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Numerical and Experimental Analysis for Flexure Behavior of Pyramidal Core Sandwich Composite

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ABSTRACT

Due to the significant need in applications for lightweight and high strength, studies began on a sandwich composite with a pyramid core because it provides design flexibility and offers improvement in bending resistance so is widely preferred compared to other core's forms. While the strength of sandwich panels with lattice cores is influenced by the material and topology, the mechanical properties of these structures have to be enhanced. It requires the use of high-strength materials, so this research presents a composite sandwich structure containing carbon fiber sheets 0/90 with epoxy used as the sandwich skin., while epoxy is used as the pyramid core. Two basic pyramidal geometries are designed according to the ASTM C393-00 standard, investigated under a three-point bending test by quasi-static bending loads, and explored to explore the effect of different basic unit cell topologies and core densities on the mechanical behavior of the sandwich. From the experimental results obtained the second design obtained the highest maximum load (3.9 kN) and the highest stiffness (88.3 MPa) compared to the first design, whose maximum stiffness is 39 MPa. According to the analysis results, the sandwich panel with the first geometry (2×5 unit cell) has the highest Von -Mises stress about (414 Mpa) and relative density of 0.28, while the second geometry (2×3 unit cell) has the lowest Von Mises stress (201.5 Mpa), lowest deformation (1.8127 mm), less elastic strain (0.06249), and low and relative density of 0.16 when compared with the first geometry, which made it a better design than the other and this agree with the experimental part.

1. INTRODUCTION

Composite materials combine two different materials, creating a new, adjustable, and high-specific mechanically efficient material with superior performance characteristics compared to individual components [1-3]. In industry, reducing the weight of structures is one of the most significant difficulties. Sandwich is a material that can satisfy this prerequisite. Sandwich panels consisting of hard skin and a light core are becoming more and more popular in many applications, in aerospace, transportation, pressure containment, energy absorption, etc., due to their exceptional strength, light weight as well as increasing the bending stiffness and capacity to absorb energy [4-6]. Sandwich plates are made from various materials, like aluminum, composite laminates, stainless steel, wood and polymers. Carbon fibers, oriented at 0°/90° (cross-ply), are gaining popularity and its prominent materials that used in the researches because of their strength and lightweight properties because they have the ability to provide better mechanical performances in several directions such high elastic modulus and low density [7, 8]. The performance of sandwich structures is mostly influenced by the core. Sandwich composites use various core materials such as honeycomb core, polymer foam core, metallic foam core, balsa core, corrugated cores [9], and more complicated core geometries., The core configuration significantly impacts sandwich panel performance, influenced by adhesive materials behavior and core design and which are continuously developed [10]. While metal foams and honeycombs are commonly used for sandwich cores due to their cost-effectiveness, thermal and sound insulation properties, and high damping. However, traditional sandwich panels cannot accommodate free fluid movement, limiting their functionality and susceptible to internal corrosion and delamination due to their closed cellular structure [11]. Open-cell core constructions with interconnected void spaces could extend sandwich panel usage. Lattice truss structures, like pyramid, octet, or Kagome truss, offer comparable strength and stiffness levels so research on lattice truss cores such as pyramid core architectures is underway [12, 13], because it is the preferred as compared with other conventional cellular solids [14]. Enabling multiple functions, from temperature control to extended stealth application, facilitating the modularity structural systems, which act as load-bearing components as well as devices [15-17]. Among other core forms the pyramidal shape offer several advantages, distributes loads evenly, reducing stress, improving durability, and providing better thermal and acoustic insulation, making it suitable for heat shields. However, it is possible to design and optimize the pyramidal lattice core such that it has a stretching-dominated topological configuration, which has been shown to be more weight-efficient than traditional bending-dominated materials. They can be customized to specific application requirements, providing enhanced resistance to bending. It also provides durability and the ability to withstand damage, which maintains structural integrity [18-20].

The polymeric core material opens up an extensive range of possibilities for customized sandwich fabrication with diverse properties [21]. Research on pyramidal core sandwich structures is mostly focused on manufacturing processes, mechanical performance, and topology configuration optimization. Khan and Riccio [22] did the basic research on the structural behavior of truss core sandwich panels by using additive manufacturing process which consider the most recent technologies. It is demonstrated that in comparison to traditional honeycomb sandwiches, truss core sandwich panels exhibit significantly higher structural performance under bending and compression stresses. While Yang et al. [23] simplified the manufacturing process of polymer composites reinforced with carbon fiber using the snap-fit technique. They found that failure in compression is due to truss fracture, while in bending, it's caused by truss fracture and de-bonding. Mesto et al. [24] proposed two new core models: C-half circle and strengthened pyramidal cells to replace pyramidal ones. The model is validated numerically and experimentally and thus the behavior can be simulated of new lattice core forms (by additive manufacturing method) to express their advantages and disadvantages compared to the pyramidal model in compression and bending results found the deformation of the skin of the half circle cell panel decreases by 15% in compression while the deflection of the reinforced pyramid cell panel decreases by 26% in bending compared to the pyramid cell panel. To enhancing the three-point bending capacity of the pyramid lattice sandwich beam, Lu et al. [25] suggested a non-uniform pyramid lattice sandwich structure to enhance the three-point bend capacity of a pyramid lattice sandwich beam. The study reveals that non-uniform coefficients significantly enhance a structure's final bending carrying capacity by 39% when compared to uniform lattice sandwich beams. The structural performance of sandwich structures made of carbon fiber composite with pyramidal cores under direct shear and three-point bending loads was tested and evaluated through analytical and experimental research by Xiong et al. [26]. Wu et al. [27] studied a pyramidal lattice core sandwich panel made using hot-press molding and interlocking techniques. The structure, reinforced by end frames and unidirectional fibers, can withstand high loads. According to the experimental findings, Comparing the current composite pyramidal lattice structure to other designs shows several benefits.

The results of previous studies indicate the stiffness and strength of this design over other designs, but most studies focused on the use of carbon fibers over other polymeric materials as pyramidal cores because it requires a lot of effort to be spent on manufacturing techniques for polymeric pyramid cores, unlike metal cores. Therefore, the aim of this research is to fabricate and design (two pyramidal cores with different number and dimensions of unit cells) for insulating structures in engineering applications and focus on pyramidal sandwich structures consisting of as a fully polymeric sandwich composite has CFRP face plates as skin and pyramidal truss cores made of epoxy resin.

To evaluate mechanical characteristics of the sandwich flexure test under quasi-static bending force are carried out experimentally and numerically analyzed to find the best properties such flexure stiffness and failure behavior, damage distribution, and knowledge of the optimal core cell design due to the important role of the core in sandwich structure.

2. EXPERIMENTAL METHODOLOGY

The pyramidal lattice truss cores were made from epoxy (hardener-amine and epoxy resin from Sika Saudi Arabia Co. Ltd. to create a thermosetting resin matrix), its properties shown in Table 1, epoxy is one of the most common and widely used polymers compared to its somewhat acceptable price for its many applications [28]. The pyramidal cores manufacturing by laser machine then assembled by interlocking. Figure 1 shows the preparation process after the molds prepared then poured the mixture of epoxy resin (with ratio 2:1) into it, after 24 hours ejected from them. Carbon fiber type cross-ply with thickness 0.23 mm (supplied by MB Fiberglass company). Its properties shown in Table 1, this material is used in the skin of the sandwich because it has high modulus of elasticity then the specification of the laminate composite will be high depending on the rule of mixture. while the skin of the sandwich prepared by hand lay-up method with different number of carbon layers (made from carbon fiber/epoxy). The detailed properties of carbon/epoxy laminate are listed in Table 1. After prepare the core and the skin then bonded together using film adhesive of the same epoxy resin and curing process it tack place for the overall structure at 110° for one hour to obtain the stacking carbon fiber preform. The unit cell geometry of pyramidal lattice truss core is shown in Figure 2. The relative density $\bar{\rho}$ of the pyramidal truss core is written as follows [29].

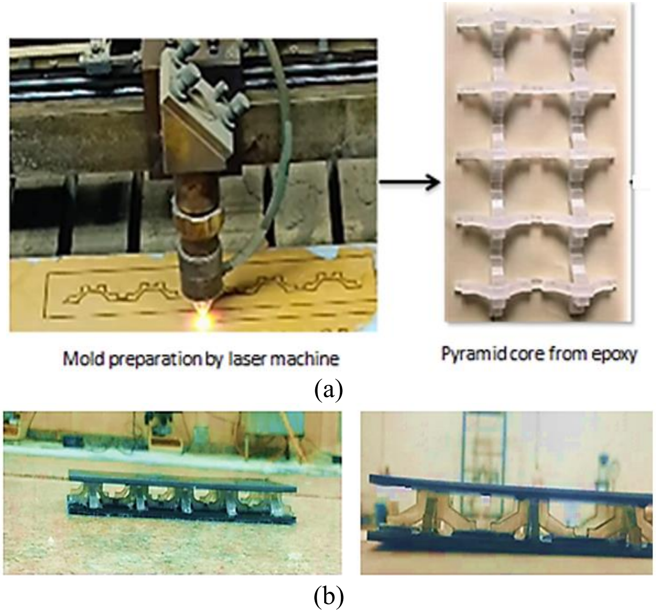
$$\bar{\rho} = \frac{\rho}{\rho s} = \frac{4[2lw + (b + c - t)h]t}{(b + c + 2l\cos\omega)(l\sin\omega + h)} \tag{1}$$

Table 1. Properties of the carbon/epoxy laminate's materials (as skin of sandwich) and pure epoxy (which act the core of the sandwich)

Symbol	Value	Property
E_{11}, E_{22}	55 Gpa	Longitudinal stiffness
E_{33}	2.38 Gpa	Transverse stiffness
v_{12}	0.34	Major Passion ratio
u_{13}, u_{23}	0.014	Manor Passion ratio
G_{12}	1.84 Gpa	Major shear modulus
G_{13}, G_{23}	1.17 Gpa	Manor shear modulus
X_t	808 Mpa	Tensile ultimate strength
Material Property (Epoxy)		**Value**
ρ (g/cm^3)		1.1
E (GPa)		1.06
υ_m		0.34
G (GPa)		1.27
X_t (MPa)		37
Material Property (Carbon Fiber)		**Value**
ρ (g/cm^3)		1.76
E(GPa)		238
G_m (GPa)		14
X_t (MPa)		3675
υ_f		0.26

Table 2. The dimensions for the longitudinal unit cell for the first and second geometry

Sample	W (mm)	C (mm)	h_0 (mm)	h (mm)	ω (mm)	I (mm)	L (mm)	t (mm)	N (mm)	M (mm)	$\bar{\rho}$
1st geometry	4.37	10	9	6	45	5.12	10.6	6	16	40	0.28
2nd geometry	5.46	10	10	6	45	15.8	10	6	20	66	0.16



(a)

(b)

Figure 1. Manufacturing process and preparation of sandwich structures with pyramidal core: (a) Laser machine for prepare core mold truss patterns; (b) assemble the pyramid lattice core with skins

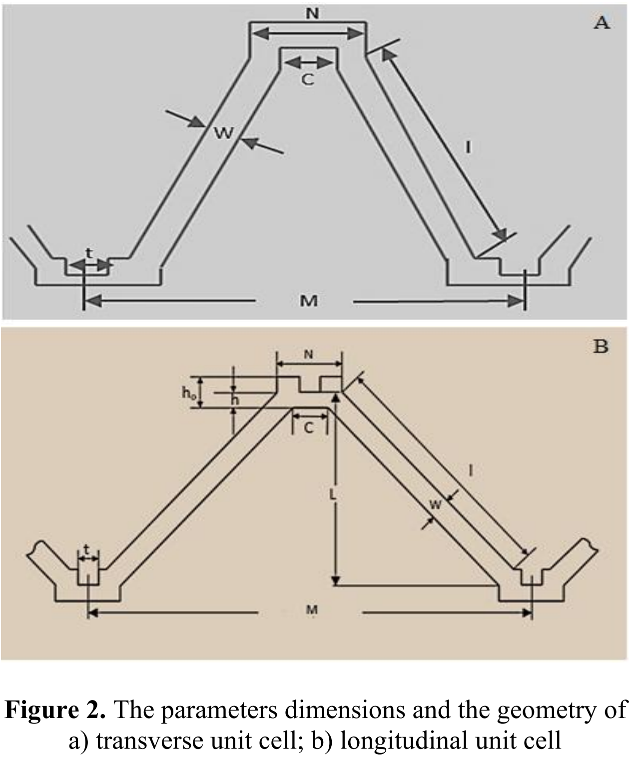


Figure 2. The parameters dimensions and the geometry of a) transverse unit cell; b) longitudinal unit cell

The main parameters that specify the geometry of the pyramidal core are outlined in Figure 2, taking into account strut length l, struts' thickness t, strut width w, node exterior width b, node inner width c, and angle ω, between the strut and the horizontal plane, respectively. Consequently, where ρ is the density of the pyramidal lattice truss core and ρs is the density of the parent materials. The first model has two longitudinal cells and five transverse unit cells, while the second model has two longitudinal cells and three transverse unit cells. The dimensions of longitudinal cells are the same for both geometries, as shown in Table 2, except the transverse dimensions are different, where M, N, and W are 40, 10, and 4.4 mm, respectively, and C, t, and l are 6, 6, and 4.4 mm, respectively, and C, t, and l are 6, 6, and 9.3 mm.

Flexure test

Bending test is an essential tool for evaluating and optimizing the mechanical performance of sandwich structure, ensuring they meet the rigorous demands of their intended applications. An experimental investigation on sandwich structures with the pyramidal lattice core A and B subjected to bending loading was conducted. The dimensions of the sandwich 200 mm length, 75 mm in width according to ASTM C393. the test using a universal testing machine (model WAW-200). applying force via a 30 mm-diameter roller and the distance between the roller was 150 mm with loading rate 3 mm/min, this test occurred for the two designs to determine the flexural sandwich's stiffness and compare between them (from Eq. (2)) [30]. The load-deformation curves and failures mode were recorded for both geometries.

$$D = \frac{P_1 S_1^3 \left(1 - {S_2^2}/{S_1^2}\right)}{48\, \Delta_1 \left(1 - {P_1 S_1 \Delta_2}/{P_2 S_2 \Delta_1}\right)} \tag{2}$$

where,

D is flexural stiffness (N-mm^2);

P indicates total applied force (N);

Δ_1= beam mid-span deflection corresponding to p_1 (configuration # 1) (mm);

Δ_2 = beam mid-span deflection corresponding to p_2 (configuration # 2) (mm);

S_1 = support span length (configuration#1) (mm);

S_2 = support span length (configuration#2) (mm).

3. NUMERICAL SIMULTION

Finite element analysis (FEA) is a computer-based method used to numerically solve boundary problems. It involves subdividing a continuous into well-defined elements and joining them at nodes. The accuracy of results depends on discretization, interpolation form, and computation method accuracy [31]. Simulation can be used for analysis and design instead of expensive testing. ANSYS software is a crucial tool for modern engineering, enabling the modeling, simulation, and analysis of complex structures and systems. and aids in the design of sustainable, safe, and effective structures [8]. The numerical simulation effectively predicts the bending behavior of sandwich panels.

3.1 Composite pyramid sandwich structure design and assumption

The present study describes the behavior sandwich composite with a pyramid core design numerically under three point bending test to calculate the amount of deformation, von-mises strain and Von-mises stress, etc., the core design depicted in Figure 3. This simulation of two sandwich panels is conducted to assess the bending load resistance of each core. Finite Elements Modeling (FEM) is used with the commercial ANSYS software package 2016 R1 software. This composite panel is defined as an elastic material, and its properties are defined as the laminated structure of the composite element shell. FEM is established according to the actual situation of the bending test according to ASTM C393, the upper and lower face-sheet thickness is 3 mm, and the height of the core is 15 mm. The span length used is 138 mm with a diameter of 30 mm for the supports the assumption used in this simulation are:

1. This simulation did not utilize any adhesive material between the core and the skin.
2. The bond between the skin and the core is perfect.
3. The behavior of the skin material is orthotropic, while the behavior, of the core material is isotropic.
4. There are no manufacturing defects in sandwich structure.
5. The loading conditions are perfect.

The orthotropic properties of carbon and epoxy are obtained from the laminator program (classical analysis of composite laminates), as shown in Figure 4. This program is a specialized program for composite materials and depends on the use of theoretical equations for composite materials, such as laminated theory, rule of mixture, and other theories, to calculate the engineering constants for composite materials as follows:

1. Input the physical and mechanical properties of the fibers used.
2. The second step is the input of the physical and mechanical properties of the matrix material utilized to create composite materials.
3. After completing the properties for both the fiber and matrix and the volume fraction of the fiber, choose the calculate property for the lamina.

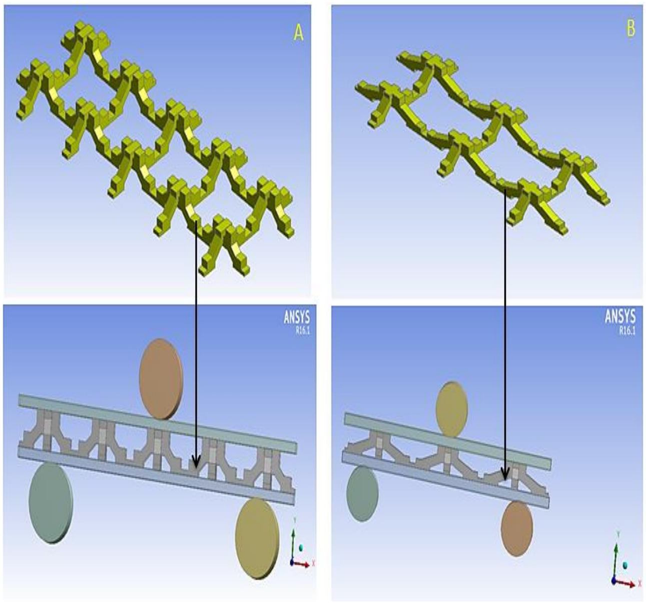
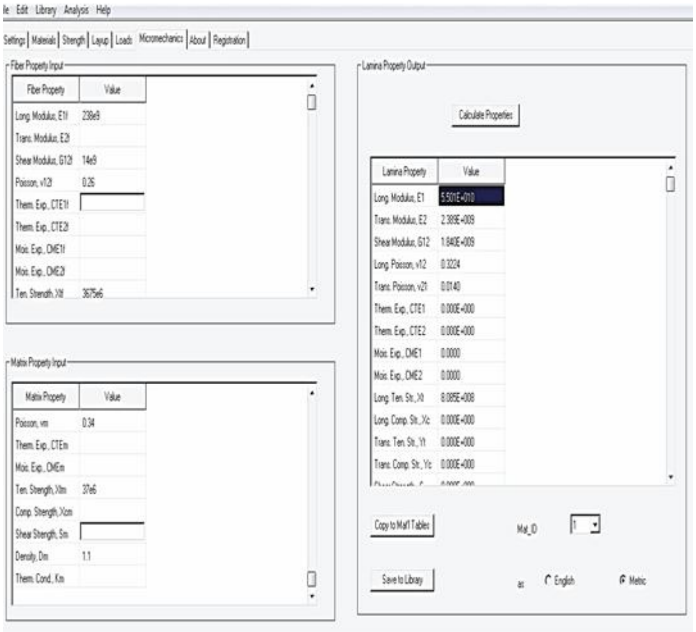


Figure 3. Model for pyramid core with the final shape of sandwich structure under three point bending test for a) first geometry; b) second geometry



Fiber Property Input

Fiber Property	Value
Long. Modulus, E1f	238e9
Trans. Modulus, E2f	
Shear Modulus, G12f	14e9
Poisson, v12f	0.26
Therm. Exp., CTE1f	
Therm. Exp., CTE2f	
Mois. Exp., CME1f	
Mois. Exp., CME2f	
Ten. Strength, Xtf	3675e6

Matrix Property Input

Matrix Property	Value
Poisson, vm	0.34
Therm. Exp., CTEm	
Mois. Exp., CMEm	
Ten. Strength, Xtm	37e6
Comp. Strength, Xcm	
Shear Strength, Sm	
Density, Dm	1.1
Therm. Cond., Km	

Lamina Property Output

Lamina Property	Value
Long. Modulus, E1	5.501E+010
Trans. Modulus, E2	2.389E+009
Shear Modulus, G12	1.840E+009
Long. Poisson, v12	0.3224
Trans. Poisson, v21	0.0140
Therm. Exp., CTE1	0.000E+000
Therm. Exp., CTE2	0.000E+000
Mois. Exp., CME1	0.0000
Mois. Exp., CME2	0.0000
Long. Ten. Str., Xt	8.085E+008
Long. Comp. Str., Xc	0.000E+000
Trans. Ten. Str., Yt	0.000E+000
Trans. Comp. Str., Yc	0.000E+000

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as ○ English ● Metric

Figure 4. Input data for fiber and epoxy in the laminator – classical analysis program

3.2 Mesh generation, boundary and loading conditions

It involves dividing complex geometries into elements that can be used to discretize a domain. In this design (Figure 5), the skin and the core have been combined, and the core is attached to the top and lower skin as a "tie constraint." the default mesh (medium) chosen to balance accuracy and computational cost, resulting in approximately 16348 nodes with 6439 elements and minimum edge 2.629e-002 mm for the first geometry and 10900 nodes with 3448 with elements and minmum edge 1.5931e-002 mm for the second geometry. A simple support beam was supported by two supports, and a load was placed in the center in order to simulate the practical part. The forces were taken constant for all cases in order to study the effect of deformation, taken approximately 10 kN, the boundary condition of the finite element analysis model is obtained. By identifying the regions on the sandwich panel's four edges, fixed support was defined. This numerical analysis was performed with a quasi-static load of about 10 kN.

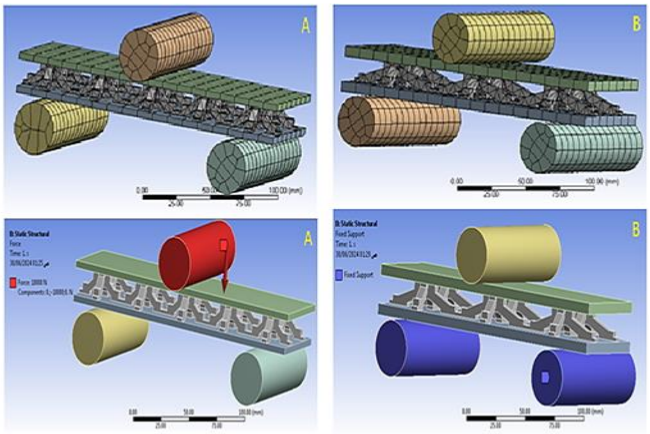

Figure 5. Mesh generation and boundary condition for both designs

4. RESULT AND DISCUSSION

4.1 Experimental results

4.1.1 Flexural stiffness

After applying the test to both designs and obtaining the values of load deformation and applying Eq. (2) (each value is an average of three models), the maximum stiffness is obtained in the second geometry (in the third layer of carbon fiber) about 88.3 MPa compared to the first design 39 MPa. This increase is due to the increasing Young's modulus (E) in three carbon fiber layers, where flexural stiffness is commonly expressed as EI, where I is the cross-sectional area's moment of inertia (a measure of the area's distribution along a particular axis) and it takes a constant for each layer addition. This can be a result of the cross-ply carbon fiber, which aids in improved fiber connection within the composites. The configuration of the pyramid core significantly affects its mechanical properties where the geometrical aspects like cell, number, cell, size, and other parameters, are the important variables that indicate the bending properties of the overall structure. This increase in stiffens lead to enhance bending resistance, absorb more energy and making the structure more resilient to damage, which is crucial in crashworthiness applications in automotive or aerospace industries.

The bending load-deformation curves are presented in Figure 6. For the two geometries. with an increase in load, a linear response is shown until the stresses reach their peaks for all curves in the initial. When the sandwich has one layer, its failure is faster after it reaches the maximum load because the core begins to absorb energy from the fiber's layer in the skin and the structure can withstand less load, while samples with two and three layers the lattice sandwich structure deforms elastically prior to peaking. Beyond the peak, many failure types take place in a gradual manner, as well as a higher peak and yield bending load that appear in the third layer compared with the first and second layers because additional fibers enhance the load-bearing capacity of the face-sheets and increase the strength of the overall structure and this observed in the second design has the maximum load bearing capacity 3.9 kN in the third layer while the first one has 1.7 kN in the same layer and this back to the different unit cell design and dimensions. Since the face-sheet material constitutes most of the weight of a sandwich panel, it plays a critical role in determining the properties of the panel as a whole. The second geometry has the failure and damages occur in the pyramidal sandwich panel under three-points bending test (i) skin wrinkling (ii) core shear failure (iii) de-bonding and (iv) face yield failure) as observed in below Figure 7.

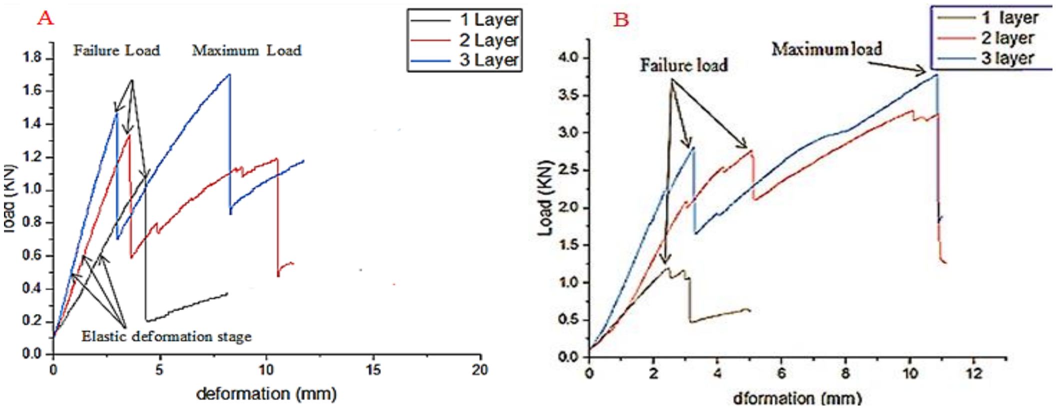

Figure 6. Load-deformation curves for the two designs with different number of layers

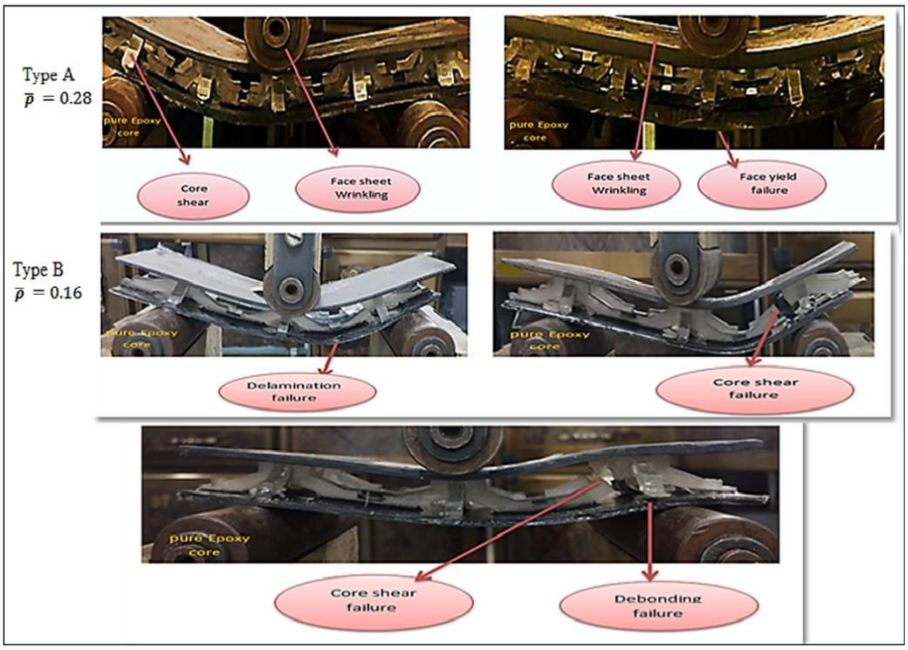

Figure 7. The deformation modes in two different cores under bending

4.1.2 Failure modes

In Figure 7, it is observed core failures of sandwich beams under a three-point bending load. As the load increase the failure mode changes. The core primarily carried applied shear loading. Failure occurs when the maximal shear stress exceeds the critical value of the core material's shear strength. In the failure modes, don't observe core buckling but an observed fracture core that's back to the material core used (epoxy), which is a brittle material. Core shear failure is the predominant failure observed in the majority of the structures. When the load is applied to a sandwich, the upper skin is usually subject to wrinkling failure because most composite materials are subjected to compressive failure in the top skin, and their compressive strength is lower than their tensile strength. Although the face wrinkling reduces the sandwich panels' stability, it does not cause an abrupt decrease in the specimen's ability to support loads; hence, it is not a dangerous event because pyramid core structures can withstand localized damage without catastrophic failure. The damage tends to remain confined to the area of impact, preserving the overall integrity of the structure., the wrinkling increase with increment of compressive load, this was followed by core de-bonding from the face sheet. The de-bonding occurred relatively gradually between the pyramidal truss core and face sheets, leading to multiple drops in the load carrying capacity of the panel and this consistence with study [32]. De-bonding failure mode is sometimes noticed because the small adhesion area in the pyramid struts causes interfacial degumming between the face sheets and the truss core, which can compromise the shear transfer between the face sheets and the core. As the deflection increases, the bottom face sheet de-bonds from the core, leading to a sharp drop in the load, while the top face sheet remains connected to the pyramidal truss core. De-bonding failure severely restricts the application of composite lattice truss core sandwich structures; it can be remedied by increasing the bonding area, which could prevent the relative slippage between the face sheets and nodes. Yield Face failure is apparent in a few cases. When the face sheet's stress exceeds the material's yield strength, a permanent deformation results from this kind of failure. As a consequence, the failure occurred at a greater deflection. The relationship between core design, core material, and skin layers plays a critical role in determining the strength and failure modes of sandwich panels. Optimizing these parameters based on the predicted loading conditions and environmental factors is essential to improving performance and avoiding failure. When transverse loads, like indentation loading, are used on composite sandwich structures, especially when face sheets are thin and cores are weak, the structures are prone to damage.

4.2 Numerical results

Figure 8 represents the result of numerical simulation for the sandwich structure with pyramid core for both designs under bending tests for different relative densities, where the maximum total deformation in the first geometry stationed in the middle of the sandwich panel is nearly 2.5466 mm. The increase in the number of unit cells is (2×5) in this geometry, which is more than in the second geometry, which has 2×3 unit cells and has less deformation of about 1.8127 mm, and this will provide good shear resistance and high stiffness. That means the second design absorbs energy and reactions more than the first one due to fewer stresses as a result of the geometric design improvement, and this is consistent with research [33]. This leads to enhanced performance in load carrying and stress distribution where the distribution of pyramidal truss have strong influence on bending behaviors of the sandwich beam, making it suitable for numerous applications requiring minimal deformations. Figure 8 shows the Von Mises stress distribution of the two designs of the pyramid core. Within the sandwich panel with a geometry (A) has the maximum equivalent stress; the concentrated load at the center generates about 414.08 MPa compared with the distributed load at the edges, while the configuration of a pyramid core significantly impacts its mechanical properties, with geometrical factors like cell, number, cell, size, and other parameters influencing bending properties so the second design will has a maximum stress in the middle of around 201.15 MPa, because it has the highest area in its pyramid cell and its unit cell dimensions are wider (M=66, N=20, I=15.8) and the number of unit cells at the same time less than the first geometry (M=40, N=16, I=5.12), which makes this design easier in the manufacturing process and help to produce lightweight pyramid core and that's we needed in many applications such bridge beams and decks, building roofs, warehouse frames, load-bearing walls, and railway sleepers typically experience quasi-static loadings which consider load-bearing structures and this lead to enhancing strength to weight ratio, so design B can carry more load than the first design and the stress decreases. The stresses in the panel are affected by the load, the panel's geometry, and the properties of the materials used in the sandwich. The stress distribution is more uniform in the bidirectional stiffened model, which primarily distributes high stress on the skin surface, which is consistent with study [34]. Elastic strain is related to the magnitude of stress and deformation. Design A has the highest equivalent stress and deformation, so its elastic strain is high (0.1295). Design B has the least elastic strain of 0.06249 due to its length of unit cell design and core angle. These are the main geometric parameters that influence the structure, where the inclined struts of the pyramids help to redirect forces and reduce the overall elastic strain on the core by optimizing the geometry, with the core angle 45° the bending strength will increase or it was the preferred angle for the pyramid struts [35]. Low elastic strain in panels ensures structural stability, reduces the risk of failure, and improves performance in applications like aerospace and precision engineering. It minimizes deformation, ensures accurate shape maintenance, and increases stiffness with the highest energy absorption. All the numerical results in the second geometry make it preferred as compared with the first geometry and this agree with the experimental result where it also obtained the maximum stiffens with higher load capacities in the second design.

From the result in Table 3, it was concluded that when the unit cells increase, the possibility of deformation of the sandwich increases, as in the first geometry, where its deformation value approximately doubles from 2.5466 to 1.8127 in the second geometry, as well as elastic strain from 0.12954 for geometry A to 0.06249 for geometry B, and Mises-stress from 414 MPa to 201 MPa. Also observed, the maximum von- Mises stress for the second design didn't exceed the ultimate tensile strength of the composite material selected in the sandwich, which was obtained from the laminator program, so it is considered a successful material. The numerical analyses correspond with experimental in terms of finding the best design of pyramid core.

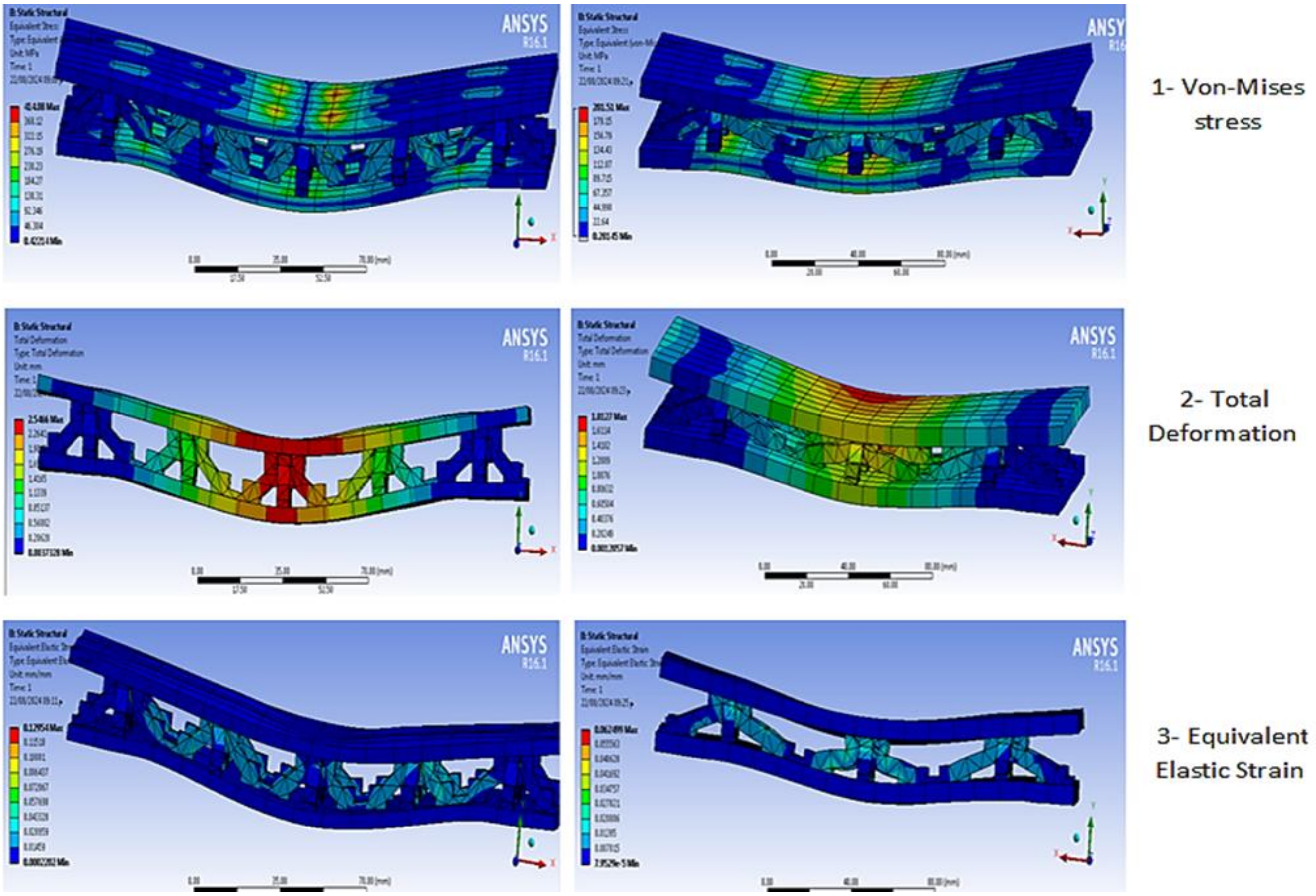

Figure 8. The result of numerical simulation for first geometry and second geometry

Table 3. Summary of results for pyramid core sandwich panels

Type of Sandwich	Maximum Von-Mises Stress (MPa)	Maximum Elastic Strain (mm)	Maximum Deformation (mm)
1st geometry	414	0.12954	2.5466
2nd geometry	201	0.06249	1.8127

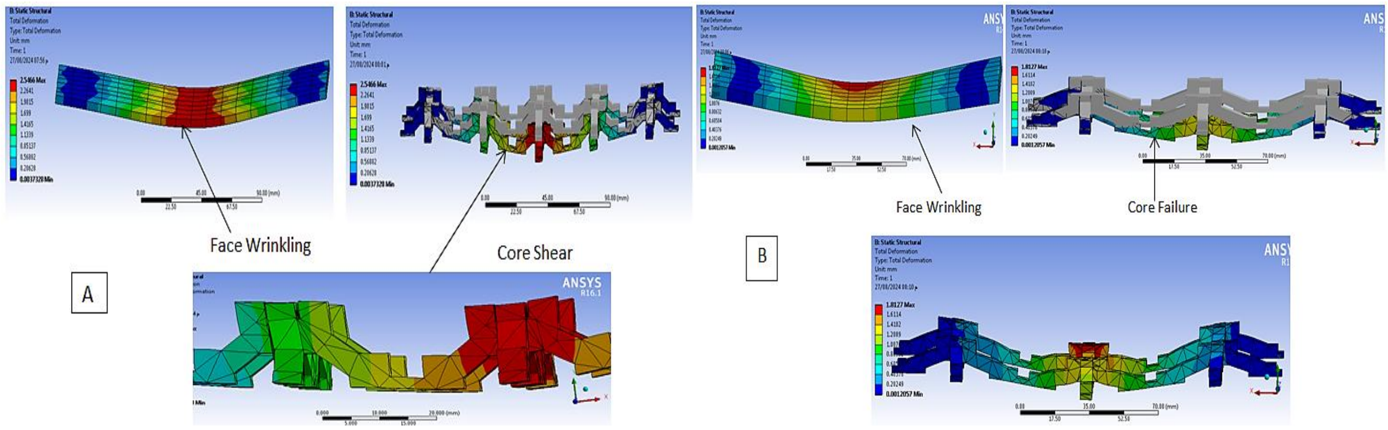

Figure 9. The numerical sandwich failure in both geometries

Civil engineering and aerospace applications (particularly aircraft wings) can benefit from the enhanced toughness provided by low Von Mises stress, and low elastic strain indicates design flexibility and improvement in structures designed to absorb impact forces. While low deformation is critical for these applications that require dimensional stability. The manufacturing technology and materials used in this research enable the design and production of other lightweight and durable structures such as (honeycomb, lattice and corrugation cores as innovative alternatives.

Figure 9 shows the numerical sandwich failure in both geometries (A and B), respectively. The finite element simulation analysis shows most damage in the top panel, While in bending test the panel subjected to compression in the top skin while the bottom skin to tension, with the red color representing the most severe damage because it represent the loading area, while the supported area, which is at the edges, is close to zero (0.0037328) represented in blue color. The damage area extends from the bending center position to both sides Firstly, failure occurs in the strut under compression in the top face during the test (because the strut forms a sharp angle with the loading direction. where all the struts of the pyramid are used in its design inclination, angle ω is 450) and is subsequently caused by the failure of the remaining struts, and then the specimen's ability to carry load is reduced. The middle trusses tends to face wrinkling. In some cases, there is a mismatch in terms of failure modes between the practical and the theoretical because the simulation material is ideal, but in reality there are manufacturing defects or microscopic defects that lead to early failure that differs from the defects of theoretical failure.

The fabrication method of novel core structures is still a challenge task, while pyramidal core has many advantages, especially for high-performance applications, time-consuming manufacturing processes still has many difficulties, especially when using a polymeric material such as epoxy resin, because it required controlled curing conditions and its viscosity can vary depending on the temperature and formulation in addition it a brittle material which make it easy to fracture under tests. Large-scale production necessitates high-quality molds and tools, which can be costly to produce and maintain. Although the process of manufacturing this form of sandwich is expensive, the good properties obtained during the research cover the high cost, especially in high-performance applications such as airplain applications.

5. CONCLUSIONS

This study focuses on the bending behavior of sandwich panels with a pyramid core with two different core geometries has carbon fiber and epoxy resin utilized as the skin and pure epoxy used as the core. was investigated in this paper using experimental and numerically simulating approaches. The conclusions were summarized as follows:

- Fabrication process for second design is more preferred than the first one due to its unit cells design withstand highest load which lead to own it high stiffness with less relative density ($\bar{\rho}$=0.16), more flexibility and this what most designers prefer in most engineering applications.
- The failure in the bending tests dominated by trusses fracture where the core material used is brittle material.
- The simulation results show that the sandwich panels' deformation behavior is significantly influenced by their core geometry, in terms of size, cell dimensions, and density, allowing for customization based on specific application requirements. This flexibility makes it easier to optimize the structure for different performance criteria.
- The maximum stress under quasi-static load in the first geometry, which has a 2×5 unit cell, was approximately 414 MPa. The second geometry, with 2×3 unit cells, has lower deformation, equivalent elastic strain, and equivalent stress than the first geometry, making it the preferred design core for sandwich structures due to its higher resistance and it has fewer pyramidal unit cells, when increasing number of unit cell sandwich deformation increase.
- The maximum deflection, occurred near the center of a plate,which is consistent with the material's standard.
- The results of this study can be practical for the design and optimization of sandwich panels for different applications.
- The experimental part agree with the numerical simulation in term of better geometry.

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