International Journal of Mechanical and Sustainability Engineering Technology

Journal homepage:
https://uniexpertsacademy.com/index.php/IJMSET/index
ISSN: 3083-8363

Revolutionizing Lattice Core Sandwich Structures: From Design and Manufacturing to Static Behavior Under Concentrated Load

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ARTICLE INFO

Article history:
Received 05 January 2025
Received in revised form 10 January 2025
Accepted 21 January 2025
Available online 21 January 2025

Keywords:
sandwich beam, lattice core, static behavior, Finite elements modeling and 3D printer

ABSTRACT

Sandwich panels with core lattice are used in many engineering applications due to their excellent mechanical properties and light weight, there are fundamental challenges facing their use, the most important of which is the separation between the core and the faces, which limits their effectiveness in real conditions. In this study, a practical solution to this problem was presented by manufacturing sandwich panels as a single piece using 3D printing technology, which eliminates the need for traditional adhesives and enhances the structural integrity. The mechanical performance of these new structures under the influence of a concentrated load was analyzed through numerical simulation using ANSYS software and practical tests. The research focused on studying the effect of design factors such as the thickness of lattice struts, thickness of face sheets, and width of lattice unit cell, on the mechanical properties, including deformation, stress, and strain energy. The results showed a high agreement between the numerical simulation and practical tests, confirming the accuracy of the used numerical model. In addition, the results confirmed that the single-piece design leads to a significant improvement in stiffness and reduction of deformation and stresses, while achieving high energy efficiency. It was observed that increasing the thickness of the struts and faces enhances the stiffness, whereas, increasing the width of the lattice unit showed a mixed effect.

1. Introduction

The Composite materials are one of the most prominent innovations in modern engineering, as they have become used in almost all industries due to their light weight compared to the excellent mechanical properties, they provide [1]. Among the important applications of composite materials is the sandwich panel design, which is based on a three-layer construction: two outer layers that act as structural facades, and an inner core that plays a crucial role in reducing weight while maintaining high performance.[2], [3]. The sandwich panel core is characterized by its variety of shapes, allowing it to be used in different applications. The most prominent of these shapes is the hexagonal core, which provides high strength and low weight, making it suitable for applications that require a

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combination of strength and light weight [4], [5]. There is also the corrugated core that enhances structural stability and provides additional support [6], in addition to the foam core that is mainly used to achieve excellent thermal and sound insulation [7].

Recently, a new form of core known as the lattice core has emerged, which has added a new design dimension to sandwich panels. This type is characterized by its extreme lightness compared to other traditional forms, along with high resistance to stresses and vibrations, making it an ideal choice for dealing with various load conditions and harsh environments. These unique properties have prompted researchers to study this advanced design, as it is seen as an important step towards improving the performance of sandwich panels. Recent studies include a comprehensive analysis of its mechanical properties and response under the influence of dynamic loads and vibrations, in addition to evaluating its efficiency in practical applications such as the aerospace industry and advanced engineering infrastructure.

Several researchers have investigated the effect of different loads conditions on lattice core sandwich panels to improve their energy absorption efficiency and failure resistance. For example, low-velocity impacts loading, Jianfeng Li et. al. [8] studied the dynamic response and failure of Kagomi lattice CFRP panels under different impact shapes. The results showed that the shape and velocity of the impactor affected the energy absorption, with the flat impactor outperforming the impactor. Hossein Taghipoor et. al. [9] focused on the effect of the geometric dimensions of the lattice core on the absorption efficiency, where a 246% increase in energy absorption capacity was achieved by choosing the optimal design. On the other hand, Fatih Usta et. al. [10] analyzed the low-velocity impact behavior of sandwich panels equipped with lattice cores with auxetic and non- auxetic properties. The results showed that auxetic cores provided greater resistance and energy absorption under high impacts, while non- auxetic cores performed better under low-energy impacts due to their larger contact area and thicker walls. While the study of low-velocity impacts provides important insights into improving the energy absorption efficiency and failure resistance of lattice core sandwich panels, vibrations represent another aspect of critical dynamic loads that affect the stability and mechanical performance of these panels. For example, Hussam Raad and colleagues studied [11] the free vibration characteristics of lattice panels made of open and closed cells using finite element simulations. The results showed that the geometric design of the lattice core significantly affects the natural frequency and elastic modulus, and that the dynamic performance can be improved by optimizing the geometric ratios and selecting appropriate materials. In addition, Zewei Wu et. al. [12] addressed the free vibration of sandwich beams with periodic lattice cores using a dynamic model based on Bernoulli-Euler and Timoshenko theories, and the performance was optimized by the NSGA-II algorithm to achieve a balance between increasing the fundamental frequency and reducing the masses. Yuyang Chai et. al. [13] focused on studying the vibration characteristics of hierarchical lattice core sandwich panels supported by an elastic foundation. A precise dynamic model and a sliding support frame were developed to achieve the conditions of the fixed edges, and the results showed a high agreement between theoretical analysis, experiments and numerical simulations.

After analyzing the impact of shocks and vibrations, bending and compression are another type of critical loads that greatly affects the structural performance and stability of lattice core sandwich panels. Many researchers have studied the bending and compression behavior of these panels with the aim of improving their design to meet advanced applications. M. J. Khoshgoftar et. al. [14] studied the response of three-layer sandwich panels with a re-entrant core under bending load using zig-zag analytical theory, numerical simulations, and experimental studies. The results showed that the cores with negative Poisson's ratio behavior offered higher bending resistance and lower shear stress compared to conventional designs. Zhaobing Liu et. al. [15] proposed lightweight metal-polymer sandwich structures with 3D-printed lattice cores. The study showed that the body-centered cubic cores achieved higher stiffness and better energy absorption under bending load compared to other designs. Numerical simulations revealed a “stress diffusion” mechanism that improves load transfer between lattice units, making them suitable for high-performance applications. Jingwei Zhang et. al. [16] studied the flexural properties of metal sandwich panels with 3D CFRP cores. The results showed that core designs such as “dome” and “octet truss” are bendable and provide a lightweight alternative to conventional metal panels in engineering applications. Mahdi Sefidi and Hossein Taghipoor [17] studied the flexural behavior of sandwich panels with lattice cores under three-point loading. The failure mechanisms and the effect of cell thickness and core dimensions on energy absorption were analyzed. The results showed that the cell strand thickness significantly affects the compressive and shear strengths, with close agreement between the analytical predictions and the experimental and numerical results. Moreover, Researcher Qianqian Wu et.al. [18] studied the failure behavior of carbon fiber hierarchical lattice core sandwich cylinders under axial compressive loads. The study involved developing a 3D map of the failure mechanisms and confirming its accuracy through experiments, providing a powerful tool for improving the design of these structures against buckling failure. After studying the dynamic and static loads, some researchers have focused on the effect of thermal loads. Zhi-Jian Li and his colleagues [19] presented an analytical model for stresses in lattice sandwich panels under the influence of heat, and the study showed that the BCCZ cores recorded higher stresses compared to F2CCZ, which contributes to the improvement of the design to achieve optimal mechanical performance.

Despite numerous studies on the performance of lattice core sandwich panels under different loads, the problem of failure due to dislocation between the core and the two faces still exists. The present study aims to overcome this drawback by manufacturing sandwich beams as a unified structure using 3D printing, with a design that includes two faces and a lattice core consisting of vertical and inclined columns to distribute the loads effectively. The static response was analyzed in terms of deflection, von Mises stress, and strain energy, while studying the effect of geometric variables such as column thickness, face thickness, and unit cell width. In addition, a deflection test was conducted experimentally, and a simulation model was built using ANSYS, where the results showed excellent agreement with low error, confirming the accuracy and efficiency of the model.

2. Problem Statement

Lattice core sandwich beams are important engineering structures that combine light weight with high mechanical efficiency, making them ideal for advanced applications. However, these structures face a major challenge of dislocation between the lattice core and face layers due to weak adhesives. This failure reduces their structural efficiency and limits their use in applications that require high performance [3], [20], [21].

In the proposed design, the beam is manufactured as a unitized structure using 3D printing, which eliminates the need for adhesives and improves the bonding strength between components. The structure consists of two face layers and a lattice core consisting of vertical columns that bear axial loads and reduce deformation, and inclined columns that effectively distribute the loads between the different parts to enhance buckling resistance and improve energy absorption.

The focus of this study was on analyzing the mechanical performance by measuring static deformation, von Mises stress, and strain energy. Figure 1 shows the details of the proposed structure, showing the face layers and the lattice core consisting of vertical and inclined struts, highlighting the importance of the core design in achieving high mechanical stability. The geometrical values used, such as thickness of lattice struts (ts), Thickness of face sheets (tf), and Width of lattice unit cell (Wu), are shown in Table 1, and were chosen to optimize the structural performance and ensure design efficiency.

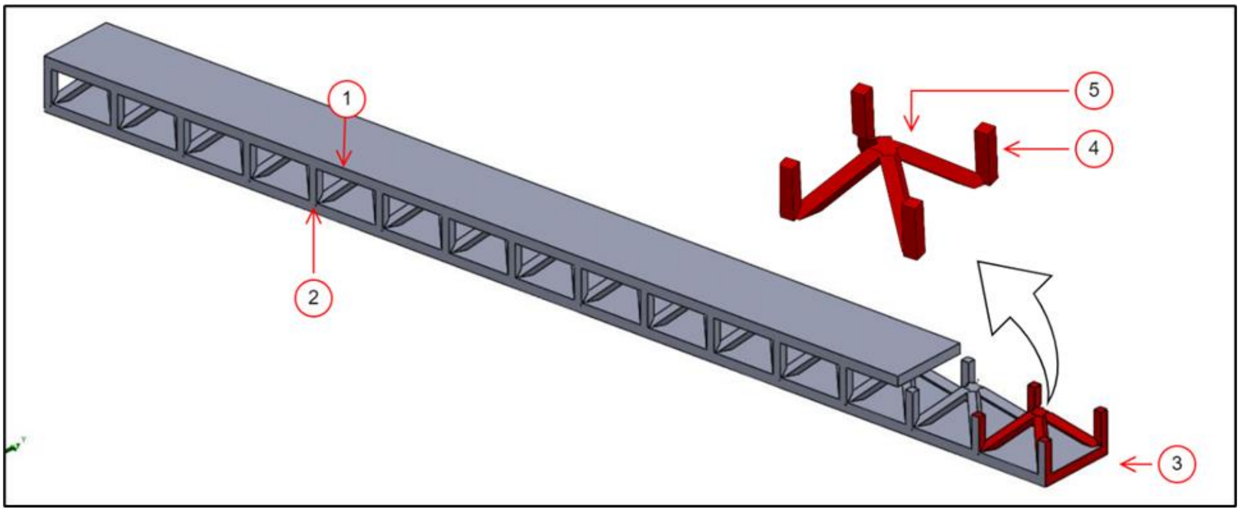

Fig. 1: Proposed structure (1-upper face, 2-lower face, 3-lattice unit, 4-vertical struts, 5-horizatial struts)

Table 1
Variable used in current study

Parameters	**symbol**	**Value**
thickness of lattice struts	t_s	0.5,1,1.5 and 2 mm
Width of lattice unit cell	W_u	20, 25,30 and 35 mm
Thickness of face sheets	t_f	2, 2.5,3 and 3.5 mm

3. Methodology
3.1 Finite Element Modelling
3.1.1 Geometry and Material Selection

In this study, the geometric model of the lattice core sandwich beam was designed using the Space Design Modular design interface available in ANSYS Workbench. The design process began by drawing the sandwich components separately to ensure accuracy and ease of control. The lattice core was designed as an independent unit, while the upper and lower face layers were drawn as separate elements representing the two outer surfaces of the beam. The beam has a fixed length of 260 mm, while its width and height vary according to the unit cell dimensions, as detailed in Table 1. PLA (Polylactic Acid) was chosen as the base material for the numerical simulation, due to its use in actual manufacturing using 3D printing. This material has suitable mechanical properties for analyzing the mechanical performance of the structure. The basic properties of PLA are listed in Table 2, including the elastic modulus, Poisson modulus, and density, which are essential for fine-tuning the model in the simulation.

Table 2
PLA properties[22]

Properties	Value
Young modules	2.5 GPa
Poisson's ratio	0.3
Density	1250kg/m^3

For example: This section discusses the results obtained from the surface pressure measurement study. The effects of angle of attack, Reynolds number and leading-edge bluntness are discussed in the next sub section.

3.1.2 Mashing

The geometric model mesh was prepared using the Mesh technique in ANSYS Workbench to divide the structure into small elements that enhance the accuracy of the numerical simulation. The mesh was designed independently for each component of the lattice beam, including the core and face layers. The meshes were then assembled to obtain the complete model [23].

The number of elements used in the mesh was 58371, and the number of nodes was 110867. These values represent a specific design condition when the mesh unit width was chosen as 20 mm, the thickness of the mesh columns was 1.5 mm, and the wall thickness was 3 mm. This mesh was adopted to provide an accurate representation of the stress distributions within the structure and to achieve a balance between the accuracy of the results and the computational time. Figure 2 shows the distribution of the mesh on the geometric model, highlighting the fine details of the division of the internal and external components.

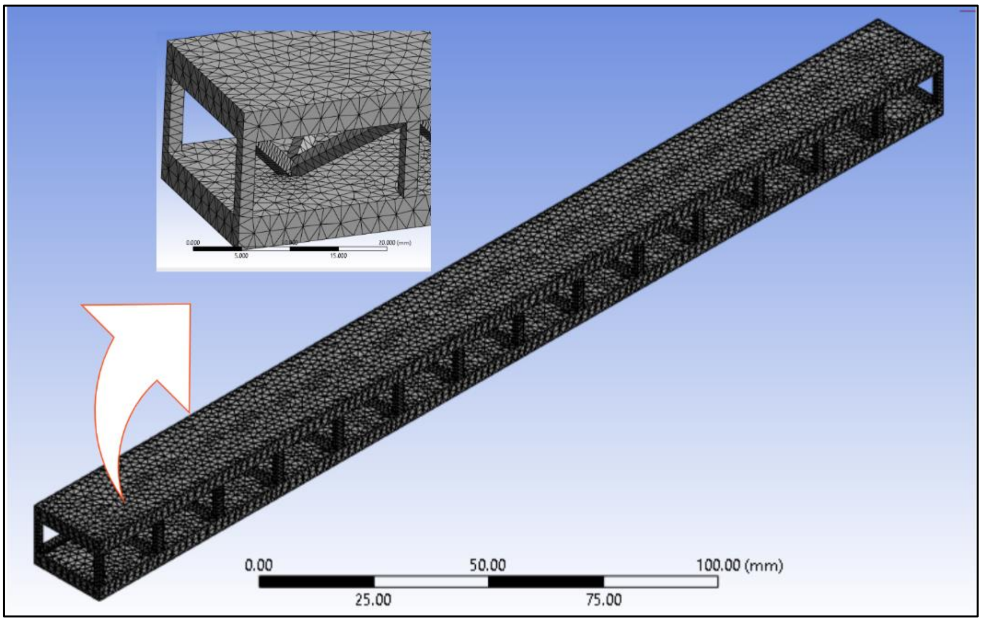

Fig. 2. finite element modeling of sandwich beam**;** thickness of lattice struts (1.5 mm), Width of lattice unit cell (20 mm), and Thickness of face sheets (3 mm).

3.1.3 Boundary condition and solution

In this study, the model was set up as a cantilever beam with one end fully fixed and the other end left free to analyze the response under a concentrated load. Simulations were performed for 64 different cases to explore the static behavior of the beam considering design variables such as thickness of lattice struts (t_s), Width of lattice unit cell (W_u), and Thickness of face sheets (t_f). The analysis focused on three main properties: Total Deformation to evaluate structural stiffness, Equivalent Stress to identify critical areas, and Strain Energy to understand the load distribution efficiency. This comprehensive approach provides accurate insights to optimize the design and ensure an optimal balance between lightweight and mechanical stiffness.

3.2 Experimental Works

Experimental work represents the second aspect of the "Methodology" section, as it aims to study the mechanical behavior of the lattice structure in a practical way and support the results of numerical modeling. This part includes a detailed description of the sample preparation process using 3D printing, in addition to identifying the equipment and devices used to conduct the tests, and explaining the experimental procedures that were followed. This part aims to provide a comprehensive understanding of how the experimental work was carried out and to verify the accuracy and efficiency of the numerical model.

3.2.1 Sample Preparation

The process of manufacturing samples using 3D printing is one of the main focuses of the research, as it highlights how modern manufacturing technologies can provide innovative solutions to improve the performance of lattice structures. A Creality CR-10 3D printer was used, which is characterized by high accuracy in manufacturing complex geometric models. The process began with designing 3D models using SolidWorks program to ensure accurate dimensions and ideal geometric details. The design was prepared to clearly show the lattice structure of the sandwich structure, taking into account basic design variables such as thickness of lattice struts (ts), Width of lattice unit cell (Wu), and Thickness of face sheets (tf). After the design was completed, it was transferred to Ultimaker Cura, where the model was converted to G-code, which is the format compatible with the printer. The printing settings were carefully adjusted to ensure high-quality manufacturing, using PLA, which is known for its excellent mechanical properties, such as stiffness and lightness.

The manufacturing process was characterized by unifying the structure as a single piece, eliminating the need for traditional adhesives that are usually used to bond the lattice core to the face layers. This approach is an important innovation that has contributed to enhancing the structural bonding and reducing the possibility of failure due to dislocation.

Figure 3 shows the different stages of manufacturing samples using 3D printing sequentially. In the first stage (Digital Design Stage), the engineering design is prepared using Ultimaker Cura software, where the required dimensions and geometry of the mesh structure are precisely determined to ensure that it matches the printing specifications. In the second stage (Fabrication Stage), the printing process begins using a Creality CR-10 3D printer, where the mesh structure is built layer by layer thanks to the printer’s high accuracy and thoughtful settings. In the last stage (Final Model Stage), the final sample is produced, highlighting the fine details of the mesh structure and the quality of manufacturing. This sample becomes ready for practical tests, highlighting the efficiency of modern manufacturing techniques in transforming theoretical designs into practical, testable models. Eight samples were manufactured to evaluate the effect of different geometric variables, as shown in Table 3.

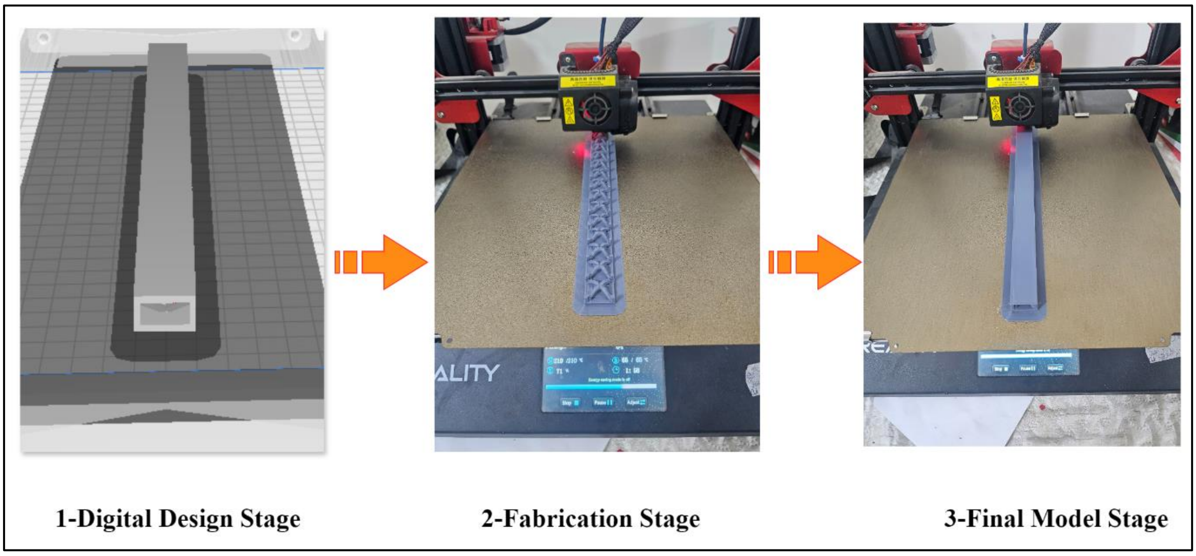

Fig. 3. the stages of manufacturing samples

Table 3
Dimensions of Experimental Samples (all dimension in mm)

No	thickness of lattice struts (t_s)	Width of lattice unit cell (W_c)	Thickness of face sheets(t_f)
1	1	20	2
2	1	20	2.5
3	1	20	3
4	1.5	20	2
5	1.5	20	2.5
6	1.5	20	3
7	2	20	2
8	2	20	2.5
9	2	20	3

3.2.2 Practical Testing

Practical tests were carried out to study the mechanical response of the manufactured samples under the influence of a concentrated load. A precision mechanical testing device, as shown in Figures 4 and 5, was used to apply the loads and accurately measure the resulting deformation. One end of the sample was fully fixed to simulate a cantilever beam, while the other end remained free to apply the load. A concentrated load of 1 N was applied at the free end, and the deformation of the sample was recorded during the gradual loading.

The testing device consists of:

1. A strong metal frame to support the sample and ensure its stability during the test.
2. A hydraulic system to apply the load.
3. An analog force and deformation gauge, which shows the amount of the applied load with an accuracy of up to 20 kN.
4. A tight clamping mechanism to firmly hold the sample at the fixed end.

Data related to the total deformation resulting from the applied load were recorded. Although the device does not measure stress or strain energy directly, the data obtained are used to support numerical modeling and verify its accuracy (a validation between the practical deformation and the simulation under the same conditions will be done later in the Results and Discussion section). The images in Figures 4 and 5 show how the specimen is fixed and the load-bearing mechanism, reflecting the practical procedures that were followed accurately to analyze the behavior of the lattice structure under concentrated loads.

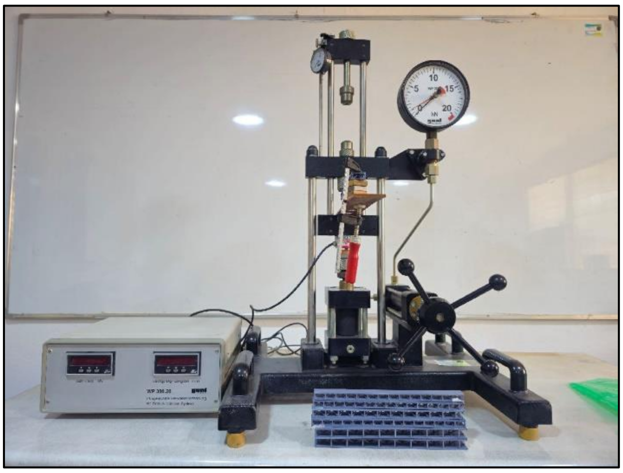

Fig. 4. Experimental apparatus

Fig.5. Experimental setup

4. Result and Discussion

This section aims to present and analyze the results obtained from numerical modeling and experimental tests to evaluate the mechanical performance of the lattice beam under transverse load. To achieve this, the results are divided into main parts: In the first part, the total deformation results generated by the numerical simulation will be presented and compared with the experimental results as part of the verification process, The second part focuses on the analysis of the directional deformation, von mises stress and strain energy of the lattice structure under transverse loads, emphasizing the effect of design variables such as thickness of lattice struts (ts), Width of lattice unit cell (Wu), and Thickness of face sheets (tf).

4.1 Experimental results and validation

Table 4 presents the results of the deformations measured through the experimental tests δ experimental, with a comparison with the values extracted from the numerical modelling using the ANSYS program δ numerical.

Table 4:
Experimental results

No	(t_s)	(W_c)	(t_f)	$\delta_{numerical}$ (mm)	$\delta_{experimental}$ (mm)	error ratio
1	1	20	2	0.047326	0.045	4.9
2	1	20	2.5	0.035184	0.032	9.1
3	1	20	3	0.027929	0.025	10.5
4	1.5	20	2	0.059458	0.055	7.5
5	1.5	20	2.5	0.047226	0.0425	10.0
6	1.5	20	3	0.037481	0.0365	2.6
7	2	20	2	0.034468	0.033	4.3
8	2	20	2.5	0.028053	0.027	3.8
9	2	20	3	0.023288	0.022	5.5

The samples used were designed according to Table 3, where the design variables included the thickness of lattice struts (ts) and Thickness of face sheets (tf). The data show a remarkable agreement between the numerical and experimental values, as the numerical values of the deformation ranged between 0.047 mm and 0.023 mm, while the experimental values ranged between 0.045 mm and 0.022 mm. This agreement reflects the accuracy of the numerical modelling in simulating the mechanical behavior of the samples, although there are slight differences that can be observed in the calculated error rates. For example, sample 6 recorded the lowest error of 2.6%, indicating a high accuracy of the modelling in this case, while sample 3 recorded the highest error of 10.5%, which may be due to additional factors not included in the modelling such as manufacturing tolerances or differences in testing conditions.

These results are further supported by a deeper understanding through Figures 6 and 7. Figure 6 shows the relationship between the thickness of face sheets and the total deformation when the thickness of lattice struts is fixed at 1 mm. It is clear from the figure that the deformation gradually decreases with increasing thickness of the faces, reflecting the improvement in the structural stiffness of the lattice faces. Figure 7 shows the relationship between the thickness of lattice struts and the deformation when the thickness of the faces is fixed at 2 mm. This figure shows a nonlinear behavior, where the deformation decreases with increasing thickness of lattice struts up to a certain value (1.5 mm), and then increases again with increasing thickness, indicating that there is a mutual effect between the struts and the faces in the stress distribution.

The results indicate that increasing the thickness of the lattice columns and faces reduces the overall deformation and enhances the structural stiffness, which supports more stable performance under applied loads. These results emphasize the importance of selecting the optimal values of the design variables to obtain improved mechanical performance, and enhance confidence in the accuracy of the numerical models used to analyze and design lattice structures in various engineering applications.

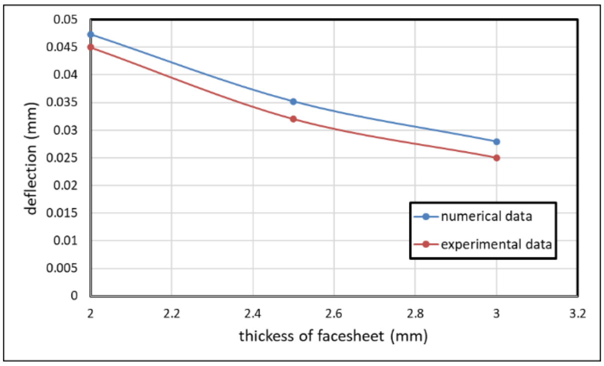

Fig. 6. Directional deformation variation with thickness of factsheet when w=20 and t_s=1

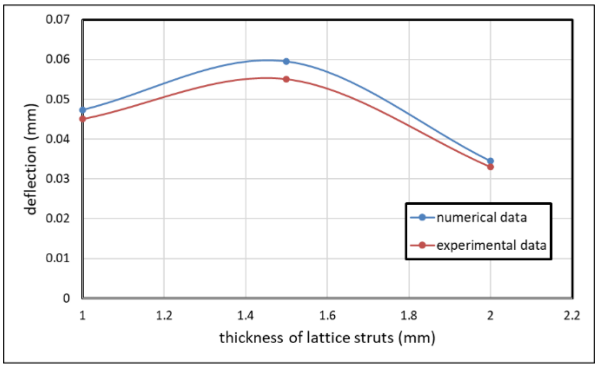

Fig. 7. Directional deformation variation with thickness of lattice struts when w=20 and t_f=2

4.2 Design parameters effect

In this part of the results, the focus will be on analyzing the effect of the main design variables, namely, the as thickness of lattice struts (ts), Width of lattice unit cell (Wu), and Thickness of face sheets (tf)., on the mechanical behavior of the lattice structure. This analysis aims to understand how these factors affect the performance of the structure under applied loads, including directional deformation, equivalent stress, and strain energy.

4.2.1 Directional Deformation

The 3D plots shown in Figures 8, 9, 10 and 11 show the overall deformation behavior of the lattice structure under the applied load, taking into account the main design variables: lattice struts thickness (ts), face thickness (tf), and lattice unit width (Wc). It can be seen that the deformation generally decreases with increasing column and face thickness, while it increases with increasing lattice unit width.

Considering the effect of face thickness, the plots show that increasing face thickness leads to a significant reduction in deformation in all cases. This is attributed to the role of face in distributing the load more efficiently, which reduces the bending caused by the loads. On the other hand, the effect of lattice struts thickness appears non-linear, as the deformation decreases significantly with increasing thickness from 0.5 mm to 1.5 mm, then starts to increase slightly at 2 mm thickness. This behavior is explained by the fact that thicker columns contribute to increasing the structural stiffness to a certain extent, but then increasing the thickness may lead to the concentration of stresses at specific points, causing a slight increase in deformation.

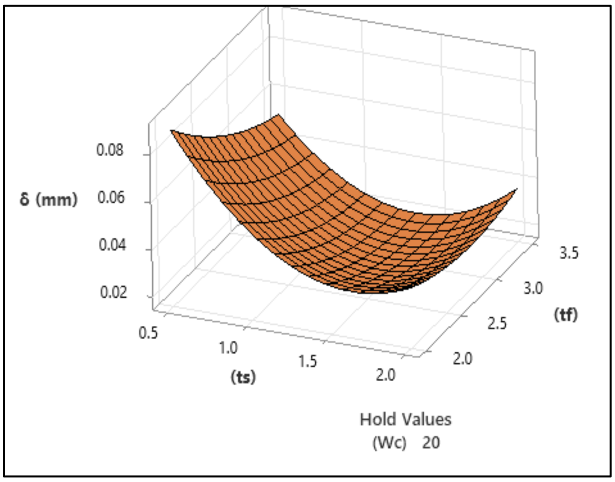

Fig. 8. variation of directional deformation with thickness of struts and thickness of factsheet when lattice unit width=20 mm

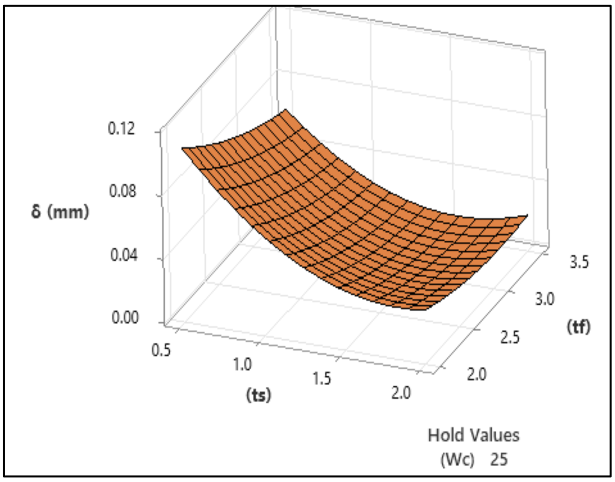

Fig. 9. variation of directional deformation with thickness of struts and thickness of factsheet when lattice unit width=25 mm

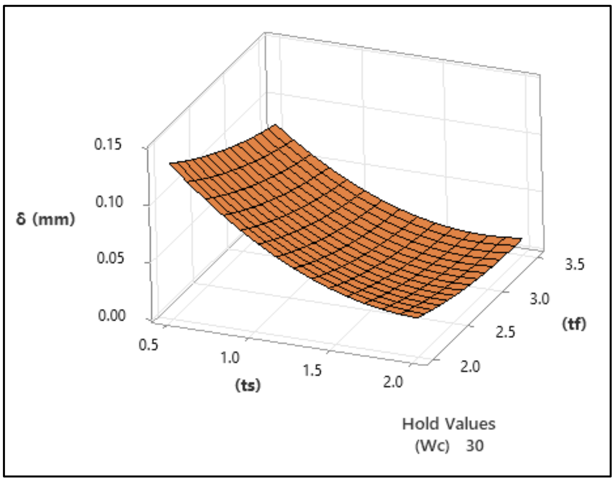

Fig.10.variation of directional deformation with thickness of struts and thickness of factsheet when lattice unit width=30 mm

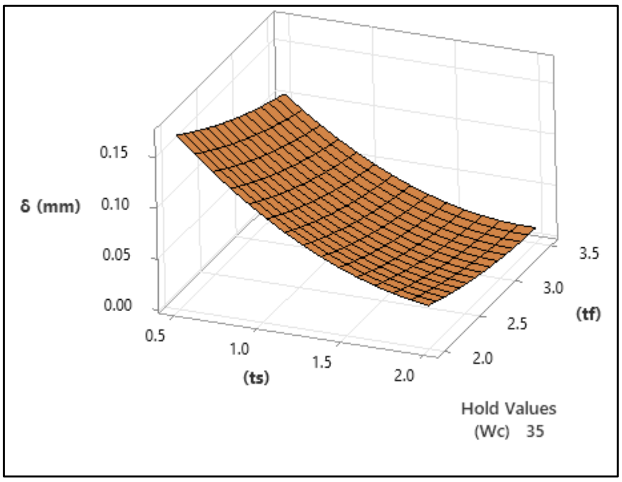

Fig. 11. variation of directional deformation with thickness of struts and thickness of factsheet when lattice unit width=35 mm

As for the effect of the width of the lattice unit, it is clear from the figures that the deformation increases with increasing width. When the width of the grid increases, the density of the struts inside the structure decreases, which reduces the ability of the structure to effectively bear loads. This leads to an increase in the flexibility of the system and a decrease in the overall stiffness, which is clearly shown by comparing the deformation at a grid width of 20 mm (Fig. 8) with a grid width of 35 mm (Fig. 11).

4.2.2 Equivalent Stress

The 3D figures (Figures 12, 13, 14, and 15) illustrate the effect of design factors on the distribution of equivalent stress within the lattice structure under the influence of applied loads. This analysis shows that the equivalent stress is significantly affected by lattice struts thickness (ts), face thickness (tf), and lattice unit width (Wc).

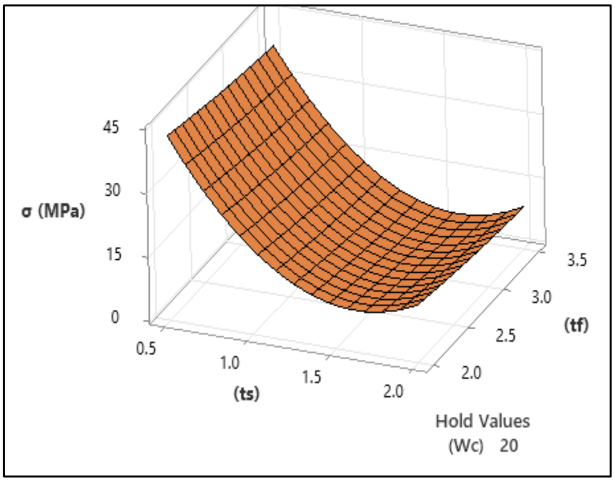

Fig. 12. variation of equivalent stress with thickness of struts and thickness of factsheet when lattice unit width=20 mm

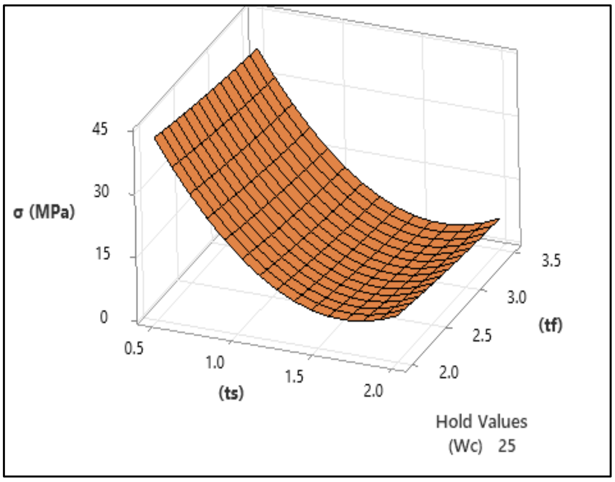

Fig. 13. variation of equivalent stress with thickness of struts and thickness of factsheet when lattice unit width=25 mm

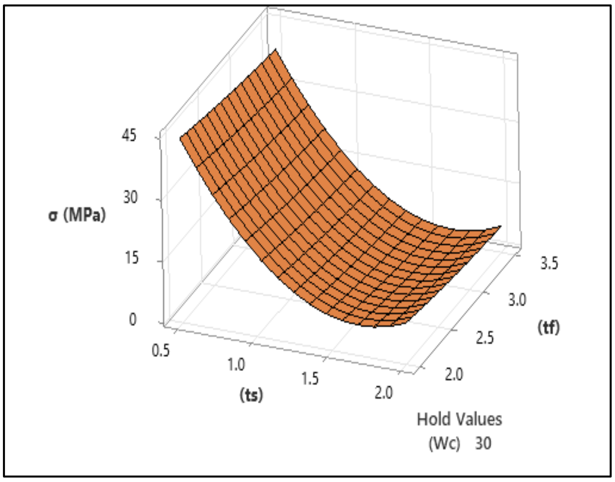

Fig. 14. variation of equivalent stress with thickness of struts and thickness of factsheet when lattice unit width=30 mm

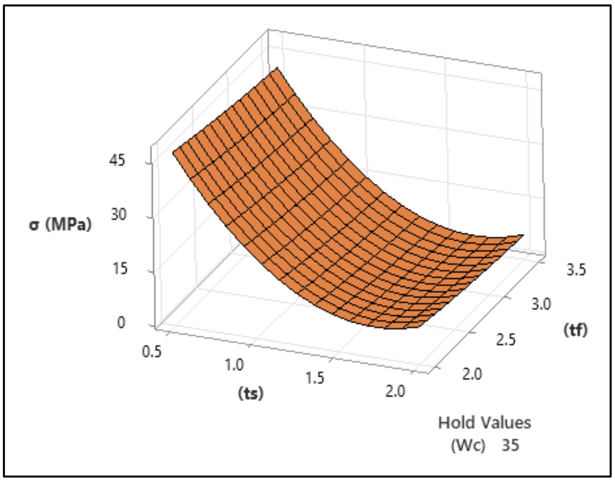

Fig. 15. variation of equivalent stress with thickness of struts and thickness of factsheet when lattice unit width=35 mm

When the lattice struts thickness increases, a significant decrease in the equivalent stress is observed. This is due to the fact that thicker struts provide higher resistance to loads, which leads to a reduction in the concentration of stresses within the structure. This effect becomes more evident at struts thicknesses exceeding 1.5 mm, where the stresses are significantly reduced.

As for the facet thickness, the results show that increasing it leads to a gradual decrease in the equivalent stress. Thicker faces improve the distribution of loads across the structure, which reduces local stresses and enhances the stiffness of the system. This effect is clearly visible in all the figures, where the stresses are lower at larger facet thicknesses. On the other hand, increasing the width of the lattice unit leads to an increase in the equivalent stress. The reason behind this behavior is that increasing the width reduces the density of the struts within the structure, which weakens its load-bearing capacity. In the drawings representing a 35 mm mesh unit width, higher stress values are observed compared to a 20 mm width, indicating a negative effect of increasing the width on structural performance.

4.2.3 Strain Energy

Increasing the three design parameters, namely lattice struts thickness (ts), face thickness (tf), and lattice unit width (Wc), clearly leads to a reduction in the stored stress energy within the lattice structure. This behavior is demonstrated by the Figure 16, 17,18 and 19 that show that increasing any of these variables leads to a significant improvement in the structural stiffness, which reduces the stresses resulting from the applied load.

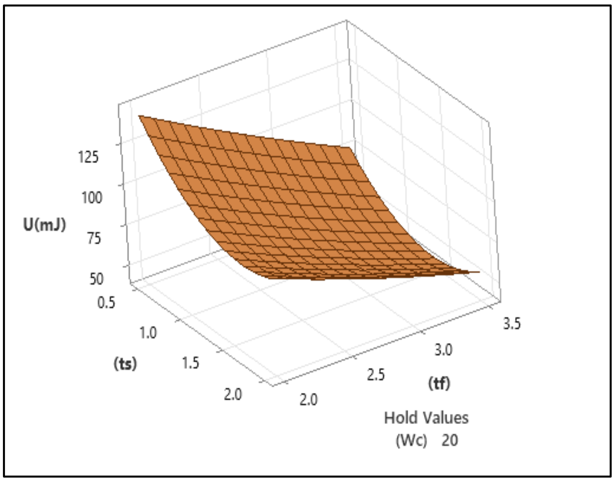

Fig. 16. variation of strain energy with thickness of struts and thickness of factsheet when lattice unit width=20 mm

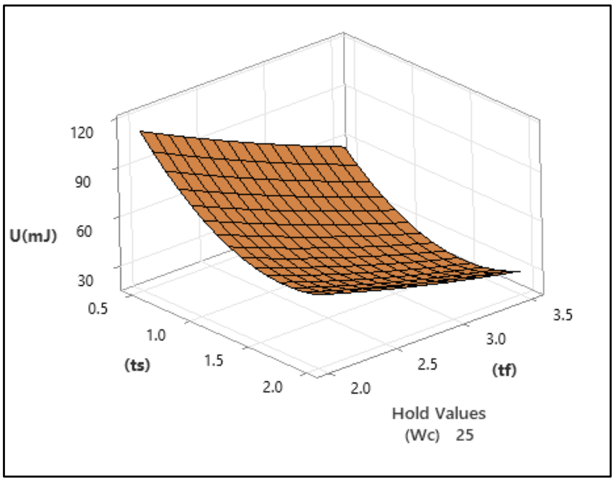

Fig. 17. variation of strain energy with thickness of struts and thickness of factsheet when lattice unit width=25 mm

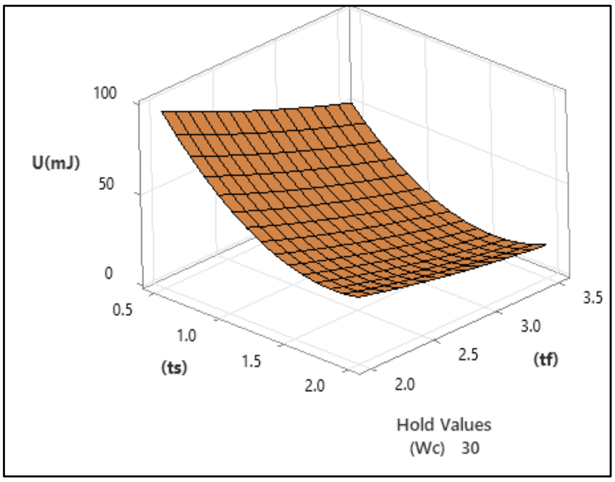

Fig. 18. variation of strain energy with thickness of struts and thickness of factsheet when lattice unit width=30 mm

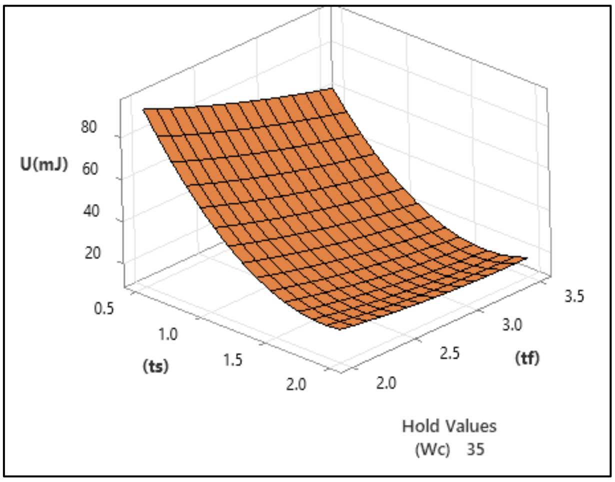

Fig. 19. variation of strain energy with thickness of struts and thickness of factsheet when lattice unit width=35 mm

As for the lattice struts thickness (ts), increasing it enhances the ability of the structure to bear loads evenly and reduces the stress concentration in sensitive areas. Thicker struts contribute to better load distribution and reduce local deformation, which in turn reduces the stress energy. As for the thickness of the faces, increasing it reduces the overall deformation of the structure and increases its resistance to bending, which leads to a reduction in internal stresses and stored energy. On the other hand, increasing the lattice unit width (Wc), leads to a reduction in the density of the structural grid, which allows for better distribution of loads over a larger area and reduces local stresses. This design change enhances the mechanical performance efficiency of the lattice structure by reducing stress concentration, although the spacing between the columns increases. Thus, it can be concluded that the three design factors play a fundamental role in improving the mechanical performance of the lattice structure, as choosing optimal values for these variables reduces stress energy and increases the efficiency of the structure in bearing loads.

5. Conclusions

The study proved that 3D printing is an effective method for manufacturing samples with high accuracy and achieving complex designs such as the lattice structure, which provides great opportunities for developing innovative structures that combine light weight and mechanical efficiency. The study reached a set of important results that highlight the mechanical performance of the lattice core sandwich beam under the influence of concentrated load. The results showed that increasing the thickness of the lattice struts (ts) and the thickness of the faces (tf) directly contribute to reducing the total deformation, equivelar stresses and strain energy, which enhances the stiffness and stability of the structure under applied loads. On the other hand, increasing the width of the lattice unit (Wc) showed a mixed effect, as it contributed to reducing the density of the structure and increasing the load distribution, which led to improving the overall efficiency and reducing the stress energy. The comparison between numerical and experimental values showed high agreement, indicating the accuracy of numerical modeling using ANSYS in representing the mechanical behavior of the lattice structure. The error rates were low, which enhances confidence in using the numerical model to analyze future designs. The research shows the importance of choosing the optimal values of design factors to achieve a balance between light weight and structural stiffness. Column thickness and face thickness emerge as key factors that directly affect the performance of the structure.

Acknowledgement

I would like to extend my sincere gratitude Technical Engineering College of Najaf, Al-Furat Al-Awsat Technical University, Iraq, for their continuous support and valuable contribution in providing an encouraging academic environment that greatly contributed to the success of this research.

References

[1] E. K. Njim *et al.*, “Mechanical Properties of Sandwiched Construction with Composite and Hybrid Core Structure,” *Advances in Polymer Technology*, vol. 2024, pp. 1–14, Jan. 2024, doi: 10.1155/2024/3803199.

[2] H. Raad, E. K. Njim, M. J. Jweeg, and M. Al-Waily, “Sandwiched Plate Vibration Analysis with Open and Closed Lattice,” *Physics and Chemistry of Solid State*, vol. 24, no. 2, pp. 312–322, 2023, doi: 10.15330/pcss.24.2.312-322.

[3] E. K. Njim, S. E. Sadiq, and M. N. Hamzah, “A RECENT REVIEW OF THE SANDWICH-STRUCTURED COMPOSITE METAMATERIALS: STATIC AND DYNAMIC ANALYSIS,” *J Teknol*, vol. 85, no. 5, pp. 133–149, Sep. 2023, doi: 10.11113/jurnalteknologi.v85.20282.

[4] M. J. Jweeg, S. H. Bakhy, and S. E. Sadiq, “Effects of core height, cell angle and face thickness on vibration behavior of aircraft sandwich structure with honeycomb core: An experimental and numerical investigations,” in *Materials Science Forum*, Trans Tech Publications Ltd, 2021, pp. 65–85. doi: 10.4028/www.scientific.net/MSF.1039.65.

[5] S. E. Sadiq, S. H. Bakhy, and M. J. Jweeg, "OPTIMUM VIBRATION CHARACTERISTICS FOR HONEY COMB SANDWICH PANEL USED IN AIRCRAFT STRUCTURE," 2021.

[6] N. Buannic, P. Cartraud, and T. Quesnel, "Homogenization of corrugated core sandwich panels." [Online]. Available: www.elsevier.com/locate/compstruct

[7] P. H. Bull and F. Edgren, "Compressive strength after impact of CFRP-foam core sandwich panels in marine applications," *Compos B Eng*, vol. 35, no. 6–8, pp. 535–541, Sep. 2004, doi: 10.1016/j.compositesb.2003.11.007.

[8] J. Li, W. Zhang, Z. Wang, Q. Wang, T. Wu, and Q. Qin, "Dynamic response and failure of CFRP Kagome lattice core sandwich panels subjected to low-velocity impact," *Int J Impact Eng*, vol. 181, p. 104737, Nov. 2023, doi: 10.1016/J.IJIMPENG.2023.104737.

[9] H. Taghipoor, A. Eyvazian, A. Ghiaskar, A. P. Kumar, A. M. Hamouda, and M. Gobbi, "Experimental and numerical study of lattice-core sandwich panels under low-speed impact," *Mater Today Proc*, vol. 27, pp. 1487–1492, Jan. 2020, doi: 10.1016/J.MATPR.2020.03.001.

[10] F. Usta, H. S. Türkmen, and F. Scarpa, "High-velocity impact resistance of doubly curved sandwich panels with re-entrant honeycomb and foam core," *Int J Impact Eng*, vol. 165, p. 104230, Jul. 2022, doi: 10.1016/J.IJIMPENG.2022.104230.

[11] H. Raad, E. K. Njim, M. J. Jweeg, and M. Al-Waily, "Sandwiched Plate Vibration Analysis with Open and Closed Lattice," *Physics and Chemistry of Solid State*, vol. 24, no. 2, pp. 312–322, 2023, doi: 10.15330/pcss.24.2.312-322.

[12] Z. Wu, J. Wu, F. Lu, C. Zhang, Z. Liu, and Y. Zhu, "Free vibration analysis and multi-objective optimization of lattice sandwich beams," *Mechanics of Advanced Materials and Structures*, vol. 31, no. 17, pp. 4037–4050, Sep. 2024, doi: 10.1080/15376494.2023.2189333.

[13] Y. Chai, S. Du, F. Li, and C. Zhang, "Vibration characteristics of simply supported pyramidal lattice sandwich plates on elastic foundation: Theory and experiments," *Thin-Walled Structures*, vol. 166, p. 108116, Sep. 2021, doi: 10.1016/J.TWS.2021.108116.

[14] M. J. Khoshgoftar, A. Barkhordari, M. Limuti, F. Buccino, L. Vergani, and M. J. Mirzaali, "Bending analysis of sandwich panel composite with a re-entrant lattice core using zig-zag theory," *Sci Rep*, vol. 12, no. 1, p. 15796, Sep. 2022, doi: 10.1038/s41598-022-19930-x.

[15] Z. Liu, H. Chen, and S. Xing, "Mechanical performances of metal-polymer sandwich structures with 3D-printed lattice cores subjected to bending load," *Archives of Civil and Mechanical Engineering*, vol. 20, no. 3, p. 89, Jul. 2020, doi: 10.1007/s43452-020-00095-1.

[16] J. Zhang, S. Ding, and J. Yanagimoto, "Bending properties of sandwich sheets with metallic face sheets and additively manufactured 3D CFRP lattice cores," *J Mater Process Technol*, vol. 300, p. 117437, Feb. 2022, doi: 10.1016/J.JMATPROTEC.2021.117437.

[17] M. Sefidi and H. Taghipoor, "Analysis of deformation and failure mechanism of sandwich beams with lattice core under three-point bending load," *Sci Rep*, vol. 14, no. 1, p. 13302, Jun. 2024, doi: 10.1038/s41598-024-64198-y.

[18] Q. Wu *et al.*, "Failure of carbon fiber composite sandwich cylinders with a lattice core under axial compressive loading," *Compos Part A Appl Sci Manuf*, vol. 155, p. 106812, Apr. 2022, doi: 10.1016/J.COMPOSITESA.2022.106812.

[19] Z. J. Li, P. H. Xie, H. L. Dai, T. X. Zhang, and P. Xiao, "Rapid stress prediction of additively manufactured sandwich panels with lattice cores in thermal environments," *Constr Build Mater*, vol. 442, p. 137559, Sep. 2024, doi: 10.1016/J.CONBUILDMAT.2024.137559.

[20] H. M. Bahabadi, A. Farrokhabadi, and G. H. Rahimi, "Investigation of debonding growth between composite skins and corrugated foam-composite core in sandwich panels under bending loading," *Eng Fract Mech*, vol. 230, p. 106987, May 2020, doi: 10.1016/J.ENGFRACMECH.2020.106987.

[21] M. Nuño, J. Bühring, M. N. Rao, and K.-U. Schröder, "Delamination Testing of AlSi10Mg Sandwich Structures with Pyramidal Lattice Truss Core made by Laser Powder Bed Fusion," *Chinese Journal of Mechanical Engineering*, vol. 34, no. 1, p. 126, Dec. 2021, doi: 10.1186/s10033-021-00643-7.

[22] Z. M. Shukur, R. A. Neamah, H. J. Abdulsamad, L. S. Al-Ansari, and S. Wittayapiyanon, “CALCULATING THE NATURAL FREQUENCY OF PRE-TWISTED BEAM,” *Journal of Engineering and Sustainable Development*, vol. 28, no. 1, pp. 1–16, Jan. 2024, doi: 10.31272/jeasd.28.1.1.

[23] M. J. Jweeg, S. H. Bakhy, and S. E. Sadiq, “Effects of core height, cell angle and face thickness on vibration behavior of aircraft sandwich structure with honeycomb core: An experimental and numerical investigations,” in *Materials Science Forum*, Trans Tech Publications Ltd, 2021, pp. 65–85. doi: 10.4028/www.scientific.net/MSF.1039.65.