Acta Mechanica Slovaca **29 (2): 6 - 13,** June **2025**
https://doi.org/10.21496/ams.2025.005

Acta Mechanica Slovaca
ISSN 1335-2393
www.actamechanica.sk

Novel Geometric Shape to Enhance Bending Resistance in Sandwich Panels: Core Optimization

Habib Achache [1], Rachid Zahi [2],*, Bachir Bachir Bouiadjra [1], Djaafar Ait Kaci [3], Ali Benouis [4]

[1] Institute of Maintenance and Industrial Safety, University of Oran 2 Mohamed Ben Ahmed, B.P 1015 El M'naouer Oran 31000, Algeria, Laboratory of Physical Mechanics of Materials Sidi Bel Abbes, Algeria
[2] Relizane University, Cité Bourmadia, BP 48000, Relizane, Algeria
[3] Department of Mechanical Engineering, University of Djillali Liabes Sidi Bel Abbes, 22000, Algeria
[4] Faculty of technology, University of Dr Moulay Tahar, Saida BP138 Saida 20000, Algeria

Abstract: The mechanical strength of a sandwich composite material is determined by the interaction between its two outer plates and core structure. This study aims to optimize the geometric and mechanical properties of a sandwich composite through a systematic approach using three-dimensional finite element modeling (FEM) combined with the design of experiments (DOE). Three core geometries (square, hexagon, and square-circle) were evaluated to identify the configuration that maximizes load-bearing capacity while minimizing displacement under stress. Each configuration was tested with various fibre orientations (0°, 45°, and 90°) and composite materials (glass/epoxy, boron/epoxy, and graphite/epoxy) in the laminate plates. The results indicate that the square-circle core design, particularly when combined with boron/epoxy plates at a 0° fibre orientation, achieves the highest force resistance with minimal deformation. This optimized configuration provides a robust framework for applications requiring enhanced structural durability, making it a valuable approach for industries such as aerospace, automotive, and civil engineering.

Keywords: displacement; fibre orientation; finite element method; honeycomb; optimization and sandwich structure.

1. Introduction

The development and application of sandwich structures have attracted significant interest across various fields, including civil engineering, construction materials, aerospace, marine, and automotive industries. The strength of a sandwich composite material is determined by both the core and the two plates. Over recent decades, research has focused on enhancing the durability and strength of sandwich structures under different loads, with particular attention to the geometric shape of the core. The honeycomb sandwich structure has been a major area of study due to its efficient load-bearing and energy absorption capabilities. Numerous studies have been conducted in this context.

Numerous studies have been conducted in this context. The dynamic response characteristics of corrugated sandwich panels have been investigated both experimentally and numerically [1]. Results indicate that corrugated sandwich panels exhibit good impact resistance. Additional studies have examined the damped dynamic response of sandwich composite structures with various core materials, such as polystyrene and polypropylene honeycomb [2]. These studies established a methodology to determine the damping factor per unit mass and length, the power

*** Corresponding author:** Rachid Zahi, ***E-mail address:*** *zahirachid72@yahoo.fr*

loss factor, and the dynamic modulus of elasticity. Research on aluminium sandwich structures with hexagonal honeycomb cores subjected to water-based impulsive loading shows that the relative density of the core significantly affects explosion resistance [3]. Additionally, the design of coconut mesocarp core sandwich panels have been shown to provide better impact resistance compared to corrugated metal cores [3]. The testing time for GFRP1-Nomex sandwich structures subjected to 3-point bending was reduced by 6.35 times, and by 7.9 times for GFRP2-Nomex samples, resulting in a significant reduction in testing costs for composite sandwich structures [5]. Results showed that this performance initially increases but then decreases with thermal exposure after 6 hours. Analytical predictions aligned with experimental results. Liu et al. [6] found that hexagonal honeycomb core sandwich panels filled with round tubes exhibit better impact resistance than conventional honeycomb panels. Kueh et al. [7] proposed a sandwich beam composed of four essential components: carbon-fibre-reinforced polymer top and bottom laminates, embedding a two-layer core of laterally arched solid hot-melt adhesive material and aluminium honeycomb. Xie et al. [8] analysed the bending behaviour and energy absorption characteristics of Nomex honeycomb sandwich panels. Ma et al. [9] focused on structural trends and the impact response of sandwich panels, aiming to improve strength and performance while reducing weight and cost. They classified core structures into three types: periodic foam-core, two-dimensional, and three-dimensional cores. Gupta et al. [10] conducted an in-depth numerical study on the nonlinear dynamic response of auxetic sandwich panels, investigating various parameters such as the geometric characteristics of honeycomb cells, path angles of curvilinear fibres, and boundary conditions. Studies on sandwich panels with a graduated polyurethane foam core have shown that panels with decreasing foam core density (HL) generate 1.5 times more contact force than panels with increasing foam density (LH) [11]. Zhu et al. [12] proposed a numerical approach for analysing the dynamic stability of sandwich plates with a porous core. Kueh et al. [13] examined the impact response of a novel bilayer core sandwich beam, which demonstrated higher impact resistance than existing designs. Georges et al. [14] introduced an analytical model to study lattice cores based on spacers made up of periodic representative volume elements (RVE) of 3D uprights in sandwich panels. An analytical model was created by Zhu et al. [15] to predict the flexural stiffness and failure modes on six types of composite sandwich panels with different core configurations (hexagonal honeycomb (HH), offset corrugated lattice (SCL), bidirectional corrugated lattice (BCL), reinforced hexagonal honeycomb (RHH) and reinforced offset corrugated lattice (RSCL)), validated by experimental and numerical results.

This article addresses the integration of the finite element method (FEM) with the design experimental (DOE) to optimize the geometric and mechanical properties of sandwich structures. The study examines three sandwich structures with different core geometries (square, hexagon, and square-circle) subjected to imposed displacement, considering factors such as core geometry, fibre orientation in the laminated plate, and other relevant parameters. The goal is to enhance understanding of the impact of core geometry and fibre orientation on the mechanical performance of sandwich structures and to establish a robust methodology for optimizing these structures across various industrial applications. This research aims to make a significant contribution to the fields of composite materials and structural engineering, providing valuable insights and practical solutions for the design and application of advanced sandwich structures.

2. Geometric Model

Main text paragraph. Our geometric model is a 300*85*24 mm^3 sandwich panel made of two laminated composite plates of eight crossed plies [+θ; -θ] (0°;10°;20°;30°;40°;45°;50°;60°;70°;80°;90°), and a core whose properties are listed in table 1 and 2 respectively. The study is carried out on three geometric models. Each model differs in the type of reinforcement material for its laminated plate and in the geometry of its core.

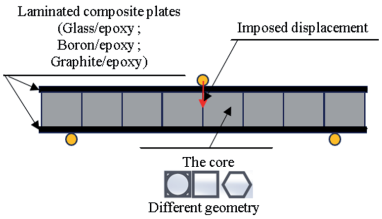


Figure 1: Geometric Model.

Table 1: Mechanical characteristics of the plate [17].

Parameters	Glass/epoxy	Boron/epoxy	Graphite/epoxy
Mass Density ρ [g.cm^{-3}]	1.660	1.967	1.535
Longitudinal modulus of composite E1 [MPa]	50000	208000	134000
Transverse modulus of composite E2; E3 [MPa]	14500	25400	10300
Composite shear modulus G12; G13 [MPa]	2560	7200	5500
Composite shear modulus G23 [MPa]	2240	4900	3200
Poisson coefficient v12; v13	0.33	0.1677	0.33
Poisson coefficient v23	0.33	0.035	0.53

Table 2: Mechanical characteristics of the core [18].

Materials	Young's modulus [MPa]	Shear modulus [MPa]	Poisson coefficient
Aluminium alloy 2024-T3	69	36.92	0.3

2.1. Core and Composite Plate Manufacturing Procedure

2.1.1 Core Structure Manufacturing

The core structures (square, hexagonal, and circular-square) were manufactured from a 2024-T3 aluminium alloy. A CNC milling machine was used to achieve precise dimensions and geometric consistency. Each core was designed to fit the sandwich panel dimensions of 300 × 85 × 24 mm. For each core geometry, specific designs were optimized to balance load capacity and weight considerations, with walls machined to thickness tolerances of ± 0.1 mm.

2.1.2 Composite Plate Manufacturing

The composite plates were manufactured with fibre orientations (0°,10°,20°,30°,40°, 45°,50°,60°,70°,80° and 90°) to assess their influence on load performance. A hand-laying process was used, followed by compression molding. Each composite plate consisted of eight cross-laminated layers of reinforced fibres (glass/epoxy, boron/epoxy, and graphite/epoxy) with a thickness of approximately 0.125 mm per layer. Curing was performed at 120 °C for 2 hours under a pressure of 0.7 MPa, in accordance with the specifications provided by the material manufacturer.

3. Finite Element Modelling

The three-dimensional geometric model of our sandwich panel structure is made up of the assembly of two laminated composite layers and a core whose properties are listed in Table 1. The three-dimensional geometric structure (CAD models) was produced using of Abaqus software. This code is a complete system, integrating not only the calculation functions themselves, but also functions for building models (pre-processor) and processing results (post-processor). Three-dimensional finite element models were developed for this study. A finite element mesh was generated using four nodded tetrahedral elements for analysis. (see Figure 2).

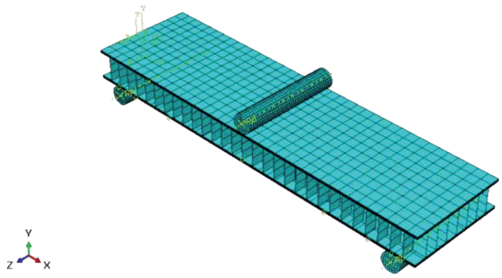


Figure 2: Finite element meshes.

The nodes in the finite element model are shared by every three-dimensional structure, allowing for stress and deformation continuity. To accurately model the complex interactions within the sandwich structure, standard 8-Node Iso Parametric Quadrilateral Elements (C3D8R, Continuum 3D 8-Node Reduced Integration). These elements are used to model the three-dimensional structure of the composite plate and the aluminium's core. They are capable of capturing the complex stress and deformation states within each layer. These elements have 3 translational degrees of freedom per node, with reduced integration to improve computational efficiency and reduce locking effects.

3D finite element models were generated for each core-plate combination using Abaqus software. A mesh sensitivity analysis was performed to determine the optimal mesh size, using four-node tetrahedral elements to ensure accurate stress distribution across the structure.

Boundary conditions were applied to simulate a fixed support at the edges, with loads applied at the centre to assess bending strength.

4. Experimental Design Method

In the present study, the design of experiments (DOE) was applied to optimize the parameters of the complete structure. This scientific method consists of controlling the validity of a hypothesis by means of repeated tests, during which the parameters of the situation are modified one by one in order to observe the effects induced by these changes. It is characterized by a series of in situ verifications whose conditions are set by a protocol which can be repeated identically by any new experimenter and is thus distinguished.

The parameters must be optimized: the material of the laminated plate as well as the orientation of its reinforcement and the geometric shape of the core. The quadratic model of the answer (F) will take the following form:

$$Y = a_0 + a_1 \cdot x^* + a_2 \cdot x^* + a_3 \cdot x^* + a_{11} \cdot x^{*2} + a_{22} \cdot x^{*2} + a_{33} \cdot x^{*2} + a_{12} \cdot x^* x^* + a_{13} \cdot x^* x^* + a_{23} \cdot x^* x^* \tag{1}$$

For the considered factors in the present study, i.e. The orientation of the fibres of the laminated plate (OF) as well as their materials (E), and the section of the lateral geometry of the core (s), the quadratic model of the response (Force "F") will take the following form:

$$F = a_0 + a_1 \cdot s^* + a_2 \cdot E^* + a_3 \cdot OF^* + a_{11} \cdot s^{*2} + a_{22} \cdot E^{*2} + a_{33} \cdot OF^{*2} + a_{12} \cdot s^* E^* + a_{13} \cdot s^* OF^* + a_{23} \cdot E^* OF^* \tag{2}$$

The main objective of this study is to maximize the force F, the experimental design method is suitable to achieve this objective. In this particular case, the maximization of the force F will be carried out by optimizing the three geometric parameters cited above.

5. Results and Discussion

The significance of this research lies in its potential to enhance the durability and mechanical performance of critical structural components in sandwich structures used across various applications, such as aerospace and automotive. By optimizing the core's geometric structure and understanding the effects of fibre orientation on the complete sandwich structure, this research could lead to more resilient and durable structural designs. Studies by Rejab and Cantwell in 2013, Huang et al. in 2016, Xie et al. in 2021, Gupta and Pradyumna in 2022, and Kueh and Tan in 2023 have emphasized the need for further investigation into the mechanical performance of essential sandwich structure components. To achieve the objectives of this study, both experimental and numerical approaches were employed, with results from each approach compared to validate findings and provide a comprehensive understanding of the impact of core geometry and fibre orientation on the performance of sandwich structures.

Figure 3 presents the matrix with all the possible combinations obtained for the three parameters of the sandwich structure. Each parameter is characterized by three levels. The MODDE 5.0 software (Modelling and Design) is used for the development of the model and the statistical analysis of the experimental plan, a known response based on: the lateral surface of the core, the Young's modulus of the laminated plate and its fibre orientation. A complete quadratic design, which deals with a second-order mathematical model.

	1	2	3	4	5	6	7	8
	Exp No	Exp Name	Run Order	Incl/Excl	surface	E	OF	force
1	1	N1	18	Incl	25,01	50000	0	26
2	2	N2	6	Incl	51,85	50000	0	31
3	3	N3	1	Incl	38,5	134000	0	23
4	4	N4	13	Incl	25,01	208000	0	38
5	5	N5	7	Incl	51,85	208000	0	53
6	6	N6	9	Incl	25,01	50000	45	18
7	7	N7	17	Incl	51,85	50000	45	22
8	8	N8	3	Incl	25,01	134000	45	23
9	9	N9	14	Incl	38,5	208000	45	17
10	10	N10	15	Incl	25,01	50000	90	20,3
11	11	N11	5	Incl	38,5	50000	90	13,3
12	12	N12	11	Incl	51,85	50000	90	24
13	13	N13	4	Incl	51,85	134000	90	27
14	14	N14	16	Incl	25,01	208000	90	30
15	15	N15	2	Incl	51,85	208000	90	35
16	16	N16	8	Incl	51,85	208000	90	35
17	17	N17	12	Incl	51,85	208000	90	35
18	18	N18	10	Incl	51,85	208000	90	35

Figure 3: Image of the table of results from running different programs.

The figure 4 shows the optimization of the results, where the value of 51.85 mm^2 corresponds to the area of the square-core circle. The optimal Young's modulus is that of the boro/epoxy composite material, and finally, the optimal fibre orientation is zero degrees.

Figure 5 presents the coefficients of the different parameters and their interactions. The mathematical model proposed by MODDE 5.0 is:

Iteration: 5002 Iteration slider:

	1	2	3	4	5	6
	surface	E	OF	force	iter	log(D)
1	25,01	208000	-0	38,8636	4768	1,1032
2	51,8499	207971	0,3766	51,089	1598	-0,5277
3	25,01	208000	90	28,7741	5000	1,5636
4	51,85	208000	90	34,9555	2461	1,3113
5	51,85	208000	24,6402	41,6513	5002	0,9168
6	25,01	208000	-0	38,8636	4768	1,1032
7	51,85	208000	0	51,27	1171	-0,6021
8	51,85	208000	90	34,9555	2461	1,3113

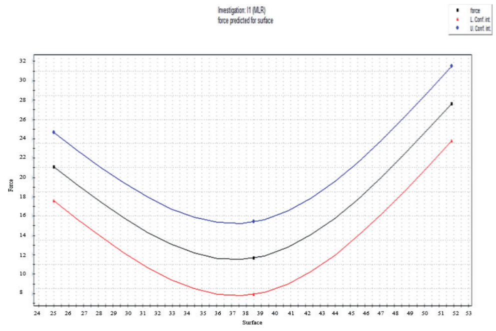
Figure 4: Image of optimization results.

	1	2	3	4	5
1	force	Coeff. SC	Std. Err.	P	Conf. int(±)
2	Constant	11,6343	1,62258	9,51812e-005	3,74168
3	s	3,27028	0,572744	0,000449257	1,32075
4	E	6,16505	0,55868	4,05041e-006	1,28832
5	OF	-4,62753	0,589217	4,98606e-005	1,35873
6	s*s	12,7414	1,33966	1,23267e-005	3,08926
7	E*E	1,44674	1,31555	0,303444	3,03367
8	OF*OF	6,47822	1,19231	0,000620869	2,74946
9	s*E	1,37665	0,597983	0,0503016	1,37895
10	s*OF	-1,55626	0,659323	0,0459302	1,5204
11	E*OF	-1,97349	0,646188	0,015724	1,49011
12					
13	N = 18	Q2 =	0,758	Cond. no. =	7,8157
14	DF = 8	R2 =	0,979	Y-miss =	0
15		R2 Adj. =	0,956	RSD =	1,9869
16				Conf. lev. =	0,95

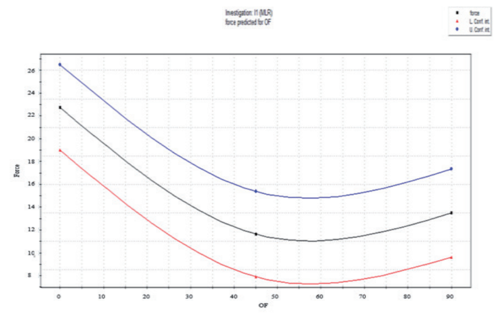
Figure 5: Image of coefficients list.

$$F = 11,6343 + 3,27028 \cdot s^* + 6,16505 \cdot E^* - 4,62753 \cdot OF^* + \\ + 12,7414 \cdot s^{*2} + 1,44674 \cdot E^{*2} + 6,47822 \cdot OF^{*2} + \\ + 1,37665 \cdot s^* E^* - 1,55626 \cdot s^* OF^* - 1,97349 \cdot E^* OF^* \tag{3}$$

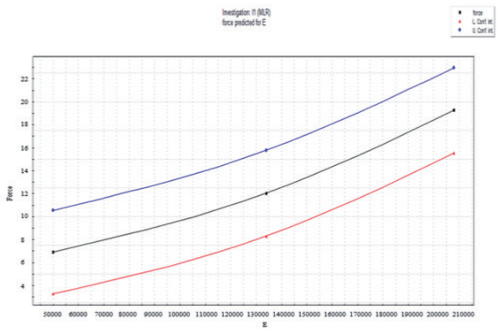
The contour plots in Figure 6 (a, b, and c) clearly show that the maximum force values correspond to the largest lateral surface areas of the core and the highest Young's modulus values.



(a) Surface

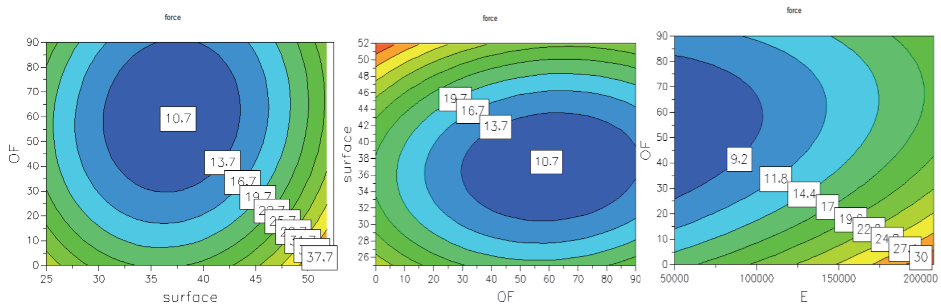


(b) Fibre orientation



(c) Young's modulus

Figure 7: Prediction plots according to: (a) Force "F" versus Surface; (b) Force "F" versus Fibre orientation; (c) Force "F" versus Young's modulus.



(a) Surface (b) Fibre orientation (c) Young's modulus

Figure 6: Contour plots of the "F" force: (a) Surface; (b) Fibre orientation; (c)Young's modulus.

Enhancing the surface area of the core improves load distribution and reduces stress concentration, thereby increasing the force resistance. Aligning fibres in the direction of the applied load (0° orientation) significantly enhances the mechanical resistance of the structure. Using materials with higher stiffness (Young's modulus) improves the ability of the structure to resist deformation under load. This indicates that to maximize the force resistance of sandwich structures, it is crucial to optimize cited the parameters.

Figure 7(a, b and c) show the contours of the effects of the different parameters on the variation of the force "F". The variation of the force "F" is visualized in three-dimensional graphics projected into the plane. We note that these figures confirm what was said in Figure 6.

Figure 8 represents a bar graph or the effect of the different parameters and their interactions on the force F experienced by a sandwich structure. The interaction effects between these parameters are represented in the combination categories on the x-axis. These combinations show how changes in one parameter affect the force F in the presence of other parameters. Significant interaction effects indicate that the combined influence of two or more parameters is not simply additive but synergistic, leading to a different F strength than that expected from individual effects alone. It was identified that the most dominant parameter as shown in the graph is indeed the lateral surface of the nucleus. The lateral surface plays a crucial role in the absorption and distribution of stresses within the sandwich structure. Larger side surfaces potentially lead to higher force absorption.

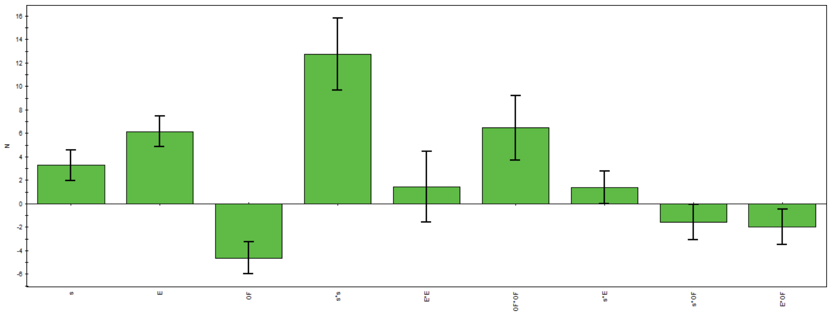
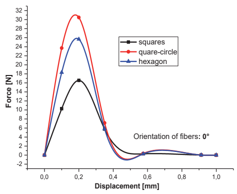
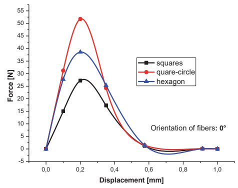


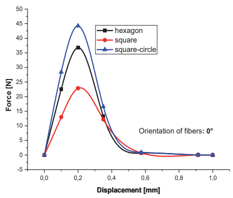
Figure 8: Effects of the different parameters on the Force "F".



(a) Glass/epoxy: α=0°



(b) Boron/epoxy: α=0°



(c) Graphite/epoxy: α=0°

Figure 9: Variation of the force as a function of the displacement of different sandwich panels for fibre orientations (α =0°) and different materials of the composite plate.

Figure 9 (a, b and c) illustrates the variation of the force as a function of the displacement of different sandwich panels for fibre orientations (α =0°) and different materials (Glass/epoxy, Boron/epoxy and Graphite/epoxy) of the composite plate. The force values of the circle-square core geometry are systematically higher in all orientations (especially at the 0° fibre orientation) and in all materials (especially the boron/epoxy composite material). This geometry is the most effective in resisting deformation. Conversely, square and hexagonal geometries have lower force values, indicating less effective resistance. These geometries are less efficient, especially under high displacement conditions. The boron/epoxy laminated plate with 0° fibre orientation is the optimal combination for mechanical resistance. This combination is most suitable for applications requiring high durability and strength. The FEM results validate the experimental findings, reinforcing the reliability of the observed trends and conclusions.

The square-circle core can be considered to have a more efficient load transfer path due to its larger surface area, which reduces stress concentrations and improves structural resilience. When the fibres are aligned with the load direction (0°), they improve the stiffness and strength of the structure due to the direct load transfer along the fibre length, while off-axis orientations (45° and 90°) can result in larger shear stresses and less optimal load transfer. The square-circle geometry can be highlighted as superior due to its ability to balance bending stiffness and shear strength, which contributes to better deformation resistance and higher load capacity.

Boron/epoxy laminates have the highest stiffness, making them less susceptible to deformation under applied loads. The combined influence of fibre orientation and core geometry on fracture toughness and how specific orientations could optimize structural resilience under applied displacements.

Finished element modeling (FEM) results align with experimental observations, confirming the reliability of the optimization methods. This alignment supports the practical application of the chosen core geometry and material configuration for structural applications.

The square-circle core geometry and fibre orientation in this study deliver enhanced performance compared to the previously cited works, reinforcing the relevance of the authors' design choices.

6. Conclusions

The study examined three types of sandwich structures with different core geometric shapes: square, hexagon, and square-circle. These structures were subjected to an imposed displacement to optimize their geometric and mechanical properties. The main conclusions are:

The comparative approach of the study highlights the significant impact of core geometry on the structural performance of sandwich panels. The circle-square core's ability to withstand higher forces suggests that it distributes stress more effectively, making it a better choice for applications requiring high strength and durability. The finding that 0° fibre orientation produces the highest peak force highlights the importance of fibre alignment in composite materials. This orientation likely optimizes load transfer and resistance to deformation, essential for maintaining structural integrity under stress. The superior performance of boron/epoxy laminated plates can be attributed to the material's inherent properties, such as high stiffness, strength, and fatigue life. This makes boron/epoxy an excellent choice for applications where maximum force resistance is required. The results of this study have practical implications for the design and fabrication of sandwich structures for high-performance applications. The optimal combination of circle-square core geometry, 0° fibre orientation and boron/epoxy composite material provides a robust solution for industries such as aerospace, automotive and construction, where structural efficiency and reliability are paramount.

References

1. Rejab, M.R.M. and Cantwell, W.J. (2013). The mechanical behavior of corrugated-core sandwich panels. Journal Composite Part B, 47, 267-277.
2. Burada, C. O., Miritoiu, C. M., Bolcu, D. and Stanescu, M. M. (2015). Experimental determinations of the damping factor and stiffness for new sandwich platbands with different reinforcement and core. Revista Română de Materiale / Romanian Journal of Materials, 44, 4, 405.
3. Huang, W., Zhang, W., Li, D., Ye, N., Xie, W. and Ren, P. (2016). Dynamic failure of honeycomb-core sandwich structures subjected to underwater impulsive loads. European Journal of Mechanics - A/Solids, 60, 39-51.
4. Liu, T., Hou, S., Nguyen, X. and Han, X. (2017). Energy absorption characteristics of sandwich structures with composite sheets and bio coconut core. Composite Part B: Engineering., 114, 328-338.
5. ZAHARIA, S. M., MORARIU, C. O. and POP, M.A. (2018). A comparative study about static and fatigue behaviour on sandwich structures with different types of glass fiber reinforced polymer skins and nomex honeycomb core. Romanian Journal of Materials, 48, 1, 91 – 100.
6. Zahi, R., Refassi, K. and Achache, H. (2018). Dynamic calculation of a tapered shaft rotor made of composite material. Advances in Aircraft and Spacecraft Science, 5, 1, 51-71.
7. Liu, J.F., Chen, W., Hao, H. and Wang, Z. (2019). Numerical study of low-speed impact response of sandwich panel with tube filled honeycomb core. Journal Composite Structures, 220, 736-748.
8. Kueh, A.B.H. and Siaw, Y.Y. (2021). Impact resistance of bio-inspired sandwich beam with side-arched and honeycomb

dual-core. Journal Composite Structures, vol, 275, 114439.
9. Xie, S. Feng, Z. Zhou, H. and Wang, Da (2021). Three-point bending behavior of Nomex honeycomb sandwich panels: Experiment and simulation. Mechanics of Advanced Materials and Structures, 28, 18, 1917-1931,
10. Ma, Q., Rejab, R., Siregar, J. and Guan, Z. (2021). A review of the recent trends on core structures and impact response of sandwich panels. Journal Compos. Materials, 55, 18, 2513–2555.
11. Gupta, A. and Pradyumna, S. (2022). Nonlinear dynamic analysis of sandwich shell panels with auxetic honeycomb core and curvilinear fiber reinforced face sheets. European Journal of Mechanics - A/Solids, 95, 104640,
12. Kazemi, M. (2022). Experimental investigation on the energy absorption characteristics of sandwich panels with layering of foam core under quasi-static punch loading. Mechanics of Advanced Materials and Structures, 29, 21, 3067-3075.
13. Zhu1, Z. and Zhu, M. (2022). Investigating dynamic stability behavior of sandwich plates with porous core based on numerical approach. Structural Engineering and Mechanics, 83, 5, 609-615.
14. Kueh, A.B.H., Tan, J.H., Abu Hassan, S. and Wahit, M.U. (2023). Repeated impact response of bio-inspired sandwich beam with arched and honeycomb bilayer core. Structural Engineering and Mechanics, 85, 6, 755-764.
15. Georges, H., Mittelstedt, C. and Becker, W. (2023). Energy-based strut stress analysis of 3D lattice cores in sandwich panels. European Journal of Mechanics-A/Solids, 100, 105007.
16. Zhu, X., Xiong, C., Yin, J., Qin, Y., Sun, H., Cui, K., Zou, Y. and Deng, H. (2024). Three-point bending characteristics of all-composite sandwich panels with different core configurations. Mechanics of Advanced Materials and Structures, 31, 15, 3289-3308.
17. Achache, H., Boutabout, B. and Ouinas, D. (2013). Mechanical behavior of laminated composites with circular holes. Key Engineering Materials, 550, 1-8.
18. Achache, H., Zahi, R., Ait Kaci, D. and Benouis, A. (2024). Behavior of structures repaired by hybrid composite patches during the aging of the adhesive. Structural Engineering and Mechanics, 91,2, 135-147.