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Research Article

Production and Testing of Bamboo Composite for Door of a Three-Wheeled Vehicle

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Natural fiber reinforced composite material has recently attracted interest due to its low density, low cost, acceptable specific characteristics, ease of separation, improved energy recovery, CO_2 neutrality, biodegradability, and renewable nature. The goal of this paper is to design and construct a three-wheeled Bajaj door panel using composite materials reinforced with bamboo fiber. Design, manufacture of the component, and experimental techniques are used to meet the goals given. The bamboo plant is the raw material chosen for this thesis project. The matrix material (polyester resin) and hardener used in this investigation, as well as the woven bamboo fiber strip that has been used as reinforcement, were all obtained from local markets. Bamboo fiber that has been chemically treated with 5% NaOH and 95% purified water is used. Keeping in mind the needs of varied testing conditions and characterization standards, polyester resin and E-glass fibers were simply stirred together by hand for 15 minutes. The mixture was then put into the molds. In three distinct orientations (0°, 90°, and 0/90°), composite samples of bamboo fiber were created. In order for the part to respond to axial loads, shear loads, and side loads, it may need 0°, 45°, and 90° plies, respectively. The paper model's 0° orientation was chosen in accordance with the findings of the samples' analysis. Due to the direction of the applied load, it affects the strength design requirements. Based on the findings of the experimental data examination, it was determined that the respective values for tensile, compression, bending, and water absorption were 160 MPa (0°), 2709.2 MPa (90°), 110 N (0/90°), and 4%, respectively. The geometric model of the door panel on the three-wheel Bajaj vehicle's door was designed. Based on these findings, it is suggested that the new exterior structural car door panel of the three-wheel Bajaj Compact 205 model be made of composite materials made of bamboo fiber reinforced with polyester and having strength of 160 MPa.

1. Introduction

The use of composite materials in the aerospace, automotive, marine, and civil construction industries has increased dramatically in recent years, replacing traditional materials like steel, aluminum, and other alloys. This is because composite materials have incredible qualities including high strength to weight ratios, great fatigue properties, and noncorroding behaviors. These benefits promote the widespread use of composite materials, notably in the automotive industry [1]. Humans naturally move from place to place to complete daily tasks within a certain amount of time, and in many nations, like Ethiopia, cars are the primary mode of mobility. Therefore, studying this area to build and deliver well-improved, quick, affordable, and aesthetically pleasing cars is a significant idea for the growth of these countries by giving them quick, efficient, and plentiful means of transportation. Intelligent material enhancement and design excellence are essential processes to achieve this goal.

Composites are being examined in the automotive industry to create lighter, safer, and more fuel-efficient vehicles. A composite is made up of a high strength fiber (such as carbon or glass) and a matrix substance (such as epoxy polymer) that, when combined, have greater qualities than the constituent parts would have on their own. Choosing the appropriate material during the choosing process is crucial. The chosen material ought to live up to the engineer's expectations. The material should be inexpensive and mechanically workable. The composite materials offer a wide range of other possible automotive uses besides bumper manufacture, including body panels, steering, brakes, suspension, and other components of the car. Other than body panels, composites are currently only used in a limited number of automotive components, including bumper systems, fuel tanks, drive shafts, instrument panels, cross wheel beams, and intake manifolds [2].

This century has seen significant developments in green technology in the field of materials science due to the production of high-performance materials made from natural resources, which is sweeping the globe. A form of renewable resource known as plant fibers has been phased out over thousands of years by both nature and technological advancement. The main barrier to the adoption of plant fiber reinforced composites (PFRCs) is the diversity of their features and traits. The properties of a PFRC are influenced by a variety of elements, including the fiber type, environmental conditions, processing methods, and fiber modification. The general characteristics of plant fibers used in composite materials, such as their source, sort, structure, content, and attributes, determine the final result of the material [3].

Construction, flooring, windows, and door panels are just a few of the structural and nonstructural applications where wood polymer composites (WPCs) are crucial. Ramesh et al. published a research on the morphological, mechanical, and structural characteristics of WPCs as well as their processing with additives such wood floor. This report also highlights the use of wood-based composites in a number of industries, including automotive, marine, structural, and defense. WPCs are widely used in both automotive and construction components, including as screens and flooring boards. In addition to these, many specialized uses for WPCs have been discovered and tested recently, including decking, cladding, paneling, fence, and furniture, to mention a few [4].

Additionally, by investigating materials for this purpose, their aesthetic look should be improved. Numerous studies have shown that composite materials offer a lightweight, fatigue-resistant, and easily moldable alternative to metallic materials that is also aesthetically pleasing. Identification of the crucial technical challenges that must be overcome is necessary if the advantages of composite materials such as their light weight, durability, good aesthetic value, high specific energy absorption ability, and ease of forming are to be more widely utilized by the automotive industry [5]. The roof, floor, dashboard, front and back bumpers, passenger safety cells, and door panels are only a few structural components that have already been made from composite materials in the automotive industry [1]. Various materials, including the composite material, are frequently used to construct the door panel of an automobile. Natural fibers and polymer matrices with complementary qualities can be used to create composite materials, which increase their tensile strength and endurance. These materials are appropriate for making vehicle outside components because they are light, robust, and provide adequate thermal and acoustic insulation. Car outer door panels are among the most crucial exterior vehicle components [6].

Both the demand for and use of plant fibers are expanding quickly, as is environmental awareness. Towards sustainable environmental impact evaluations by making plant fibers stronger, EIA has promoted the growth of biomaterials. Life-cycle assessment is a method to look at the effects of products or services, whereas environmental impact assessment assesses the environmental impact of a product or service. Plant fiber reinforced composites are of interest to researchers because of worries about the economy and environment. The forest's timber reserves will diminish and finally run out as a result of environmental issues caused by natural and renewable resources. The higher energy consumption during production of biocomposites raises concerns about their environmental friendliness. This can be avoided by taking into account both the life-cycle and service-life performance when the material is designed. It lessens environmental dangers associated with manufacturing [7].

Historically, different grades of steel and aluminum have been the principal materials utilized to make car bodies. Additionally, the majority of the interior sections of vehicles are made of plastic and other synthetic materials [5]. The manufacturers adjust the approximate design of their vehicle's structure and add the required structural components that match the predominant design goals in order to meet the requirements of a specific crashworthiness standard and fuel economy [8]. The designer can alter structural elements like geometry while also modifying the material's characteristics by altering the orientation and volume of the fibers. These characteristics of composite materials foster a favorable environment in the automotive industry because they give the necessary strength while weighing less than steel and aluminum [9].

The goal of this research is to create a composite material made of natural fibers that may be used for car door panels. According to the literature assessment, bamboo strips were gathered for this project from a three-year-old bamboo plant in Ethiopia's Enjibara area of the Amhara region. The bamboo strip is mixed with polymer epoxy and E-glass to create the door panel, and a hardener is added to ensure a quick cure. The Ethiopian Conformity Assessment Enterprise in Addis Ababa and the Belayab Cable Manufacturing Plc Corporation in Adama, Ethiopia, respectively, do the testing on the sample specimens that are prepared at the Addis Ababa University Institute of Technology. A door panel is successfully created using the material and installed on the desired three-wheeler vehicle. The novelty of this research is how easily a door panel may be produced locally. In order to finish this investigation, a number of obstacles must be overcome. The lack of sophisticated workshops and the challenge of locating the essential material types in the needed sizes for making the intended product are few of the challenges.

2. Materials and Methodology

2.1. Production Material and Equipment. The materials used in this work are given in Table 1. The equipment used is given in Table 2.

Table 1: Materials used.

Nos.	Items	Units	Quantity
1	Bamboo fiber (woven two roll 8 kg)	Roll	2
2	Epoxy resin	kg	6
3	Hardener	Lit.	1/2
4	Wax	Kg	1
5	Gel coat	Kg	1/2
6	PVa	Kg	1/2
7	NaOH	Lit.	0.37
8	Plastic sheet	Meter	2 × 2
6	Distilled water	Lit.	20
7	Fiber glass (E-glass)	kg	1

Table 2: Equipment used.

Nos.	Items	Quantity (units)
1	Molds (two flat surface plate & two thick sheet metal)	4
2	Mixing container	2 lit
3	Normal brush	4
4	Roller brush	1
5	Steel rule	1/2 m
6	Test machines	2
7	Weighting machine	2
8	Grinding machine	1
9	Welding machine	1
10	Drilling machine	1

2.2. Fabrication. A traditional hand layup process is used to prepare the fabrications of the composite sample. Bi-directional (woven form, 90°), unidirectional (0°/90°), and bamboo (0°) fibers are employed as reinforcement, while polyester is used as a matrix.

2.2.1. Bamboo Fiber-Reinforced Composite Preparation

(1) Modification of Bamboo Strip. The samples were made using the manual layup method. The prepared mold was filled using the hand layup method. As shown in Figure 1(a) waved roll bamboo, 1(b) splitting process, 1(c) splinted bamboo, and 1(d) the final prepared bamboo strip, the natural bamboo fiber was obtained from a local market with the dimensions of 3-meter length by 2-meter width and 0/90° meshed and ready to sell for other purposes. Utilizing a single roller, separate the entire mesh into individual pieces to create the first sample. This procedure aids in converting the thickness of the preceding bamboo strips into the required study sample size.

(2) Chemical Treatment of Bamboo Fiber. The bamboo strips were divided into 60 cm lengths and left to soak for 6 hours at room temperature in a 5% NaOH solution. Water was used to thoroughly clean the treated bamboo strips, and any extra water was dried. 95% water and 5% sodium hydroxide (NaOH) were employed in this study. 7 liters of distilled water and 0.037 litters of NaOH were combined with the sample solution. The 60-cm-long bamboo strips with stripes were soaked in a chemical solution for six hours. The chemical solution was removed from the fiber after 6 hours of soaking, and the PH value was maintained by rewashing it with tap water. The fiber was then allowed to dry for roughly 6 hours in direct sunlight. The chemical processing of the bamboo strips is shown in Figure 2. Following alkali treatment, the following reaction occurs:

$$\begin{aligned}&\text{Fiber} - \text{OH} + \text{NaOH} \longrightarrow \text{Fiber} - \text{O}^{-} - \text{Na}^{+} + \text{H}_2\text{O}\\&\text{NaOH} + \text{water} = \text{mixing NaOH with } \text{H}_2\text{O} \longrightarrow \text{bamboo immersing.}\end{aligned} \quad (1)$$

(3) Fiber Orientation. In accordance with the previous study, a mold in 0° and 0/90° woven form will be made, and its weight will be determined using a digital weight metering machine. The initial fiber arrangement depicted in Figures 3 and 4 can be used to prepare the numbers 0° and 90°. The first sample below, articulation changed by condition as shown in Figure 3, was created utilizing both orientations on the same layer. Only two different fiber orientations (a) 0° orientation and (b) 0/90° orientation are used based on the aforementioned research data.

(a) (b) (c) (d)

Figure 1: Preparation of bamboo strip steps. (a) Waved roll bamboo. (b) Splitting process. (c) Splinted bamboo. (d) Final prepared bamboo strip.

Figure 2: Chemical treatment of bamboo strips.

Figure 3: 0° and 0°/90° orientation fiber weaving.

(a) (b)

Figure 4: 0° and 0°/90° degree bamboo strip orientation. (a) 0° orientation. (b) 0/90° orientation.

(4) Hand LayUp Technique. When the hand layup technique is used to construct the composite, the layers deposited are in direct contact with the atmosphere, resulting in an open mold method of shaping to form a structure. The processing stages are also relatively straightforward. To prevent polyester resin from adhering to the mold surface,

release gel or wax was first applied to the surface of the mold. Polyester resin is hardened with 1 (one) weight percent methyl ethyl ketone peroxide catalyst. Following the placement of bamboo fiber in the mold, mixed resin was poured on it, brushed over the fiber to disseminate the resin, and then another longitudinal bamboo fiber was added to support the weight. Until the desired thickness was reached, this process was repeated. For bamboo fiber reinforced composite, specimens with various fiber orientations, including 0°, 90°, and 0°/90°, were created as shown in Figure 5.

After curing at a set temperature or at room temperature, the mold was finally opened, releasing the produced composite product for further processing. The prepared mold had a final dimension of 300 × 400 square millimeters and 3.5 millimeters in thickness.

3. Experimental Results and Discussion

3.1. Experimental Results

3.1.1. Tensile Test. For this research work, the specimen is prepared by cutting with a band saw available in the Addis Ababa Institute of Technology, which is shown in Figure 6, as per the requirement of company's machine capability and precision according to the given dimension.

Tensile tests are conducted at Ethiopian Conformity Assessment Enterprise in Addis Abeba, Ethiopia. The UTM is connected to a computer display, allowing us to visualize the test results and the stress-strain curve in this scenario. According to the load utilized to shatter the specimen, the machine used for the testing has a strength correction factor following direct computer printout data.

For repeatability, a total of three samples were used for each orientation. The reported test result variation between the three specimens in each orientation is not statistically significant. Three test specimens must be taken from each fiber orientation composite plate in order to take an average that will be more accurate.

Specimens are designated as $A_{11}, A_{12}, \ldots, A_{33}$, for 90°, 0°, and 0/90°, respectively for researchers' identification as shown in Figure 7. The graph shows that stress [N/mm^2] to strain [%] properties of different fiber orientation of natural fiber to polyester matrix composite.

According to the graph reading of the first test of the 90° fiber orientation composite in Figure 8 (A_{11}, A_{12}, and A_{13}), the material with bamboo fiber to polyester resin composite has tensile strength. Finally, with a strain of 68.3% elongations, the average tensile strength of the composite with the 90°-specified fiber orientation is 77.2 MPa. The material with bamboo fiber to polyester resin composite has tensile strength, according to the graph reading of the first test of 90° fiber orientation composite in Figure 8 (A_{11}, A_{12}, and A_{13}).

Finally, with a strain of 68.3% elongations, the average tensile strength of the composite with the 90°-specified fiber orientation is 77.2 MPa.

According to the graph reading of the second test of 0° fiber orientation composite in Figure 9 (A_{21}, A_{22}, and A_{23}), the material with bamboo fiber to polyester resin composite has tensile strength. Finally, with a strain of 34.67% elongations, the average tensile strength of the composite with this stated fiber orientation is 175.73 MPa. The strength evaluation is shown in Figure 9. Typically, the comparison is carried out by taking into account corrective factors and averaging those test results for an orientation.

According to the graph reading of the third test of 0/90° fiber orientation composite in Figure 10 (A_{31}, A_{32}, and A_{33}), the material with bamboo fiber to polyester resin composite has a tensile strength. Finally, with a strain of 79.67% elongations, the composite's average tensile strength with the stated fiber orientation of 0/90° is 76.67 MPa. The strength evaluation is illustrated in the figure below. Typically, the comparison is carried out by taking into account corrective variables and averaging those test results for an orientation.

It can be seen from the tensile strength of bamboo fiber-reinforced composites that the 0° fiber orientation composite has higher tensile strength than both the bidirectional (0/90°) fiber orientation composite and the 90° fiber orientation composite (Figure 11).

In general, draw the conclusion that the higher tensile strength is observed in the 0° fiber orientation of bamboo fiber-reinforced composite as the fiber orientation varies.

3.1.2. Compression Test. The ability of a material to bear loads that tend to diminish its size is known as its compressive strength. Tensile strength is the reverse of compressive strength. Since there may occasionally be a fracture in the structure at this limit, compressive strength is crucial in determining the compressive load limit. Three different fiber orientations were used to prepare the compression test specimens. Their specimens were processed for reproducibility for each fiber orientation. The compression test set up is shown in Figure 12.

The test load against the deformation correlation graph of the composite material is shown below in Figure 13.

The load (kN) to material deformation (mm) relationship property is displayed in Figure 14, as shown below.

The load (kN) to material deformation (mm) relationship property is displayed in Figure 15, as shown below.

Based on the composite's compressive strength and bamboo fiber reinforcement, it can be seen that the 0° fiber orientation composite has a higher compressive strength than the 90° fiber orientation composite and the bidirectional (0/90°) fiber orientation composite (Figure 16). Results of compression test are given in Table 3. The abovementioned compression test result is for pure compression stress, and there is no shear force involvement due to the orientation of the test sample and the machine.

3.1.3. Buckling Test. The universal machine with the buckling testing setup is shown in Figure 17 while the machine's upper jaw is just beginning to move downward. The test specimen is created in accordance with ASTM D790 while taking into account machine specifications that are available and the advice of the technician.

Figure 5: The final prepared mold for specimen in both sides and measuring data.

Figure 6: Test specimen preparation using band saw in AAiT.

Figure 7: Test samples for tensile strength.

In general, this apparatus can be used to test a material's tensile, compressive, or buckling properties. The only ways to distinguish between tests for tensile, compression, and buckling properties are to simply choose on the display screen and insert the necessary parameters.

Bending mechanical properties comparison for different fiber orientation composite materials is summarized on Figure 18.

The graph above compares three distinct fiber orientations of a hybrid composite made of bamboo and sisal fibers. The highest flexural strength is found for the 0° fiber orientation (188.48 MPa) and the lowest for the 90° fiber orientation (92.25 MPa).

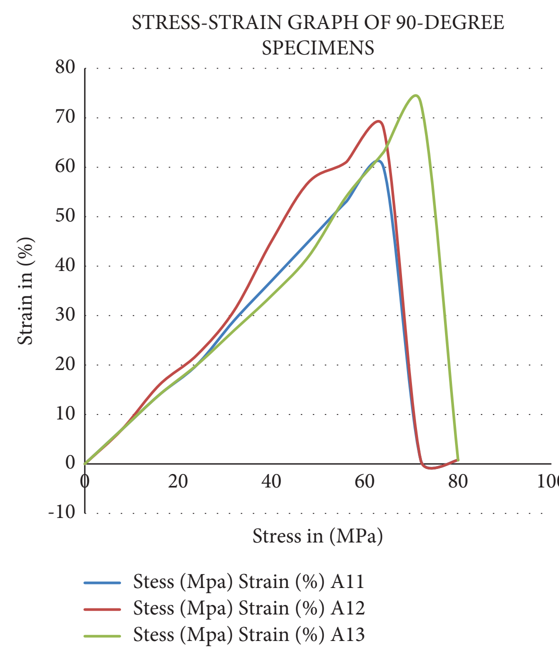


Figure 8: Stress-strain graph of 90° fiber orientation.

Due to the bidirectional fiber orientation sample thickness, the specimen can withstand the highest maximum tensile force even though its flexural strength is smaller than the 0° fiber orientation. Bidirectional fiber orientation shows the highest bending moment, whereas unidirectional fiber orientation shows the highest bending stress. The main assurance was receiving test results for various thicknesses. Hence, 3– 4 mm was chosen from among those various thicknesses based on a number of test result acceptances.

3.1.4. Water Absorption Test. Using equation (2), it was possible to determine how much water the bamboo fibers that were extracted absorbed. Before being submerged in

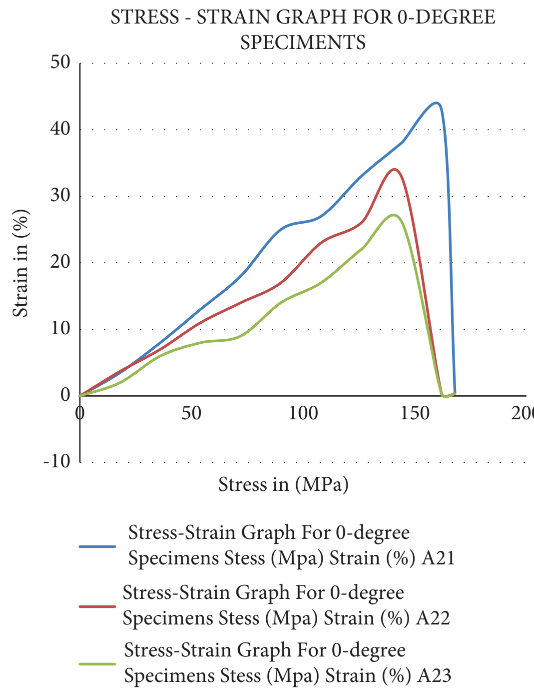


Figure 9: Stress-strain graph of 0° fiber orientation.

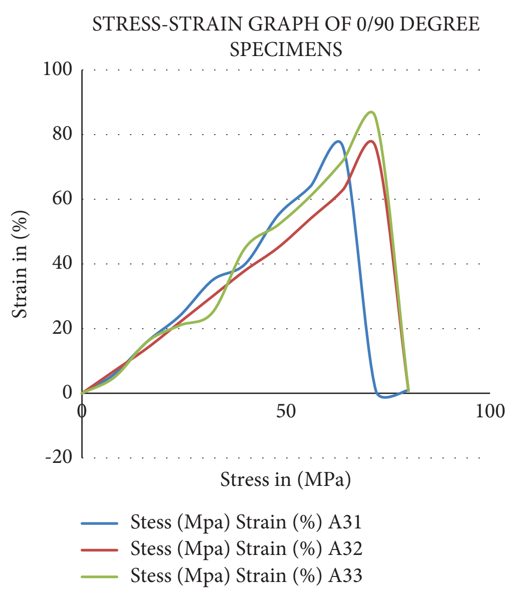


Figure 10: Stress–strain graph of 0°/90° specimen.

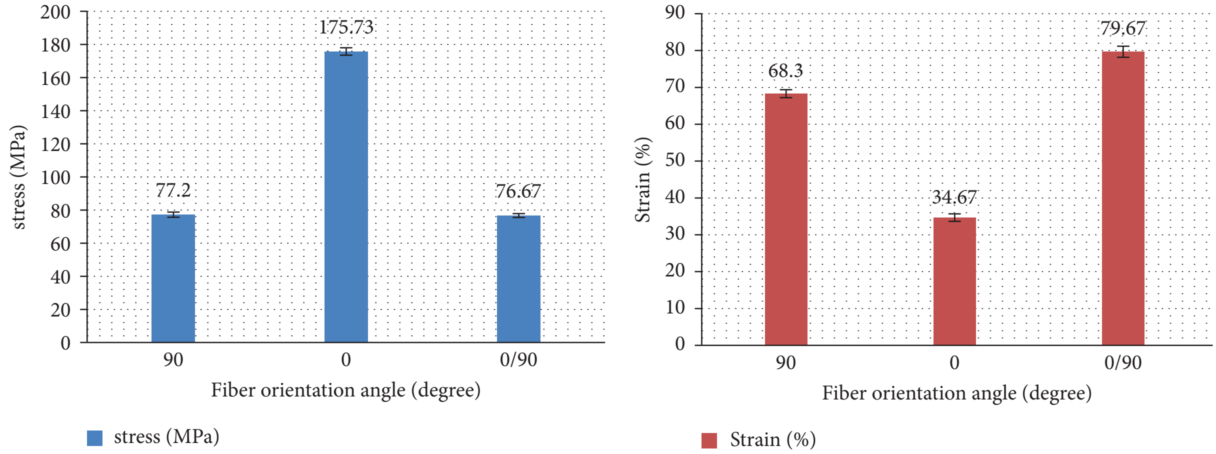
distilled water as M_o, the weight of a group of extracted fibers was measured per portion and recorded equally. Every 24 hours, the immersed bamboo fibers in the distilled water were retrieved, cleaned with filter paper, and then continually weighed. The weights of the samples were then determined and recorded independently from every other component of the four bamboo species.

$$\text{Water absorption } (W_A) = \left((M_t - M_o)/M_o \right) \times 100, \quad (2)$$

where M_t is the mass of fibers after soaking in water at different time intervals, and M_o is the mass of fibers before soaking in water.

According to the above equation, measured data calculation has been taken from 48 hours results.

(1) 90°: initial mass = 9.8600 g ⟶ final mass = 10.3468 g



(a) (b)

Figure 11: (a) Average tensile strength (MPa). (b) Strain in (%) value of different fiber orientation graphs.

Figure 12: Setup of the compression test.

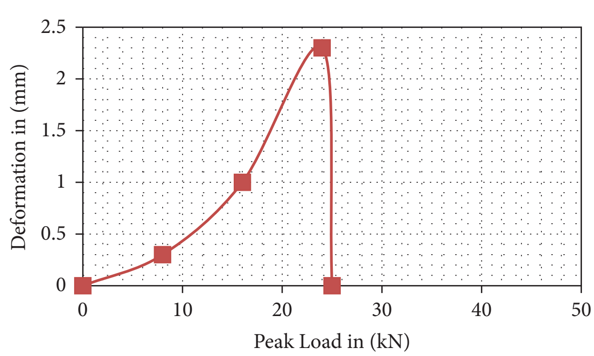


Figure 13: 90° fiber composite peak load Vs. deformation.

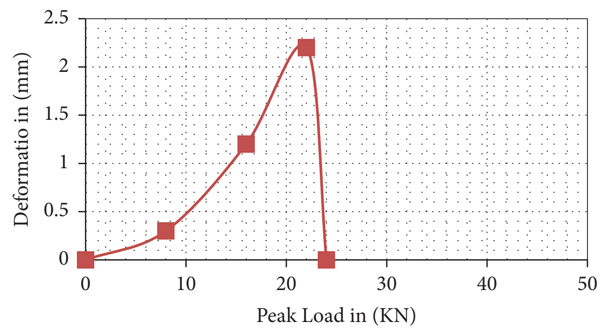


Figure 14: Fiber orientation 0° composite peak force (kN) Vs. deformation (mm).

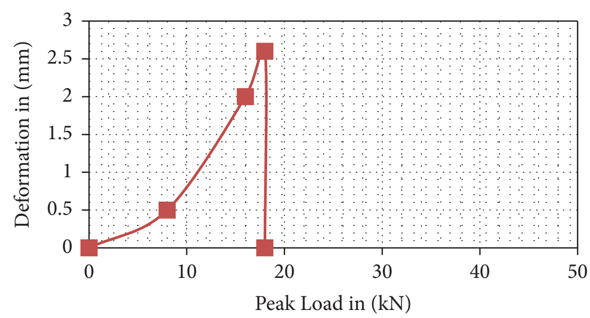


Figure 15: Fiber orientation of 0°/90° composite peak load (kN) Vs. deformation (mm).

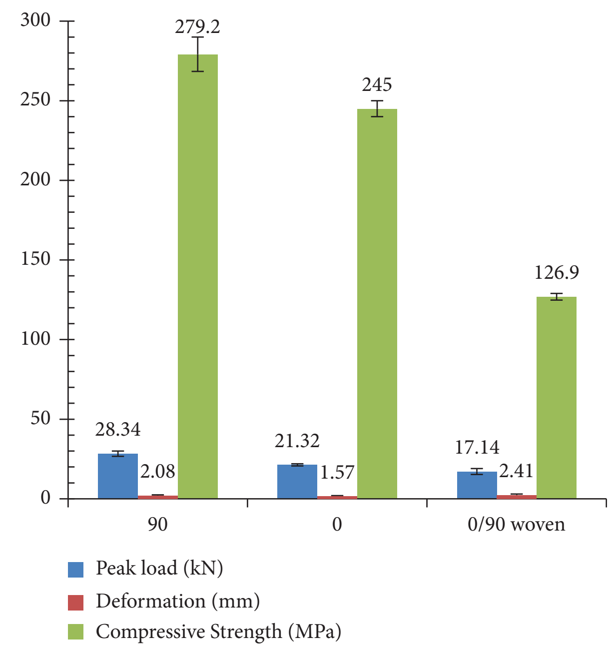


Figure 16: Different fiber orientation and compression test results.

Table 3: Results of the compression properties of fiber-oriented 90°, 0°, and 0/90° composites.

Orientations	Peak loads (kN)	Deformation (mm)	Compressive strengths (MPa)
90°	28.34	2.08	279.2
0°	21.32	1.57	245.0
0/90° woven	17.14	2.41	126.9

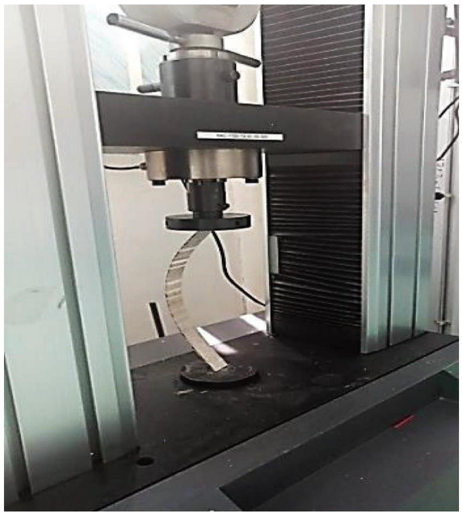


Figure 17: Buckling test setup.

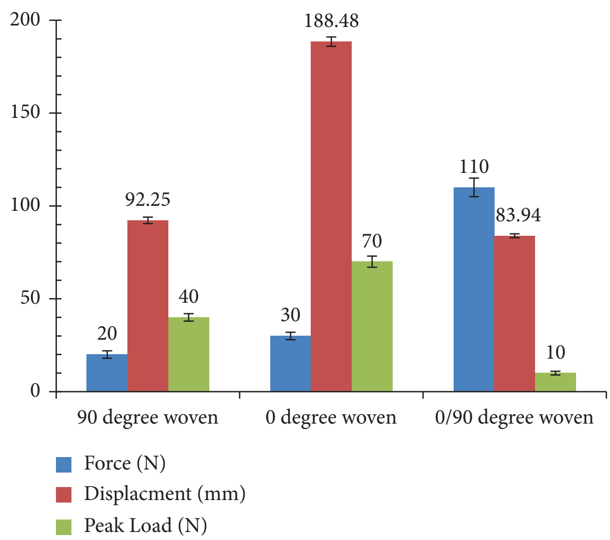


Figure 18: Buckling test result comparison.

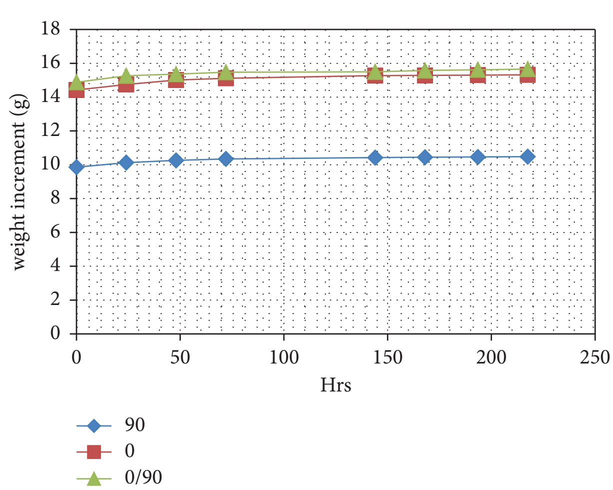


Figure 19: Water absorption.

(2) 0°: initial mass = 14.4221 g ⟶ final mass = 15.1173 g

(3) 0/90°: initial mass = 14.8792 g ⟶ final mass = 15.4716 g

Solution:

(1) $(10.3468 - 9.8600)/9.8600 \times 100 = 0.4868/9.8600 \times 100 = 4.9\%$

(2) $(15.1173 - 14.4221)/14.4221 \times 100 = 0.6952/14.4221 \times 100 = 4.8\%$

(3) $(1.4716 - 14.8792)/14.8792 \times 100 = 0.5924/14.8792 \times 100 = 3.98\% \approx 4\%$

Water absorption results are shown in Figure 19.

4. Conclusion

The following conclusions can be drawn from the tensile, compression, and bending analysis properties experiment data studied in this work:

(i) According to the experiment's findings, the mechanical properties of the bamboo fiber composite material have improved with diverse fiber orientation

(ii) 0°-treated bamboo fiber reinforced unsaturated polyester resin composite was found to have better tensile strength than 90° and 0/90° based on the findings of the tensile experimental test

(iii) According to the results of the compression experimental test, 90°-treated bamboo fiber-reinforced unsaturated polyester resin composite has a higher tensile strength than 0° and 0/90°

(iv) 0/90° woven-treated bamboo fiber-reinforced unsaturated polyester resin composite has superior bending strength than 0° and 90°, according to the findings of the experimental bending tests

(v) The result of the moisture content test, which measured how much water was absorbed by auto body door panels, was within the acceptable range

(vi) The hand layup technique is determined to be the ideal method for producing the sample composite materials as well as the prototype door due to its simplicity and lack of the need for extra accessories.

(vii) Benefits of making a door panel from bamboo fiber composite material include lower costs, improved customer satisfaction, reduced fuel consumption, and a significant ability to replace imported raw materials

(viii) The bamboo fiber composite material could also be used for various applications such as leaf spring, dashboard panel, pillars, interior door covers, and other vehicle component parts.

Data Availability

Data used for the findings of the study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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