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# Evaluation of Damping Characteristics of 3D Printed CF-reinforced PLA/ABS Composite Sandwich Panels

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*Abstract:* - This study aims to investigate the influence of carbon fiber (CF) as reinforcement on the vibration-damping behavior of sandwich composite panels made of Polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS). The fabrication is done by 3D printing through Fused Deposition Modelling (FDM) technology. This study explores the application of 3D printing by FDM to develop composite sandwich panels for diverse purposes, investigating the use of commercially available polymers such as PLA and ABS, reinforced with carbon fiber. The finite element analysis is carried out for different combinations of core, and skins of fabricated sandwich panels, and modal tests are carried out in order to obtain the mode shapes and natural frequencies. It is found that the geometrical parameters of the core have an influence on the vibration damping of sandwich panels. The obtained results show that the sandwich panels with skins made of carbon fiber/PLA composites have around 14.84 percent higher damping properties as compared to pure PLA/ABS cores. The maximum deflection is higher for the core with thin wall thickness, and the maximum load is smaller for the horizontal core sandwich as compared to the vertical core. The results showed that so as to fabricate lightweight, high-strength, and low-cost sandwich panels the additive manufacturing technology using 3D printing can be used promisingly. It is found that the addition of CF considerably increased the energy absorption capacity as compared to pure PLA/ABS sandwich panels. In a nutshell, the fabrication of sandwich panels from the CF-reinforced PLA/ABS composites using 3D printing technology and its testing for damping properties is not explored to a greater extent.

*Keywords:* Damping, 3D Printing, PLA/ABS composites, Sandwich Panels

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## 1. INTRODUCTION

Sandwich panels are lightweight structures having two thin face sheets on either side of a solid/foam core. Today, sandwich panels are extensively being

used in the wind turbine, shipbuilding, auto, and aerospace sectors in addition to in civil structures for their characteristics such as high energy absorption, strength, and lightweight. In a sandwich panel, the tensile as well as compressive loads are carried by the

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face sheets which are acting on the structure whereas the middle core carries the shear loads on the structure. Over the past years, different types of core structures for sandwich panels have been proposed. A very high strength-to-weight ratio is the major advantage offered by sandwich panels. Low construction cost is also a primary for these structures. Various studies have been conducted on the potential application of sandwich panels in different industries [1].

Bull and Edgren [2] and Buannic et al., [3] reported the use of sandwich panel construction for the shipping industry. Particularly Bull and Edgren carried out a study related to the assessment of residual strength and damage resistance during impact for sandwich composite panels with face sheets made of carbon fiber-vinyl ester and core of PVC foam. Khameel B. Mustapha [4] presented a short overview of sandwich structures made from wood. The methods of manufacturing, properties, and applications of these sandwich structures were also discussed. Proenca et al. [5] highlighted the applications of sandwich panels in the civil engineering industry.

Mohammad Nejati et al., [6] executed the vibration behavior of curved sandwich panels in a thermal environment having embedded wires of shape memory alloy in the skin and core of the panels. H. Li et al. [7] investigated the damping performance of the composite sandwich plates. The vibration testing was carried out on a honeycomb core having a hexagonal shape which was filled with soft foam by exciting it at different amplitudes. It was reported that the damping can be improved by increasing the filling ratio of the soft foam and it was more sensitive to the shear modulus of foam. A. Redmann et al., [8] analyzed the carbon fiber composite sandwich panels having cores made from aramid and aluminum. The damping property of the sandwich structure was reported to be dependent on the application of the static load, thickness, and material used for the core. Rajeshkumar Selvaraj et al., [9] explored the damping and vibration features of the rotating sandwich panels made from carbon nanotubes (CNT) which were reinforced with a magnetorheological (MR) elastomeric core. The damping loss factors, natural frequencies, and mode shapes were found to be greatly affected by the reinforcement of CNTs in MR elastomer. Hui Li et al., [10] proposed an integrated structure design and material approach for the fabrication of the sandwich plates. The sandwich structure consists of a grille core and is made of carbon fiber/resin polymer. Bing Mei et al., [11] performed vibration and wave propagation analysis of a sandwich plate having composite face sheets and a flexible bio-based core. The wave propagation

velocity of the plate was found to be initially increasing and then decreasing for the increase in the ratio of thickness of core to layers. A. Gupta and S. Pradyumna [12] performed forced and free vibration analysis of the variable stiffness composited laminated and spherical, cylindrical shell panels. The frequency ratio was reported to be decreasing with increasing the payers of the particular fiber orientation. M.E. Çetin [13] investigated the influence of the CNTs strengthening to polyurethane adhesive on the low-impact behavior of the aluminum honeycomb sandwich panel.

Currently, additive manufacturing (AM) technology is applied to print honeycomb cores used in sandwich panels. The various industries such as aerospace, marine, robotics, etc. make use of modeling and manufacturing methods used in 3D printing technology. One of the distinctive characteristics of applying AM technology for manufacturing and printing sandwich panels is one-step manufacturing for lower cost, higher speed, and improved accuracy. Lyes Azzouz et al., [14] examined the mechanical properties of the sandwich panel having 3D printed lattice cores made from Polylactic acid (PLA) and skins made from the polypropylene-flax. The skins were joined to the core by adhesive bonding. Dikshit et al., [15] performed the studies on sandwich panels which were 3D printed and had trapezoidal cores and were tested for impact loading. By making use of indenters of different types such as conical, flat rectangular, and hemispherical indenters the testing was carried out. Sabah P. and Afshin Z. [16] examined the bending characteristics of 3D-printed glass/epoxy sandwich panels for the different cell thicknesses of the honeycomb core. Also effect of orientation of the honeycomb core structure such as horizontal and vertical honeycomb core are studied for the flexural behaviors. The panel with a core wall thickness of 1.5 mm and horizontal honeycomb orientation exhibited the maximum energy absorption. The bending properties were found to be greatly improved by the replacement of core material from Nomex to PLA.

Sugiyama et al., [17] explored the fabrication of a sandwich composite structure with the use of continuous carbon fiber reinforcement to Polylactic acid (PLA) from 3D printing technique. Various core geometries such as rectangular, circular, zebra, and rhombus were printed. By increasing the effective density of the core geometries, the stiffness and bending strength were found to be increasing. From the literature review, it is clear that the mechanical and dynamic properties of sandwich panels are highly influenced by the material and geometry combinations of the honeycomb cores, such as their wall thickness, size and height, etc. [1-17].

Alperene Dogru et al., [20] explored the effect of infill pattern and aging on the mechanical pattern of the PLA composite reinforced with Hemp fiber. In this study, the specimens are produced with the FFF method. The study showed that the specimens printed parallel to the tensile direction had lower tensile strength than transversely printed specimens. Also, the adhesion performance in the direction through the thickness was low. Natural fibers tend to absorb moisture from the air. So, doing chemical treatment on them will improve mechanical properties and will also improve the interface.

Vaishally Dogra et al., [21] evaluated the mechanical properties of the epoxy resin composite reinforced by bagasse fiber. The samples for testing were fabricated using the hand layup technique. The tensile and compressive strength increases as a result of reinforcement compared to pure resin and as the weight ratio of the fiber is increased the tensile and compressive strength decreases. The flexural properties of the pure resin specimen are better compared to the reinforced composite and flexural strength decreases with an increase in the weight ratio of the reinforcing fiber. The decrease in strength as the reinforcement weight ratio increases is due to the improper binding and cavities in the composite.

Hoque et al., [22] the overall idea of natural fibers and their composites, referred to as natural fiber-based composites or biocomposites, was discussed with their manufacturing and modification methods. Their various properties such as mechanical properties, thermal properties, and chemical properties were studied. Also, the recent applications of bio-composites in the medical field have been reviewed. The main contribution of this study is to explore the effect of carbon fiber reinforcement in biodegradable PLA/ABS materials on the damping characteristics of 3D-printed sandwich panels. Damping performance is a key aspect for the sandwich panels in the end applications and has not been explored greatly for the PLA/ABS-CF material combination and is attempted here both numerically and experimentally.

## 2. FINITE ELEMENT (FE) SIMULATION

To conduct the finite element (FE) simulation, the Solidworks software is utilized to create the model of the sandwich panel. The FE analysis is performed using the ANSYS Workbench. The material specifications as mentioned in Tables 1 and Table 2 are entered in engineering data. The model file is imported to perform the modal analysis. The model is meshed and the mode shapes in free-free conditions are obtained with the modal frequencies at each mode. The Finite Element Analysis employed

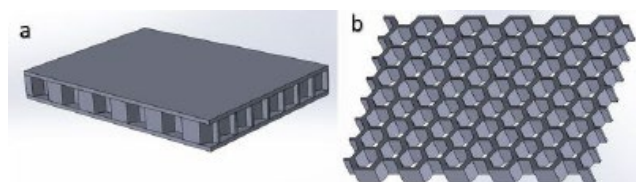
specific parameters and settings, including a mesh size of 5mm, hexahedral elements as the chosen element type, and free boundary conditions, ensuring no fixation of any part of the model. Figure 1 illustrates the 3D CAD model of the proposed sandwich panel. The FE analysis is carried out for two combinations viz., Skin made of PLA/ core made of ABS, Skin made of CF reinforced PLA/ core made of ABS

**Table 1.** Material Properties of ABS & PLA

Property	ABS	PLA
Density (kg/m <sup>3</sup> )	1060	1230
Poisson ratio	0.37	0.33
Young's Modulus (MPa)	2400	3420

**Table 2.** Material Properties of CF-reinforced PLA

Property	SI Value
Density(kg/m <sup>3</sup> )	1290
Young's Modulus (Longitudinal) (MPa)	7541
Young's Modulus (Transverse) (MPa)	3920
Poisson ratio in xy direction	0.4
Poisson ratio in xz direction	0.15
Shear modulus (Longitudinal)(MPa)	1268
Shear modulus (Transverse)(MPa)	1268



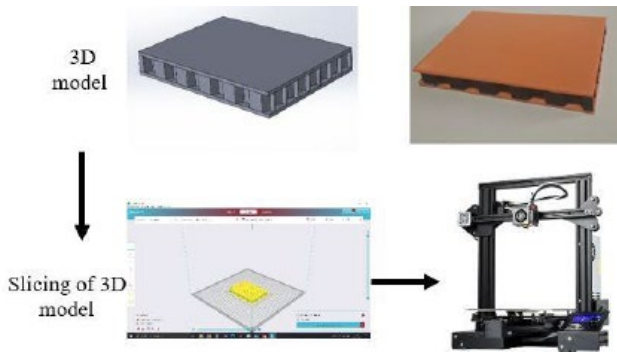
**Figure 1.** 3D CAD model of (a) Sandwich panel and (b) Core of the sandwich panel

## 3. EXPERIMENTAL STUDIES

### 3.1 Fabrication process

A sandwich panel made of laminated composite material with a 3D-printed core is one of the latest versions of lightweight construction. It exhibits excellent properties such as very high energy absorption and strength-to-weight ratio under bending and impact loads. The sandwich panel test specimen is fabricated by using the technique of Fused Deposition Modeling (FDM). The process and flow chart for the 3D printing of the test specimen are depicted in Figure 2.

Initially, utilizing Solid Works software, a CAD model of the specified dimensions is constructed, incorporating a honeycomb core region with a thickness of 10 mm. The hexagonal structure within the core region features a cell size of 10mm and a cell thickness of 2mm.



**Figure 2.** Process of fabrication of test specimens by FDM technique

This CAD model is exported to the Creality slicer software in STL format. The CAD model is sliced and the G-codes for printing are generated and fed to the 3D printer. Then, the model is printed using an FDM 3D printer (Model: Creality Ender 3 V2). In the slicing software, the material and other parameters for printing are specified. The model is then sliced and the G-codes for the printing procedure are produced. This G-code file is exported to the 3D printer. The composite material in filament form is fed to the heater unit by rollers. The heating of the filament to a specified temperature is done in the nozzle while the required nozzle movement is achieved according to the provided G-code to deposit material onto the developed platform. This process is continuously repeated until the desired sample is obtained.

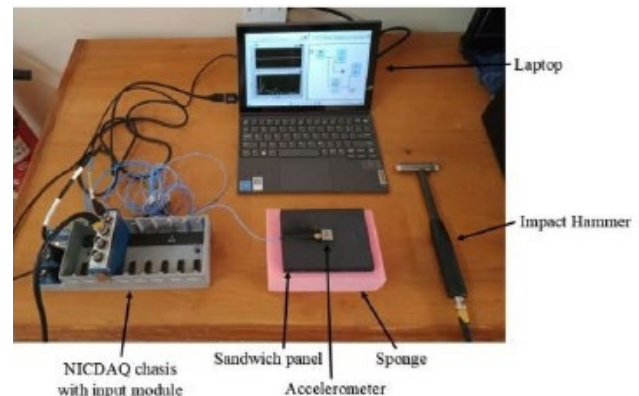
**Table 3.** Printing parameters for fabrication of test specimen

Filament	PLA	CFR-PLA	ABS
	Print settings		
Nozzle size	0.4	0.4	0.4
Printing Temp. (°C)	200	210	230
Build plate Temp. (°C)	60	60	60
Layer height (mm)	0.2	0.2	0.2
Infill density (%)	100	100	100
Print Speed (mm/sec)	70	70	80
Orientation direction	[90,90]	[90,90]	[90,90]
Orientation	Vertical	Vertical	Vertical
Infill pattern	Line	Line	Line
Infill overlap %	30	30	30

Two test specimens are printed using the 3D printer. A thermoplastic polymer Acrylonitrile Butadiene Styrene (Make: eSUN ABS filament) with dia. of 1.75mm is used to print the honeycomb core of the sandwich panel. Also, Polylactic Acid, which is a thermoplastic polymer (Make: eSUN PLA filament) with a dia. of 1.75 mm is made for printing face sheets of the sandwich panel for one test sample and for another test sample CF reinforced PLA filament of the same diameter is used. The CF-reinforced PLA filament has a volume fraction of 15% CF in the PLA resin. The specifications of the filament are shown in Table 3.

### 3.2 Modal Vibration Test

Modal vibration tests are performed on the test samples of the 3D-printed sandwich panels. The free-free condition of the test is simulated by placing the test specimen on a sponge/foam surface, as shown in Figure 3.



**Figure 3.** Experimental Setup for Modal Vibration Analysis

To find the free vibration of the sandwich panel National Instruments Compact Data Acquisition system (NIC-DAQ) with the modal analysis software LabVIEW was used. The NI 9234 Analog sound & vibration input module was mounted on the NICDAQ 9178 chassis. A Triaxial accelerometer (356A15, PCB Piezotronics Inc., Depew, NY) which is connected to the DAQ was attached to the sandwich panel. The DAQ chassis is connected to the laptop installed with the LabVIEW software.

The code required to acquire the frequency response function was written in the LabVIEW software. The specimen is then excited with an impact using the Impact hammer (08603, PCB Piezotronics Inc., Depew, NY).

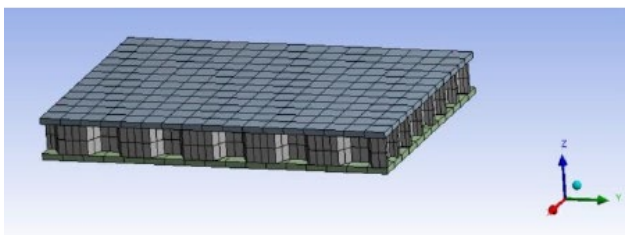
## 4. RESULTS AND DISCUSSIONS

The simulation study findings are presented comprehensively through frequency/time response curves, mode shapes, and natural frequencies, which

provide valuable insights into the behavior of the composite sandwich panel. These results showcase the dynamic characteristics and vibration properties of the panel, aiding in the understanding of its performance and potential applications. The frequency/time response curves illustrate the panel's response to various excitation frequencies and highlight its resonance behavior. The mode shapes visually depict the vibration patterns and modes of the panel under different operating conditions. By analyzing the natural frequencies, valuable information is obtained regarding the panel's inherent oscillation frequencies and corresponding modes. These simulation results contribute significantly to the overall understanding and analysis of the composite sandwich panel's dynamic behavior and aid in optimizing its design and performance for specific engineering applications.

#### 4.1 FE Analysis Results

The finite element analysis was conducted in ANSYS workbench. The analysis was conducted and the first six mode shapes and the natural frequencies associated with these mode shapes were taken for the two variants of the test specimens. Figure 4 shows the meshed sandwich panel.



**Figure 4.** Finite Element Meshing of Sandwich panel for Modal analysis

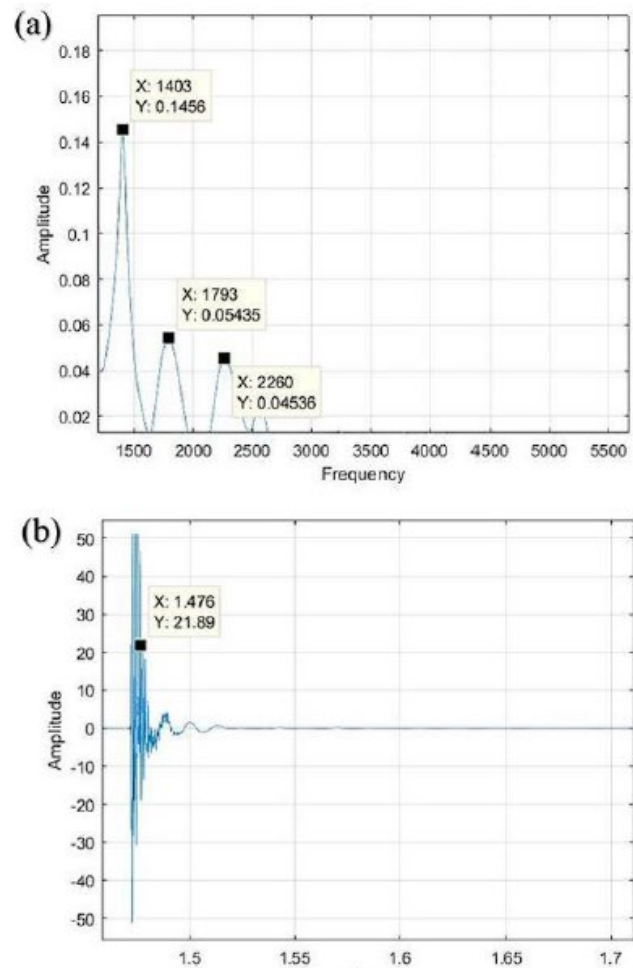
Mode 1 is twisting, Mode 2 is the first mode of bending about the x-axis, mode 3 is the second mode of twisting, mode 4 is the first mode of bending about the y-axis, mode 5 is combined bending and twisting, mode 6 is a combination of the second mode of bending about both x and y axes [18].

#### 4.2 Experimental Results

The modal vibration analysis conducted using the NI-cDAQ gives the results in the form of time and frequency response graphs. The data from the modal analysis is imported to MATLAB and the curves are plotted and the natural frequencies for different modes are specified. Figure 5 depicts the frequency and time graphs for the developed sandwich panels.

The first three modal frequency values obtained by experimentation are compared with the first three

modal frequency values obtained by FE analysis using ANSYS software for the two sandwich panel samples. Figure 6 (a)-(b) gives the bar chart for comparison of the results of simulation and experimentation.



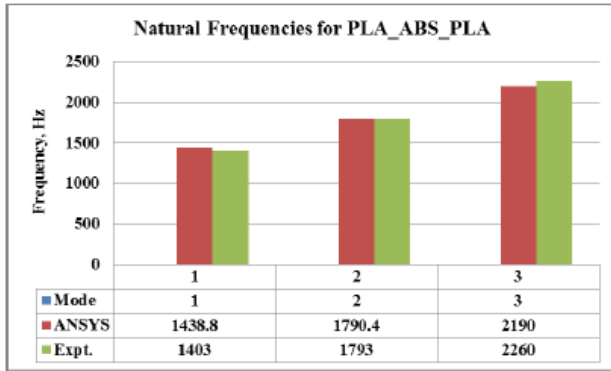
**Figure 5.** PLA\_ABS\_PLA Sandwich panel experimental result:  
(a) Frequency plot (b) Time plot

It is observed that the experimentally determined natural frequency values agree well with the numerical analysis values. The logarithmic decrement method is used to calculate the damping ratios of the sandwich panel using the time domain curve [19]. The damping ratios are listed in Table 4.

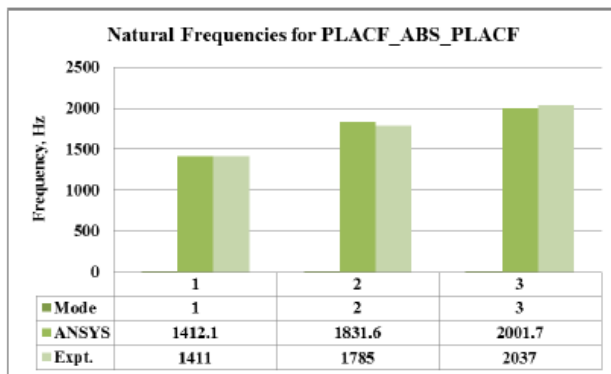
**Table 4.** Damping ratio ( $\zeta$ ) values for sandwich panel

Specimen	Damping ratio
PLA_ABS_PLA	0.2357
PLACF_ABS_PLACF	0.2707

The damping ratio increases when the face sheet material i.e., PLA is reinforced with carbon fiber providing better damping capacity.



(a)



(b)

**Figure 6.** Comparison of the natural frequency of (a) PLA\_ABS\_PLA and (b) PLACF\_ABS\_PLACF Sandwich panel

## 5. CONCLUSIONS

Two specimens are fabricated using the Fused Deposition Modeling method:

The first specimen consists of PLA face sheets and an ABS core.

The second specimen consists of carbon fiber-reinforced PLA face sheets and an ABS core.

The impact of carbon fiber reinforcement on the energy-damping capacity of the composite sandwich panel is investigated.

The core region of the sandwich panel is designed in the shape of a hexagonal honeycomb to reduce its mass while maintaining mechanical properties.

Experimental results show that the natural frequencies of the sandwich panel in a free-free condition align closely with those obtained from finite element analysis.

The panel with an ABS horizontal honeycomb core, reinforced with carbon fiber PLA face sheets, exhibits higher vibration-damping properties compared to the one with pure PLA face sheets

The sandwich panels with skins made of carbon fiber/PLA composites have around 14.84 percent

higher damping properties as compared to pure PLA/ABS cores.

## ACKNOWLEDGMENTS

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