THE EFFECT OF CORE ON ENERGY ABSORPTION OF 3D PRINTED SANDWICH STRUCTURE SUBJECTED TO IMPACT TEST

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ABSTRACT

Sandwich structures are utilized for a variety of engineering applications including biomedical, aircraft, and transportation because of their specific mechanical behavior and excellent impact energy absorption. In this work, a novel design for the sandwich core which is a type of closed-cell foam with spherical pores was proposed and compared with a typical hexagonal structure. A 3D printer was used to manufacture all the samples. In accordance with ASTM standards, tensile specimens in the form of dog bones were 3D printed using the same material as that used for all architected sandwich panels to get the material properties that were used for the simulation. The low-velocity impact test is conducted to evaluate the influence of unit cell geometries on mechanical performance, specifically energy absorption capability. The impact simulation was performed using ANSYS software with the same boundary conditions as those used in the experimental test. The simulation was utilized to predict the effect of the core geometries on the performance of sandwich panels and to compare the results with experimental data. Results illustrate that the topology and geometrical parameters have significant effects on the failure mechanism and energy absorption of meta-sandwich structures. These findings pave the way for developing a new class of lattice structures through a combination of rational design and 3D printing.

1 INTRODUCTION

The development of innovative composite materials with multi-functional qualities is a result of a growing demand for lightweight yet strong materials in engineering applications, such as biomedical, aerospace, defence, building, and vehicle components. Strength, stiffness, cost, durability, and static and dynamic qualities are just a few of the multifaceted decisions that must be made when selecting the most appropriate material for a specific structural issue. In order to guarantee the durability and effectiveness of the construction, the ideal balance must be struck between these factors [1]. Sandwich structures are a type of composite material that represent an important class of materials. They comprise two high-strength skins that are divided by a lightweight core and offer special mechanical properties including lower density, a higher stiffness-to-weight ratio, higher specific properties, and well-developed energy absorption properties. As a consequence, they have attracted a lot of interest and are widely used in many industries [2, 3]. Recent studies have highlighted the significant impact of cellular core geometry on the multifunctional performance of sandwich structures [4]. By optimizing the microarchitecture of the cellular core, including its shape, size, and distribution, the sandwich structure's mechanical behaviour and energy absorption properties can be improved [5].

In contrast to subtractive manufacturing techniques, which typically involve removing material from an object to create it, additive manufacturing (AM) involves manufacturing an object by systematically depositing layers of material based on 3D model data [6]. Additionally, AM is a powerful technology that is transforming the manufacturing industry by providing a new approach to creating complex geometries with high precision and accuracy [7]. The layer-by-layer approach used in AM allows for the production of parts with intricate internal features, such as the architected cellular cores used in sandwich structures [8]. In order to develop and enhance cellular structures for particular purposes, such as energy absorption, thermal insulation, and impact resistance, it is crucial to understand the mechanical behavior of cellular materials [9]. The topology of the unit cell and its relative density, which is calculated as the density of the cellular material divided by the density of its constituent materials, are two factors that affect the physical properties of cellular materials and have a major impact on their mechanical properties [10].

In this study, we used a combination of numerical simulation and experimental impact testing to evaluate the mechanical performance of sandwich panels with a novel unit cell geometry.

2 MATERIALS AND METHODS

The main aim of this study is to enhance the energy absorption capacity of sandwich panels by optimizing their core geometry. To this end, we investigated novel closed-cell foam and honeycomb structures. Dimensions of the sandwich panel, which include the length (a), width (b), and total thickness (h) are illustrated in Figure 1.

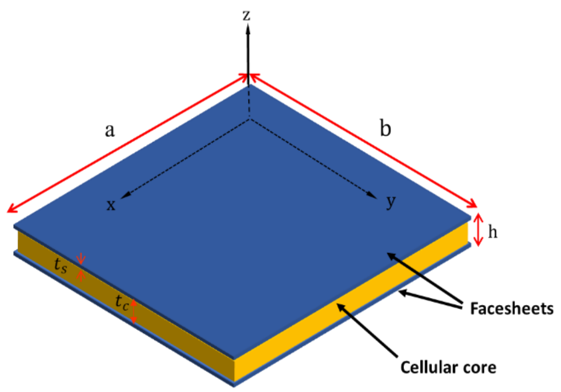

Figure 1: Geometry of sandwich panel and the considered coordinate system

The coordinate system (x, y, z) is located in the middle plane of the panel. The investigation was carried out using square sandwich panels with dimensions as shown in Table 1, which were selected based on ASTM standard D3763 [11].

Length (a)	**Width (b)**	**Total thickness (h)**	**Core thickness (t_c)**	**Face-sheet thickness (t_s)**
100 mm	100 mm	50 mm	40 mm	5 mm

Table 1: Geometric parameters of sandwich panels

In order to investigate the impact of core geometries on sandwich panel performance with greater accuracy, all cellular structures were standardized to possess the same unit cell dimensions and a constant relative density of 40%. Specifically, each model's cell size measured 10×10×10 mm, and the sandwich cores were assembled by four hundred arrangements of unit cells (10×10×4). CAD representations of the unit cells and sandwich panels are illustrated in Figure 2.

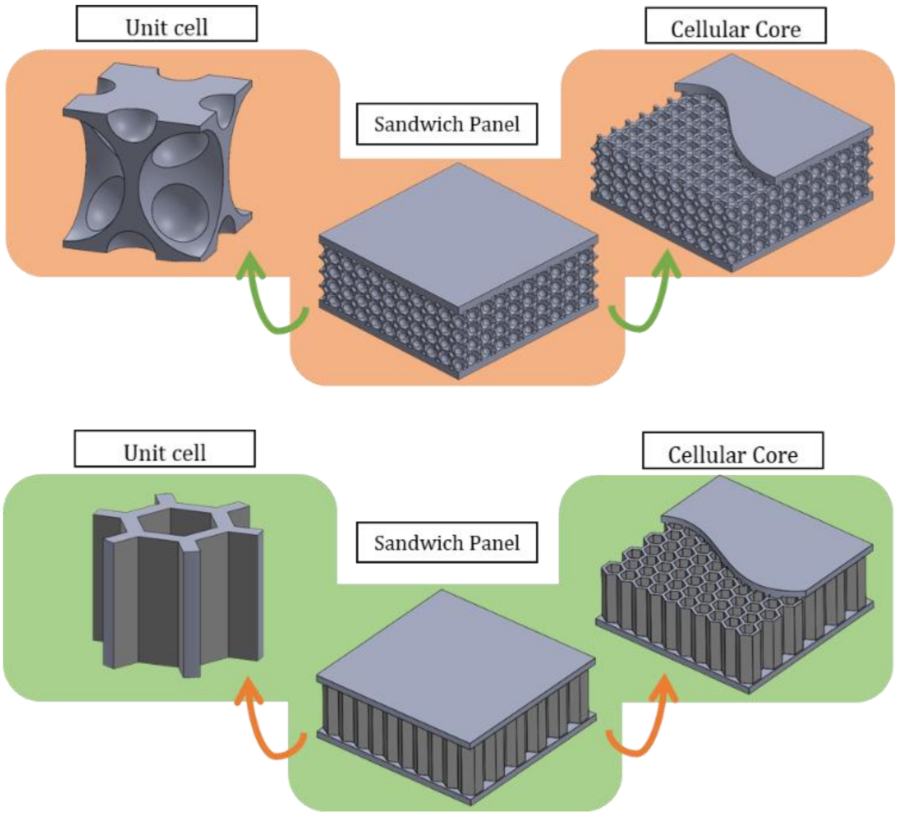

Figure 2: Architected sandwich panels with unit cells and section view of core (CAD file)

The architected sandwich structures were fabricated using the MK2 3D printer, which uses the fused deposition modelling (FDM) method. The structures were printed using HATCHBOX Mint Green PLA filament with a diameter of 1.75 mm. FDM is a widely used 3D printing technology in which molten polymers are extruded through an extrusion head that deposits them in x- and y-coordinates, while the build table lowers the object layer by layer in the z-direction [12]. All samples were printed in the same direction and position, as the layer-by-layer build direction can influence the mechanical response of the structure. The 3D-printed panels were made up of closed-cell foam and honeycomb structures, which were designed to achieve specific mechanical properties, **as** shown in Figure 3.

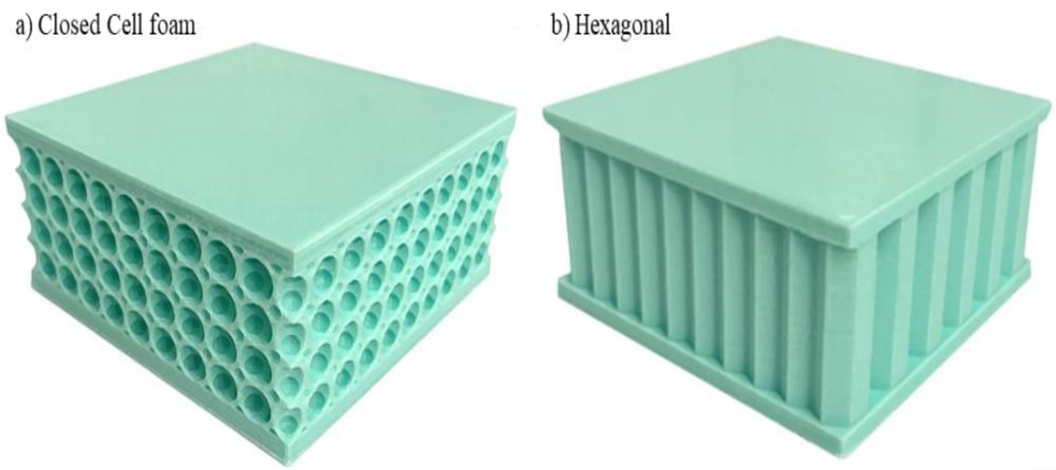

Figure 3: PLA 3D printed sandwich panels fabricated by FDM technology

Measuring the qualities of the underlying material is essential to accurately calculate the mechanical properties of the sandwich panels. Dog bone-shaped tensile specimens based on the ASTM Standard D638 [13] were 3D printed using the same material as that used for all architected sandwich panels. Therefore, four specimens were fabricated with 100% infill for each of the different angles, i.e., -45°, 0°, 45°, and 90°, with respect to the loading axis, as shown in Figure 4, and subjected to the tensile tests. The average mechanical properties of PLA were mentioned in Figure 4.

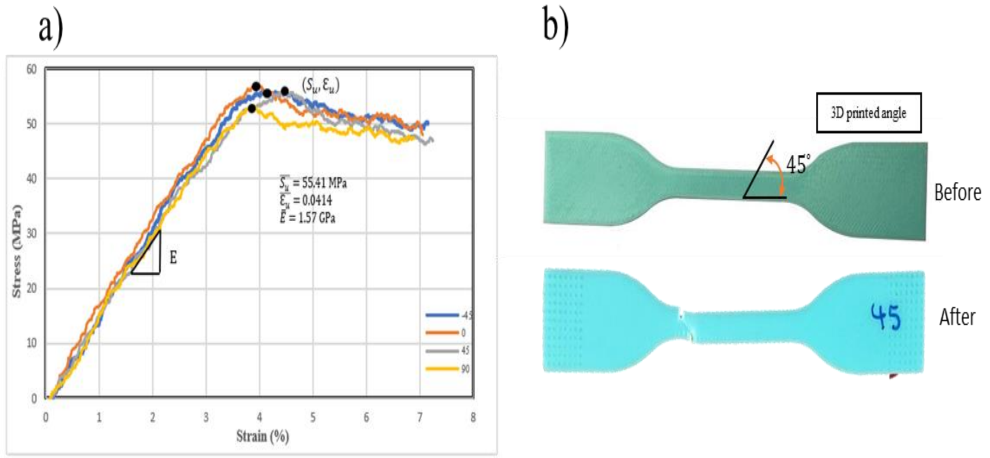

Figure 4: (a) 3D printed dog-bone specimen before and after tensile tests (b) Engineering stress-strain curves of 3D printed PLA dog-bone

3 EXPERIMENTAL PROCEDURE

The dynamic energy absorption capability of the meta-sandwich plates was evaluated through low-velocity impact tests, which were conducted using an INSTRON 9340 Drop Test Machine (shown in Figure 5). The impact tests were performed with an impactor having a diameter of 19 mm and a mass

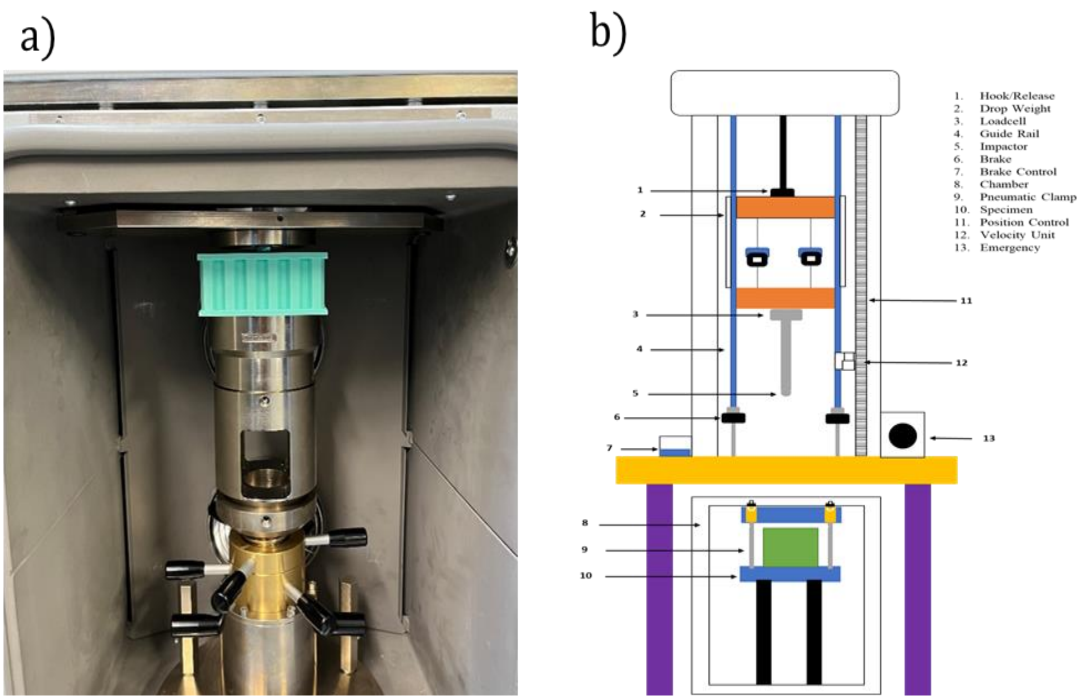

Figure 5: (a) Low velocity impact test configuration (b) schematic diagram of Impact test machine

of 22.5 kg (2.5 kg for the holder and 20 kg of additional weights) with a hemispherical striker tip. The specimens were placed between two parallel rigid supports with 75 mm diameter holes at their centres and clamped tightly to prevent any slippage during the experiments.

The impactor was dropped at a speed of 3.91 m/s to generate an impact energy of 25 J, which was found to be sufficient to investigate the impact resistance of different samples under deformation. During the experiment, the two parameters that were measured were impact energy and impact velocity over the time of the impact test. A load cell was used to measure the load, while a velocity detector, consisting of a photodetector block and a flag, was used to measure the velocity of the impactor. The experimental setup was designed to capture the deformation and energy absorption capabilities of the architected sandwich panels fabricated in this study.

4 NUMERICAL MODELING

The ANSYS 2022 R1 commercial software's explicit solver was employed to perform a finite element analysis of low-velocity impacts on sandwich structures used in architecture. The simulation involved testing the closed cell foams and honeycomb panels under low-velocity impact conditions, as depicted in Figure 6. A 19 mm diameter impactor was modelled, and the sandwich structure's clamped section was defined at the centre of the facesheets with a 75 mm diameter, as illustrated in Figure 6. The facesheets and the core meshed using quadrilateral and triangular elements, and a convergence study was conducted to prevent mesh size dependency in the FEM results. A semi-spherical impactor was defined as a rigid body, and an initial velocity of 3.91 m/s was assumed for the dynamic load of the rigid impactor. The top and bottom surfaces of the panel were held entirely fixed on the clamped section with circular holes in the centre of both surfaces, as depicted in Figure 6.

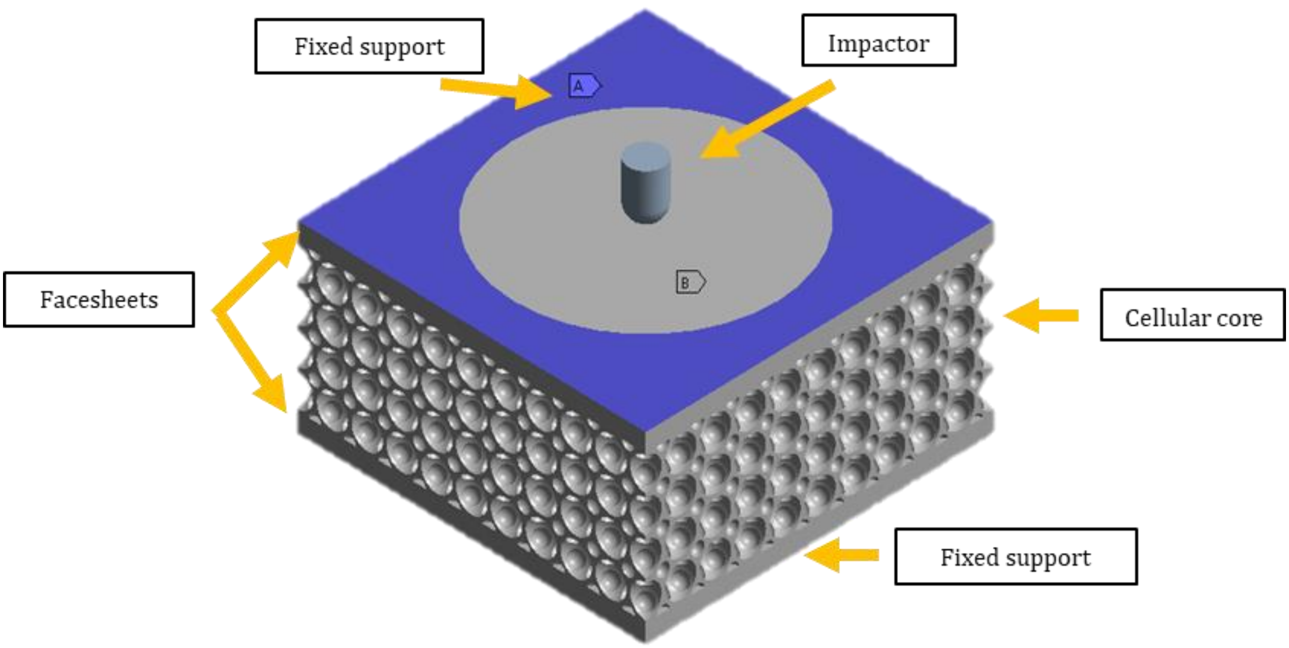

Figure 6: Sandwich panel simulated in ANSYS software

5 RESULTS AND DISCUSSIONS

In this section, the force-displacement response, energy-time, and energy absorption capability (i.e., the area under the force-displacement curve) of the architecture sandwich panels developed were discussed. The effects of unit cell geometries on energy absorption capabilities were studied. The sandwich panels with closed-cell foam and hexagonal unit cells were designed, manufactured, and tested under impact loads to identify the optimum geometrical design for energy absorption capabilities. In the following the dynamic energy absorption mechanisms were determined via FEA simulation to improve the energy absorption performance of the architecture design.

Figure 7 presents the contact force-displacement curves (at the tip of the impactor) obtained from the experimental testing of 3D-printed architected sandwich panels. The results demonstrate that the closed cell foam geometry makes the panels deflect more in comparison with hexagonal cellular cores. Furthermore, the architected sandwich panels with closed-cell foam cores have a lower contact force compared to hexagonal cores.

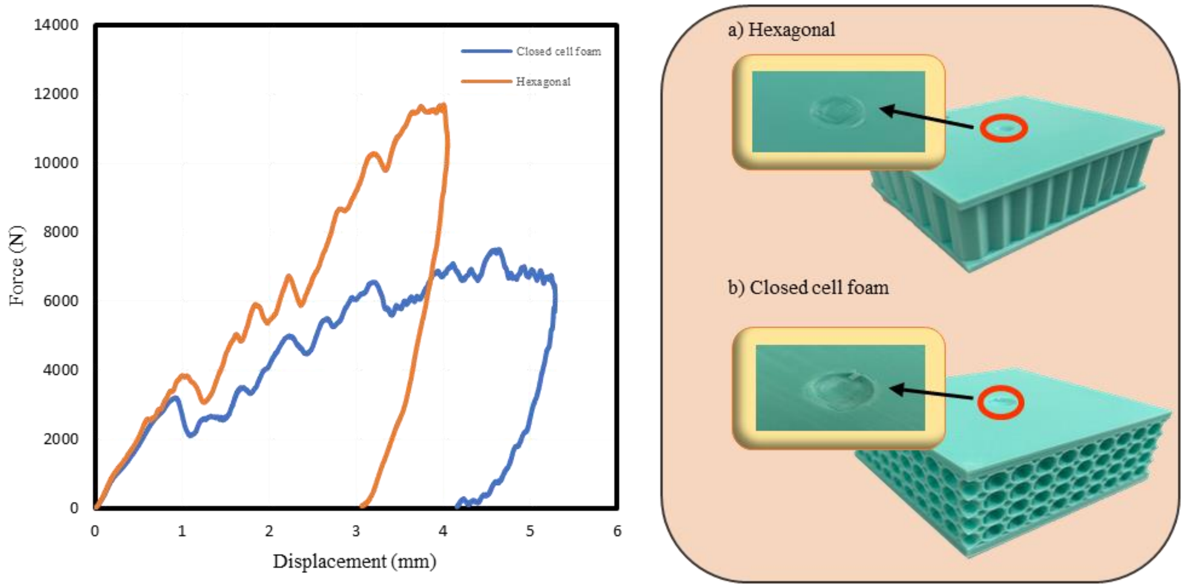

Figure 7: Experimental force-displacement curves of 3D printed architected sandwich panels with deformation zone of panels under low-velocity impact test

The experimental energy-time curves (at the tip of impactor) of 3D printed architected sandwich panels are presented in Figure 8. The results show that the hexagonal sandwich panel reaches 25J sooner than the closed-cell foam panels. Furthermore, it took more time for the closed-cell foam structure to absorb the energy. According to the comparison of absorbed energy via these panels, closed-cell foam absorbed more energy than hexagonal. Therefore, the closed-cell foam design shows a better improvement in energy absorption than the hexagonal design. Furthermore, the architected sandwich panels with the closed cell foam cores have the lowest contact force, while the hexagonal cores reveal the highest contact force.

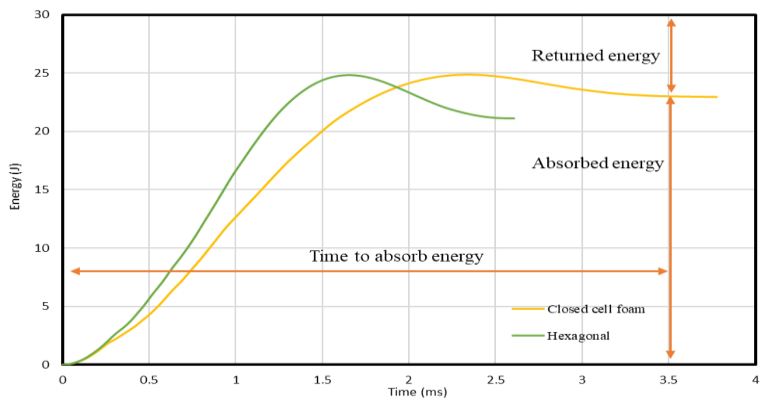

Figure 8: Experimental energy summary comparison of closed cell foam with hexagonal

The energy-time curves obtained from the experiments on the 3D-printed sandwich panels are presented in Figure 8. The results demonstrate that the hexagonal sandwich panel reaches the 25J energy absorption mark sooner than the closed-cell foam panels, indicating that the hexagonal structure is better suited for rapid energy absorption. However, it took more time for the closed-cell foam structure to fully absorb the energy, indicating that it is better suited for sustained energy absorption.

When comparing the total amount of absorbed energy between the two structures, it was found that the closed-cell foam core absorbed more energy than the hexagonal core, suggesting that the closed-cell foam design offers better overall energy absorption capabilities. Additionally, the experimental results indicate that the architected sandwich panels with closed-cell foam cores exhibit lower contact forces compared to hexagonal cores. This suggests that the closed-cell foam design is more appropriate for impact situations where minimizing contact force is desirable.

The energy absorption capabilities of two alternative sandwich panel structures, closed-cell foam and hexagonal, were compared in Figure 9 using both experimental and finite element analysis (FEA) results. The comparison revealed a good agreement between the experimental and numerical analysis results, indicating the accuracy of the FEA model. Moreover, the deformation behaviour of the sandwich panels also matched well between the experimental and FEA results.

During the low-velocity impact test, the sandwich panels absorbed a portion of the impact energy through various failure mechanisms. The results revealed that the hexagonal unit cell structure had a faster kinetic energy response than the closed cell foam panel. However, the closed-cell foam panel exhibited a better overall energy absorption capacity and lower contact forces than the hexagonal design, making it more suitable for sustained energy absorption.

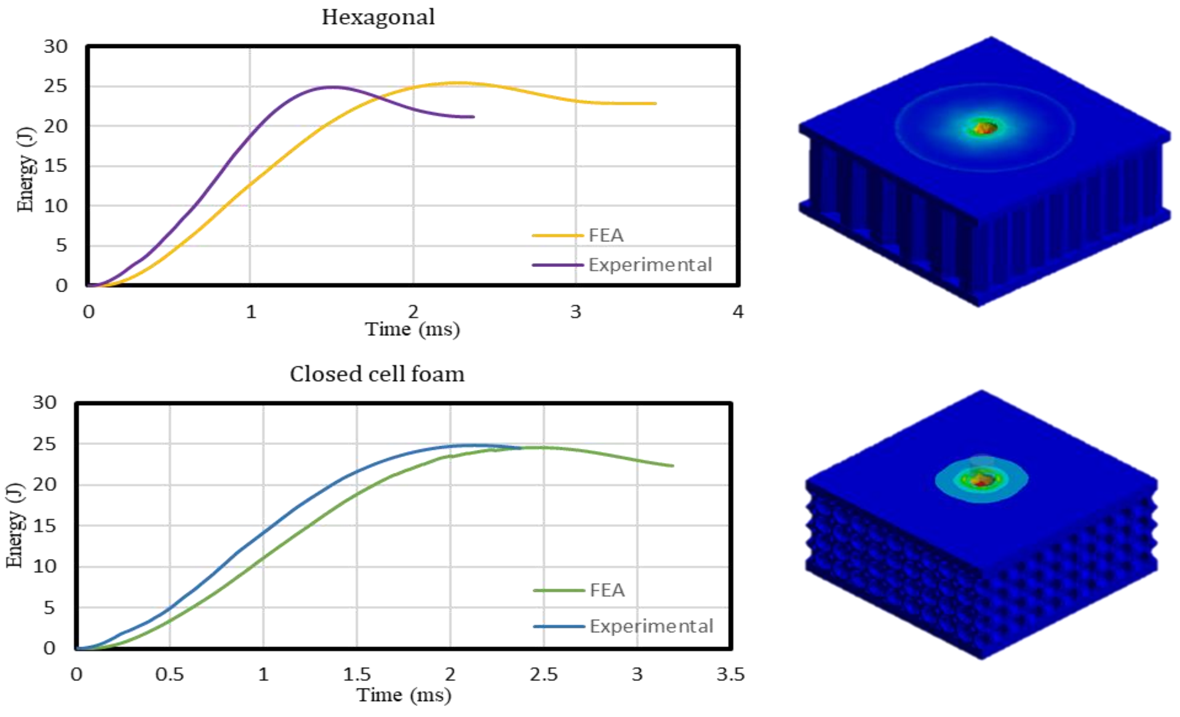

Figure 9: Experimental and FEM results for the energy absorption capability of 3D-printed architected sandwich panels

The experimental and numerical energy absorption capabilities of sandwich panels with closed-cell foam and hexagonal core topologies are presented in Figure 10. There is a good agreement between the results of experimental tests and numerical analyses. It should be mentioned that the closed-cell foam core is the preferred core, in terms of energy absorption, for the architected sandwich panel subjected to this specific impact energy.

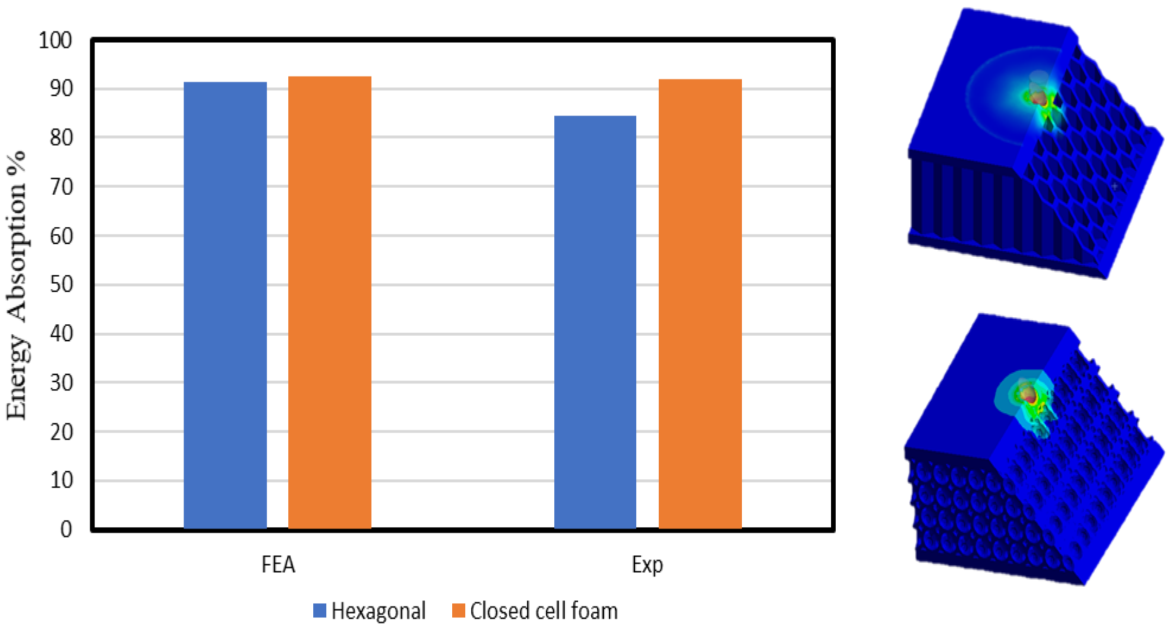

Figure 10: Experimental and FEM results for the energy absorption capability of 3D printed architected sandwich panels

Taken together, these results demonstrate that the closed-cell foam design of the architected sandwich panels offers superior energy absorption capabilities and reduced contact forces compared to the hexagonal design. Our study provides valuable insights for the development of more resilient and energy-absorbing structures in the future.

6 CONCLUSION

The present study aimed to evaluate the mechanical behaviour of closed-cell foam and hexagonal structures under a low-velocity impact test and determine the optimized geometry of architected 3D-printed sandwich panels with a closed-cell foam core. Comprehensive numerical and experimental studies were conducted to investigate the energy absorption capability and failure mechanism of 3D-printed architected sandwich panels made of PLA. In this study, the dynamic energy absorption capabilities of architected sandwich panels with closed-cell foam and hexagonal unit cells were evaluated through low-velocity impact tests and numerical modelling using ANSYS 2022 R1 software. The results revealed that the closed-cell foam design had a better overall energy absorption capacity and lower contact forces than the hexagonal design. While the hexagonal design was more appropriate for rapid energy absorption, the closed-cell foam design was more suitable for sustained energy absorption. Therefore, the closed-cell foam design could be considered a preferred core for architected sandwich panels subjected to similar impact energies. These findings could significantly contribute to the development of more resilient and energy-absorbing structures in the future.

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