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Modal Analysis and Parametric Study on Composite Sandwich Structure with PLA Core

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Abstract : The purpose of this paper is to investigate the natural frequencies of a sandwich structure composed of a PLA honeycomb core and a CFRP composite face sheet. The ANSYS workbench software suite was used to create and evaluate finite element models for the sandwich panel with the honeycomb core. This research is validated by employing a homogenized core to simplify the analysis complexity. Parametric study for various facesheet and core thicknesses were conducted to investigate the effect of sandwich properties on vibration characteristics.

***IndexTerms* – composite,sandwich structure,honeycomb,CFRP,PLA,modal analysis.**

I. Introduction

Sandwich structures that use a honeycomb core between two relatively thin skins are desirable in many engineering applications that require high strength-to-weight ratios. The usage of honeycomb sandwich structures in engineering is currently widespread in aerospace engineering. Composite panels, shells, and tubes made of lightweight honeycomb materials can have excellent structural performance.

Sadiq.[1] analyzed the free vibration characteristics of aluminium sandwich structures used in aerospace applications to find the optimum honeycomb parameters. Boudjemai.[2] performed modal analysis on the sandwich structure used in satellite structure with different materials and various design parameters. Simulating a huge number of core cells makes a simulation expensive to run on computers. To replace the core with a simpler solid layer that has effective (equivalent) material properties, some type of homogenization technique is required. Numerous studies have been done and published that present various analytical techniques for figuring out the mechanical properties of homogenized core geometries that can avoid modelling the honeycomb geometry explicitly. Sather & Krishnamurthy.[3] compared the various analytical methods to calculate the effective material properties of honeycomb. Gibson & Ashby.[4] assumed the linear-elastic response of the honeycomb deformations and found core properties that depend only on the bending of the core cell walls. Marythraza.[5] performed finite element analysis on sandwich structure assuming sandwich structure as an isotropic plate. Havildar [6] used a Gibson method to determine the vibration characteristics of the FRP sandwich structure. Sakar & bolat.[7] compared free vibration analysis results of both the 3d model and continuum model of the honeycomb sandwich structure. From the above literature analysis, it can be noticed that mainly homogeneous honeycomb sandwich structures were analyzed, but to achieve high strength and less weight use of composite sandwich structures has increased in recent times. The composite material is made up of two or more distinct materials with varied qualities. benjuddou[8] analyzed the vibration characteristics of both GFRP and aluminum sandwich structures. Al-khazraji[9] compared various composite sandwich structures made from carbon fiber, foam, and glass fiber. Cho[10] performed vibration analysis on the composite sandwich structure of carbon fiber and aluminium used in satellite structures. Polymer composites are being progressively employed as a substitute for traditional materials. The introduction of 3D printing in the development of sandwich structures helps to achieve rapid prototyping and design complex core structures easily.3D printing materials have seen an upsurge in their use in the industry in recent years. Wannarong [11] compared the sandwich structure with 3d printed honeycomb core made of Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA), this paper explains their mechanical characteristics and their ability to be used as core material for sandwich structures. In this study, a composite sandwich structure consisting of PLA, the most widely used material in 3D printing is considered for the honeycomb core and CFRP is considered for the face sheet.

II. MATERIAL AND METHOD USED

The first in designing a sandwich structure is the selection of materials for different constituents. A typical sandwich structure consists of the following parts 1. facesheet 2. adhesive 3.core. the various parameters of sandwich are t-thickness of the facesheet, h – thickness of core, a- length of the sandwich structure, b- breadth of the sandwich structure, H – height of the sandwich structure, ρ_c – density of core and ρ_t – density of facesheet (see Fig.1). A unit cell of the honeycomb core is represented below in Fig. 2.the various parameters of the honeycomb cell are l- length of wall length, t- thickness of the wall, c- cell diameter (distance between vertical wall) ,and θ - (angle between walls -90°). the table.1 gives the value of various parameters of the honeycomb unit cell and sandwich structure used in the paper.

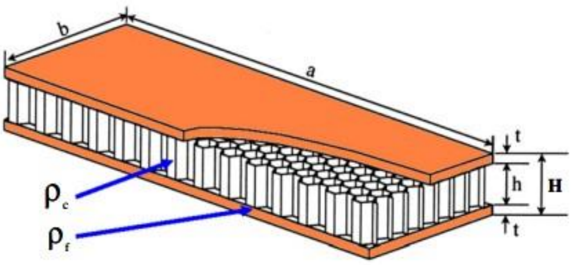

figure 1. parameters of sandwich structures [2]

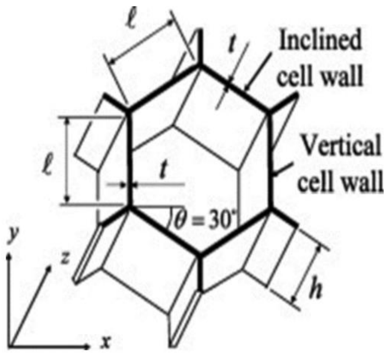

figure 2. honeycomb unit cell [11]

table 1. sandwich parameters

Properties of sandwich structure					
a 0mm	b mm	h mm	t mm	ρ_c Kg/m^3	ρ_t Kg/m^3
290	40	9	1	1240	1490
Properties of unit cell					
t_{cell} mm		C_{dia} mm		material	
0.2		2		PLA	

The honeycomb comb is converted into an orthotropic plate. So, the effective material properties of the core are found using the analytical expression given by Gibson [4]. these analytical expressions were derived assuming the walls of the honeycomb unit cell deform solely due to the bending of inclined walls. The effective in-plane and out-plane moduli are given. the effective material properties of the core are found using the expressions given above considering PLA as the core material. the facesheet used is a carbon fiber-reinforced polymer. Carbon fibers are usually available as a unidirectional or bidirectional fabric. Facesheets are prepared using a layup process where each sheet of different angles is stacked together. For unidirectional fabrics usually, they are stacked in either of these angles 0o,90o,45o,-45o and bidirectional fabrics are available as 0o/90o or 450/-45o. the epoxy resin is used as a matrix in CFRP. The combined properties of carbon fiber and epoxy resin considering unidirectional fiber are taken from the engineering data of ANSYS workbench. the effective orthotropic properties of the core and the epoxy carbon UD are given in Table 2. Both the modelling and finite element analysis was carried out in ANSYS workbench. the ACP module and modal analysis of ANSYS are combined to perform the entire analysis. This below Fig. 3. explains the step-by-step method followed in finite element analysis in ANSYS workbench.

$$E_{xx} = [E_c(t/L)^3\cos\Theta]/[(1+\sin\Theta)\sin^2\Theta] \quad (1)$$

$$E_{yy} = E_c(t/L)^3(1+\sin\Theta)/\cos^3\Theta \quad (2)$$

$$E_{zz} = \rho/\rho_c * E_c \quad (3)$$
$$\nu_{xy} = \cos^2\Theta/(1+\sin\Theta)\sin\Theta \quad (4)$$

$$\nu_{xz} = \nu_c * E_{xx}/E_{zz} \quad (5)$$

$$\nu_{yz} = \nu_{yz} * E_{yy}/E_{zz} \quad (6)$$

$$G_{xy} = E_c(t/L)^3(1+\sin\Theta)/3\cos\Theta \quad (7)$$

$$G_{xz} = G_{yz} = G_c(t/L)\cos\Theta/(1+\sin\Theta) \quad (8)$$

table 2. material properties

material	density (Kg/m^3)	EX (MPa)	EY (MPa)	EZ (MPa)	GXY (MPa)	GYZ (MPa)	GZX (MPa)	poisson's ratio XY	poisson's ratio YZ	poisson's ratio XZ
Epoxy carbon UD (230 GPa) prepag	1490	1.21E5	8600	8600	4700	3100	4700	0.27	0.4	0.27
PLA	1240	3500	-	-	1346.15	-	-	0.3	-	-
Core	247.93	41.96	41.96	699.81	10.49	134.57	134.57	0.99	0.001	0.001

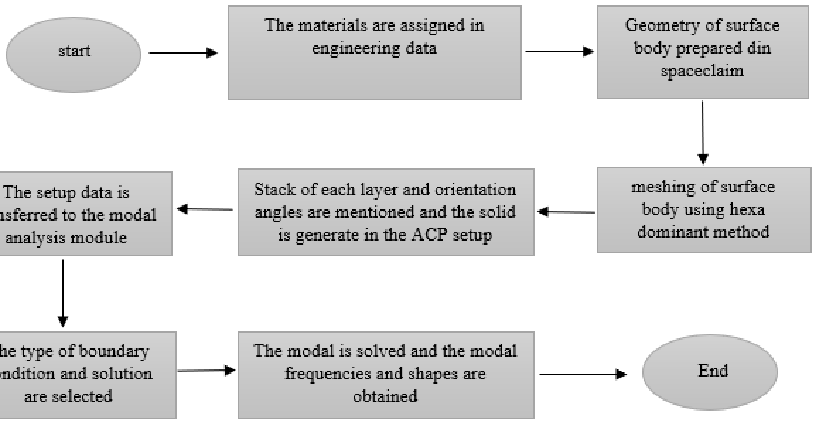

figure 3. workflow in Ansys

III. **FEA STUDY ON COMPOSITE SANDWICH STRUCTURE**

3.1Mesh Convergence and validation of natural frequency

The comparison of the present method results with reference [2] helps us validate that our present method is accurate and reliable. therefore, analysis is performed based on the data from the reference [2]. So as per reference the material used for both facesheet and honeycomb is aluminium (E=72000 MPa, ρ=2800 kg/m3, Poisson ratio=0.33). the dimension of the sandwich structure and honeycomb are the same as specified in Table 1. The modal is developed following the above-discussed method where the honeycomb core is represented as an orthotropic plate using the Gibson analytical expressions. after the results, the modal is repeated for different mesh sizes to check for convergence. The variation in natural frequencies and convergence attained is shown in figure 4. The comparison of present results with the reference shows that the present method produces outcomes that are close to that of the reference. (see table 3)

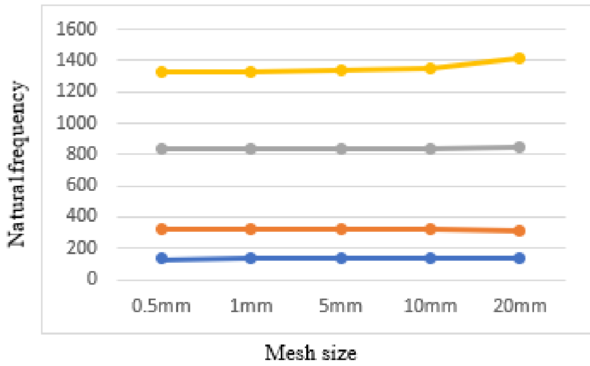

figure 4. mesh convergence

table 3. validation results

Mode	Natural frequency (Hz)		Error %
	reference	present	
1.	130.98	136.47	4.19
2.	300.91	324.01	7.67
3.	807.69	832.03	3.01

3.2 Problem Setup

The validated modal is used for the current study of PLA and CFRP sandwich structure. So as per the data, the material property of the facesheet is chosen from a material library of ANSYS under composite material and the core properties are defined taking orthotropic elasticity, and data is entered as per Table 2. The surface body is created in ANSYS SpaceClaim, which is used in the ACP module to define the stack of core and laminates (see Figure 5). The stacking is done in the order of [0o/90o/core/90o/0o]. Each layer of CFRP is of thickness 0.5mm, so the entire laminate is about 1mm. this data is transferred to the modal analysis module (see Figure 6). In modal analysis, the one-end fixed boundary condition is assigned and total deformation is selected in the solution tab for 6 modes. solving the modal gives the natural frequencies of 6 modes and their corresponding mode shape.

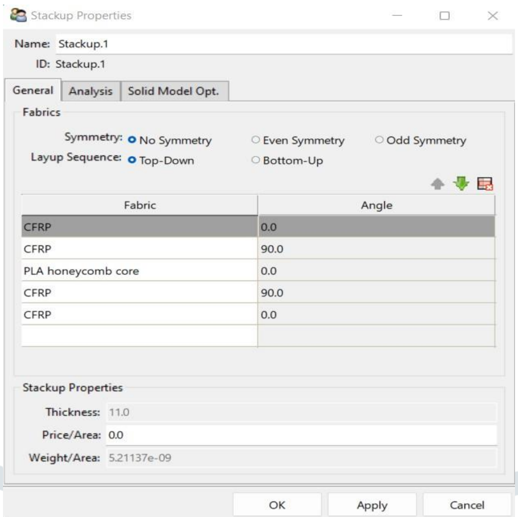

figure 5. stackup sequence

figure 6. data transfer from ACP to modal analysis module

3.3 Mode shapes and frequency results

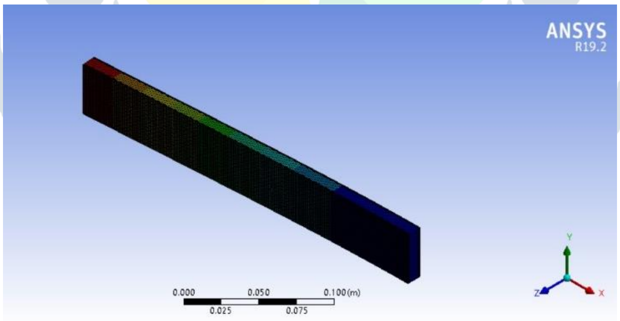

Figure 7. mode 1 (166.15 hz)

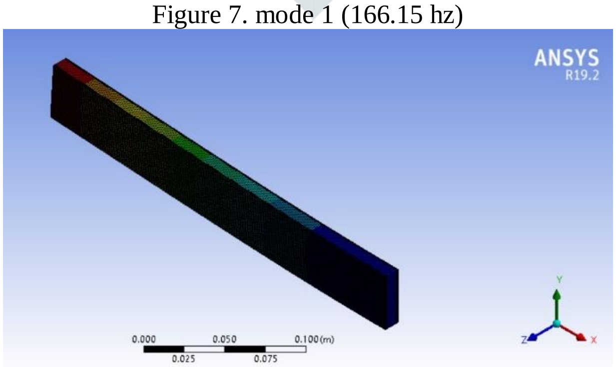

Figure 8. mode 2 (379.09 hz)

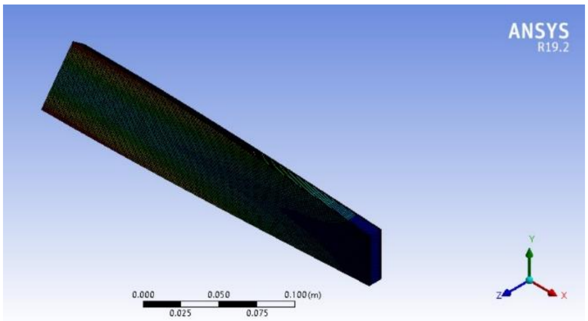

Figure 9. mode 3 (619.44 hz)

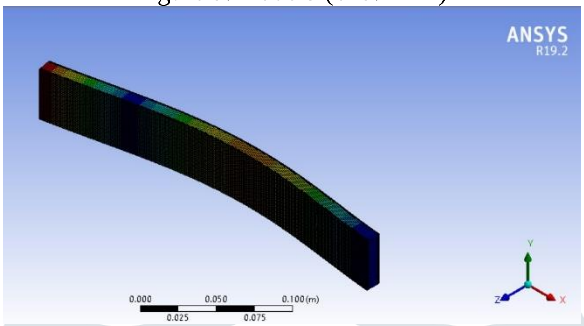

Figure 10. mode 4 (809.4 hz)

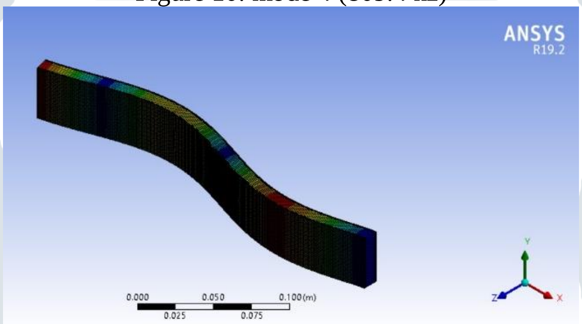

Figure 11. mode 5 (1803.5 hz)

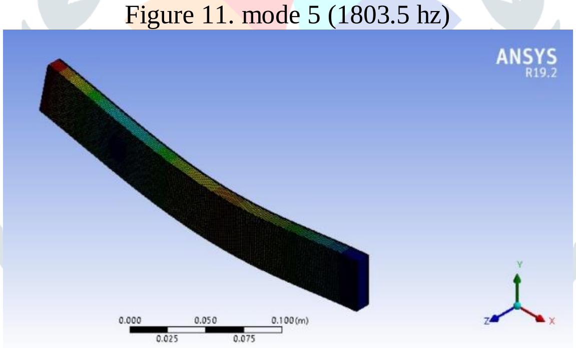

Figure 12. mode 6 (1811.6 hz)

IV. PARAMETRIC STUDY

4.1 The effect of symmetric and asymmetric sandwich structure

The stacking order of the sandwich structure was tested for both symmetric and asymmetric conditions. In symmetric conditions, the sequence is such that both the top and bottom of the midplane are a mirror of each other. In symmetric condition, the natural frequency for stacking sequence [0º/90º/core/90º/0º] and [90º/0º/core/0º/90º] are tested and in asymmetric condition, the natural frequency for stacking sequence [0º/90º/core/0º/90º] and [90º/0º/core/90º/0º]. the results of the above sequence are shown in Table 4.

table 4. Symmetric and asymmetric results

Symmetric		Asymmetric	
0º/90º/core/90º/0º	90º/0º/core/0º/90º	0º/90º/core/0º/90º	90º/0º/core/90º/0º
166.15 Hz	152.69 Hz	159.43 Hz	159.43 Hz
379.07 Hz	373.5 Hz	375.96 Hz	375.96 Hz
619.44 Hz	619.26 Hz	619.34 Hz	619.34 Hz
809.4 Hz	744.3 Hz	777.02 Hz	777.02 Hz
1803.5 Hz	1658.5 Hz	1731.6 Hz	1731.6 Hz
1811.6 Hz	1793.5 Hz	1798.1 Hz	1798.1 Hz

4.1 The effect of face sheet and core thickness in natural frequency

In this case, the impact of facesheet thickness in sandwich structure is investigated. The same dimension and material properties are used as mentioned in Table 1 & Table 2. The facesheet thickness were varied by the values

0.6mm,0.8mm,1mm,1.2mm,1.4mm. the comparison the results show that as the thickness of facesheet increase the natural frequency also increase. The natural frequency of corresponding thickness and graph to illustrate the change is shown in Figure 13 & Table 5.

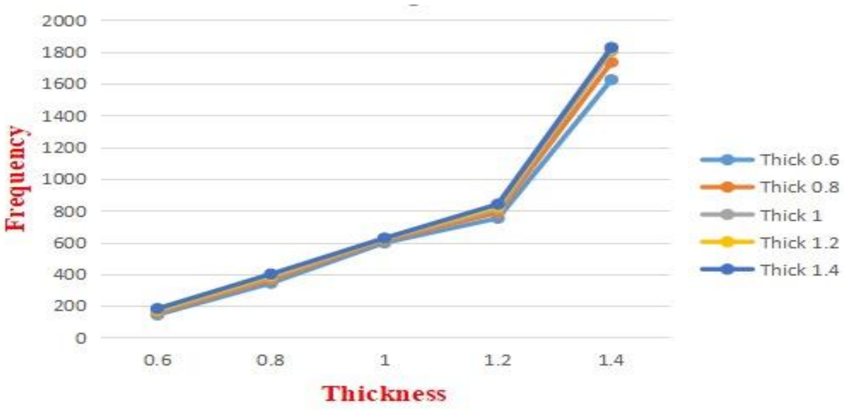

figure 13. facesheet thickness vs frequency

Table 5. Natural frequency for different facesheet thickness

Facesheet thickness	Natural frequency (Hz)					
	Mode 1	**Mode 2**	**Mode 3**	**Mode 4**	**Mode 5**	**Mode 6**
0.6mm	143.29	342.25	596.21	751.13	1623	1744.6
0.8mm	155.95	363.65	611.66	786.02	1732.5	1782.8
1mm	166.15	379.07	619.44	809.4	1803.5	1811.6
1.2mm	174.78	390.75	623.54	826.49	1816.3	1862.1
1.4mm	182.34	399.94	625.84	839.95	1825.5	1869.3

dimension and material properties are used as mentioned in Table 1 & Table 2. The core thickness were varied by the values 3mm,6mm,9mm,12mm,15mm. the comparison of the results show that as the thickness of core increase the natural frequency also increase. The natural frequency of corresponding thickness and graph to illustrate the change is shown in Table6 & Figure 14.

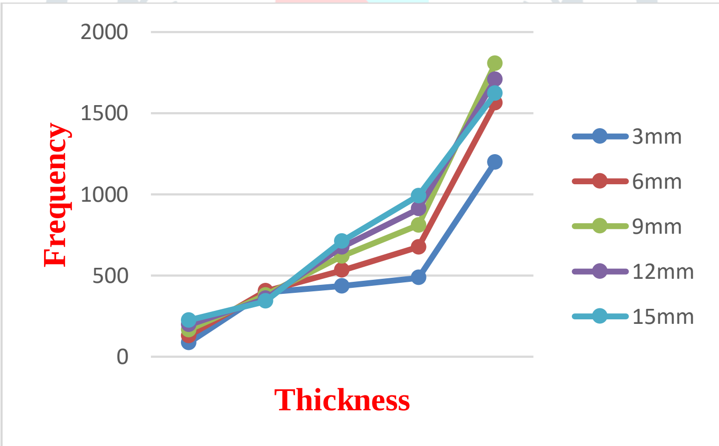

Figure 14. core thickness vs frequency

Table 6. Natural frequency for different Core thickness

Core thickness	Natural frequency (Hz)					
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
3 mm	86.068	395.41	435.67	486.21	1198.4	1199.9
6 mm	129.65	404.06	532.71	674.86	1561.1	1596.2
9 mm	166.15	379.07	619.44	809.4	1803.5	1811.6
12 mm	197.45	358.57	675.42	910.63	1707.3	1979.3
15 mm	224.73	341.31	711.02	989.96	1620.1	2113.5

V. CONCLUSION

The modal analysis of PLA honeycomb core and CFRP, composite sandwich structures was performed using ANSYS workbench software, which was validated using reference. The resulting model is 8-9 times lighter, and its modal frequencies are closer to those of the homogenous aluminium sandwich structure. The impact of both symmetric and asymmetric conditions was analysed. The sequence [0o/90o/core/90o/0o] appears to have a greater natural frequency. The effect of facesheet and core thickness on modal frequency values was analyzed, and the findings indicate that as thickness increases, so do the modal frequency values.

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