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Bending behaviour of Foam-Packed 3D Printed Honeycomb Core and Flax Laminate Sandwich Composite for Battery Casing in Electric Cars

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Abstract

The vehicle's weight has a considerable impact on the overall economy of electric cars (EVs). When the vehicle's dead weight is decreased, its overall economy improves. Composite materials made up of many polymers have found use in the automotive industry. This study's principal purpose is to validate a sandwich architecture that can be utilized in battery housing for EVs. Which aims to design a sandwich composite structure that is 10-15% lighter than a comparable state-of-the-art solution. This is accomplished by testing the physical and experimental characteristics of composite material for a new sandwich architecture where the core of the sandwich is made of a foam-packed 3D-printed honeycomb structure and natural fiber laminates are utilized as the sandwich structure's face sheets.

The core is 3D printed utilizing FDM technology with a lattice honeycomb structure, printed using Acrylonitrile Butadiene Styrene (ABS) thermoplastic polymer. Where a hexagonal-cell composite is less in weight and absorbs more energy than solid composites. Also, flax fiber laminate is used as a face sheet for sandwich composites. This study validated the characteristic performance of sandwich composites for the flexural test to investigate the bending behaviour of sandwich composites and was analyzed using the finite element model developed in ANSYS Workbench R2.

Keywords: *Bending behaviour, Honeycomb, Sandwich composite, Electric Vehicles, weith Fabrication, Experimental Measurement, Finite element analysis.*

1.0 Introduction

In the sphere of the automotive manufacturing industry, cost-effective and lightweight designs will be of the biggest significance both now and in the future. The electrification of the drivetrain is currently a top priority for vehicle manufacturers. But, the weight of the vehicle plays a significant role in increasing the overall efficiency of EVs. The vehicle's efficiency improves when its dead weight is reduced (JÜrGEN JooS, 2019).

It is anticipated that the usage of composite materials in the automotive and transportation industries would expand in the future years as a result of ongoing improvements in performances like high weight-to-strength ratio, enhancement in thermal insulation, decreased costs, greater safety, and weight savings afforded by composite materials (Z. Li, 2011). As a result, researchers are investigating new combinations of composite materials to fulfill the demands of the industry. Fibers with high strength and modulus are implanted in or bonded to a matrix with discrete interfaces or boundaries between them in composite materials. While each component retains its individual characteristics, they work together to create a unique combination of features that can't be accomplished by either of them alone.

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Numerous researchers, like (GEBKEN, 2017) have improved thermal management by working on closed-cell aluminum foam with oxide layers. (Baumeister et al., 2014) have remarked that innovative materials and intelligent mechanical engineering can significantly increase the energy density of battery packs for pure EVs. (Friedrich & Almajid, 2013) emphasize that fiber-reinforced polymers provide great potential for lightweight constructions with high specific strength and stiffness. Comparing sandwich structures with foam-packed honeycomb cores to those with pure honeycomb cores reveals several advantages. By filling honeycomb cells with foam, both the longitudinal cell walls and the foam can support the uniaxial load. So, it is anticipated that the foam will lessen the discontinuity of the young's modulus found in pure honeycomb cores. Polyurethane foam is an incredibly versatile elastomer and its creative combination of chemistry can isolate and control polyurethane foam's mechanical properties, creating the unique potential to solve issues with unmatched performance (Zhao et al., 2022). Natural fibers such as flax seed fiber have gained the attention of researchers due to their physical, mechanical, and chemical properties (Amiri et al., 2017).

As a result, the project aims to utilize the benefits of current breakthroughs in additive printing, polyurethane foam, and flax seed fibers face sheet to produce battery housing for EVs with the main aim of reducing their weight while simultaneously preserving their structural integrity. Here the sandwich is comprised polyurethane foam packed in a 3D-printed honeycomb core with flax fiber facing sheets. The sandwich construction in this study is made with a 3D-printed lattice honeycomb core, which offers core strength to the composite material, which is packed with polyurethane foam. To investigate the young's modulus of foam-filled honeycombs, a finite element model was created using ANSYS Workbench.

2.0 Fabrication Methodology

2.1 Geometric Description

Here, the lattice honeycomb core with a hexagonal cell configuration is used. In two-dimension, cell configuration is defined by two major geometries of a hexagonal unit cell i.e., the size of a unit cell (*w*) and the cell wall thickness (*t*). And, the specimen dimensions for the foam-packed honeycomb core are defined by length (*L*), breadth (*B*) and height (*H*). In this study, the cell size w and the cell wall thickness *t* are selected to be 15mm and 2mm respectively. Figure 1 depicts the cell configuration of the lattice honeycomb core. Three number of samples in total are used in this study.

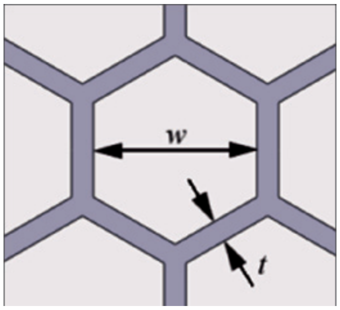

Figure 1: Cell configuration of lattice honeycomb core

2.2 Material Characterisation

Sandwich composite specimens are fabricated and evaluated in this work. The lattice honeycomb structure is 3D-printed using ABS polymer. Because, ABS possesses superior mechanical characteristics, improves its durability and it is also lighter in weight. The ABS polymer's physical properties are detailed in Table 1.

The lattice honeycomb structure is packed with polyurethane foam, which improves the mechanical properties of the sandwich composite specimen during impact resistance testing. The polyurethane foam's physical properties are detailed in Table 2. Polyurethane foam packed into a 3D-printed honeycomb structure forms the core of sandwich composite.

Face-sheets used above and below the core are made from the flax plant and are also commonly known as flax fiber. Flax fiber is provided by Fiber Region. Flax fiber face-sheets physical properties are listed below in Table 3.

Table 1: Physical Properties of ABS Polymer

Density	1.05g/cm^3
Tensile strength	46MPa
Flexural strength	79MPa
Impact strength	18KJ/m^3
Flexural modulus	2700MPa

Table 2: Physical Properties of Polyurethane Foam

Density	46kg/m^3
Ultimate tensile strength	15.31MPa
Youngs' modulus	95MPa

Table 3: Physical Properties of Flax Fiber Face-Sheet

Colour	Brownish
Fiber length	90-125cm
Density	1400kg/m^3
Thickness	0.9mm
Ultimate tensile strength	700MPa
Youngs' modulus	60MPa

2.3 Fabrication of Sandwich Panel

The lattice honeycomb core is 3D-printed in this project using an FDM-based additive manufacturing printer Hydra-300. Figure 2 depicts a honeycomb structure 3D-printed with a Hydra-300 printer. The heater melts the ABS material, and the motor's extrusion force aids in the pre-impregnation of the ABS fiber. The printing procedure is subsequently completed by utilizing the tension of the ABS fibers.

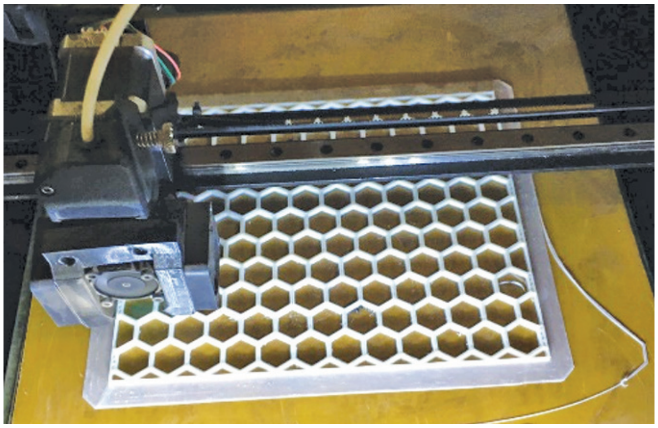

Figure 2: 3D-printnig of honeycomb core with HYDRA-300

When prototyping a lattice honeycomb construction, it is critical to predefine the printing path to avoid the printer's fiber-cutting mechanism. As a result, because the printing paths for the odd and even layers are distinct, the printing is completed without nozzle hopping. Figure 3 depicts these two modes of transportation. The x-y plane is used for single-layer printing, and the printing route begins at the "starting-point" and ends at the "ending-point" based on the sequence number (T. Li & Wang, 2017).

After the first layer of printing is completed, the nozzle is raised 0.5mm in the z plane. The next layer of the lattice honeycomb structure starts at the end of the preceding layer and prints in the pre-set printing path for a new layer. The lattice honeycomb structure was created by stacking 20 layers in total. The 3D-printing process parameters are as follows: a nozzle temperature of 220-260ºC, a heated bed temperature of 80-110ºC, and a printing speed of 30-50mm/sec.

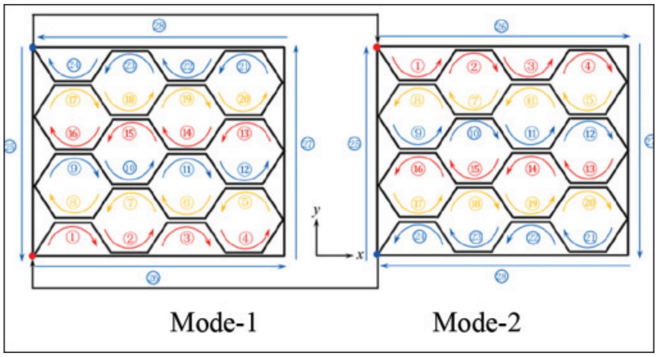

Figure 3: Two modes of nozzle transportation

The lattice honeycomb structure is packed with polyurethane foam, which is made by combining two liquid chemical agents-polyol and isocyanate, both of which have densities of 50Kg/m^3 at 25ºC. Polyol and isocyanate are mixed in the weight-to-weight ratio of 1:1.2 by continuous stirring. The mixture is then poured into the skeleton of the lattice honeycomb core which is placed in a mould, immediately after which the mixture starts solidifying and eventually becomes harder in 15-20 minutes. The foam-packed core is then sandwich laminated using a vacuum bagging process, where flax fiber face-sheet and core are glued together with the help of epoxy and hardener mixed at a weight-to-weight ratio of 1:10. Vacuum is applied for 3 hrs and was left for curing for 24hrs at the room temperature. Figure 4 depicts the fabricated sandwich panel.

Figure 4: Composite sandwich panel

3.0 Experimental Measurement

3.1 Mechanical Testing

The flexural test is performed according to ASTM d7250 standards at ambient conditions by an M-100 universal testing machine having a maximum loading condition of 100KN and maximum deflection of 1000mm. The size of a flexural test specimen is cut from the sandwich panel. Test specimen dimension of 250×25×10 mm is selected according to ASTM standards and the details are depicted in Table 4.

The flexural test is carried out at a constant loading rate of 2mm/min until the rupture with a span length of 200mm between the supports and the load was applied exactly in the middle of the span. Figure 5 depicts the experimental setup

Table 4: Dimensional details of specimen

Unit Cell		Test Specimen		
w	t	L	B	H
15mm	2mm	250mm	25mm	10mm

Figure 5: Experimental setup for flexural test

for the flexural test.

For the analysis of the composite sandwich test specimen, the length L, width b, and thickness h are considered, and thickness h includes the thickness of two face-sheets t_f and core thickness t_c ($h=t_c+2t_f$). The load F is applied in the middle of the sandwich specimen as depicted in Figure 6.

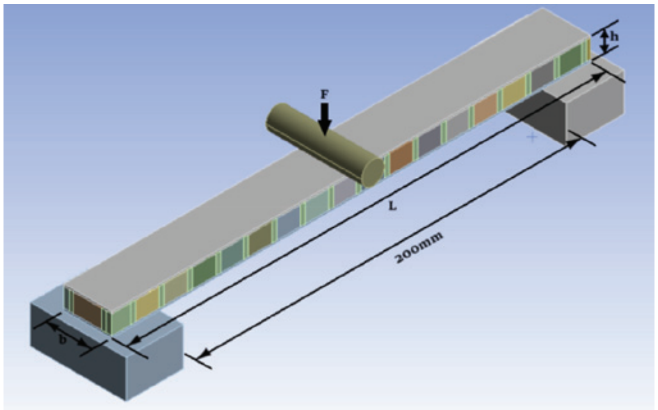

Figure 6: Composite sandwich beam under flexural load (F)

Deflection is dependent upon not only the material but also the configuration of cross-section and unsupported length.

Hence, Max deflection,

$$\delta_{max} = \frac{FL^3}{48D} + \frac{FL}{4S} \quad \text{... (1)}$$

The modulus of elasticity in bending is the measure of stiffness. Stiffness in bending is tested for three identical specimens under identical conditions so as to be compared. Therefore, bending stiffness D and shear stiffness S are given by,

Bending stiffness,

$$D = \frac{E_s t_f h^2 b}{2} \quad \text{... (2)}$$

And shear stiffness,

$$S = bhG_c \quad \text{... (3)}$$

Here E_s is the modulus of elasticity for the face-sheets and G_c is the shear modulus for the core. The above obtained equations are valid at the straight portion of the curve.

3.2 Finite Element Analysis

The simulation model was modelled in Solidworks, the model is created using different materials and assembled together. The same was analyzed using the finite element method in ANSYS Workbench 2021 R2 software for the flexural test. In this analysis material non-linearity condition is considered. The true stress-strain relation of the composite sandwich specimen is observed from flexural bending and is directly exported from ANSYS Workbench for the sandwich specimen.

4.0 Results and Discussion

4.1 Flexural Test

The flexural test was carried out on all three samples with a span length of 200mm, which are used in this study. Figure 7 depicts the flexural test specimens.

The load vs displacement curves for the foam packed 3D-printed honeycomb core with flax fiber face-sheet specimens were obtained from the flexural test. Figure 8 depicts the mechanical response of flexural test specimen-1 when subjected to a uni-axil bending load. Figure 9 depicts the mechanical response of flexural test specimen-2. Figure 10 depicts the mechanical response of flexural test specimen-3.

Figure 7: Flexural test specimens

Table 5: Results of Flexural Test

Specimen	Peak load kN	Deflection at peakmm	Flexural strength N/mm^2
Sample 1	0.184	10.762	12.774
Sample 2	0.165	9.822	11.617
Sample 3	0.206	11.452	14.377
Average	0.185	10.678	12.922

Table 6: Details of Nodes and Elements from Ansys

Number of total nodes	123313
Number of contact elements	48546
Number of solid elements	21570
Number of total elements	70116

As it is seen in Figures 8, 9 and 10 that all three specimens have shown similar behaviour under uni-axial bending. The load is reached to the peak load in the non-linear behaviour and the failure of the specimen has occurred at the peak load.

The peak load and deflection at peak of each specimen were obtained from the load vs displacement graph. Peak load, deflection at peak load and flexural strength for all three flexural test specimens are detailed in Table 5.

4.2 Finite Element Analysis

In order to simulate the flexural test, a finite element method in ANSYS Workbench was developed. Figure 11 depicts the stress vs strain graph for the composite sandwich flexural test specimen. The details of nodes and elements for the mesh body are tabulated below in Table 6.

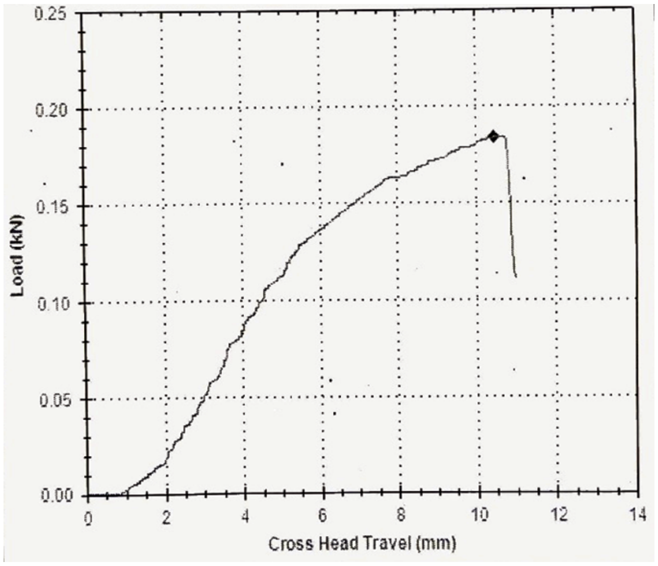

Figure 8: Mechanical response for sample specimen-1

Table 7: Stress-Strain Values Obtained from FE Analysis

Strain (mm/mm)	Stress (MPa)
0.022416	361.58
0.030027	452.17
0.033492	515.01
0.039353	602.16
0.049155	733.18
0.063863	927.88
0.078789	1123.5
0.094611	1319.1
0.10865	1514.5
0.12387	1709.8
0.14221	1905.1
0.15499	2100.4
0.16618	2215.3
0.17365	2330
0.023496	381.94

The values of stress and strain that are obtained from the FE analysis are detailed in Table 7.

Figure 12 depicts the regression analysis for the stress vs strain graph obtained from finite element analysis done in Ansys. The equation obtained for the line is,

$y = 12937x + 88.114$ ... (4)

which is of the form $y = mx + c$ ... (5)

where m is the slope of the graph i.e.,

$m = \frac{y}{x}$ ... (6)

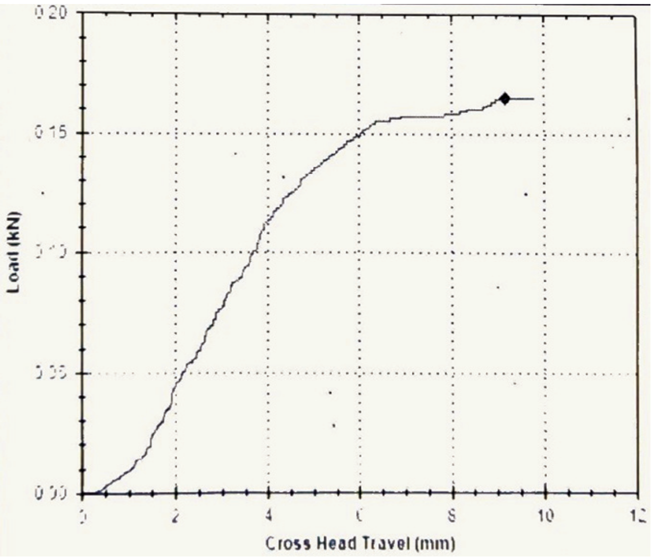

Figure 9: Mechanical response for sample specimen-2

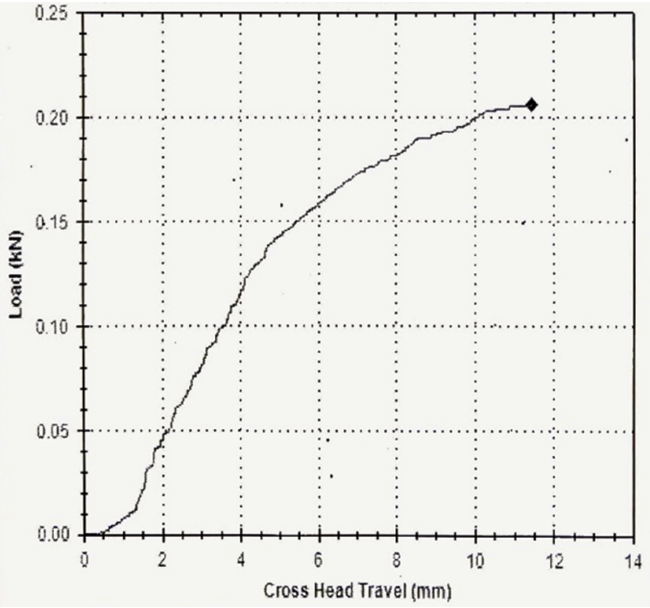

Figure 10: Mechanical response for sample specimen-3

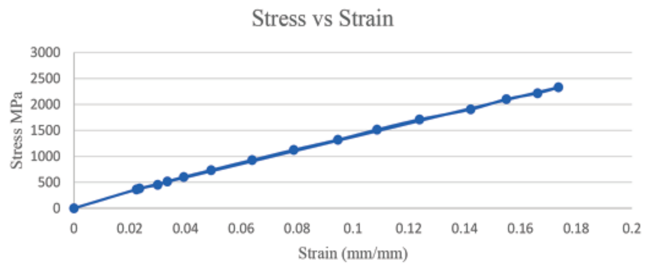

Figure 11: Stress vs Strain plot for flexural test uni-axial loading

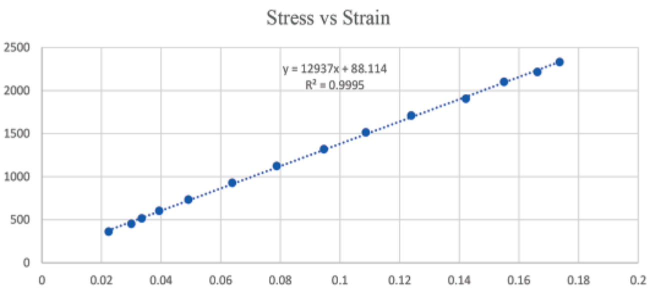

Figure 12: Regression analysis for stress-strain graph

In the stress vs strain graph slope of the line is stress upon strain which gives the young's modulus of the material. Therefore, from equation (4) it can be said that the young's modulus of the foam packed 3D-printed honeycomb core with flax fiber face-sheet is 12937MPa. R squared value of 0.9995 obtained is very high and close to 1 which falls under the acceptable range.

5.0 Conclusion

The goal of this article is to manufacture and structurally evaluate specimens of a foam-packed 3D-printed honeycomb core with a natural flax fiber laminate face sheet. Flexural stiffness is a key bending property for sandwich constructions that transport loads. Flexural stiffness is an important efficiency indicator in sandwich structures because they are composed of a range of materials. Flexural stiffness was tested in a sandwich structure with a foam core and flax fiber facings. In most computations, a designer/builder must first establish the young modulus of both the facings and the core material. The flexural strength and Young's modulus of composite sandwich constructions are measured. These findings throw new light on sandwich composite materials with diverse mechanical characteristics for mechanical and structural applications.

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