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Analysing the Mechanical Behaviour of Sandwich Beams and the Impact of Geometric Shape on Bending Performance

Naili Takieddine [1], Ghouari Lahcene [2,a,*], Benatmane Charafeddine [3,b], Nouar Salim [4]

[1] Mechanical Engineering Department / Djillali Liabes of Sidi Bel Abbes University, Algeria
[2] Mechanical Engineering Department/ Dr YAHIA Fares de Medea University, Algeria
[3] Mechanical Engineering Department/Abbes Laghrour University, Algeria
[a] LMP2M Laboratory, University of Medea, (26000), Algeria
[b] Laboratory of Engineering and Sciences of Advanced Materials (ISMA), 40000 Khenchela, Algeria

Abstract: This study attempts to study the effect of geometric and mechanical properties on the bending behaviour of simply reinforced sandwich beams. According to the theory of simple beams. We used ABAQUS 2016 and the C3D8R element type with a consistent mesh size of 2 mm to simulate a three-point bending configuration with displacements of 0.1 mm to 0.6 mm. Tangential behaviour was used to simulate contact interactions. Numerical results for stresses and displacements were calculated. We modelled the bending behaviours of two models of aluminium alloy EN AW-1050A beams loaded with imposed displacements by bending. The comparison was made using a honeycomb sandwich beam as a reference model that we developed from simulations. X core had the most displacement (up to 2.812 µm), which meant it was very flexible but not very strong; O core had the least displacement (up to 3.672 µm), which meant it was very stiff; and NIDA B core had behaviour in between (maximum displacement around 4.472 µm). The presented models are suitable for studying bending on a simple, supported sandwich beam subjected to intense mechanical loads used in special technical applications in the aerospace, automotive, and civil engineering industries.

Keywords: Modeling, Sandwich Beam, Core, Abaqus, Three Point Bending

1. Introduction

Sandwich structures are considered one of the most important materials in terms of applications in various engineering fields. It is distinguished by its bending rigidity, and its mechanical properties are advantageous compared to different alloys [1-2]. Sandwich structures consist of two thin layers and a core between them. Sandwich structures contain composite materials or metallic materials that are transformed into various shapes according to their use. It can be said that sandwich structures are distinguished by the ability to bear impulsive and sudden loads [3-4].

Sandwich constructions are defined as insulating barriers on the outside and inside of buildings to lessen heating and cooling. In recent years, sandwich structures with insulation have been developed [5–6]. In shipbuilding and the aviation sector, sandwich structures are utilized to reduce impacts and prevent corrosion underwater [7-8]. Sandwich constructions are made of beams or panels. Most of papers and research papers discussed sandwich structures and their properties. [9]. In order to understand how circular and perforated sandwich panels will react to deformation shocks, they created an analytical model. Two thin panels connected by a thick core composed of low-density material make up a standard sandwich. The findings demonstrated

*** Corresponding author:** Ghouari Lahcene, ***E-mail address:*** *ghouari.lahcene@univ-medea.dz*

that the face plates can withstand nearly all applied loads and bending moments, and that the sandwich structure's core responds most strongly to transverse and shear stresses. Another study demonstrated that increasing the thickness of metal sandwich beams can improve their shock resistance capability by examining their dynamic response under loads both numerically and experimentally. The plates or core thickness, and that the centre has the greatest amount of stretching deformation, which diminishes as one moves further away from it. [10]

A research study worked on developing an analytical homogeneity model for the behaviour of a sandwich panel with a corrugated core in the shape of a trapezoid. This model is based on reducing the initial sandwich cell that represents the sandwich core, following the approach proposed by Libove et al. [11-12] The analytical model was compared directly to the response through a three-dimensional numerical model of a primary cell. The values of elastic constants obtained through numerical simulation showed good agreement with analytical predictions. All tests indicated a significant effect of the transverse shear deformation component. As it turns out, it is impossible to ignore out-of-plane shear [13]. One may say that the sandwich panels' bending outcomes with the polyester core and composite vegetable skin FRCM. The sandwich panels made of hemp and FRCM have great bending strength. Numerical simulations were useful to reproduce the experimental behaviour of the beam with 5 conductors and the maximum bending stiffness. [14]

Underwater protection and collision mitigation are appropriate uses for steel sandwich structures with a Y-shaped core. However, the utilization of steel goods is limited due to their weak resistance to fatigue and corrosion [15]. Carbon fibre and reinforced resin were employed to create the sandwich structure beams. Unlike steel, these composite materials won't rust. Examining also reveals the sandwich beam's mechanical behaviour. [16]

In contrast to a sandwich beam with a metal foam core, simulations demonstrated that a Y-shaped sandwich beam can absorb energy [17–18]. To examine the compressive behaviour of composite sandwich structures with a Y-shaped core, a hot compression modeling technique was created. with varying relative densities. The obtained results demonstrate that the mechanical behaviour of sandwich beams with a Y-shaped core is clearly influenced by the relative density, and the numerical and experimental results agree [19].

Sandwich structures with honeycomb cores are considered basic materials. These materials are highly valued in various industries due to their lightweight and strong properties. Their unique design allows for excellent energy absorption and structural integrity, making them ideal for applications in aerospace, automotive, and construction. Additionally, the versatility of honeycomb cores enables engineers to customize the thickness and configuration, further enhancing performance for specific uses. As advancements in manufacturing techniques continue, the potential for these materials to revolutionize design and engineering processes only grows. This ongoing evolution not only leads to improved efficiency but also encourages innovation in creating more sustainable and environmentally friendly products. As a result, industries are increasingly investing in research to unlock new possibilities and applications for these remarkable materials. It has a high bearing capacity against sudden and impulsive loads [20-21]. The results obtained showed that the behaviour under the influence of asymmetric bending of composite beams with two thin faces (T800M300) and an aluminium honeycomb core is evidence for modeling sandwich beams and predicting failure modes. Stresses increase as loads and angles increase. The asymmetric bending resistance of the skin is much greater than that of the core. As the loads increase, the displacements increase [22].

Results demonstrated that, in comparison to alloy characteristics, tensile strength, shock resistance, and hardness are all high. One may argue that the strength of sandwich structures is significantly influenced by the size of the core when it is utilized as a core. When compared to other sandwich constructions, sandwich structures with a honeycomb core have superior fatigue-failure characteristics. [23]

In this work, we attempt to investigate the effect of geometric and mechanical properties on the bending behaviour of simply reinforced sandwich beams. According to the theory of simple beams, they were adapted to sandwich beams using the numerical modeling models using ABAQUS

2016 software. Numerical results for stresses and displacements were calculated. We modeled the bending behaviour of two models of aluminium/aluminium (1050A) sandwich beams loaded with imposed displacements. The comparison was made with a honeycomb (NIDA) sandwich beam as a reference model that we developed from the simulation. The boundary conditions are that the sandwich beam is stressed in bending by imposed displacements. The supports are embedded; we used the finite element C3D8R (Global Seeds) to construct the model meshes; we placed sensor points in the mesh. The curves and histograms obtained were processed by programs compatible with digital modeling models.

2. Design and Production

Due to the manufacture of the sandwiches, the mechanical properties are adapted by varying the nature of the skins (identical or not), the core, and the thickness of each of the phases. As a rule, the skins have the same thickness, and the *tf/hc* ratio (hc being the thickness of the core) is between 0.01 and 0.1. Sandwiches are classified into three categories according to the value of the *d/tf* ratio, d being the distance between the neutral axes of the sandwich skins: For a *d/tf* ratio less than 5.77, the sandwich is said to have thick skin. For a *d/tf* ratio between 5.77 and 100, the sandwich is said to have thin skin and for a *d/tf* ratio greater than 100, the sandwich is said to have very thin skins. These limits are defined in relation to the contribution of each constituent to the bending and shear rigidity of the sandwich [24].

3. Bending Rigidity

Sandwich constructions typically experience compression buckling or bending load. Therefore, it is essential to understand how the core and skin materials behave under this kind of stress to maximize their qualities for a particular application. The bending rigidity, D, of a sandwich material is its characteristic quantity and may be found using the following relation [25].

$$D = \int Ebz^2dz = \frac{Ebt^3}{6}f + 2Epbep^{\left(\frac{d}{2}\right)^2} + \frac{E_c bt_c^3}{12} \tag{1}$$

After simplifying the equation, we find:

$$D = 2D_f + D_0 + D_c \tag{2}$$

The bending rigidity is limited to shear; the stiffness S is mainly governed by the characteristics of the core, the contribution of the skins being negligible. This rigidity is expressed by the formula:

$$D \approx E_f \frac{bt_f d^2}{2} \tag{3}$$

$$S = G_c \frac{bd^2}{t_c} \tag{4}$$

Stresses and deformations of sandwich materials. In the general case, the distribution of stresses in a sandwich beam is described in Fig. 1. To simplify the study, the beam is only subjected to a bending moment M_x and a transverse force. T_x [25]

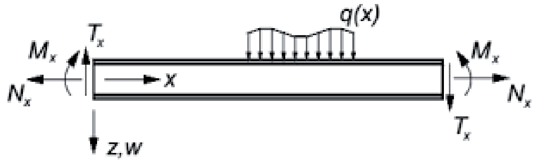

Figure 1: Load applied to a sandwich beam

The neutral axis is positioned in the centre of the core of a symmetrical sandwich, which is made up of the same skin with a high modulus of elasticity and low thickness. Tensile strains:

$$\int O_s d_z = 0 \tag{5}$$

The compressive stress in the upper skin is given by:

$$\sigma_s = E_s = \frac{M_X}{D}Z \tag{6}$$

B(z) is the surface moment of order l, calculated by:

$$B(Z) = \int_Z^{\frac{d+t_f}{2}} E(Z)d \tag{7}$$

For a symmetrical sandwich of the same thin skin with: $E_{f1} = E_{f2}$, $t_{f1} = t_{f2}$, $e = d/2$ a core having a low modulus of elasticity, the shear stress remains constant in the core, and it is given by the equation:

$$\tau_C = \tau_{xz}(Z) = \frac{T_x}{bd} \tag{8}$$

The low density of the material making up the core associated with a more or less constant shear stress in the cross section means that, in any mechanical analysis of this type of structure, considering shear deformations is essential. We can admit that the deformation is composed of a classical contribution due to bending and another due to shearing.

The shear stiffness S is given by:

$$S = \frac{Gh}{K} \tag{9}$$

Behaviour of sandwiches in bending, sandwich structures are generally subjected to bending (three or four points). In order to optimize the characteristics of their constituents (core and skins), for a given application, it is necessary to know their behaviour for these two types of stress [24].

Presently digital simulation plays a crucial role in the mechanical structure design and validation process. With the rising efficiency of simulation tools, phenomena can be described in detail. Additionally, the study of safety under dynamic or static loads is interested in these techniques because they are no longer restricted to linear mechanics but have been evolved to describe increasingly complex behaviours up to the destruction of structures [26].

Numerical techniques and somewhat complex material behaviour principles are needed to compute the deformations of terrain and structures under different stresses. The process of modeling entails building a model that captures the set or subset of properties of an object or system. A model may differ from the genuine system due to approximations, or it may be precisely the same as the original system. [27]

4. Materials and Methods

We have chosen the "ABAQUS" software, which deals with the majority of structural mechanics problems. It can provide powerful tools for analysis in two and three dimensions.

4.1. Geometric study

Two sandwich beam models' bending behaviour was examined, and their results were contrasted with those of a reference honeycomb model that had imposed displacements. The sandwich beams were designed using the aluminium alloy EN AW-1050A (O) and H12 casings. The exterior layers (skin) of the sandwich beams were made of H12 for increased strength and resistance, while the core was made of (O) for the necessary flexibility and light weight. We decided to use three-point bending in this experiment (Fig. 1). Table 1 below lists the mechanical characteristics of the suggested material.

4.2. Finite element model and boundary conditions

Using a 3D finite element model, the current work examines the bending behaviour of an aluminium sandwich beam. Length (L) = 900 mm, width (b) = 40 mm, overall thickness (d) = 50 mm, face sheet thickness (ep) = 5 mm, and core height (ec) = 40 mm are the model's measurements. Optimized for lightweight stiffness and bending resistance, the structure consists of two aluminium face sheets (Al 1050A-H12) encasing a honeycomb aluminium core (Al 1050A-O).

C3D8R elements (8-node linear brick elements with decreased integration and hourglass control) with a consistent element size of 2 mm were used to mesh the whole model. This mesh preserves computational efficiency while enabling precise tracking of the stress-strain distribution.

All interacting components, such as the face sheets, core, supports, and loading indenter, have surface-to-surface contact defined. While tangential behaviour was represented using frictional interaction to enable realistic sliding, contact behaviour in the normal direction was specified as firm contact, prohibiting penetration.

The two bottom supports were completely secured in terms of boundary conditions to stop any rotational or translational movement (U1=U2=U3=UR1=UR2=UR3=0). In order to simulate a progressive three-point bending scenario, a displacement-controlled loading was applied at the midspan through a cylindrical indenter. The displacement values ranged from 0.1 mm to 0.6 mm.

A realistic simulation of the bending performance, stress distribution, and interface behaviour of sandwich structures under increasing displacement loads is made possible by this modeling technique, Figure 3.

We have selected ABAQUS 2016 which enables us to handle the most of structural mechanics difficulties, for our analysis. It provides strong two- and three-dimensional analysis tools.

Table 1: Mechanical properties of aluminium alloy EN AW-1050A

Shade	Si	Fe	State	Rm (MPa)	Rp0.2	A (%)
1050A	0.25	0.40	O	70-100	-	35
			H12	90-120	65	9

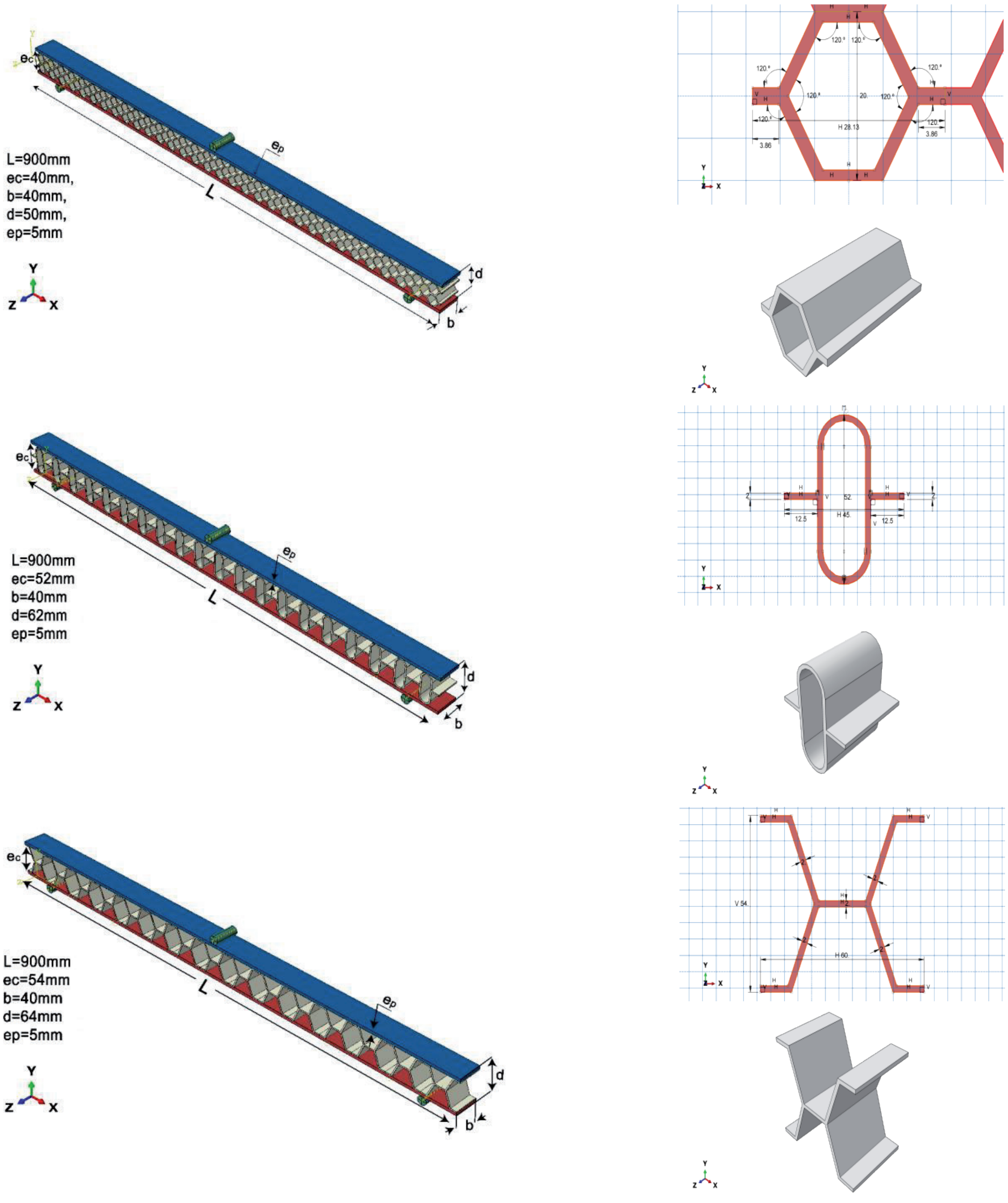

Figure 2: Sandwich beam geometry

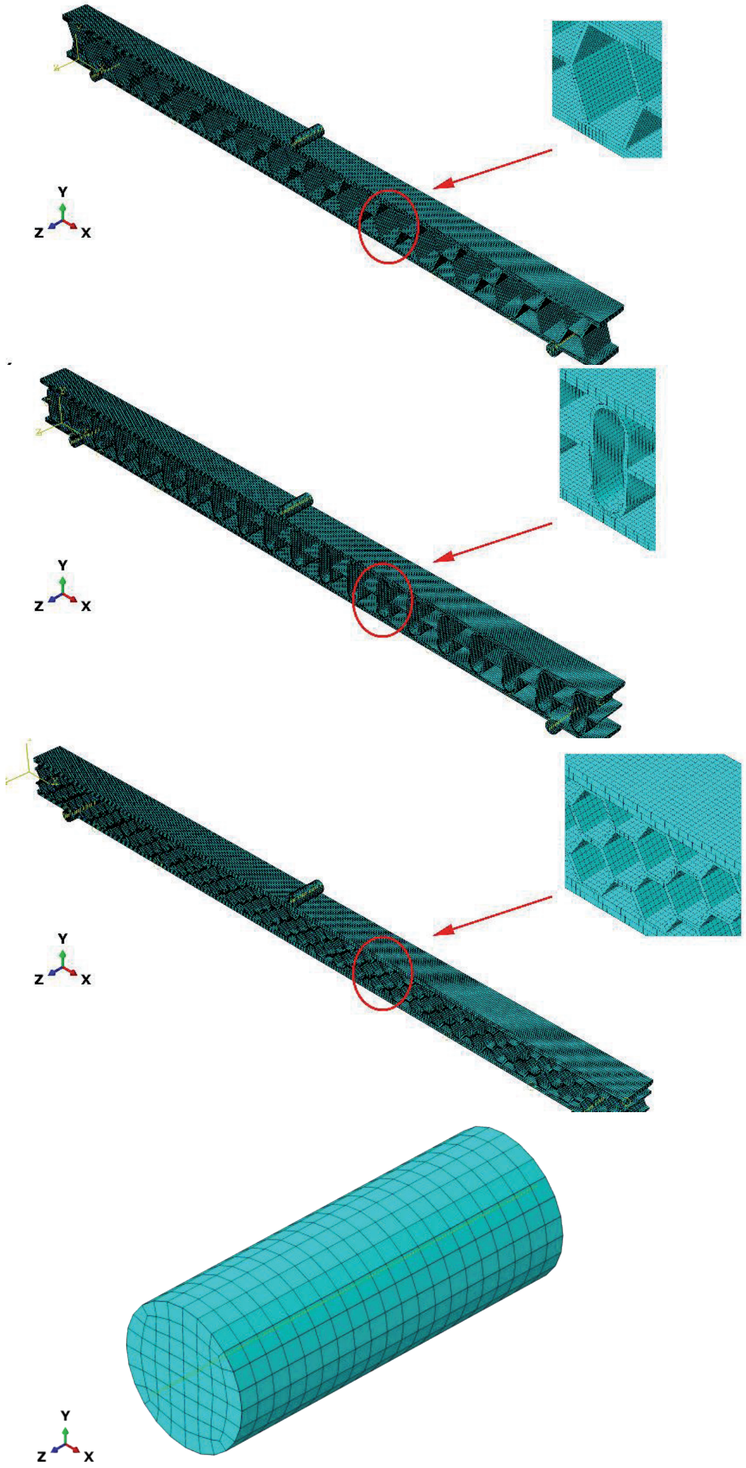

Figure 3: Mesh of model

Table 2: Finite element connection formula to engineering support

	Types of Mesh	Number of Elements			Total Number of Elements
		Skin 1	Skin 2	Core	
Reference Model (NIDA)		18000	18000	52600	88600
Model 1(O)	C3D8R	18000	18000	52600	88600
		27000	27000	42000	96000
Model 2(X)		27000	27000	30720	84720

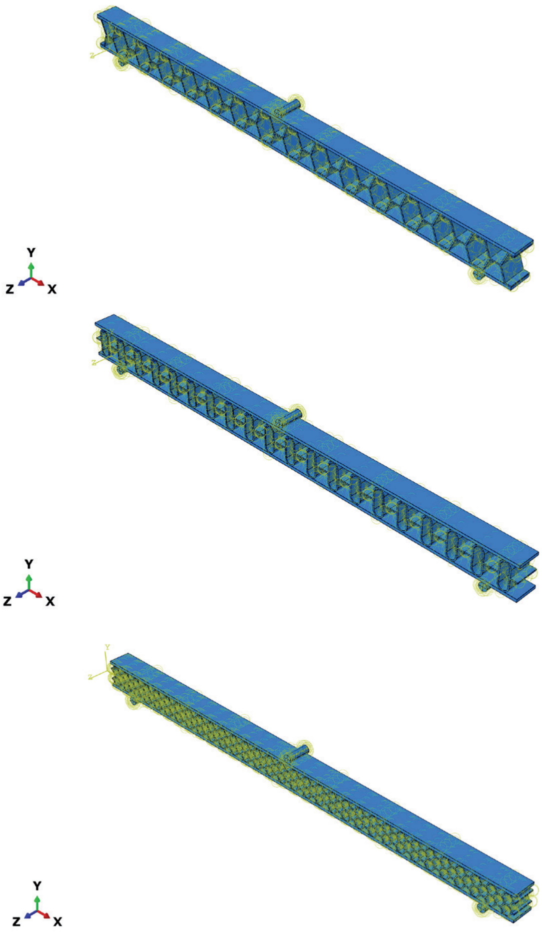

Figure 4: Models' interaction

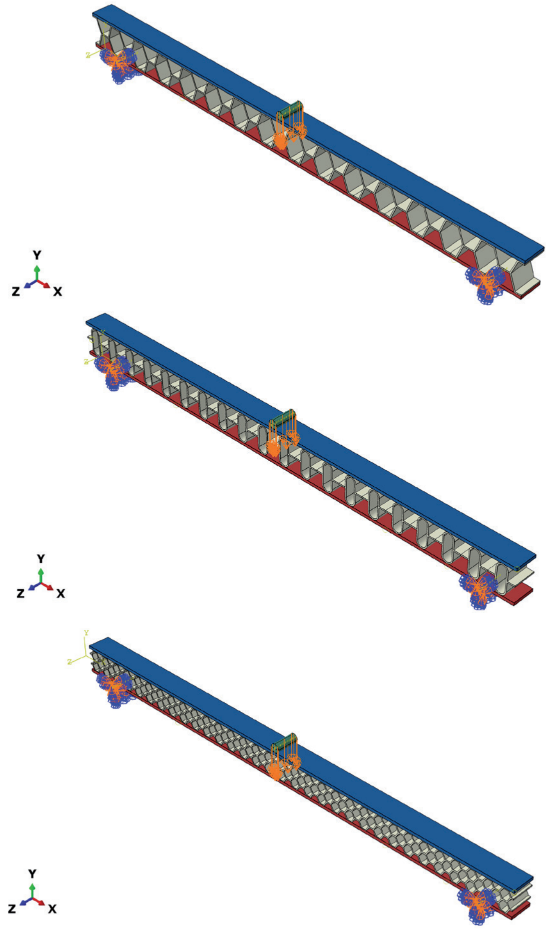

Figure 5: Loading

4.3. ISO-Value of stress

Based on the visual colour scale previously established in Figure 5, which goes from dark blue (low stress) to red (high stress), von Mises results were produced for the suggested sandwich constructions. The corresponding value of σVM is the relationship below represents the Von Mises stress:

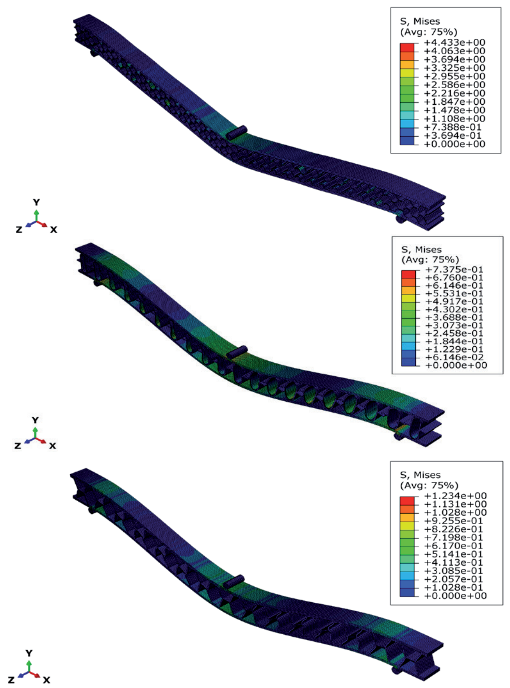

Figure 6: Constraints V. Misses; a) model O, b) model X, c) NIDA

5. Results

5.1. Comparative studies

A comparative study of a honeycomb sandwich beam was conducted to verify the results obtained from a previous study of a honeycomb sandwich beam made of composite materials. The results showed good agreement with this study. It is indicated in the table 3 below.

5.2. Parametric study

To study the effect of model geometry on the development of applied stresses σxx, σyy, σzz, τxy, τxz, and τyz on the core and skin in order to understand the mechanical behaviour of sandwich structures. We placed sensor points in the network

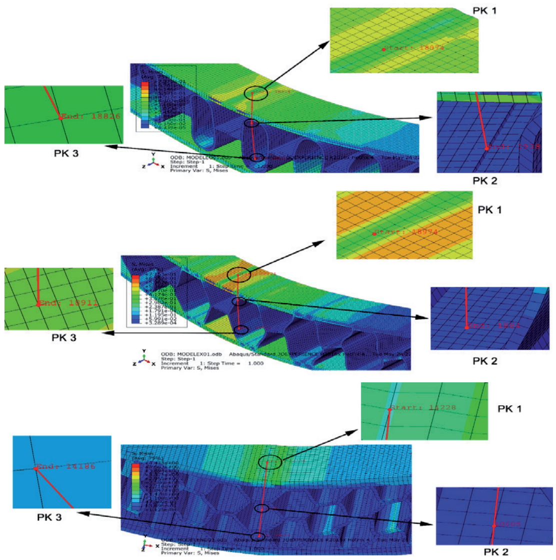

Figure 7: The sensor points (PK1, PK2 and PK3) for models

The models' sensing sites (PK1, PK2, and PK3) are displayed in Figure 4. It is possible to conclude that the values obtained demonstrate the degree of geometric effect on the sandwich constructions. When compared to the reference model, the suggested models respond well.

The critical points, or maximum stress values, of the sandwich material's core and skin can be

Table 3: Comparison of displacements at sensor points

Points of Sensing	The Coordinates				
	X(mm)	**Y(mm)**	**Z(mm)**		
Pk1 (skin 1)	-	-	-	[22]	
	55.563	**24.437**	**40.000**		Present
Pk2 (core)	60.000	30.760	40.000	[22]	
	55.089	**21.926**	**40.000**		Present
Pk3 (core)	60.000	29.000	40.000	[22]	
	51.890	**3.961**	**40.000**		Present
Pk4	60.000	-9.000	40.000	[22]	
(skin 2)	**50.781**	**-11.519**	**40.000**		Present

Table 4: Development of stresses and displacements according to the applied loads

δ (delta minuscule)	**σ_{xx}(PK1)**	**σ_{xx}(PK2)**	**σ_{xx}(PK3)**	**U_y(PK1)**	**U_y(PK2)**	**U_y(PK3)**	**σ_{max}**
Reference Model (NIDA)	1,48303008	0,12545722	1,02462112	0,10000000	0,09800615	0,09840192	4.433
Model 1(O)	0,20172084	4,74524E-06	0,393504143	0,100000001	0,098529384	0,09913642	0.7375
Model 1(X)	0,30932474	0,002165452	0,513317466	0,100000001	0,099045947	0,099928938	1.234

Table 5: Displacements (max, min) of imposed displacement

δ	**U_X max (µm)**	**U_X min (µm)**	**U_Y max (µm)**	**U_Y min (µm)**	**U_Z max (µm)**	**U_Z min (µm)**
Reference Model (NIDA)	5.308	2.903	4.462	100.1	0.1212	0. 121
Model 1(O)	6.563	6.228	3.673	100	0.04656	0.04660
Model 2 (X)	2.379	2.388	2.812	100.1	0.04870	0.04902

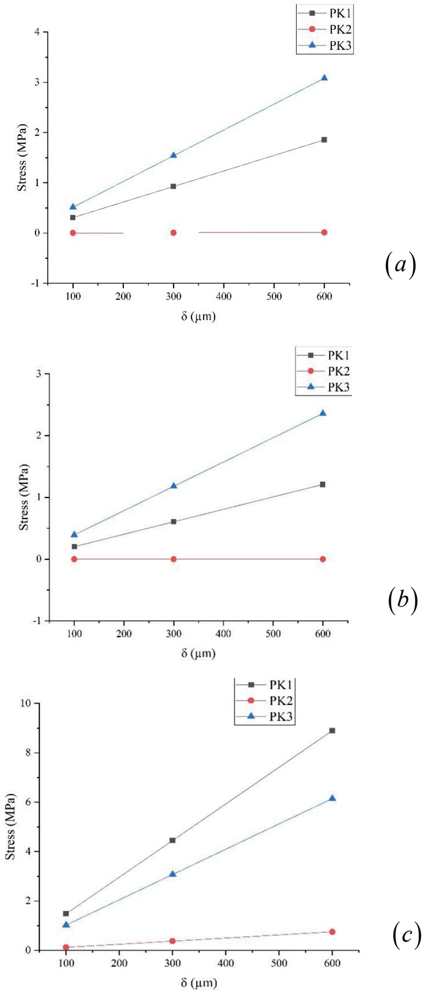

Figure 8: The evolution of stress a) MX, b) MO, c) NIDA

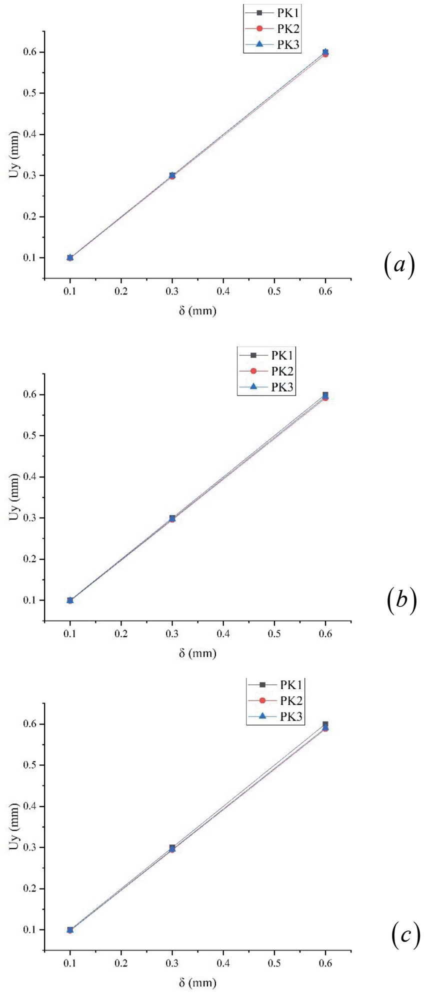

Figure 9: The sensor points depending on the changes applied

found using the stress evolution curves that were produced. The modeling findings demonstrate how the geometry of the hollow mesh affects the performance of sandwich beams. We can determine that the two suggested models outperform the reference honeycomb model in terms of bending resistance by comparing the sandwich beam models. Despite minor variations between the two models' crucial points, figure 4. Hollow sandwich beams can be effectively stabilized by both models.

From the diagram in Figure 5, we can say that the stresses increase as the imposed displacements (PK's) applied by bending increase. Model (X) The stresses are concentrated in PK1 and PK3, but in PK2 they are almost completely absent. Also, PK3 was greatly affected compared to PK1 with the change in the imposed displacements by bending 0.1, 0.3, and 0.6 mm, respectively. Also, the sensing point PK3 was affected more than PK1 for Model (O) from (0.1-0.3-0.6) mm, respectively. In the honeycomb model, we notice that PK1, PK2, and PK3 were affected differently. Also, the sensing point PK 1 was greatly affected, and in PK2 it was noted that it was also affected by the imposed displacements by bending (0.1 - 0.3 - 0.6) mm.

The displacements' maximum and minimum values are displayed in Table 3. The significance of geometric shapes for sandwich constructions is demonstrated by these values. In Model 1, we may say that the displacement in terms of X is the highest value. In contrast to Models 1 and 2, the reference model was impacted by the Y-axis displacement. Compared to X and Y, the Z axis can be disregarded because the displacements are essentially non-existent.

Based on the applied changes in the imposed displacements of 0.1 mm, 0.3 mm, and 0.6 mm on the Y-axis, Figure 6 shows the displacements at the sensor sites. We can observe that the displacements at the sensor point diminish and become linear anytime we alter the imposed displacements from the lowest value of 0.1 mm to the highest value of 0.6 mm.

Table 4: Comparison of stress σxx values

Models	Stress σxx of tensile (MPa)		Δσ (%)	
	Positive	Negative	Positive	Negative
Reference Model (NIDA)	4.295 (reference value)	2.872 (reference value)	/	/
Model 1(O)	0.6801	0.7392	84.16%	74.26%
Model 2(X)	0.6604	0.7342	84.62%	74.43%

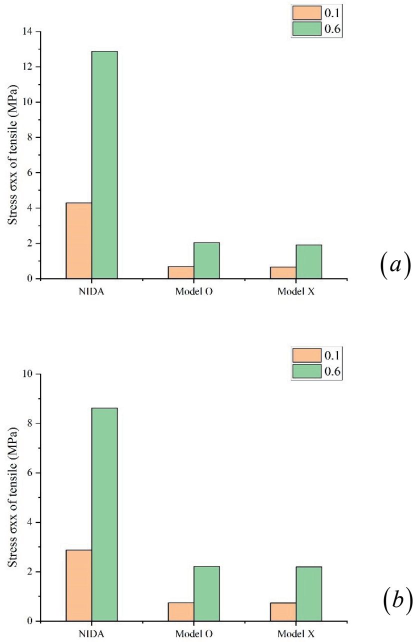

Figure 10: Histogram comparison of stress models σxx; a) positive; b) negative

Tensile stress comparison in terms of bending-imposed displacements (0.1, 0.3, and 0.6 mm). We may conclude that the suggested sandwich structure models' positive and negative tensile stress values are significantly lower than those of the reference model. The stress graphs of the suggested models and the reference model are contrasted in Figure 7. Based on the graphs, we can conclude that models O and X are capable of withstanding tensile strength, and as a result, we may conclude that model 2's simulation is superior to that of the other models.

The reference model and the displacement values of the (X)' (O) models are crucial. As illustrated in Fig. 10, we can conclude that models (X) and (O) respond to displacements less than the honeycomb model. It is evident by comparing the displacements of the three models that model 1 is more rigid than the NIDA. The rigidity of Model 2 is superior to that of the honeycomb model. According to our simulation, model 2 is more rigid.

Table 7: Displacement comparison

Models		Displacement (µm)	Δσ (%)
Reference Model (NIDA)	Uy Max (imposed displacement by bending)	4.462 (reference value)	/
Model O		3.673	17.68%
Model X		2.812	36.97%

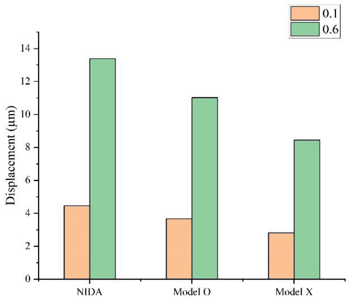

Figure 11: Histogram comparison of model displacement.

6. Discussion

The results are compiled into tables that show the displacements and constraints respectively. The impact of the sandwich's geometric shape was of interest to us in this investigation. The honeycomb sandwich beam and the models created by modeling and subjected to bending-imposed displacements were contrasted. The outcomes demonstrated the X-O sandwich's capacity for energy absorption. Additionally, it lessens damage to the honeycomb sandwich structure, which was demonstrated by the homogenous sandwich beams' strong stress-resistance. [28–29]. According to Figure 7 [30], the suggested models X and O respond better than the honeycomb, with 84.36% for X and 84.16% for O. The models created to compare them during the application of displacements induced by bending are shown in Figure 8. The numerical findings demonstrated how well the X and O models can tolerate displacements. When it comes to bearing displacements, the sandwich beams' core is crucial. As seen in figure 4 [31–23], the deflection begins in the centre and spreads out to run along the thin plates on the other side of the honeycomb. There are elastic vibrations that occur when reaching the maximum values corresponding to where the more the values of displacements imposed by bending the deflection are close to the permanent deflection [33]. Figure 8 represents a comparison of displacements for the three models. The results showed that the X-shape has good resistance to deflection with 36.97%, while the O-shape has good resistance with a lower degree of 17.68%.

The suggested models' analytical results for loads and stiffness agreed well with the findings of the study. The stiffness, which was predicted to be within acceptable technical bounds and not to exceed 11.58 %, is the source of the inaccuracy, improving the validity of the models in the design. Because of the models' numerical stability, the findings gained demonstrated how mesh size affects stiffness.[34].

The geometric comparison of the three models was also given a numerical dimension by the loading positions, thickness, skins, core, and design angles. Furthermore, the upper and lower layer shaking and the bending comparison are highly dependent on the core's thickness. This is because the thickness of the core increases the inertia torque, which significantly reduces deflection and improves stiffness.[35].

The way stressors are distributed. The axial stress is the greatest state in the middle of the skin, with tension at the bottom and compression at the top. Shear stress also happens at the site of contact and progressively diminishes as one moves away from the (T X Rad).

High performance and lightweight characteristics are combined in sandwich structures, and their mechanical behaviour depends on several technical criteria that need to be modified based on the application. Additionally, numerical modelling works well for forecasting how sandwich constructions will behave mechanically. [36-37].

7. Conclusion

In this research paper, the geometric effect of the core and the displacements imposed by bending on sandwich structures on the values of stresses and displacements in the X and Y axes was studied based on numerical modeling. The results obtained showed that the mechanical behaviour of each part of the sandwich structures is linear elastic. Despite the great importance of the honeycomb core, it was shown that it does not withstand the applied loads to a lesser extent than other models, as the proposed models can withstand bending loads and displacements due to the cavity in the cores that distributes the applied loads to their edges. The model with X cores has very good bending resistance and stiffness compared to other models. Aluminium alloy EN AW-1050A (H12) has shown to be a good choice for the skin as it provides greater stiffness and durability. It can withstand mechanical stress and external factors. The aluminium alloy EN AW-1050A (O) core is ideal here as it is easy to form and flexible, allowing it to take a geometric shape easily. This structure will remain light but strong enough to withstand the external weight. Future studies may contribute to improving the prediction of damage states for these beams using finite elements.

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