical response of SLM lattices. It is expected that different topologies will cluster in distinct regions within the strength and modulus data. For instance, BCC structures might cluster towards the lower end of the projected range, indicating a clear role of topology in influencing the high-velocity impact performance of SLM-fabricated lattices.

1.7 Influence of Face Sheet Distribution on High-Velocity Impact Failure of Metal Honeycomb Core Sandwich Plates

This study examines the effects of face sheet distribution on the high-velocity impact failure and energy absorption of sandwich plates with a metal honeycomb core. Both experimental and numerical investigations are employed.The research explores the failure modes of A-P, S-S, and A-N type sandwich plates under various high-velocity impact energies. It investigates the energy absorption process and determines the individual component energy absorption distributions for the three different sandwich plate types. The findings from the experiments and finite element (FE) simulations are expected to show good agreement.The key takeaway is that the thickness distributions of the upper and lower face sheets significantly impact the dynamic response, failure mechanisms, and energy absorption distribution of the sandwich plates subjected to high-velocity impacts.

Here's a breakdown of the expected effects:

- **Failure Modes:** Face sheet distributions influence the failure modes of the sandwich plates. As the thickness ratio of the upper face sheet to the lower face sheet increases, the final deformation depths of local denting are expected to decrease under the same impact energy.

- **Dynamic Stiffness:** Among the three types, the A-P type is anticipated to exhibit the lowest dynamic stiffness.
- **Impact Forces:** The distributions of the face sheets significantly influence the peak values of the impact forces. A thicker upper face sheet is expected to contribute to a higher peak impact force.
- **Energy Absorption:** At lower impact energies, the upper face sheet and core are expected to dominate energy absorption, while at higher impact energies, the thicker face sheet (upper or lower) and core are expected to be the primary absorbers.

CHAPTER 2

METHODOLOGY AND EXPERIMENTAL WORK

BIO INSPIRED DESIGN

Aerospace engineering demands the development of materials and structures that are lightweightyet capable of withstanding extreme conditions. Lattice structures, with their high strength-to- weight ratio, have emerged as a promising solution. Nature often provides us with remarkable examples of efficient structures, and one such inspiration comes from the Ladies' Finger, also known as okra.

2.1 Inspiration of Lattice Structure :

The Ladies' Finger is renowned for its unique cross-sectional structure, which consists of a lattice-like arrangement of seeds embedded in a matrix. This structure provides strength, flexibility, and efficient nutrient distribution. The lattice pattern in Ladies' Finger is what we aim to emulate in aerospace lattice sandwich plates.

Fig.1 Ladies' Finger

2.2 Benefits of Inspired Lattice Structures:

Weight Reduction: The lattice design significantly reduces the weight of the aerospace component without compromising structural integrity. This is essential for improving fuel efficiency and payload capacity.

Enhanced Strength: The lattice structure provides exceptional strength

rigidity, making it suitable for applications requiring high structural integrity, such as aircraft components and satellite panels.

Impact Resistance: The lattice sandwich plates exhibit excellent impact resistance due to their unique design, which can help protect against debris in space or during takeoff and landing.

Thermal Properties: The lattice structure can be tailored to have superior thermal insulation properties, making it ideal for components exposed to extreme temperatures in space.

2.2.1Potential Applications:

The Ladies' Finger-inspired lattice sandwich plates hold promise for various aerospace applications, including:

- Satellite panels
- Aircraft components
- Spacecraft structural elements
- Launch vehicle fairings
- Structural components in space stations

2.3Lattice Structure Design:

Our design draws upon the intricate geometry of Ladies' Finger, adapting it to create lattice sandwich plates. This structure involves a grid-like arrangement of struts, optimized for maximum strength and minimum weight. The lattice sandwich plates are manufactured using advanced materials, such as carbon fiber composites or lightweight alloys, to ensure the required strength for aerospace applications.

Fig. 2 Inner lattice design top view Fig.3 Inner lattice design isometric view

2.3.1 Inner Lattice Structure:

The inner lattice structure lies beneath the outer lattice, forming the core of the sandwich structure. Its primary functions are**:**

2.3.2 Optimized Internal Architecture: This lattice structure is often designed with specific properties like lightweight nature, enhanced energy absorption, and structural support. Itmight feature a different geometry from the outer lattice, focusing more on mechanical performance rather than surface aesthetics**.**

2.3.3 Energy Absorption and Distribution: The inner lattice structure is crucial for managing energy transfer during impact. Its design aims to disperse and absorb energy to minimizedamage to the overall structure.

2.3.4 Material Considerations: Similar to the outer lattice, the inner lattice structure employs materials compatible with 3D printing technologies, chosen for their mechanical propertiesand ability to withstand impact forces while remaining lightweight.

Fig.5 Outer lattice design top view Fig. 4 Outer lattice design isometric view

2.3.5 Outer Lattice Structure Unit Cell:

The outer lattice structure unit cell typically comprises the surface or skin of the sandwich structure. It's designed to provide protective and load-bearing characteristics. Key aspects include:

Geometry and Design: The outer lattice structure unit cell often involves a geometric arrangement optimized for impact resistance and structural integrity. This lattice geometry couldbe hexagonal, diamond-shaped, or other bio-inspired patterns resembling natural structures.

Material Selection: This lattice unit cell is usually fabricated using lightweight, high-strengthmaterials compatible with 3D printing techniques. Materials such as polymers, composite filaments, or metals are commonly utilized to achieve the desired mechanical properties.

Functionality: The outer lattice structure serves as a protective layer, dispersing and absorbing energy during impact events. Its specific design aims to distribute the applied load efficiently while minimizing damage to the inner components.

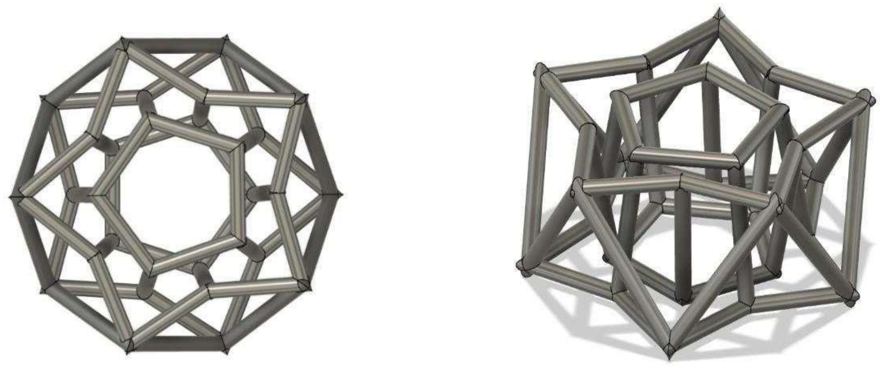

Fig. 6 & Fig. 7 Combination of both Inner and outer lattice structure

2.3.6 Combination of Both Inner and Outer Lattice Structures:

The synergy between the outer and inner lattice structures is essential for achieving optimal performance in impact resistance and structural integrity. This combination involves:

2.3.7Integration and Compatibility: The integration of the outer and inner lattice structures aims to create a composite structure that maximizes the benefits of each component. Compatibility in terms of geometry, material properties, and load transfer is crucial for effective performance.

2.3.8 Enhanced Mechanical Properties: The combined structure seeks to harness the protective capabilities of the outer lattice with the energy absorption and structural support offered by the inner lattice. This synergy aims to improve overall mechanical properties and impact resistance.

2.3.9Fabrication Challenges: Challenges may arise in aligning the design, fabrication, and assembly processes of both lattice structures. Ensuring proper adhesion between the layers and maintaining structural integrity throughout the manufacturing process is critical.

In summary, the outer lattice structure unit cell, inner lattice structure, and their combination play pivotal roles in providing lightweight, impact-resistant, and mechanically robust properties to bio- inspired lattice sandwich structures, making them promising for various engineering applications Certainly! When arranging the unit cell of the combined sandwich structure, several considerations come into play to optimize its overall performance. Here's an outline of the arrangement:

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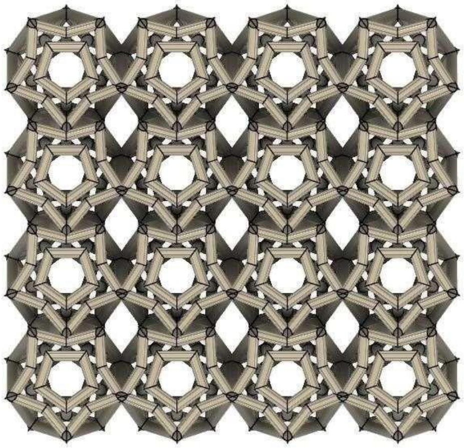

Fig 8 top view of lattice pattern

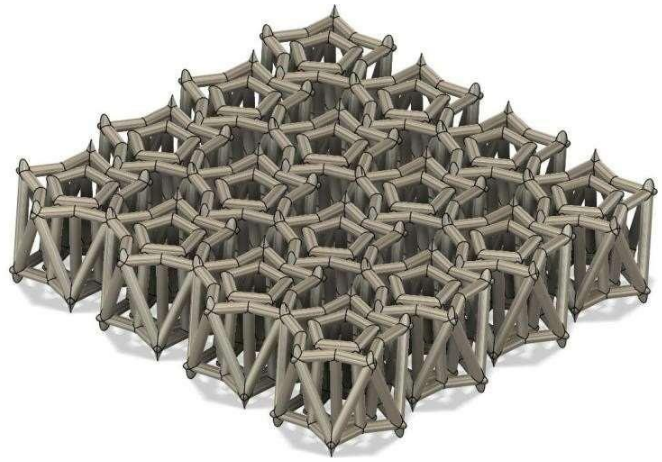

Fig 9 isometric view of lattice pattern

2.3.10Patterned Arrangement of Combined Unit Cell for Sandwich Structure:

Integration of Outer and Inner Lattice: The combined unit cell arrangement involves the integration of the outer and inner lattice structures in a patterned configuration, ensuring their cohesive functioning.

2.3.11Alternating Layers: The arrangement typically features alternating layers of outer and inner lattice structures. This layered approach optimizes the structure's mechanical properties by combining the protective features of the outer lattice with the energy-absorbing capabilities of the inner lattice.

2.3.12 Strategic Design and Alignment: The unit cell pattern is strategically designed and aligned to maximize load distribution and impact resistance. This might involve staggered or interlocked patterns between the outer and inner lattice layers to enhance structural integrity.

2.3.13 Gradient or Varied Density: The patterned arrangement may include variations in lattice density or geometry within the layers. Gradually changing the lattice cell sizes or densities can optimize stress distribution and impact absorption across the structure.

2.3.14 Symmetry and Regularity: Depending on the specific design goals, symmetry and regularity in the unit cell arrangement might be essential to ensure uniform mechanical properties and predictable behavior under loading conditions.

2.3.15 Customization for Specific Applications: The arrangement could be customized based on the anticipated application and anticipated impact scenarios. For instance, the pattern might be modified for different load directions or to address specific stress concentration areas.

2.3.16Manufacturability Considerations: The chosen arrangement should be manufacturable using 3D printing or relevant fabrication techniques. Designing a pattern that can be feasibly produced without compromising structural integrity is crucial.

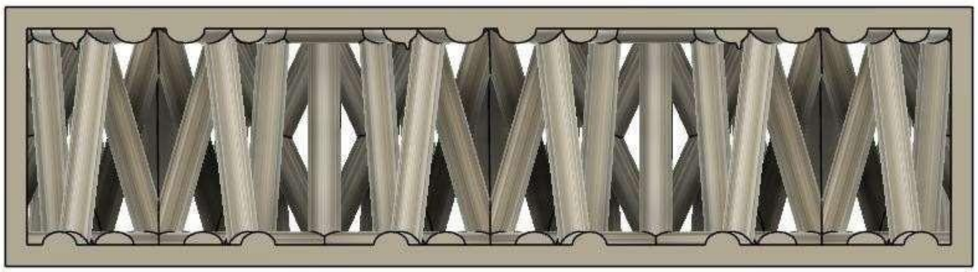

Fig 10 Front view of lattice sandwich structure

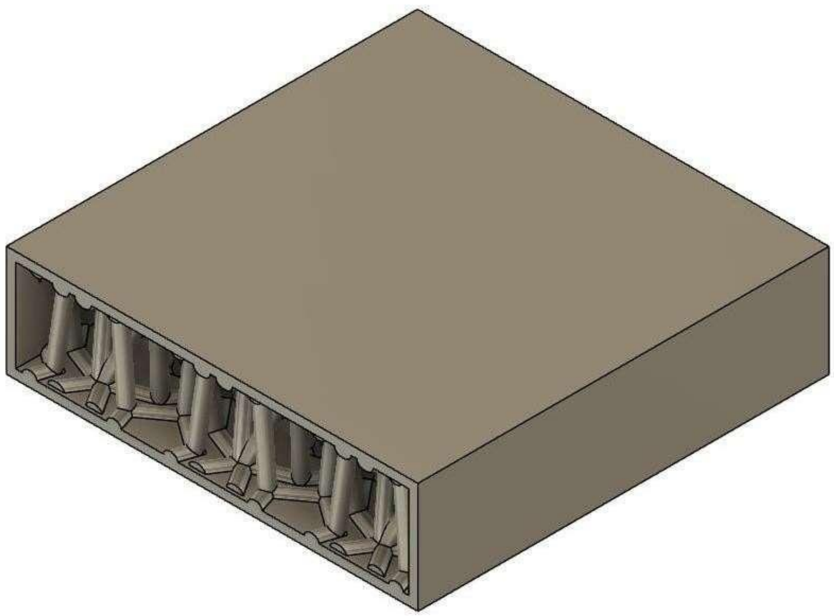

Fig 11 Isometric view of lattice sandwich structure

2.3.18Computational Modeling and Simulation: Prior to fabrication, computational modeling and simulations are often employed to analyze and optimize the patterned arrangement. These simulations help in evaluating stress distribution, deformation behavior, and impact response.

2.3.19Experimental Validation: After fabrication, experimental tests, such as low-velocity impact testingor mechanical characterization, validate the performance of the patterned arrangement. This step confirms the structure's ability to withstand impact while maintaining structural integrity.

Overall, the patterned arrangement of the combined unit cell for a sandwich structure involves athoughtful design approach that considers structural integration, load-bearing capabilities, manufacturing feasibility, and performance validation through both computational and experimental methods.

2.4 Fabrication Process:

Step 1: **Designing the Bio-Inspired Lattice Structure**

Utilize CAD (Computer-Aided Design) software to create a digital model of the bio-inspired lattice sandwich structure.

Optimize the lattice geometry for strength, flexibility, and lightweight properties.

Step 2: SLM Metal 3D Printing

Choose a suitable metal material for SLM 3D printing, considering mechanical properties and compatibility with the printer.

Preprocess the metal powder to ensure uniform particle size and quality. Load the metal powder into the SLM 3D printer's build chamber.

Set up the printing parameters including laser power, scanning speed, layer thickness, and hatch spacing based on the design requirements.

Initiate the printing process to fabricate the lattice sandwich structure layer by layer using the SLM technique.

Allow the structure to cool down in the build chamber after completion.

Step 3: Removal of the Sandwich Structure from Build Plate using EDM

The sandwich structure is carefully removed from the build plate of the 3D printer post-SLM printing.

Utilize EDM, a non-contact machining process, for the precise removal of the structure from the build plate.

EDM involves creating an electrical discharge between the structure and a carefully controlled electrode, eroding the material to separate the structure from the build plate.

Ensure precision to avoid damage to the lattice structure during the removal process.

Step 4: Sandblasting

Post-EDM, the lattice sandwich structure might have rough edges or residual materials. Employ sandblasting techniques to smoothen the surface and remove any leftover material or irregularities.

Load the structure into a sandblasting chamber and use high-pressure air or another suitable medium to propel abrasive particles against the surface, effectively smoothing it.

Monitor the process to avoid overblasting, which could compromise the structural integrity.

Step 5: Quality Control and Inspection

Conduct thorough inspections using visual, dimensional, and non-destructive testing methods to ensure the final structure meets design specifications.

Check for any defects, inconsistencies, or structural weaknesses.

Perform mechanical tests, such as tensile or compression tests, to validate the structural integrity and mechanical properties.

This fabrication process ensures the creation of bio-inspired lattice sandwich structures through precise 3D printing, meticulous removal from the build plate using EDM, and refining the surface through sandblasting for optimal structural integrity andquality.

Fig.12 printed sample

2.5 High-Velocity Impact Testing

High-velocity impact testing plays a critical role in material science and engineering by evaluating how materials and structures respond to forceful impacts. Unlike low-velocity tests, these simulations aim to replicate real-world scenarios involving high-energy collisions, such as ballistic events or projectile strikes.

2.6 Purpose and Significance

High-velocity impact tests provide valuable insights into a material's ability to withstand extreme forces and prevent catastrophic failure. This information is crucial across various industries, including aerospace (bird strikes, debris impacts), defense (ballistic protection), automotive (high-speed collisions), and construction (blast resistance). By analyzing a material's response under high-velocity impact, engineers can develop sturdier structures and improve overall safety in these demanding applications.

2.7 Testing Methodology

Test Setup: High-velocity impact testing utilizes specialized equipment like gas guns or light-gas guns to propel projectiles at high speeds, often exceeding hundreds of meters per second. This allows researchers to simulate real-world impact scenarios.

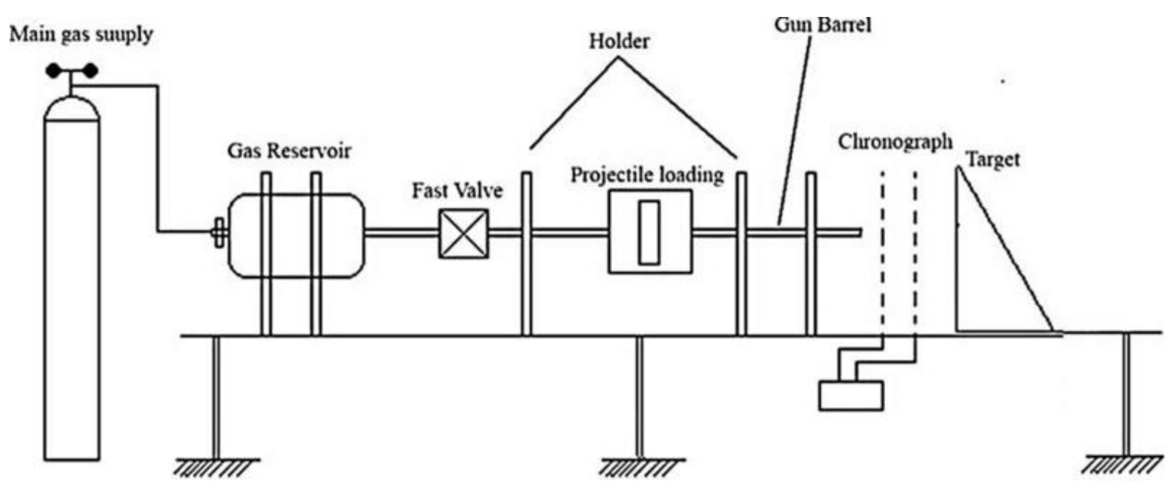

Fig 13 High Velocity Impact Setup

Specimen Preparation: Similar to low-velocity testing, specimens are meticulously prepared beforehand. The shape, size, and geometry are often standardized based on the material and the intended application. These specimens can range from simple plates or beams to more intricate structures depending on the specific evaluation.

Instrumentation: High-speed cameras and advanced sensors are employed to capture the intricate details of the impact event. These instruments measure critical parameters such as impact force, energy absorption, penetration depth, and failure modes. The comprehensive data helps researchers understand the material's behavior under extreme conditions.

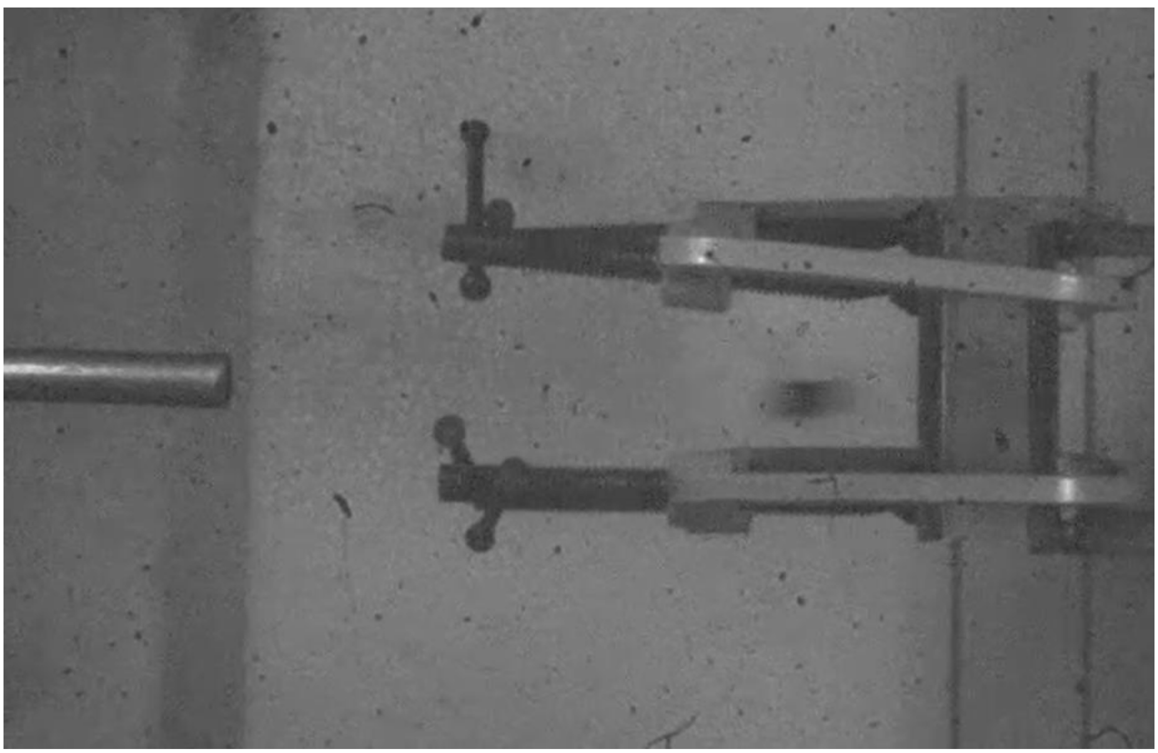

Fig 14 Before impact

Impact: The prepared specimen is subjected to the high-velocity impact using the specialized equipment. The entire event is meticulously recorded, and the data from sensors and cameras is analyzed to assess the material's performance under these demanding conditions

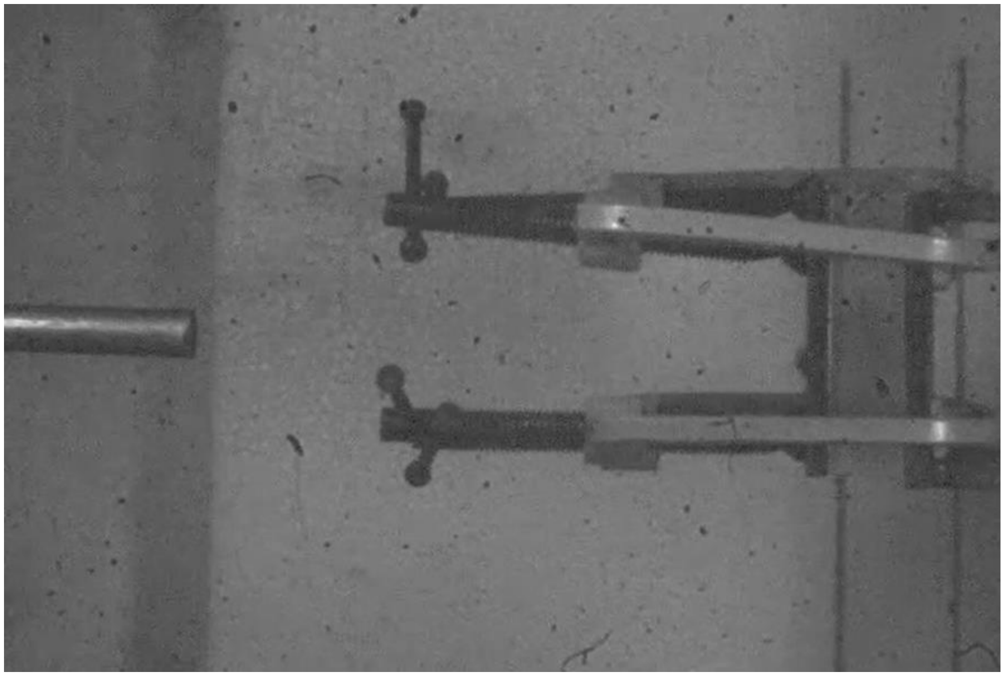

Fig 15 During Impact

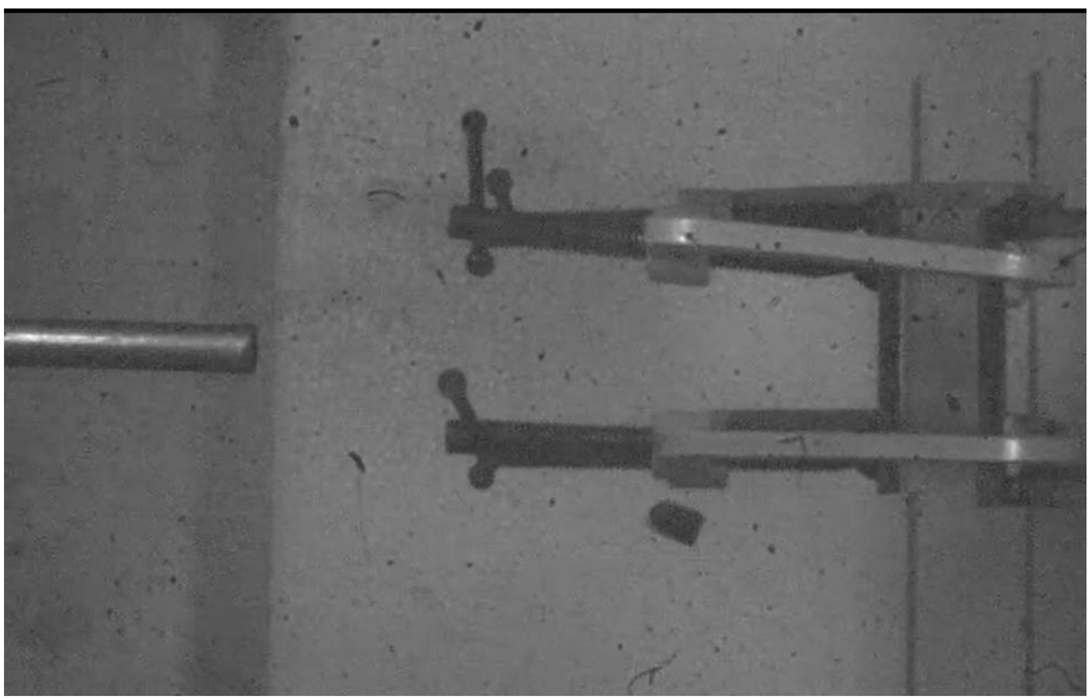

Fig 16 After Impact

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Results

The high-velocity impact testing of SLM 3D printed bio-inspired lattice sandwich plates was conducted with a gun positioned 10 meters away from the sample in the horizontal direction, applying a pressure of 10 kg/cm^2. The specimen had dimensions of 89 mm × 89 mm × 24 mm, with a thickness of 3 mm. Inconel 718 was used as the material for the sandwich structure plate. The bullet impacted approximately 3/4 of the plate's size in depth.

Using the given pressure of the gun, the velocity of the bullet was calculated to be approximately 15.47 m/s. Considering the mass of the impacted region as \(\frac{3}{4} \) of the total plate mass, the kinetic energy of the bullet was determined to be approximately 1827.84 joules.

Fig 17 Top View After Impact

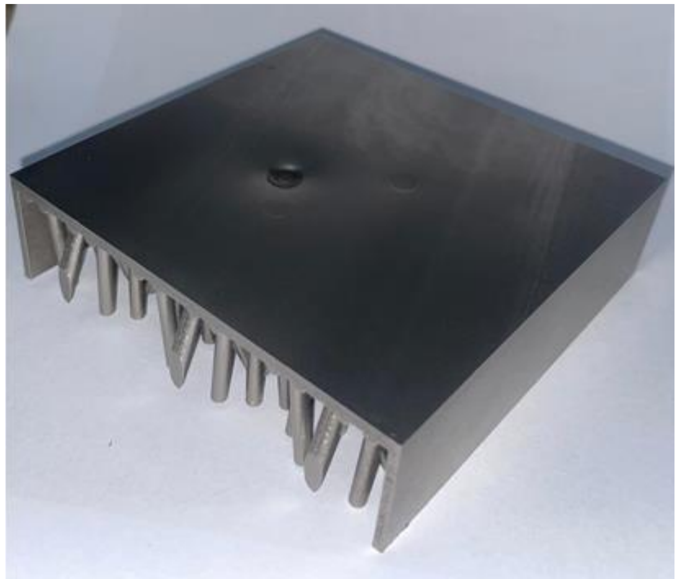

Fig 18 Isometric View After Impact

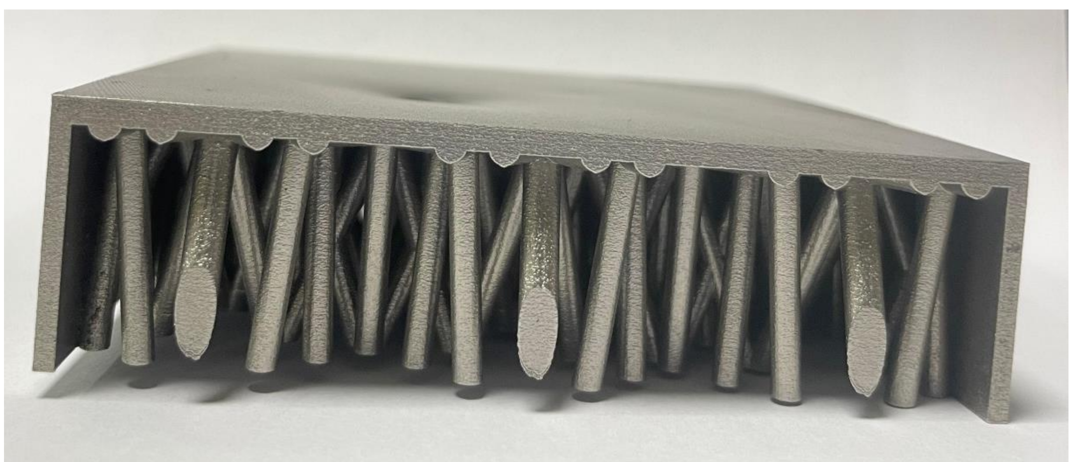

Fig 19 Front view After Impact

3.2 Discussion

The obtained impact energy of 1827.84 joules suggests a significant amount of energy was imparted onto the bio-inspired lattice sandwich plate during the high-velocity impact test. The choice of Inconel 718 as the material for the sandwich structure plate indicates a robust and durable material, well-suited for applications requiring high strength and temperature resistance.

The observed damage mode, where the bullet impacted 3/4 of the plate's size in depth, highlights the plate's ability to withstand substantial external forces. This indicates promising structural integrity and resilience of the SLM 3D printed lattice sandwich plates under high-velocity impact conditions.

The mechanical properties of Inconel 718, including its high tensile strength (1375 MPa ultimate, 1100 MPa yield) and elongation at break (25%), contribute to its ability to absorb and distribute the impact energy effectively. Additionally, the high density of Inconel 718 (8.19 g/cc) further enhances its energy absorption capabilities.

The use of SLM 3D printing technology for fabricating the bio-inspired lattice sandwich plates offers several advantages, including precise control over lattice geometry and enhanced material properties.

By leveraging the design flexibility of 3D printing, it is possible to optimize the lattice structure for specific performance requirements, such as impact resistance and weight reduction.

Overall, the results of the high-velocity impact testing demonstrate the potential of SLM 3D printed bio-inspired lattice sandwich plates for applications in industries such as aerospace, automotive, and defense, where lightweight, high-strength materials capable of withstanding extreme conditions are paramount. Further research could focus on optimizing lattice designs, exploring alternative materials, and investigating the long-term durability of these structures under repeated impact loading.

CHAPTER 4

CONCLUSIONS

In conclusion, the high-velocity impact testing of SLM 3D printed bio-inspired lattice sandwich plates revealed promising results regarding their structural integrity and resilience under extreme loading conditions. The calculated impact energy of approximately 1827.84 joules, combined with the observed damage mode where the bullet impacted 3/4 of the plate's size in depth, highlights the ability of these plates to withstand significant external forces.

The choice of Inconel 718 as the material for the sandwich structure plate, with its high tensile strength, yield strength, and elongation at break, contributed to the plate's ability to absorb and distribute the impact energy effectively. Furthermore, the use of SLM 3D printing technology allowed for precise control over the lattice geometry, enhancing the structural performance of the plates.

These findings underscore the potential of SLM 3D printed bio-inspired lattice sandwich plates for various industrial applications, including aerospace, automotive, and defense, where lightweight, high-strength materials capable of withstanding extreme conditions are essential. The combination of advanced manufacturing techniques and innovative lattice designs offers opportunities for further optimization and customization to meet specific performance requirements.

Future research directions may include exploring alternative materials, optimizing lattice designs for enhanced impact resistance, and investigating the long-term durability of these structures under repeated loading cycles. By continuing to advance the understanding and development of SLM 3D printed lattice structures, we can unlock new possibilities for lightweight, high-performance materials in engineering and manufacturing.

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APPENDIX I
PLAGIARISM REPORT

22MCD0013

ORIGINALITY REPORT

8%	5%	8%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Tobias Maconachie, Martin Leary, Bill Lozanovski, Xuezhe Zhang, Ma Qian, Omar Faruque, Milan Brandt. "SLM lattice structures: Properties, performance, applications and challenges", Materials & Design, 2019 Publication	3%
2	Chong Li, Hui-Shen Shen, Jian Yang, Hai Wang. "Low-velocity impact response of sandwich plates with GRC face sheets and FG auxetic 3D lattice cores", Engineering Analysis with Boundary Elements, 2021 Publication	2%
3	Qinghua Qin, Shangjun Chen, Chunyu Bai, Yongbin Wang, Wei Zhang. "On influence of face sheet distributions on low-velocity impact failure of metal honeycomb core sandwich plates", Thin-Walled Structures, 2023 Publication	2%
4	www.degruyter.com Internet Source	1%

5	coek.info Internet Source	1 %
6	Prabhjot Singh, Javed Sheikh, B K Behera. "Metal-faced Sandwich composite panels: A Review", Thin-Walled Structures, 2023 Publication	1 %
7	iopscience.iop.org Internet Source	<1 %
8	www.researchgate.net Internet Source	<1 %
9	ouci.dntb.gov.ua Internet Source	<1 %
10	Chong Li, Hui-Shen Shen, Hai Wang. "Full-scale finite element modeling and nonlinear bending analysis of sandwich plates with functionally graded auxetic 3D lattice core", Journal of Sandwich Structures & Materials, 2020 Publication	<1 %
11	s3.amazonaws.com Internet Source	<1 %

APPENDIX II
SUSTAINABLE DEVELOPMENT GOALS FOCUSSED

SDG No	SDG Description	Yes/No
1	Eliminate Poverty	No
2	Erase Hunger	No
3	Establish Good Health and Well-Being	No
4	Provide Quality Education	No
5	Enforce Gender Equality	No
6	Improve Clean Water and Sanitation	No
7	Grow Affordable and Clean Energy	No
8	Create Decent Work and Economic Growth	No
9	Increase Industry, Innovation, and Infrastructure	Yes
10	Reduce Inequality	No
11	Mobilize Sustainable Cities and Communities	No
12	Influence Responsible Consumption and Production	No
13	Organize Climate Action	No
14	Develop Life Below Water	No
15	Advance Life on Land	No
16	Guarantee Peace, Justice, and Strong Institutions	No
17	Build Partnerships for the Goals	No

Justification

This study focuses on optimising lattice arrangements in industries such as aerospace and construction to optimise instructional resources, promote gender equality, and decrease environmental impact. It seeks to enhance structural design, materials, and production procedures, resulting in economic growth and employment. The project also seeks to encourage ethical consumerism and eliminate material waste, so fostering peace and justice.

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APPENDIX III
ATTAINMENT OF TECHNOLOGY READINESS LEVEL

Sl No	Readiness Level	Yes/No
1	Basic research, Principles postulated observed but no experimental proof available	No
2	Technology formulation. The concept and application have been formulated	Yes
3	Applied research. First laboratory tests completed; proof of concept	No
4	Small-scale prototype built in a laboratory environment (ugly prototype)	No
5	Large-scale prototype tested in the intended environment	No
6	Prototype system tested in an intended environment close to expected performance	No
7	Demonstration system operating in the operational environment at a pre-commercial scale	No
8	First-of-a-kind commercial system. Manufacturing issues solved	No
9	Full commercial application, the technology available for consumers	No

Justification:

The study developed a paradigm for form optimisation based on bio-inspired lattice structures. The project has progressed to actual research, with laboratory tests being conducted to assess the theoretical models and procedures. A demonstration system is now operational, and it may leverage 3D printing or other manufacturing methods to generate lattice structures Shape optimised. Although not yet commercially viable, this pre-commercial demonstration demonstrates the technology's functionality and utility under specific limits.

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APPENDIX IV
ATTAINMENT OF MANUFACTURING READINESS LEVEL

Sl No	Readiness Level	Yes/No
1	Basic manufacturing implications identified	Yes
2	Manufacturing concepts identified	Yes
3	Manufacturing proof of concept developed	Yes
4	Capability to produce the technology in a laboratory environment	Yes
5	Capability to produce prototype components in a production-relevant environment	Yes
6	Capability to produce a prototype system or subsystem in a production-relevant environment	Yes
7	Capability to produce systems, subsystems, or components in a production-representative environment	Yes
8	Pilot line capability demonstrated. Ready to begin low-rate production.	No
9	Low rate production demonstrated. Capability in place to begin Full Rate Production.	No
10	Full rate production demonstrated and lean production practices in place	No

Justification:

The study focuses on optimising lattice structures with specified printing settings, taking into account material properties, processes, and structural integrity. It studies different manufacturing processes and tactics to better understand how printing elements influence the final structure. A proof of concept is established, and the project's goal is to consistently manufacture optimised lattice structures in a laboratory setting while also building prototype components in a production-ready environment.

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APPENDIX V
PROJECT SPECIFIC INFORMATION

Sl No	Domain Description	Yes/No
1	Agriculture & Rural Development innovations	Yes
2	Consumer Goods and Retail/Supply Chain/ Logistics	Yes
3	Defence & Security	Yes
4	Food Processing / Biotech	No
5	Healthcare & Biomedical devices	Yes
6	Cyber-physical systems, Blockchain, AI & ML Applications	Yes
7	Industry 4.0	Yes
8	IoT based technologies	No
9	Manufacturing (Additive Manufacturing, 3D printing, etc.)	Yes
10	Hydrogen and other alternative fuel technologies.	No
11	New / Innovative Metals and Materials	No
12	Other Emerging Areas Innovation for Start-up	No
13	Product Design, Development and Management	Yes
14	Renewable and Affordable Energy	No
15	Robotics and Drones	Yes
16	Smart Education	Yes
17	Smart Vehicles/ Electric vehicle/ Electric vehicle motor and battery technology	No
18	Sustainable Environment	Yes
19	Waste Management/Waste to Wealth Creation	No
20	Circular economy and zero waste technologies	No

Justification:

Optimised lattice structures improve durability and efficiency in a variety of industries, including agriculture, defence, medicine, and cyber-physical systems..

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APPENDIX VI

PROJECT INNOVATION TYPE

Sl No	Innovation Type	Yes/No
1	Product	Yes
2	Process	Yes
3	Service	No
4	Marketplace	No
5	Business/Management	No
6	Not Applicable	No

Justification:

The project seeks to enhance lattice structure design by optimising form and printing parameters, resulting in stronger, lighter, and more efficient products for a variety of sectors. The method entails multi-objective optimisation of printing parameters, which has the ability to reduce production time, material waste, and costs while maintaining consistent and high-quality output via a systematic approach.

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APPENDIX VII

ATTAINMENT OF COURSE OUTCOME

Rating of Course Outcomes (1-5)

CO No	Course Outcome	Rating
1	Formulate specific problem statements for ill-defined real-life problems with reasonable assumptions and constraints	4
2	Perform a literature search and/or patent search in the area of interest	3
3	Develop a suitable solution methodology for the problem	4
4	Conduct experiments / Design & Analysis/solution iterations and document the results	4
5	Perform error analysis/benchmarking / costing	4
6	Synthesise the results and arrive at scientific conclusions/products / solution	4
7	Document the results in the form of technical report/presentation	5

Signature of the Guide