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NUMERICAL INVESTIGATION FOR BENDING BEHAVIOR OF HYBRID CORE COMPOSITE SANDWICH STRUCTURE

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Abstract: This study provides a numerical study of the bending behaviour of hybrid-core composite sandwich panels being modeled using finite element method (FEM) using the software ANSYS Workbench 17 R1. This work emphasizes the use of core materials with well-defined mechanical response mechanisms to achieve optimum structural behavior as a way to advance the stiffness-to-weight efficiency and potency of the material for various high-performance engineering applications. The four sandwich core configurations that were modeled and analyzed under the same three-point bending condition were: (i) a conventional PVC foam core, (ii) a carbon/epoxy corrugated core, (iii) a hybrid corrugated core filled with polyurethane (PU) foam, and (iv) a hybrid corrugated core filled with PVC foam. Numerical findings showcased that the hybrid design with PVC foam gave the best mechanical behavior characterized by moderate equivalent stress (≈258 MPa), balanced elastic strain (≈0.022 mm/mm) and least total deformation (≈0.485 mm). Higher mechanical compatibility between the PVC foam and the corrugated composite structure was apparent, therefore, enabling effective stress transfer and stabilizing deformation behaviors. In contrast, the mismatched stiffness of the components in the PU-filled hybrid core resulted in significant strain and base instability, while the carbon-corrugated and neat PVC foam designs exhibited either localized high stresses or an undesirable brittle failure behavior. As viewed from a materials engineering perspective, the results presented here demonstrate that performance in terms of structural stability and durability of sandwich composites is critically dependent on core/textile morphology and material characteristics. The corrugated + PVC foam hybrid provides a good balance between rigidity, toughness, and lightweight properties and is ideal for aerospace, marine, and structural pieces where strength-to-weight is critical, and flexural energy absorption is required.
Keywords: bending, hybrid core, sandwich panels, finite element method (FEM), ansys.

1. INTRODUCTION

Sandwich structures are often preferred in weight-sensitive designs because they deliver high stiffness with relatively little mass. This performance is mainly due to their high stiffness-to-weight ratio, which reduces the tendency to deform under static as well as dynamic loading. In addition, recent developments in composite manufacturing and in core configurations, including corrugated cores, compact cores, foam-filled hybrid cores, and graded-density cores, have strengthened the mechanical response of sandwich structures and broadened their implementation in aerospace, marine, and transportation applications (Studziński and Pozorski, 2018; Sahu et al., 2022; Kovács, 2021; Li et al., 2023). In parallel, numerical modeling and finite element analysis have become essential tools for investigating bending behavior, dynamic response, and complex loading scenarios, often producing numerical predictions that closely match experimental observations (Sun et al., 2019; Wei et al., 2025; Zhu and Sun, 2020; Hou et al., 2000; Vaidya, 2011; Wang et al., 2024).

It has also been showed that the geometry and material composition of the core (honeycomb, foam-filled or hybrid) have a great effect on load transfer modes and bending strength as proven by previous studies (Mani et al., 2023; Liu et al., 2022; Nampally et al., 2020; Hamzah et al., 2020). Most of these basic periodic cell designs also offer good energy absorption both under low and high velocity impacts, which accounts for their application in safety-critical structures, so specifically in aeronautical and automotive bodies (Taghipoor and Sefidi, 2023; Ke et al., 2021; Zhang et al., 2023; Yang et al., 2024; Charkaoui et al., 2025). On corrugated and hybrid core patterns, however, researchers have demonstrated that characteristics such as the corrugation geometry, slope angle and even the foam filler in some cases can have a profound effect on flexural stiffness and common modes of failure including core shear failure and debonding between cores and face skins (Dereli et al., 2024; Zhou et al., 2022; Sayahlatifi et al., 2021; Khaledi and Rostamiyan, 2023; Derseh et al., 2023). Furthermore, there can be complex failure process of sandwich panels under dynamic loading which includes the generation of internal damage, incremental static cracking, cyclic load effects and stress dispersion by geometrical heterogeneity (Farokhi et al., 2021; Zheng et al., 2023; Xia et al., 2022; Njim et al., 2024; Guo et al., 2024). In general, these results emphasize that the core architecture and material choice is crucial for increasing the mechanical performance of sandwich panels in case of bending-dominated circumstances.

Although corrugated and hybrid cores have been widely studied, the literature offers limited like-for-like numerical comparisons of foam-filled hybrid corrugated cores when the bending configuration, boundary conditions, and geometric parameters are kept the same. To address this gap, the present work assesses the flexural response of four sandwich panel configurations: (i) a PVC foam core panel, (ii) a corrugated core panel, (iii) a corrugated hybrid core filled with PU foam, and (iv) a corrugated hybrid core filled with PVC foam. Finite element analysis is then used to perform a consistent comparison and to identify the configuration that offers the most efficient performance for advanced engineering applications.

2. NUMERICAL SIMULATION

Finite element analysis (FEA) is a powerful numerical method for boundary problem solving by discretizing structures in small elements, the accuracy highly depends on mesh quality and calculation methods. Simulation tools like ANSYS provide a cheaper alternative to experimentation, which facilitates a more accurate prediction of the flexural behavior of insulating sandwich panels and such simulations can help in going towards an effective and reliable designs (Ashcroft and Mubashar, 2017; Stanisavljević et al., 2023).

2.1. Preparing the Numerical Model

Numerical investigation of the mechanical response of sandwich panels with four-core sandwich panel concepts such as PVC foam core, a corrugated core, hybrid corrugated core with PVC foam, and hybrid corrugated core with PU foam to a three-point bending test to obtain deformation, von Mises stress, etc. The basic design shown in Figure 1.

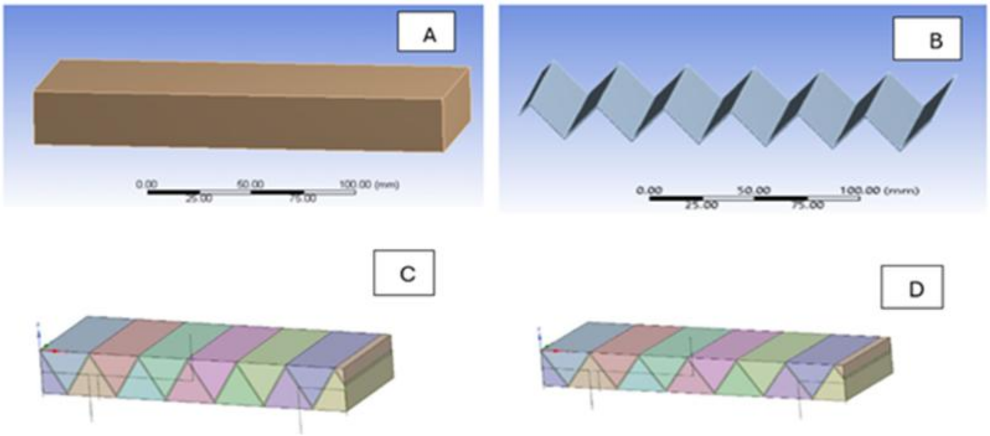

Fig. 1. Core Design A- PVC Foam Core, B- Corrugated Core, C- Hybrid Core: Corrugated +PVC Foam, D- Hybrid Core: Corrugated + PU Foam.

Simulations were conducted on four different sandwich panels to evaluate each core's ability to resist bending loads. Numerical modeling was based on the finite element method (FEM) using the commercial ANSYS 17 R1 operating system. The composite panel was defined as an elastic material, while its properties were defined based on the laminated structure of the shell layers. A finite element model was constructed to match the actual bending test conditions according to ASTM C393. The thickness of the top and bottom layers was 3 mm, while the core height was set at 30 mm. The span length used was 138 mm, with 30 mm diameter supports, the final shape of the sandwich structure under the three-point bending tests shown in Figure 2.

This simulation was based on a number of assumptions.

1. The bond between the core and the upper and lower skins is perfect.
2. The mechanical behavior of the outer surfaces is anisotropic, while the core's behavior is homogeneous (isotropic or orthotropic).
3. There are no manufacturing defects or interfacial separations in the numerical model.
4. Quasi-static loading.

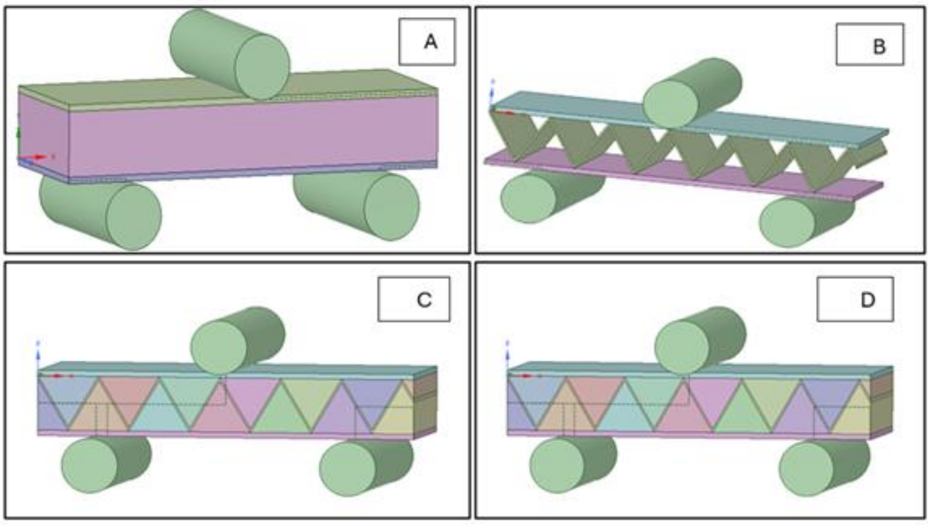

Fig. 2. Final Shape of Sandwich Structure types A- PVC Foam Core, B- Corrugated Core, C- Hybrid Core: Corrugated +PVC Foam, D- Hybrid Core: Corrugated + PU Foam.
Under Three-point Bending Test.

2.2. Mesh Generation, Boundary, and Loading Conditions

The analysis methodology is based on dividing complex geometries into smaller elements to facilitate numerical modeling. In this design Figure 3, the outer shell was integrated with the core, and the shell was connected to the upper and lower layers via a "tie-in" condition. To achieve a balance between computational accuracy and time efficiency, a medium-density virtual mesh was chosen, resulting in approximately 23,391 nodes with 4,256 elements and a minimum edge length 3.0 mm for the first geometry (PVC foam core), while the second geometry (Corrugated Core) had 26868nodes and 3,786 elements with a minimum edge length 2.0 mm, the third and Four geometry(hybrid CF/Epoxy +PU foam core)(hybrid CF/Epoxy +PU foam core) had 115,328 nodes with 21,914 elements and a minimum edge-length 2.0 mm.

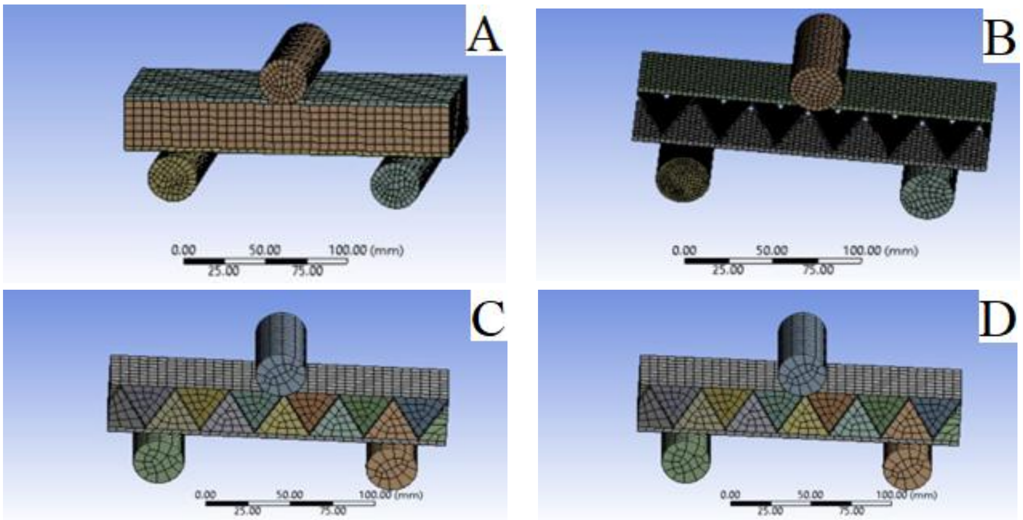

Fig. 3. Mesh Generation of Numerical Models A- PVC Foam Core, B- Corrugated Core, C- Hybrid Core: Corrugated +PVC Foam, D- Hybrid Core: Corrugated + PU Foam.

The beam was supported by two simple supports, with a load applied at the center to simulate the practical situation. Forces were constant in all models to study the deformation response. Using a load value of approximately 10 KN, the boundary condition for the finite element model was obtained. By defining the regions on the four edges of the sandwich panel, fixed bracing conditions were imposed. The numerical analysis was performed using a quasi-static load of about 10 KN.as shown in Figure 4.

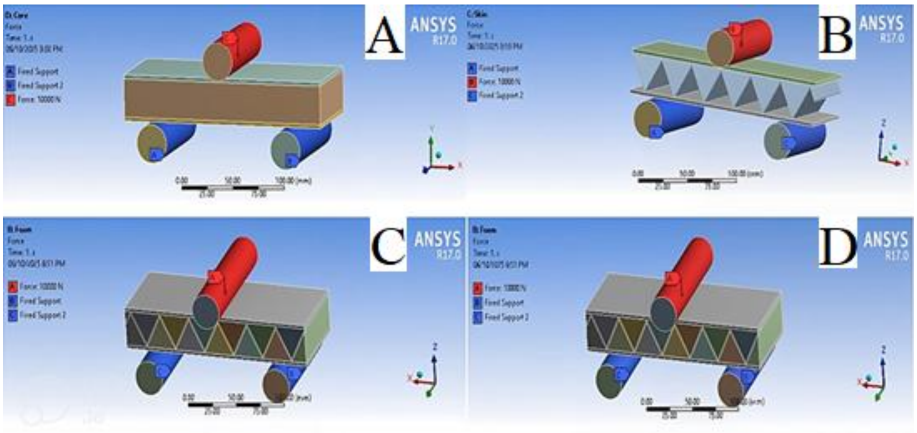

Fig. 4. Boundary Conditions for A- PVC Foam Core, B- Corrugated Core, C- Hybrid Core: Corrugated +PVC Foam, D- Hybrid Core: Corrugated + PU Foam.

3. RESULTS AND DISCUSSIONS

3.1. Equivalent Stress Result

The results showed a marked difference in core performance across the internal composition and core type as shown in Figure 5. The traditional PVC foam core evidenced the most resistance to shear loads (Kennelly stress concentration, 238.28 MPa) and was thereby close to failure. The carbon corrugated core achieves high load-transfer efficiency; however, the maximum surface stresses sustained by the faces were;688.51 MPa, near the limit of the fracture resistance and thus safety factor. In contrast, the hybrid design performed poorly with PU foam, signaling now the loss of stiffness in the foam.

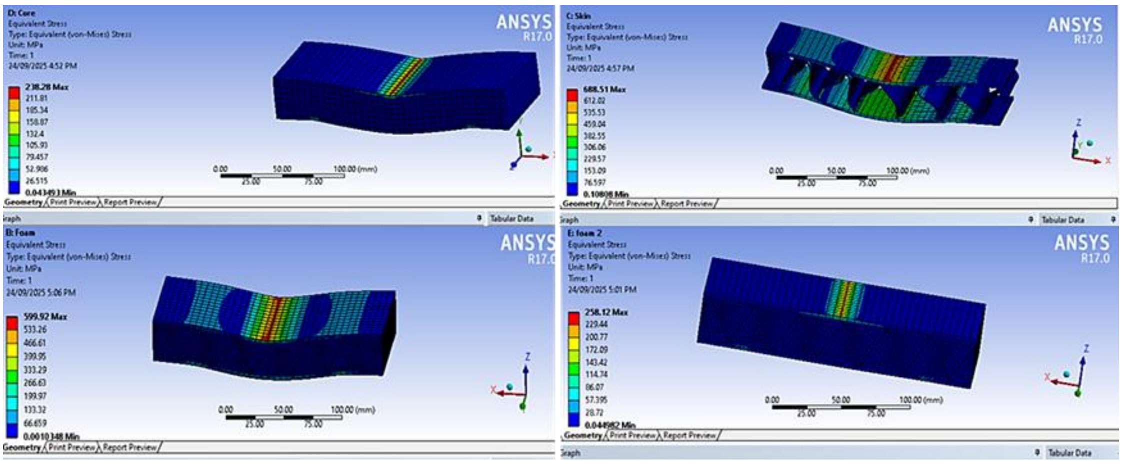

Fig. 5. Result of Equivalent Stress.

The adhesion between the foam and the corrugated was very weak, producing an extreme stress of 599.92 MPa. The hybrid design that incorporated PVC foam performed the best due to its homogenous stress distribution and effective mechanical cooperation between the foam and the corrugated structure with a maximum stress value of 258.12 MPa. The stress resistance and distribution criteria based on this comparison indicates that the best is the hybrid (corrugated + PVC foam) followed by carbon corrugated design, PVC foam and hybrid with PU foam. It shows how important mechanical compatibility of core materials is for obtaining optimal performance of sandwich panels.

3.2. Equivalent Elastic Strain Result

The first design (PVC foam) recorded low strain (0.00879 mm/mm) as shown in Figure 6, suggesting a brittle behavior where the material nears its load-bearing limit without undergoing significant elastic deformation. The carbon corrugated core plays a very beneficial role in transferring load and capability, achieving a maximum face strain of 0.20724 mm/mm that could be the excessive deformation failure mode of the face. Of all the hybrid design that housed PU foam, H8 had the greatest strain (0.32623 mm/mm), hinting at a mechanical incompatibility between the flexible foam and the corrugated structure. Because of this, the deformation was localized, and the design failed.

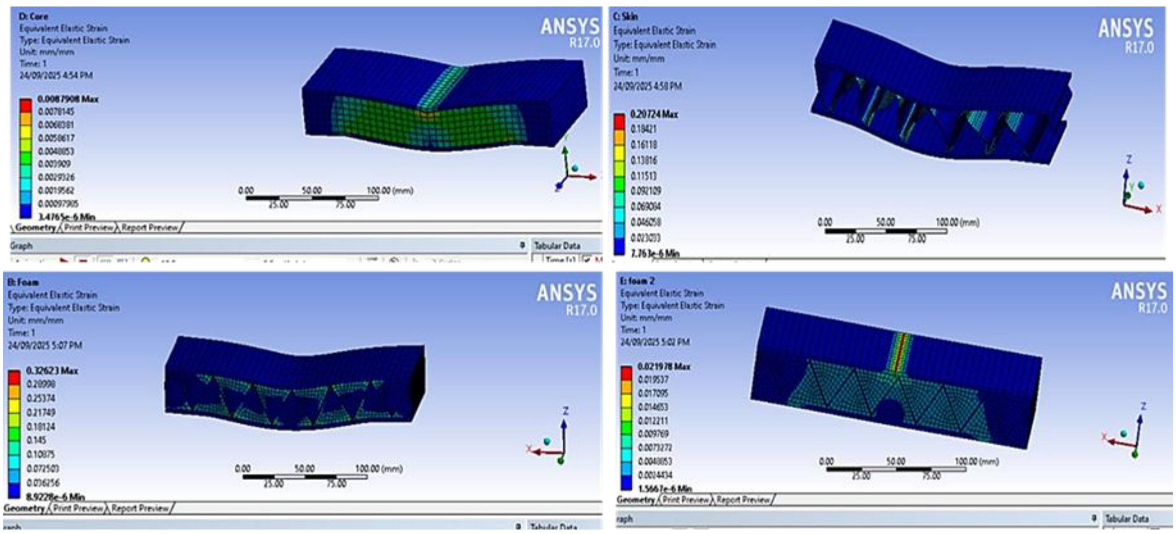

Fig. 6. Equivalent Elastic Strain Result.

However, in the case of PVC foam-infused hybrid design, moderately distributed behavior with a strain of 0.021978 mm/mm across the three parts suggested acceptable mechanical synergy of parts. In the comparison, PU foam is the most unsuitable for structural use and the fourth design, which is corrugated + PVC foam, is the best alternative offering an effective combination of stiffness and flexibility. After that, the carbon design takes second place. These results indicate that to ensure structural integrity and prevent unwanted deformation, the mechanical compatibility of the corrugated structure with the core materials necessarily lies at the heart of the performance of the system.

3.3. Total Deformation Result

The PVC foam-filled hybrid design, which performed best was effective at structural cooperation and achieving a balance of stiffness and toughness, as shown in Figure. 7. It achieved a low displacement of 0.48517 mm with a uniform distribution of stress. But, due to the high stresses at the faces, carbon-corrugated design exhibited the biggest displacement of 5.3243 mm, therefore an unstable behavior at high loads was shown. The conventional PVC foam design, despite low displacement (0.48363 mm), was associated with high stresses that may suggest a brittle behavior of material, while the PU foam hybrid design presented a moderate displacement (4.0742 mm) at the expense of poor mechanical compatibility of components as a whole. It is evident from the comparison that mechanical compatibility of core components is the common most effective aspect that negatively affects the displacement and yields the optimum structural performance. Hence, the hybrid design packed with PVC foam plays the most effective in construction applications with high stiffness and good deformation stability.

Therefore, the results from the numerical analysis showed that mechanical compatibility of the core constituents is the main contributor to the performance of sandwich panels. The hybrid design filled with PVC foam had the best overall performance in stress and strain and deformation, respectively, offering good mechanical response combining high structural stability, stiffness and elasticity while the other designs exhibited brittle behaviour or excessive deformations. So, the Hybrid design (corrugated + PVC foam) is the ideal configuration for heavily loaded structural applications.

Numerous simplifying assumptions have been made in the study which can greatly influence the predicted structural response. The most prominent of these assumptions is the permanent face sheet/core interfacial bond. This does not account for the partial debonding/slip which can occur at the interface when high shear/bending loads are applied. As stating complete bond conditions may lead to the stiffness and load-carrying capacity of the structure being over-predicted. However, there is a shear deformation, local face wrinkling, and a bending type of strain gradient that is within the sandwich structure itself, but this is rarely characterized experimentally. Other failure modes such as core shear failure, interfacial debonding, and local buckling of the face sheets, were not explicitly analyzed in this study, but should be included in future research. Addressing these issues would make the engineering numerical results more curiosity stimulating.

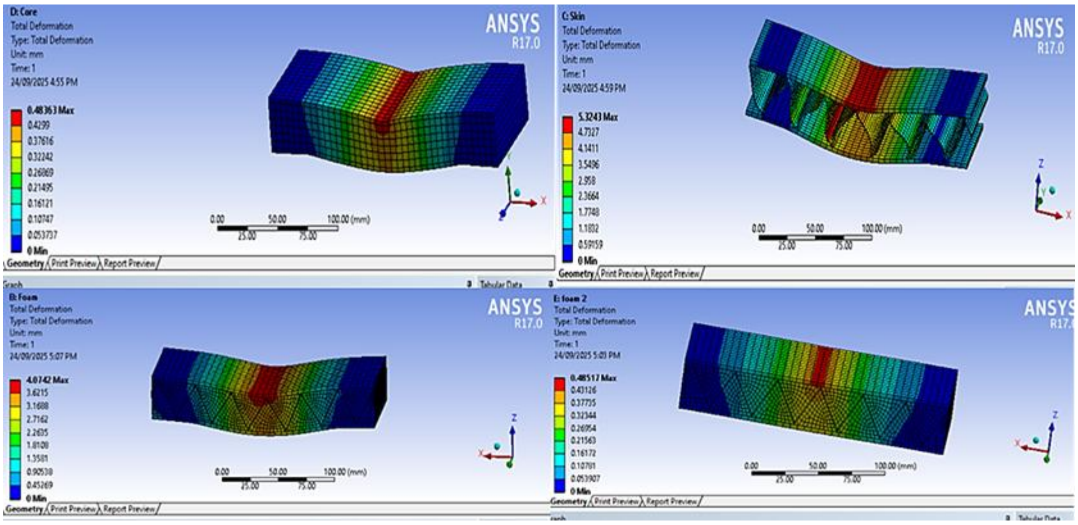

Fig. 7. Total Deformation Result.

Table 1
The Result of the Numerical Simulation

Sandwich panel sample	Equivalent Stress (MPa)	Equivalent Elastic Strain(mm/mm)	Total Deformation(mm)
PVC foam core	236.28	0.0087208	0.4836
Corrugated foam core	688.51	0.20724	5.3243
Hybrid (corrugated+ PVC) core	258.12	0.021978	0.48517
Hybrid (corrugated+ PU) core	599.92	0.32623	4.0742

This table summarizes the numerical responses of the four sandwich panel configurations under a 10 kN three-point bending load. The equivalent stress (MPa) represents the maximum von Mises stress, the equivalent elastic strain (mm/mm) indicates the peak deformation gradient, and the total deformation (mm) reflects the global displacement of the structure. These parameters collectively allow a direct comparison of stiffness, stress distribution, and deformation behavior among the tested core architectures.

4. CONCLUSION

Numerical analysis was conducted to examine flexural properties of sandwich composites with four different core configurations, in particular that the role of core shape and material matching were considered. Stiffness level was more uniform with the hybrid corrugated core made of PVC foam and a better stress distribution was observed. Better engagement between the foam and the corrugated substructure enabled a more efficient load transfer, thus achieving better flexural effectiveness when compared to the other configurations. Meanwhile, such results need to be viewed with caution given the limitations of this study. The numerical models, developed under idealizing conditions such as perfect adherence at the skin–core interface, simplified characterization of isotropic and orthotropic material behavior and assuming the absence of any manufacturing/interfacial imperfection, would enable modelling other skins and core properties in future studies. Also, no experimental test was carried out. Good correlation with regard to the numerical trends is essential for any validation to also see potential practical failure modes like core debonding, localized buckling and core shear failure under service-like loadings.

Future research should incorporate experimental three-point bending tests, interface characterization, and advanced damage or cohesive zone modeling to improve prediction accuracy and address the limitations associated with these idealizations. Integrating validated numerical and experimental approaches will provide a more robust understanding of the failure mechanisms and enhance the reliability of hybrid corrugated sandwich structures in aerospace, marine, and automotive applications.

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