Fabrication and Mechanical Performance of Banana Fiber–Glass Fiber Reinforced Epoxy Hybrid Composites for Lightweight Applications

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Abstract: The need for sustainable, lightweight, and high-performance materials has encouraged researchers to explore hybrid composite materials composed of natural and synthetic fibers. The present study aims to explore the fabrication and characterization of banana fiber-reinforced epoxy composite materials, which are further enhanced by incorporating glass fibers. The composite materials were prepared using hand-lay-up techniques to ensure proper dispersion of materials in the composite materials' matrices. An epoxy resin composed of LY556 resin and HY951 hardener was used as the binding agent in the composite materials due to their adhesive properties and stability.

Mechanical characterization of the developed composite materials was performed by conducting standardized tests to evaluate their tensile, compressive, Rockwell hardness, and impact strength properties using Izod and Charpy impact machines. The study also aims to investigate the effect of fiber orientation on the overall performance of composite materials. The results of the experiments show that specimens with 90° orientation exhibit high tensile strength, hardness, and impact properties when compared to those with 45° orientation.

The results have proved that the banana fiber glass-reinforced hybrid epoxy composite materials have the potential to be used as sustainable, cost-effective, and lightweight composite materials in comparison with conventional synthetic composite materials. These composite materials have the potential to be used in the automobile industry, aerospace industry, and building industry.

Keywords: Hybrid Composite, Natural Fiber, Banana Fiber, Light weight structures, Epoxy Resin.

1. INTRODUCTION

The composite materials are also highly favored in the contemporary field of engineering because of their high mechanical characteristics, low-weight nature, and designability. Composite material is a material that is created through the synthesis of two or more different materials that have different physical and chemical characteristics in order to create a new material that has superior performance [1]. Composites usually have a matrix phase and reinforcement phase. The reinforcement is transferred by the matrix and strength and stiffness of the structure are added by the reinforcement. Polymer Matrix Composites (PMCs) are the most popular among the different types of composites due to their low density, high specific strength, resistance to corrosion and easy fabrication [2]. The thermosetting or thermoplastic polymers that are usually used as the matrix material to be reinforced with fibers or particulates by PMCs include epoxy, polyester, or vinyl ester [3].

The high demand of sustainable and environmental friendly material in recent years has necessitated more studies on natural fiber reinforced composites [4]. The natural fibers, like the banana, jute, sisal, coir and hemp [5] are renewable, biodegradable, lightweight and also cheaper than the synthetic fibers [6]. Of this group, banana fiber has received a lot of attention as it contains high levels of cellulose, has good tensile and low density. Banana fiber [7-8] is obtained by extraction of pseudostem of banana plant and includes cellulose, hemicellulose and lignin and these properties make the fiber mechanically stable and rigid. Due to these attributes, banana fibers have found increased use as reinforcement in polymer composites in applications in automotive parts[9], packaging materials, structural panels and lightweight structures [10]. Nevertheless, natural fibers also have some shortcomings like the absorption of moisture, reduced thermal stability, and inconsistency of mechanical strength. Certainly, these limitations have the capacity to diminish the overall performance of natural fiber reinforced composite in comparison with synthetic fiber reinforced composite [11-12].

To eliminate these shortcomings, hybrid composite systems have been created involving the use of synthetic reinforcements along with natural fibers [13-14]. Hybrid composites are the composite where two or more forms of reinforcement material are used in the same matrix to attain better mechanical and functional properties. Banana fibers hybridization with synthetic fibers [15] like glass fibers or glass powder can be dramatically designed to augment strength, stiffness and impact resistance without the negative effect on the environment that natural fibers have [16]. Glass fiber is common in composite manufacturing

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because it has good mechanical characteristics, resistant of corrosion as well as relatively cheap [17]. Glass fiber is used to enhance the structural integrity and strength of the composite material when it goes together with natural fibers [18]. Hardness, compressive strength and dimensional stability of polymer matrix reinforcing also improves with the addition of glass powder or glass fiber reinforcement [19].

Along with the composition of reinforcements, the orientation of the fiber is one of the most crucial factors when defining the mechanical behavior of composite materials. Fiber orientation has an impact on the effectiveness of load transfer between the reinforcement and the matrix, and this eventually has an effect on tensile strength, compressive strength and impact resistance [20-21]. Correct alignment of fibres can lead to better distribution of stresses and minimise chances of early failure. Nonetheless, there are few studies that have dwelled on the role of fiber orientation on banana fiber-glass hybrid composites [22].

Hence, the current research is aimed at machining and mechanical characterizing the banana fiber reinforced epoxy-glass fiber hybrid composites through hand lay-up process. Two fiber orientations, i.e. 90^o and 45^o were done to measure the effect of fiber orientation in mechanical performance. Tensile testing, compressive testing, Rockwell hardness testing, Izod impact testing and Charpy impact testing were mechanical tests carried out to determine the strength, stiffness, and toughness of the fabricated composites. This study is aimed at establishing the best fiber orientation as well as assessing the appropriateness of banana fiber-glass hybrid composites in lightweight structural applications.

2. MATERIALS AND METHODS

2.1. Materials

The hybrid composite specimens to be subjected in this study were manufactured by use of banana fibers, glass fibers, epoxy resin, and a curing agent (hardener) indicated in Fig. (**1**). The choice of banana fiber as the natural reinforcement was based on its biodegradation, low density and good tensile properties. Banana plants dried the pseudo-stem then extracted the fibers which were then washed with water to eliminate impurities and water. The banana fibers are primarily made of cellulose, hemicellulose and lignin which make them strong and stiff. Banana fiber has environmental benefits since it can be used in polymer composites with reasonable mechanical performance.

The secondary reinforcement to enhance the overall mechanical strength and durability of the hybrid composite, was made of glass fiber. Glass fibers are very strong in terms of tensile properties, corrosion resistance and thermal stability and are therefore extensively utilized in structural composite. The mixture of banana fiber and glass fiber assists in the struggle of achieving a balance between the natural fibers due to their eco-friendly nature and synthetic fibers due to their higher mechanical performance.

The material as a matrix used in this study was epoxy resin (LY-556). Polymer matrix composites made with epoxy resins are common because it bonds very well, goes through minimal shrinkage on cure and is fairly resistant to chemicals. Epoxy resin was combined with a curing agent, HY-951 hardener to start the polymerizing process and create a stiff polymer framework. Weights of epoxy resin and hardener were maintained at 10:1 to have the right curing and maximum mechanical behavior of the composite.

2.2. Composite Fabrication

Hand lay-up technique was used in the manufacture of the hybrid composite specimens as one of the simplest and most widely applied techniques of producing fiber reinforced polymer composite. This technique was chosen due to its cheapness, simplicity of the processing and applicability to laboratory-scale composite fabrication.

In the first step, the foam board material was used to prepare molds based on the specifications of the required specimen to be used in mechanical testing as indicated in Fig. (**2**). Foam boards were used based on

a) Banana Fiber b) Glass Fiber c) Epoxy Resin LY556 and Hardener HY951

Figure 1: Materials for Hybrid Composite.

a) Tensile Specimen b) Compressive Specimen c) Charpy and Izod Specimen d) Rockwell Hardness Specimen

Figure 2: Different Molds for Mechanical Testings.

their light weight, ease of cutting and also their capability to retain dimensional accuracy. In the mold cavities, transparent plastic sheets were put in order to avoid sticking of the composite material to the surface of the mold.

The epoxy resin and hardener were combined after the preparation of the mold in a 10: 1 proportion. Banana fibers and glass fibers were subsequently placed in the mold in the orientation that was intended. The ready resin blended was coated on the fibers uniformly to get the fibers wet and bonded together. Several layers were applied until the desired thickness of the composite specimen had been obtained.

After the lay-up procedure was done, the composite laminate was left to dry at room temperature. The specimens were taken out of the molds after they had cured and trimmed to the specifications of test specimens. Two types of fiber orientations, i.e. 90^o and 45^o were made so as to assess the effect of fiber alignment on mechanical performance.

2.3. Composition of Hybrid Composites

A total of eight hybrid composite specimens were made in the experimental study. Four specimens were also prepared with 90 degree fiber orientation and four specimens with 45 degree fiber orientation. The weight ratio of the epoxy matrix was kept at 80 percent in all the specimens with the other 20 percent comprising the reinforcement fibers.

Under the reinforcement section, the ratio of banana fiber to the glass fiber was manipulated to determine the impact of the hybridization on the mechanical properties. Various specimens of the same were flattened by increasing the content of glass fiber and decreasing that of banana fiber gradually to changes in strength, stiffness, and impact resistance. The synergistic effect of the combination of natural and synthetic reinforcements in the epoxy matrix could be studied with the help of this approach.

2.4. Mechanical Testing

The mechanical behavior of the hybrid composite specimens fabricated was measured using a series of mechanical tests that were standard. Such tests were tensile test, compressive test, Rockwell hardness test, Izod impact test and Charpy impact test. The strength, hardness, and impact resistance of the composites were determined using standard testing equipment to test all tests.

The experiment of tensile testing was conducted to determine the maximum tensile strength and elongation of the composite samples under the axial loading as it is demonstrated in Fig. (**3**). Tensile samples were made with a length, width and thickness size of about 165 mm, 12.5 mm and 3 mm respectively. The tensile strength was computed using the load exerted and the cross-sectional area of the specimen.

Compression test was carried out to establish the capacity of the composite specimens to compressive

Table 1: Material Composition of Specimens at Different Orientations

Orientation	Specimen	Epoxy,%	Banana Fiber,%	Glass Fiber,%
90^o	1	80	20	0
	2	80	15	5
	3	80	10	10
	4	80	5	15
45^o	1	80	20	0
	2	80	15	5
	3	80	10	10
	4	80	5	15

loads without breaking. This test was prepared using cubical specimens with the dimensions of 30 mm x 30 mm x 30 mm. The deformation properties of the composites were to be analyzed by recording the stress strain behavior.

Figure 3: Tensile Test Setup.

Hardness test on rockwell was conducted to check rockwell surface hardness of the composite samples. A ball indenter was 5 mm in diameter and the test was done with a load of 100 kg. The values of hardness were taken and the mean hardness figure was taken in each specimen.

Izod and Charpy impact tests were used to determine impact resistance of the composite materials. These are tests that are used to quantify the energy that is absorbed by a specimen at the time of fracture when loaded suddenly through impulse. The impact testing specimens were 75 mm long, 10 mm wide and 10 mm thick. The impact energy which has been absorbed represents the toughness and resistance characteristics of the composite to sudden loading conditions.

3. RESULTS AND DISCUSSION

The tensile, compression, hardness, and impact tests were performed to assess the mechanical performance of the fabricated banana fiber reinforcement of epoxy hybrid composites using glass fiber. The aim of the tests was to explore the impact of fiber orientation and hybrid reinforcement to the mechanical behavior of the composite materials. The reinforcement alignment in two variants, which include 90, and 45 were taken into consideration to determine the effect of load transfer, strength and energy absorption properties.

3.1. Tensile Test

The tensile experiment was done to identify the final ultimate tensile strength and deformation properties of the manufactured hybrid composite samples. The experimental findings suggested that the tensile strength of the specimens that were oriented at 90 degrees fiber was more than the tensile strength of the specimens oriented at 45 degrees fiber. The tensile strength attained at the maximum tensile angle of 90 was recorded at about 51.4 Mpa, but on the 45deg oriented specimen the tensile strength was found to be about 31.6 Mpa.

This increased tensile behavior in the 90 degree orientation may be explained by the fact that the fibers are well oriented in the direction of the load that enables easy transfer of the load between the reinforcement and the matrix. Banana fibers as well as glass fibers play a good role in tensile resistance in this set-up. Conversely, the 45o orientation yields inclined fiber orientation with respect to the force exerted and hence shear stresses in the matrix and low load bearing capacity. Glass fiber reinforcement greatly enhances tensile stiffness and the strength of the composite as it offers high modulus

Table 2: Tensile Test Results - 90° Orientation

Specimen Number	Load (N)	Elongation (mm)	Tensile Strength (MPa)	Tensile Strain	Tensile Modulus (GPa)
1	1720	2.7	34.4	0.0027	1.274
2	2340	3.7	46.8	0.0037	1.264
3	2570	2.4	51.4	0.0024	2.141
4	2170	2.1	43.4	0.0021	2.066

Table 3: Tensile Test Results - 45° Orientation

Specimen Number	Load (N)	Elongation (mm)	Tensile Strength (MPa)	Tensile Strain	Tensile Modulus (GPa)
1	990	1.1	19.8	0.0011	1.800
2	1200	1.4	24.0	0.0014	1.714
3	1340	1.4	24.0	0.0013	2.061
4	1580	1.7	31.6	0.0017	1.858

support in the epoxy matrix. These findings confirm that orientation of fibers is a crucial factor in tensile behavior of composite structures that are hybrid.

3.2. Compression Test

Compression test was conducted in order to test how the hybrid composites could resist compressive loads without structural collapse. The compression tests yielded stress strain curves that indicated that the 90 degree oriented specimens were stronger in compressive strength and that they were better resistant to deformation as compared to the specimens of 45 degrees orientation as seen in Figs. (**4** and **5**).

This is primarily because the reinforcing fibers in the direction of the load are more uniformly distributed and this enhances the structural stability of the composite material. Glass fibers being present in the epoxy matrix improve the stiffness of the composite and limit the undue deformation under compressive load. The banana fibers as well aid in the absorption of energy and slow down crack propagation in the matrix. The hybrid reinforcement structure hence enhances the total compressive load-bearing ability of the composite.

3.3. Rockwell Hardness Test

The hardness of the surface of fabricated composite materials was tested through Rockwell hardness test. Each of the specimens was subjected to multiple readings on hardness, and the mean of the hardness readings was calculated. It was found that 90° oriented specimens had better values of hardness than the orientation of 45°s.

Mean Rockwell hardness of the 90° oriented specimen was around 89.25 RHN and that of the 45° oriented specimens was relatively low. The hardness increment is largely explained by the fact that there is a glass fiber reinforcement in the epoxy matrix. Glass fibers are stiffer and harder than natural fibers which help in enhancing the resistance to indenting the surface. Also, correct adhesion of the epoxy matrix and reinforcement fibers leads to increased structural integrity and greater local deformation resistance. The values of hardness of 90° and 45° orientation are presented in Table **4** and **5** below.

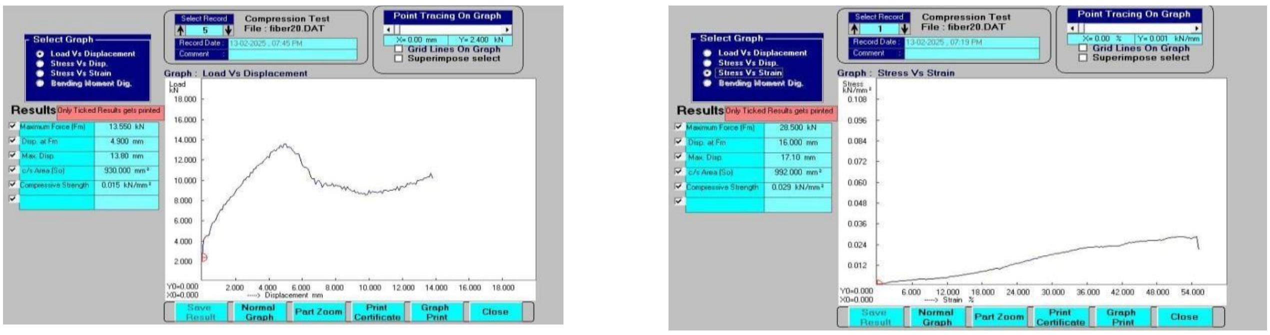
3.4. Impact Properties

Impact test was conducted on both Izod and Charpy impact tests to determine the toughness and the energy absorption ability of the hybrid composites when they are subjected to sudden loading. The outcome of both impact tests was that 90 oriented specimens were absorbing more impact energy than the 45 degree oriented specimens.

The 90° specimens in the Izod impact test obtained energy absorption values of about 39 to 46 units and the 45° specimens of the test obtained slightly lower

a) 90° orientation b) 45° orientation

Figure 4: Compression test Specimens.



Specimen 1 @90° Specimen 1 @45°

Figure 5: Stress vs Strain.

Table 4: Rockwell Hardness @90°

Test	Specimen 1	Specimen 2	Specimen 3	Specimen 4
RHN(Trail 1)	37	49	80	77
RHN(Trail 2)	53	41	78	97
RHN(Trail 3)	33	58	73	85
RHN(trail 4)	53	57	83	98
RHS(Avg)	44	51.25	78.5	89.25

Table 5: Rockwell Hardness @45°

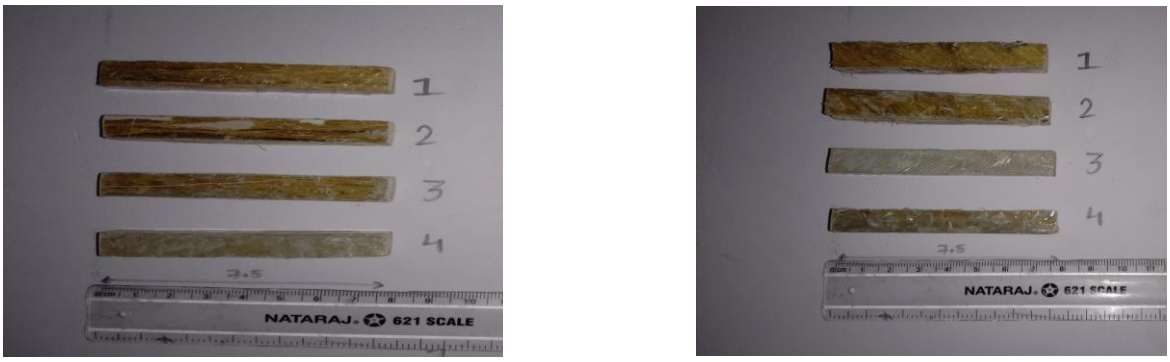
Test	Specimen 1	Specimen 2	Specimen 3	Specimen 4
RHN(Trail 1)	35	55	54	65
RHN(Trail 2)	41	56	50	59
RHN(Trail 3)	42	57	48	79
RHN(trail 4)	36	67	70	52
RHS(Avg)	38.5	58.75	55.5	63.75

values of between 38 and 42 units. The same case is in the Charpy impact test, where the 90° specimens had a higher impact energy absorption, with the values as high as 44 units, compared to the 45° specimens which had lower energy absorption values.

The enhanced impact resistance of the 90° specimens may be attributed to the increased bonding of the fiber and matrix and also the ability to align the fibers and get to dissipate the impact energy effectively in the composite structure. The hybrid type of reinforcement made of banana fibers and glass fibers also adds to the toughness through the combination of the flexibility of natural fibers with the high strength of synthetic fibers. In impact loading, banana fibers are used to absorb the energy by fiber deformation and the glass fibers are used to give the composite a structural rigidity to avoid catastrophic failure.

3.5. Impact of Hybrid Reinforcement

Experimental findings clearly show that the banana fibers hybridization with glass fibers attains high performance in epoxy-based composites in terms of mechanical performance. Glass fiber reinforcement improves the tensile strength, hardness and stiffness



a) 90° orientation   b) 45° orientation

Figure 6: Izod test Specimens.

Table 6: Izod Test

Variant	Specimen 1	Specimen 2	Specimen 3	Specimen 4
90°	39	42	45	46
45°	38	40	41	42

a) 90° orientation

b) 45° orientation

Figure 7: Charpy test Specimens.

Table 7: Charpy Test

Variant	Specimen 1	Specimen 2	Specimen 3	Specimen 4
90°	41	42	43	44
45°	38	40	41	43

whereas the banana fibers also add in the enhanced energy absorption and toughness. The combination of the natural and synthetic reinforcement creates a composite material that has balanced mechanical characteristics to be used in lightweight structures.

Comprehensively, 90° fiber orientation had better mechanical performance with tensile strength, compressive strength, hardness and impact. The findings indicate that hybrid reinforcement design and correct fiber placement are very important in maximizing the applications of natural fiber reinforced hybrid composites.

4. CONCLUSION

This paper has been able to produce banana fiber reinforced epoxy hybrid composites with glass fibers in hand lay-up method and tested the mechanical properties of the hybrid composite. Natural reinforcement was done using banana fiber, whereas glass fiber was used to strengthen and enhance the durability of the composite. The matrix material was epoxy resin (LY556) and epoxy hardener (HY951) to provide an effective bonding between the fibers. To examine the overall performance of the composite material, mechanical characterization was conducted using tensile, compressive, Rockwell hardness, and Izod impact as well as Charpy impact tests so as to determine the influence of hybrid reinforcement and fiber orientation to the overall performance of the composite material.

It was found through the experiments that fibers orientation is very important in determining mechanical properties of the hybrid composites. The 90° fiber oriented specimens had better performance than the 45° oriented specimens. The 90° specimens exhibited higher tensile strength values up to 51.4 MPA, better compressive strength values and higher values of Rockwell hardness of about 89.25 RHN. On the same note, the impact tests revealed that the 90° oriented composites took more impact energy which translates to toughness and resistance to impulsive loading conditions. These findings indicate that adequate fiber orientation increases transfer of the load between the reinforcement and the epoxy matrix thus increasing the mechanical efficiency of the composite.

In general, the hybrid composites of banana fiber-glass fiber reinforced epoxy that have been developed exhibit a potential of application to lightweight structural applications. Due to the balance of natural and synthetic fibers, strength, stiffness, and toughness are enhanced without compromising partially sustainable material properties. These hybrid composites may be said to be applicable in the automotive parts, construction panels and other lighter engineering structures. The future studies can concentrate on the optimization of the fiber content, a better bonding of fibers and matrix by using chemical treatments and testing further properties like thermal behavior and environmental life to make these hybrid composites more effective.

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