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*Research Article*

# Analysis of effect of variation of Honeycomb core cell size and sandwich panel width on the stiffness of a sandwich structure

Anil Kumar*[1,a], Surjit Angra[2,b], Arindam Kumar Chanda[1,c]

[1]*Department of Mechanical and Automation Engineering, G.B.P.E.C., New Delhi, India*
[2]*Department of Mechanical Engineering, N.I.T., Kurukshetra, India*

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**Abstract**

A sandwich structure consists of three main parts i.e. the facing skins, the core and the adhesive. It acts in a way similar to that of the I- Beam. In this research, a sandwich structure has been designed with a regular hexagon honey-comb core made up of Kevlar® and face sheet of carbon fiber. The design has been modelled and the model has also been validated with the experimental and analytical method. Six different configurations of sandwich structures have been proposed. Out of these six, three configurations have the varying cell size i.e. 3.2 mm, 4 mm and 4.8 mm and the other three configurations have the varying panel width i.e. 40 mm, 45 mm and 50 mm keeping rest of the design parameters unchanged. Using ANSYS, analysis has been performed for all these six configurations and equivalent stiffness has been calculated. It has been observed that the honeycomb core cell size does not have a significant effect on the stiffness properties of a composite sandwich panel. The analysis also reveals that with the increased panel width the stiffness of composite panel increases significantly.



## 1. Introduction

A composite is a combination of two or more materials, where each material retains its unique characteristics and contributes its own structural properties, enabling the newer material to have better properties in many aspects. The composites have many desirable properties as compared to the other conventional materials such as light weight, higher stiffness, resistance to heat and corrosion, lower cost and easy availability. The composites structures are the most valuable products for the future of space and automobile industries as they have higher strength with the lowest weight. [1]

There are three main classifications of composites materials i.e. particle-reinforced, fiber-reinforced and structural composites.

A fibre-reinforced polymer composite material can provide considerable high tensile strength but they lack in bending strength. The bending strength of a fibre-reinforced polymer composite can be enhanced by increasing the thickness of the composite. But increasing the thickness of composite may lead to higher cost and considerable time consumption. One more side effect of fabrication of thicker composite materials is the possibility of generation of exothermic reactions leading to the detrimental effects on different chemical and physical properties of the fabricated materials. So to avoid these limitations related with higher thickness of the composite materials, a unique type of reinforcement is needed to increase the bending load bearing capacity of composite materials. The composites having this type of reinforcement are called as Composite sandwich structures.

*Corresponding author: anilapmae@gmail.com
[a] orcid.org/0000-0001-8264-0586; [b] orcid.org/0000-0002-4863-7815; [c] orcid.org/0000-0002-5689-3149;
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Composite sandwich structures and different core dimensions are shown in Figure 1. A composite can be produced by inserting a low density, lightweight and thick core between two strong, stiff and thin facesheets. To join these different layers of facesheets with core, an adhesive material has to be used. Due to the insertion of a thick core, the overall thickness of the composite structure increases which ultimately leads to an increased bending load bearing capacity of the composite sandwich structure.

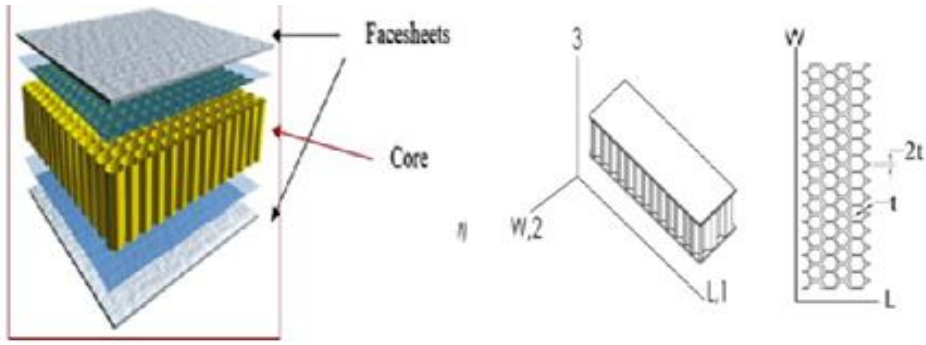



Fig. 1. Composite sandwich structure and core directions

The three basic elements of a composite sandwich structure can be described as –

**Face Sheet -** It will be responsible for bearing the bending stress of the sandwich structure. Carbon, Glass and Basalt Fibers are most widely used as Facesheet materials for fabrication of composite sandwich structures [15]. Kumar et al. [12] observed that the stiffness of sandwich structure initially increases at a faster rate and then reduces and tends to become constant with increasing thickness of face sheet.

**Core -** Mainly four types of cores are used in sandwich structures i.e. Corrugated, Honeycomb, Balsa wood and Foams. Most required property of a core of a composite sandwich structure is "the low density" to reduce the sandwich weight. Vamja et al. [2] describes that the sandwich panels having hexagonal core leads to a weight savings of approximately 39% as compared to other sandwich panels. The density, shear modulus, shear strength etc. are the most important properties of a core. J. S. Kumar et al. [3] observed that cell size along with core height was the most influencing structural parameters and the cell wall thickness was the least influencing one. Kumar et al. [6] in his study on sandwich structure observed that the tensile and flexural strength of the composite sandwich increases with increases of the height of the core. Arbaoui et al. [8] observed that the stiffness of the sandwich structures increase with core thickness. Thomas et al. [9] observed that Honeycomb core performance was dependant on geometrical parameters like cell size, node length, cell wall thickness and cell configuration. Rao et al. [10] in their research observed that the core height is not very effective parameter on the crushing behavior of sandwich structure having honeycomb core. But the wall thickness of a core cell is a pretty important parameter for the crushing strength of the sandwich panels. Akiwate et al. [11] made **e**xperimental investigation of bending behavior of aluminum alloy honeycomb sandwich structure using four point bending tests. They studied the Effects of the variation in honeycomb core height and honeycomb sandwich panel skin. Mohammed et al. [13] made experimental and numerical Study of bending behavior for honeycomb sandwich panel with different core configurations. Their results show that the square honeycomb's core shape bears the highest load from the other core shapes and the hexagonal have the lowest value and this value increased by increasing the facing thickness. Wahl et al. [17] observed that the stresses are highest at a core orientation between the L or X and W or Y -direction and the weakest angle is 62° and the L-direction is the strongest direction. Lister [18] also observed that Core ribbon orientation has an important role in a sandwich beam's bending behavior. Kiran et al. [21] described that core cell size and core sheet thickness has negligible effect i.e. they contribute only 4% towards the stiffness per unit weight as compared to other design factors.

Core is always supposed to bear the shear and the core shear strains produce deformations and core shear stresses. For this reason, always such a core has been chosen which would not fail under the applied transverse load and whose shear modulus is high enough to give the required shear stiffness. The core shear stresses in composite sandwich can be found using straight forward formulas loaded by transverse forces. Zhang et al. [22] explain that the out of plane shear strength and stiffness of honeycombs are independent of core cell size ultimately they have very little effect on the stiffness of the composite sandwich panel. Prakash et al. [7] found that for the given core density the core shear modulus of the Fiber Reinforced Plastic (FRP) honeycomb core is far higher than that of Polyurethane (PUR) foam, but the shear strength of the FRP sandwich panels is only a little bit higher than PUR foam sandwich panel.

Honeycomb core can be made of metallic or non-metallic materials such as aluminium, impregnated glass or Aramid fibre mats, such as Nomex. Uddin et al. [14] found that an Aramid honeycomb sandwich structure with carbon Prepreg system can be used as primary structures in aircraft, in wind turbine, automotive etc. Liu et al. [19] observed that due to the different manufacturing methods the different honeycombs have different in and out-of-plane properties. But, Nomex honeycomb core is weak in, out-of-plane direction.

**Adhesive -** The purpose of an adhesive in a composite sandwich structure is to provide a good bond between the materials components. Epoxy Resins are most widely used adhesive as they are low temperature curing materials, normally between 20 to 90 °C. The biggest advantage of use of epoxy is that due to the absence of solvents, epoxies can be used with almost every type of core material. Epoxies are available in almost every form such as paste, films, powder, or as solid adhesives. The shear strength of most of the epoxies are about 20-25 MPa. Also other adhesives are available such as Modified Epoxies**,** Phenolics and Polyurethanes and Polyester and Vinyl ester Resin etc. [6]

Rupani et al. [4] supported modelling of sandwich structure as equivalent homogeneous structure leading to best results. They observed that core gives high compressive strength in Z direction whereas face sheet gives shear strength in Z and Y direction. Altan et al. [5] successfully determined the reliability of the individual in-plane and out-of-plane effective elastic constants of honeycomb cores. Ijaz et al. [16] observed that the modified 'Gibson and Ashbey model' is the best analytical model to determine the orthotropic properties of a honeycomb core. Gibson and Ashbey initially determine the formulae for detection of nine orthotropic properties for honeycomb materials with constant wall thickness followed by the number of revisions by 'Zhang and Ashbey' to include the double wall thickness for the out of plane values. [22]

Hussain et al. [24] observed that the "Three point bending test (3PBT)" can be performed using numerical analysis and its result can be verified using the experimental setup. The FEA is the best option for testing of different sandwich structures.

Form the literature review; it has been observed that the performance of a composite sandwich panel depends on the different design factors such as material, thickness, orientation of factsheet and core, core cell size, use of adhesive, panel shape etc. Double-wall thickness regular hexagon honeycomb type cores are the extensively used cores because of its low density and relatively higher shear properties. Aluminium, Steel and Nomex have been widely used materials for making honeycomb cores. The finite element Analysis (FEA) is the most widely used and accepted simulation method to predict the physical behaviour of systems and structures. For FEA the core can be converted onto an equivalent solid. But to develop an equivalent solid of a honeycomb core, the elastic orthotropic properties have to be calculated.

The most of the research has been done on determining the effects on various mechanical properties of sandwich structure due to variation only in the Sandwich's core height, core materials and core cell wall thickness [6, 7]. So the objective of this research is to find out the effect of two other design factors i.e. varying 'Honeycomb Core Cell Size & Panel Width' on Stiffness of a composite sandwich structure.

In this research, for numerical modelling of a sandwich structure, a sandwich structure, having Carbon fiber reinforced face sheet and a non-metallic material (Kevlar® Honeycomb) will be modelled. Gibson and Ashbey model formulae for honeycomb core will be employed to determine the equivalent orthotropic properties of Kevlar® Honeycomb core so that the honeycomb core can be converted into an equivalent solid. 3PBT will be performed on sandwich panel using Ansys as per C393 ASTM standard and ultimate load, deformation and the equivalent stiffness will be calculated. Then for experimental results, a composite sandwich will be fabricated and a 3PBT also will also be performed on it. The stiffness value obtained from numerical and experimental model will then be compared and if the values from different analyses will be successfully match then the model will be assumed as valid and will be recommended for numerical modelling of other similar sandwich panels. Then the three panels with different Core cell size and three panels with different Panel Width, with all others parameters remaining constant, will be designed and tested as per ASTM C393 standard [20] using ANSYS. After finding the values of equivalent stiffness for different configurations, an analysis of the effect of varying Honeycomb Core cell Size and Panel Width on the equivalent stiffness of sandwich panels will be made.

## 2. Material and Methods

### 2.1 Materials for different elements of a Sandwich Panel

The Carbon Fiber Reinforced Plastic, Regular Hexagon Kevlar Honeycomb and Epoxy have been used as the Face sheet, Core and Adhesive material respectively for design and fabrication of the sandwich structure. These different materials have been chosen as they are responsible for providing the different properties to the final Sandwich Structure. The different characteristics of face sheet, core and adhesive materials are as under-

#### Face Sheet Material (Carbon fiber)

Carbon fibers have elastic constants almost equivalent to steel, so they act as best material for face sheet manufacturing. They are resistant to moisture and chemicals and low in weight resulting in, reduced overall weight of the panel [15]. The different properties of Carbon Fiber Reinforced Plastic are shown in Table 1.

Table 1. Properties of Epoxy Carbon Woven (230 GPa) [6]

| Property | Value |
|---|---|
| Young's Modulus (X- Direction) | 61340 MPa |
| Young's Modulus (Y- Direction) | 61340 MPa |
| Young's Modulus (Z- Direction) | 6900 MPa |
| Poission's Ratio XY | 0.04 |
| Poission's Ratio YZ | 0.3 |
| Poission's Ratio XZ | 0.3 |
| Shear Modulus XY | 195000 MPa |
| Shear Modulus YZ | 2700 MPa |
| Shear Modulus XZ | 2700 MPa |

**Core Material (Kevlar Honeycomb core**)

It is made up of Aramid fibers which are arranged in the form of Para-Aramid fibers. Kevlar is about five times lighter than steel in terms of the same tensile strength. PK2 (Plascore) [23] has been used here as core material and the different in and out plane properties of the core has been shown below in Table 2.

Table 2. In and Out plane properties of the core [22]

| S.N. | Property | Cell Size 3.2 mm | Cell Size 4.0 mm | Cell Size 4.8 mm |
|---|---|---|---|---|
| 1 | $E_x$ (MPa) | 0.287 | 0.25 | 0.142 |
| 2 | $E_y$ (MPa) | 0.287 | 0.25 | 0.142 |
| 3 | $V_{xy}$ | 0.999 | 0.999 | 0.999 |
| 4 | $G_{xy}$ (MPa) | 0.013 | 0.009 | 0.006 |
| 5 | $E_z$ (MPa) | 480.48 | 450 | 420.42 |
| 6 | $V_{xz}$ and $V_{yz}$ | 0 | 0 | 0 |
| 7 | $G_{xz}$ (MPa) | 70 | 65 | 60 |
| 8 | $G_{yz}$ (MPa) | 110 | 100 | 100 |

**Adhesive** (**Epoxy Resin)**

Epoxy Resins are low temperature curing materials, available in almost every form such as paste, films, powder or as solid adhesives and mostly have the shear strength of about 20-25 MPa.

### 2.2 Design Parameters

For designing the sandwich panels, four different design parameters i.e. Core Cell Size, Face Sheet Thickness, Core Height and Panel Shape have been selected.

To analyze the effect of variation of core cell size on stiffness property of a sandwich structure, three different sandwich Structures having three different core cell sizes i.e. 3.2 mm, 4 mm and 4.8 mm have been chosen. The other three design parameters i.e. Face Sheet Thickness, Core Height and Panel Shape for all the three sandwich structures have been kept same having the values .8 mm, 12.7mm and 45x200 mm$^2$ respectively.

To analyze the effect of variation of panel width on stiffness of a sandwich structure, three more sandwich structures having three different panel widths i.e. 40 mm, 45 mm and 50 mm have been chosen. The other three design parameters i.e. Core cell size, Face sheet thickness and Core height for the three sandwich structures have been kept same having the values 3.2 mm, .8 mm and 12.7 mm respectively. The Figure 2 shows an equivalent composite sandwich structure having b, c, t and d as width, core thickness, face sheet thickness and overall thickness of composite respectively with a panel size of 45x200 mm$^2$.

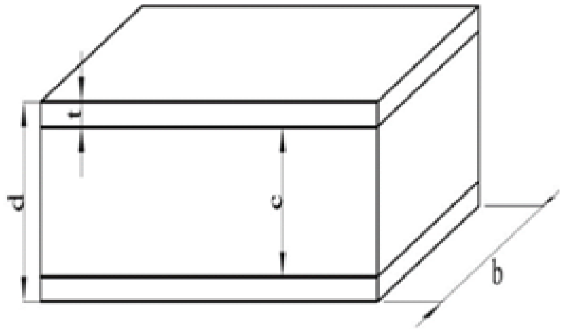
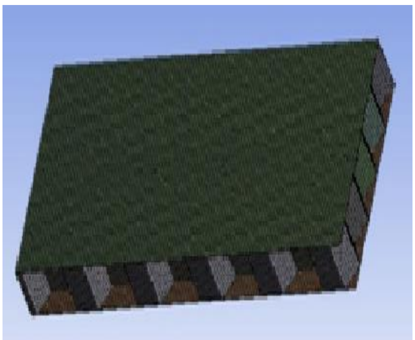



Fig. 2. Equivalent Composite Sandwich structure

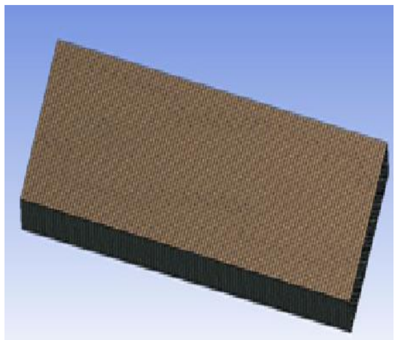
### 2.3 Modelling and FEA of Sandwich Panel

Modelling is done in the Ansys. The Face sheets are modelled orthotopically in the Ansys composite prep-post while the homogenised core is modelled in Design modeller available in Ansys. The homogenised core is modelled by replacing honeycomb cells with a solid core that acts as a honeycomb itself in a macroscopic view as shown in Figure 3(a, b). The solid core is given the same orthotropic properties as the honeycomb core. The main advantage of this method is that the number of elements in solid core is highly reduced than the actual honeycomb geometry. Hence this method is computationally cheap. The homogenized core is meshed using SOLID 186 elements while face sheet is meshed using SHELL 181 elements.

Bonded contact is assigned such that face sheet have 'contact body' and core have 'target body' setting. Default 'program controlled' was used to set up the formulation of contact, hence it considers the FEA approach as penalty method.



(a)



(b)

Fig. 3. Sandwich model (a) honeycomb core (b) equivalent solid core

The Finite Element Analysis is the best and much powerful numerical techniques to solve the complex physical phenomenon regulated by the differential equations. Lots of practical engineering problems can be analyzed by the Finite Element Analysis. Out of the above mentioned 6 sandwich configurations, a sandwich panel having core cell size 3.2 mm, face sheet thickness .8 mm, core height 12.7mm and panel shape of 45x200 $mm^2$ has been randomly selected for Finite Element and Experimental Analysis, so that the model can be validated.

### 2.4 Fabrication of sandwich panel

The process of fabrication of sandwich structure having Honeycomb Core and Carbon fiber has been completed using the "Vacuum Assisted Hand Layup Method". Initially a surface has been prepared and a mold has been set with double side tape. Than wax coating has been applied on the working area for easy removal of sandwich plate after fabrication. After 10 minutes of application of wax, epoxy resin has been applied on the surface and then a carbon fiber of required specification has been placed on it and again epoxy has been applied on it. Then honeycomb core has been placed on the carbon fabric layer and again epoxy resin has been properly applied on it followed by placing of carbon fabric on the top of honeycomb core. Then the structure has been covered with a blue perforated film followed by peel ply. Then the entire set up has been covered with breather fabric so that the vacuum process can be easily performed. After fixing of breather fabric layer vacuum bag is connected and close the all sides carefully. After that a vacuum pump has been switched on so that air can be sucked from the bag as shown in Figure 4. Utmost care has to be taken during this process as leakage in the system and possibility of air bubble can lead to defects in the sandwich structure layer bonding.

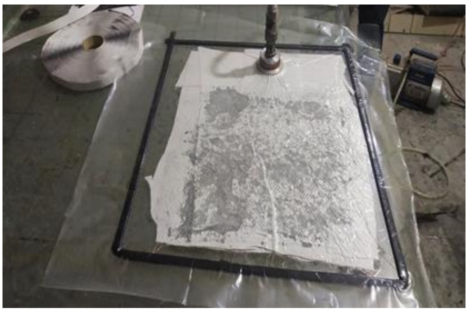


Fig. 4. Final set up for sandwich structure

Then this set up has been left for about a day for curing and then the sandwich has been brought out followed by cleaning of the edges of the sandwich panel with carbide tip/grit. Figure 5 shown below gives the view of a finally fabricated sandwich structure having Kevlar as a honeycomb core.

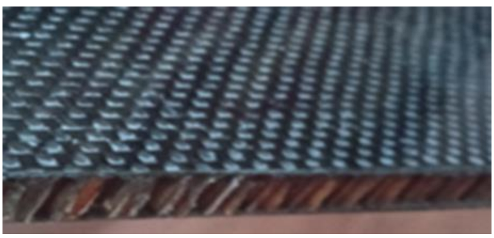


Fig. 5. Final sandwich structure

The Three Points Bend Test has been performed on two sandwich panels as per ASTM C393 standard and the values of critical load and deflection has been calculated for both of these specimens. The testing setup on universal testing machine has been shown in Figure 6.

Fig. 6. Three-point bend testing set up for sandwich pane

# 4. Results and Discussion

## 4.1 FEA of Sandwich Panel

After defining the material properties and modelling of the sandwich panel, the panel is imported in the static structure module of Ansys. A load is applied until the failure of the panel according to the standards of ASTM C-393. The sandwich will fail due to shear crimping which arrives due to weak core material as compared to the face sheets and when the shear stress due to load in the homogenized core reaches the shear strength in the X direction. This load is called the Ultimate load.

Ultimate Force calculated by FEA for sandwich panel using Ansys as per ASTM C 393 standard has been shown in Figure 7 and it has been observed that the Ultimate Load achieved for this sandwich panel is 1949.5 N.

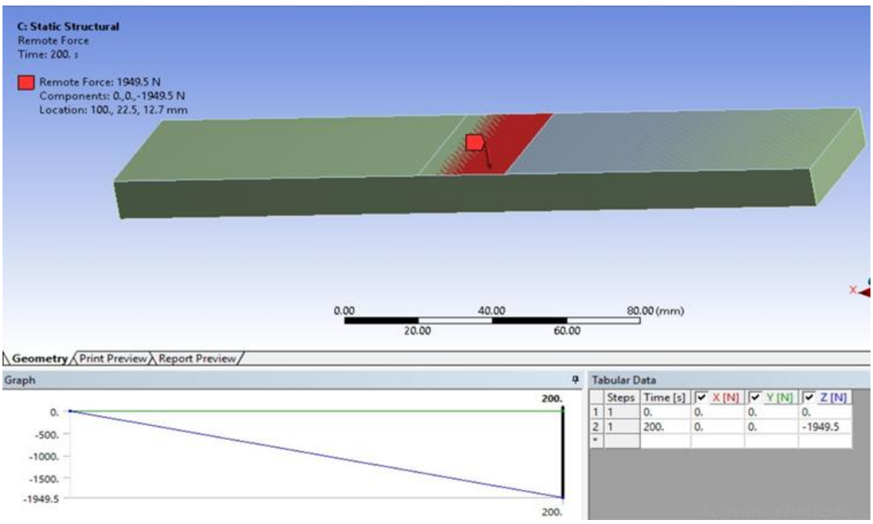



Fig. 7. Ultimate load using FEA

Figure 8 shown below determines the deformation of composite sandwich panel using Ansys as per ASTM C 393 standard. The Deflection found at Ultimate load is 2.017 mm.

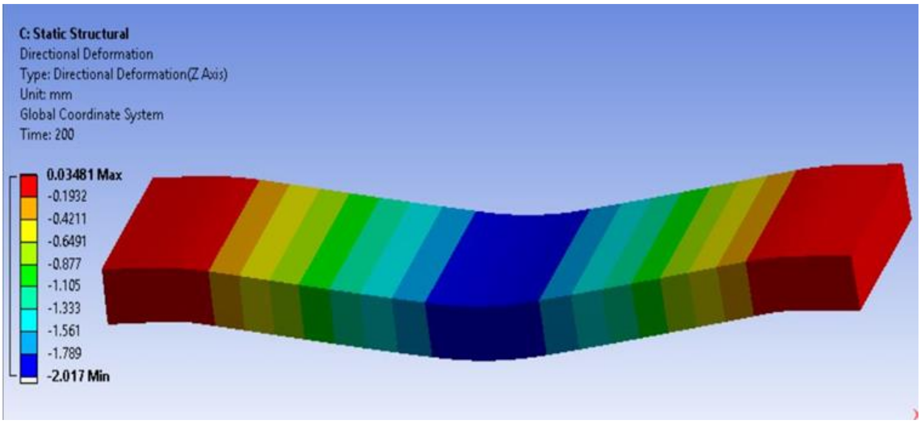



Fig. 8. Deformation at ultimate load using FEA

For Pre-buckling stage i.e., from starting of application of load to the ultimate load condition, the sandwich panel gives a linear elastic deformation and the ratio of ultimate load to deflection gives the stiffnessof the sandwich panel.

Ultimately, the Stiffness of panel= Load/deflection= 1949.5/2.017= 966.53 N/mm.

### 4.2 Experimental Analysis of Sandwich Panel

3PBT have been performed on two samples of sandwich panel as per ASTM C393 standard. Figure 9 (a) shows the condition of a test specimen during the 3PBT whereas the Figure 9(b) shows the condition of two test specimens after 3PBT. The values of critical load, deflection and stiffness have been calculated for two samples as shown in Table 3. It has been observed that the sandwich panel failed due to shear crimping which arrived due to weak core material.

(a) (b)

Fig. 9. Test specimens (a) under 3PBT (b) after 3PBT

Table 3. Load, Deflection and stiffness of Test Samples

| Critical Load, Pc [N] | Avg. Critical load [N] | Deformation [mm] | Average Deformation [mm] | Stiffness [N/mm] |
|---|---|---|---|---|
| 1703 | 1719.5 | 1.680 | 1.696 | 1013.85 |
| 1736 | | 1.713 | | |

### 4.3 Validation of Finite Element model

To check the validity of the generated model, the values of stiffness obtained from 2 types of analyses has been compared as shown in the Table 4-

Table 4. Comparison of results of FE and Experimental analyses

| FEA Results Stiffness (N/mm) | Experimental Results Stiffness (N/mm) | % Error |
|---|---|---|
| 966.53 | 1013.85 | 4.66% |

Table 4 shows that the difference between the results of Numerical and Experimental methods is below 5%. This shows that the two types of analysis are in good agreement with each other and the Model generated is valid and hence this model can be utilized for analysis of similar type of composite sandwich structures.

### 4.4 FEA of all six Sandwich Structures

FEA of all sandwich panels have been done using same model with different design parameters mentioned above and the results obtained are under in Table 5.

Table 5- Stiffness of panels for varying cell size and panel width

| Confi. No. | Design Factor | Value | Ultimate Load (N) | Deformation (mm) | Stiffness (N/mm) |
|---|---|---|---|---|---|
| 1 | Core Cell Size (mm) | 3.2 | 1949.5 | 2.016 | 967.01 |
| 2 | | 4 | 1932 | 1.99 | 970.85 |
| 3 | | 4.8 | 1928 | 2.0 | 964 |
| 4 | Panel Width (mm) | 40 | 1741.5 | 1.86 | 936.29 |
| 5 | | 45 | 1949.5 | 2.016 | 967.01 |
| 6 | | 50 | 2181 | 1.62 | 1346.29 |

Table 5 shows the different values of ultimate load, deformation and ultimately the stiffness of these sandwich structures. The stiffness for three sandwich panels having cell sizes as 3.2 mm, 4mm and 4.8 mm are 967.01, 970.85 and 964 N/mm respectively and it is evident from the Table 5 that honeycomb core cell size does not have a significant effect on the stiffness properties of a composite sandwich panel. This is in accordance with the analytical results made by Gibson and Ashbey [1] that, the stiffness in mainly a factor dependent on the properties of the facesheet and the thickness of the core of sandwich panel.

Also three different panel widths i.e. 40 mm, 45 mm and 50 mm have been chosen for 3 different sandwich structures and FEA for these sandwich panels have been done. The stiffness for three sandwich panels having panel widths of 40 mm, 45 mm and 50 mm are 936.29, 9670.01 and 1346.29 N/mm respectively. It is clear from the Table 5 that with the increased panel width the stiffness of composite panel increases significantly.

## 5. Conclusions

This research is aimed to analysis the effect of variation of core cell size and panel width on stiffness property of sandwich panels, for which six different configurations of sandwich structures have been proposed, three configurations have the varying cell size i.e. 3.2 mm, 4 mm and 4.8 mm and the other three configurations have the varying panel width i.e. 40 mm, 45 mm and 50 mm keeping rest of the design parameters unchanged. Then FEA in ANSYS has been performed for all these six configurations and stiffness has been calculated for each panel. From the analysis of the stiffness values based on different criteria-

- It has been observed that honeycomb core cell size doesn't have a significant effect on the stiffness properties of a composite sandwich panel. This is in accordance with the observations made by Kiran et al [21] and Zhang and Ashbey [22] that the core cell size of a honeycomb core has negligible effect on the stiffness property of a composite sandwich panel.
- Also it has been found that with increased panel width the stiffness of composite panel increases significantly.

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