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# Numerical and Experimental Investigation of Unprocessed Banana Fiber Composite Laminates

**Misbah Mohiuddin Nowman[1], Dr. Afroz Mehar[2], Dr. Naseeb Khan[3]**
[1]P.G. Student, Mechanical Engineering Department, Shadan College of Engineering and Technology, Hyderabad, Telangana, India. Email Id: misbahnowman@gmail.com
[2,3]Professor, Mechanical Engineering Department, Shadan College of Engineering and Technology, Hyderabad, Telangana, India.

**Abstract**
In this research, the mechanical characterization of BFRC thru epoxy resin as the matrix is given priority. Composite laminates be situated formed via the hand layup method, a popular method in research because of the issue ease and affordability. Mechanical tests that are tensile, flexural, and compression were performed following ASTM standards for consistency and dependability in the results. Specimens were subjected to testing on a Universal Testing Machine (UTM) to find out their load-bearing capacity. The experimental data so collected were then analyzed numerically using ANSYS, with the bi-directionality of the banana fibers simulated with [0°/90°] fiber orientation. This permitted precise modeling of the performance of the composite material beneath different frightened conditions. The experimental and numerical results were found to compare well with each other, confirming the simulation model and the efficacy of the experimental results. This experimental-numerical methodology forms a sound foundation for the exploration of the viability of banana fiber composites in real-world applications. The findings illustrate that BFRCs can provide acceptable mechanical performance, which indicates their viability as a sustainable alternative to synthetic fiber composites, particularly in applications that value sustainability and cost-efficiency.

**Keywords:** Hand Layup, Banana Fiber, Composite materials, Epoxy resin, Numerical Analysis

## 1. INTRODUCTION

Composition materials or Composites are usually terms for Composite materials. When two or multiple material constituents comprising various/different physical and chemical attributes/properties are combined, it is referred as composite material. When two different materials integrate, they evolve into a new composite material which will display different behaviour and characteristics as compared to individual materials. The evolved Composite material will similar behaviour raising the capability of by-product of the combined materials showing and contributing to factors such as lighter weight, stronger strength, lower costs and prolonged durability in comparison to the metal-based materials.

The environment caused by manufactured fibres, more and more research is being done on natural fibres. Because natural fibres are biodegradable, easy to find, and strong, they could be used instead of manufactured fibres. Mix of Composites made of two or more different fibres are called fiber-reinforced compounds. The banana and jute fibres are preferred for the reason that they are strong, can absorb water, and are easy to find. The epoxy glue is chosen as a base to hold the fibres together and spread the load evenly [1]. The optimized natural fiber~reinforced composites` for different fiber orientations. Finite element models were created for natural fiber-reinforced composites in an epoxy with a constant fiber volume fraction of 30%. The fibers were oriented at 0˚, ±22.5˚, ±45˚, ±67.5˚, and 90˚. Tensile, flexural, and impact tests were performed under conditions of standard loading to assess the mechanical performance [2]. Mechanical assets of epoxy-based natural fibers are investigated was geared towards the determination of momentous influences upsetting the mechanical performance of the composites. Different natural fibers were taken into account during the examination. The review identified the significance of these factors in establishing mechanical strengths. Moreover, the comparison of various fiber-reinforced epoxy systems gave a deeper understanding of their relevance in structural and semi-structural applications, affirming the viability of natural fibers as green substitutes for synthetic reinforcements [3].

Epoxy resin with natural fiber of birch, palm and eucalyptus. The fiber was moulded into a fiber plate and resin was injected thru RTM system. The mechanical assets of the epoxy resin armoured with birch, palm and eucalyptus were evaluated [4]. Tribological behaviour of the natural fibers reinforced in epoxy. Since epoxy is widely used resin and easy to process with good mechanical properties hence it will help the future Researchers in studying the tribology on epoxy-based composite [5]. Carbon fiber armoured in epoxy and reviewed the applications. He explained the various stages of preparation involved in synthesis of CFRP composite. Also suggested the application of CFR epoxy composite for use in power cells [6]. The mechanical assets of epoxy~matrix composites' having different type of graphite fillers and CFR epoxy composites. it was established for Tensile and Flexural test. it was concluded that graphite fraction increases with CFR shows improved mechanical belongings on comparing with carbon fiber epoxy composites [7]. Determine the bond shear strong point of CFRP by using 45˚ fiber pack test and compared the results with Transverse fiber bundle test. The results proved that the 45˚ FBT showed better results than TFBT [8].

The natural fiber armoured in epoxy and the factors of influence in natural fibers reinforced in epoxy. He also studied the various factors effecting the thermomechanical properties of natural fibers [9]. A critical understanding of the bonding interface is a defining feature in the overall performance of fiber-reinforced composites. Stress transfer, distribution of load, and initiation and propagation of damage during mechanical loading are all influenced by the quality of the fiber-matrix interface. Defects or poor bonding at this interface can result in composite failure at an earlier stage. Thus, the exploration of these interfacial properties assists in the promotion of composite strength, durability, and reliability. Enhancement of adhesion by surface treatments or coupling agents can greatly improve the mechanical recital of the end composite` material [10]. the flexural properties of carbon-basal Flexural modulus were tested for the hybrid composite's of basalt material /epoxy hybrid composites. The conclusion stated that carbon basalt epoxy composite with carbon fiber reinforcement on its outer most layer showed better flexural properties [11]. Synthesized and characterized new polymer composites made up of glass/epoxy, and filler material like titanium dioxide ($TiO_2$) and zinc sulfide (ZnS). The complexes were prepared by standard procedures and undergoing multiple mechanical tests for the assessment of their performance. The addition of $TiO_2$ and ZnS fillers was to improve the composite's mechanical strength, stiffness, and durability [12].

## 2. EXPERIMENTAL METHODOLOGY

To appraise the mechanical and durability appearances of banana /epoxy composite`s to optimize their performance and ensure environmental sustainability. Experimental testing and numerical simulation through ANSYS will be utilized to corroborate the findings. The main goals are to produce bidirectional laminates of banana fibers, examine their tensile, flexural, and compressive strengths according to ASTM standards, and conduct corresponding numerical simulations. The research aims at filling gaps in the design of natural fiber composites and creating consistent data for general industrial applications towards the creation of sustainable and high-performance composite materials [13-19].

## 3. SELECTION OF MATERIALS AND FABRICATION PROCESS

Banana fibers were employed as the fortification material, and epoxy was cast-off as the medium to develop fiber~reinforced polymer composites` as shown in fig. 1. The laminates of the composite were produced at room temperature over the conventional hand lay~up process, a very popular technique for fabricating fiber-reinforced composites because of its ease and affordability. The process of fabrication was initiated by blending the epoxy resin with its respective hardener in a proportion of 10 ml of hardener for each 100 ml of epoxy. The blend was made to undergo proper curing and bonding of the matrix material. Banana fibers were selected for reinforcement based on their favorable properties like increased tensile strength and modulus, low weight, good fire resistance, high moisture absorption strength, low elongation at break, and good stiffness. These are the reasons banana fiber is a valuable natural fortification quantifiable for merged uses. A wooden mould of 340 mm × 290 mm × 6 mm internal dimensions was prepared. The mould was used as a casting platform for the composite laminates. As per ASTM C1275 standards, the specimen size to be tested was 250 mm × 250 mm, and from these sheets, test specimens were cut into 25 mm × 250 mm dimensions as shown in figs. 2 to 4. To start the lay-up operation, a plastic sheet and a metal sheet were positioned at the mould base. The plastic and metal sheets served as protective coverings and facilitated laidback exclusion of the laminate after curing. Wax was pragmatic thinly over the plastic sheet to foil the complex from protruding on the mould exterior.

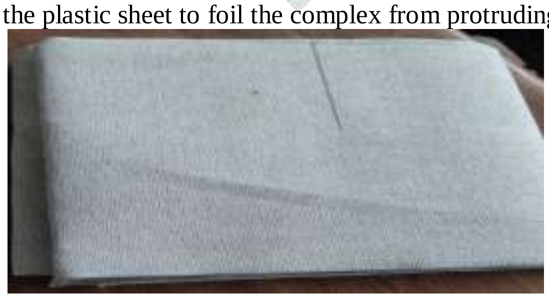


Figure 1: Fabric of Banana fiber

The fabric of banana fibers was cut according to mould size. The inside of the mould was covered by the first layer of fabric and then evenly spread with the mixture of epoxy-hardener with a brush. A second layer of fabric was positioned on top after ensuring the spreading of the mixture evenly, and epoxy was also applied evenly once more. This cycle continued until the laminate thickness was reached.

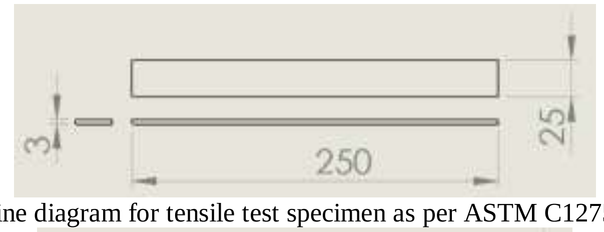



Figure 2: Line diagram for tensile test specimen as per ASTM C1275 Standards.

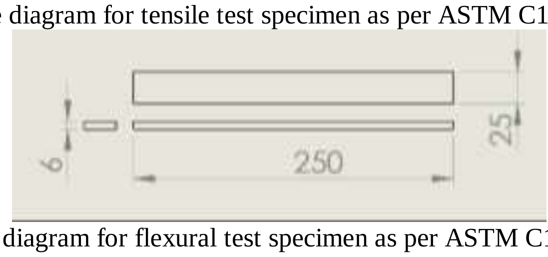
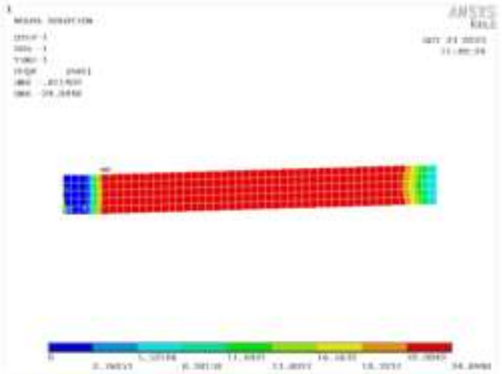



Figure 3: Line diagram for flexural test specimen as per ASTM C1275 Standards.


Figure 4: Line diagram for compression test specimen as per ASTM C1275 Standards.

### 4. Numerical Analysis of Composite laminate

Numerical analysis was used to govern the compressive, flexural, and tensile strong point of BFRP composites for various fiber orientations, namely 0˚, 30˚, 45˚, 60˚, and 90˚. The aim was to determine how fiber alignment affects the mechanical chattels of the complex beneath various loading situations. A model was created with ANSYS in which the composite laminates were modeled with different fiber angles in order to pretend the directionality of stress spreading and transfer of load. Young's modulus, Poisson's ratio, and strength values of the banana fibers and epoxy were entered into the model. Boundary conditions and loading were simulated according to the experimental test setup for consistency. The simulation outcomes revealed a high correlation of mechanical performance with fiber orientation as shown in figs. 5 to 10. The highest tensile and flexural strength was obtained for the 0˚ orientation (facing in the direction of loading), while orientations of 45˚ and 60˚ represented improved shear resistance with less axial strength. The orientation 90˚ possessed the lowest strength as the fibers were normal to the direction of loading.



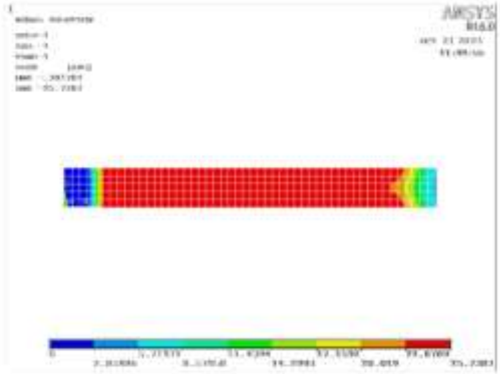
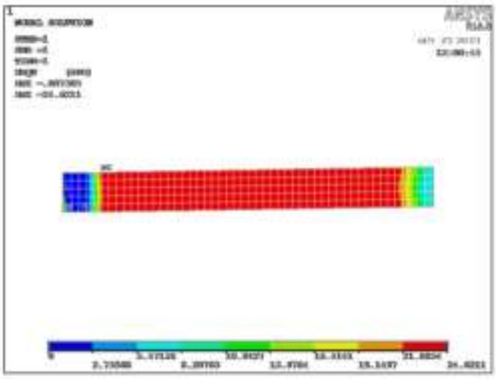


Figure 5 Figure 6

Figure 5: Compressive Strength of BFRP at 0˚-90˚

Figure 6: Compressive Strength BFRP at 90˚



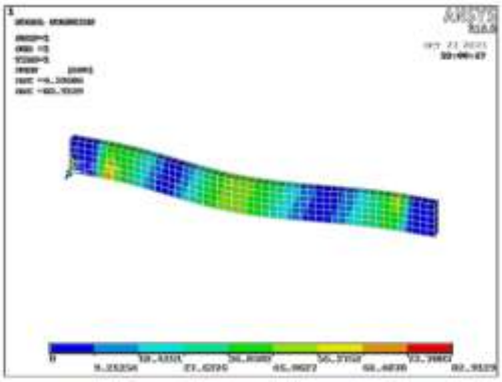
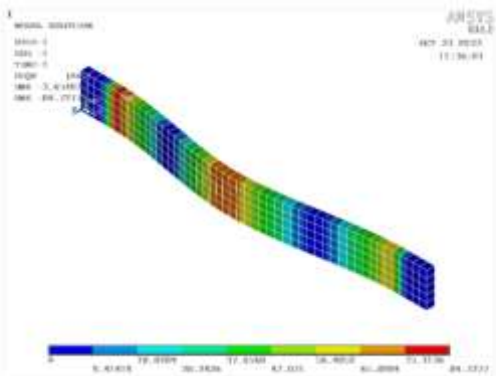


Figure 7 Figure 8

Figure 7: Compressive Strength BFRP at 0˚

Figure 8: Flexural Strength BFRP at 0˚- 90˚



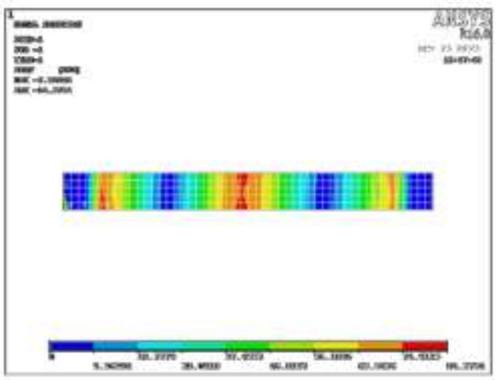
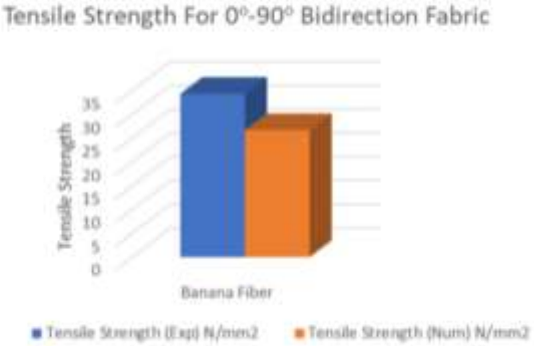


Figure 9 Figure 10

## 5. RESULTS AND DISCUSSIONS

Tensile strength, flexural and compressive strength on natural fiber i.e. banana~fiber fabric is determined. As it is bi-directional fabric which has 0,90 fiber angles. Therefore, this fabric is reinforced in epoxy resin and are fabricated, cut according to ASTM standard for studying the behaviour of composite laminate. The experimental and numerical results of banana fiber, its corresponding graph in figs. 11 to 13.



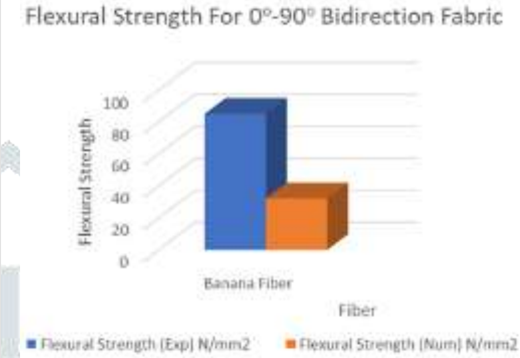




Figure 11 Figure 12

Figure 11: Tensile strength of bi-direction fabric i.e. 0º-90º fiber angles

Figure 12: Flexural strength of bi-direction fabric i.e. 0º-90º fiber angles

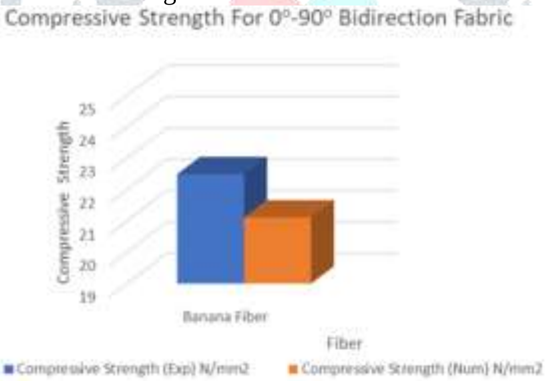



Figure 13: Compressive strength of bi-direction fabric i.e. 0º-90º fiber angles

The mechanical belongings of BFRP composite laminates were examined by tensile, flexural, and compressive strength tests under different angles of fiber orientation of 0°, 30°, 45°, 60°, and 90°. The results of these examinations, as presented in Figures 14, 15, and 16, indicate considerable fluctuations in mechanical strength with variations in fiber orientation.

In tensile strength, the laminate showed the highest results at 0° and 90° with readings of 37.42 N/mm² and 37.51 N/mm², respectively. A steady decrease in tensile strength from 0° to 60° was observed down to a reading of 32.5 N/mm², after which it increased at 90°. This indicates that fiber orientations in whichever corresponding or abrupt directions of loading greatly improve tensile strength. At 0°, the fibers will resist the axial load directly, whereas at 90°, the load can be transferred through the matrix and transverse fibers, providing a different type of resistance. This behavior shows that fiber positioning with reverence to the track of load is important in establishing the tensile response of the composite.

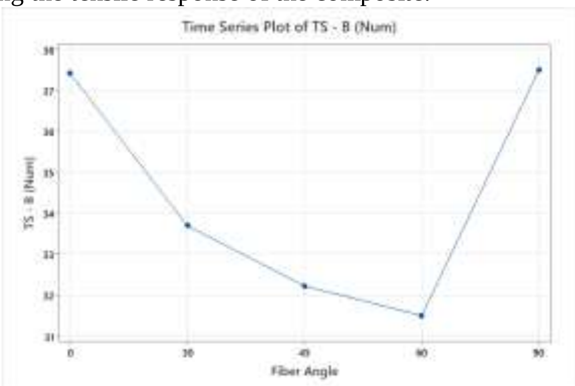



**Figure 14: Tensile strength of Banana composite laminate at different fiber angles**

The flexural strength also fluctuated with fiber orientation, and maximum strength was seen at 90° (84.72 N/mm²) and 45° (84.5 N/mm²). These values are indicative of the best fiber orientations in terms of resistance against bending loads. The trend exhibited moderate variations between other fiber orientations, revealing that some orientations, particularly the mid-angles such as 45°, facilitate more effective stress transfer via the fiber-matrix interface under flexural loading. The resistance of the fiber to bending is a function of its location in the cross-section with respect to the moment applied. At 90°, fibers are in a better position to resist tensile and compressive stresses formed on either side of the neutral axis under flexural loading.

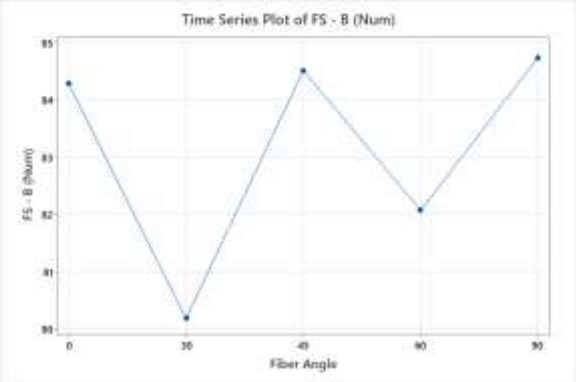



**Figure 15: Flexural strength of Banana composite laminate at different fiber angles**

For compressive strength, the greatest values were once more at 90° (25.73 N/mm²) and 0° (24.62 N/mm²). From 0° to 60°, the compressive strength fluctuated, pointing to a less stable response to fiber orientation than with tensile and flexural behaviors. The enhanced performance at 0° and 90° can once more be explained by the orientation of the fibers in directions that are more resistant to axial compressive loads. At intermediate angles, fiber buckling and matrix-fiber debonding can more readily occur, causing reduced strength.

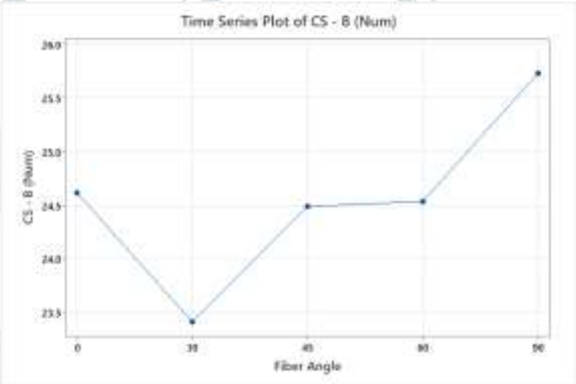



**Figure 16: Compressive strength of Banana composite laminate at different fiber angles**

The overall results emphasize the profound impact of fiber alignment on the machine-driven property of BFRC. The improved mechanical performance at 0°, 45°, and 90° orientations in all three strength parameters—tensile, flexural, and compressive—indicates that strategic fiber orientation could be employed to manipulate composite properties for structural applications. These results reinforce the viability of banana fiber composites in engineering fields where light, biodegradable, and economical materials with consistent mechanical strength are needed. In addition, the measured mechanical behavior is in good agreement with theoretical predictions, highlighting the significance of fiber architecture in composite design.

## 6. CONCLUSIONS

The current research endeavored to analyze the mechanical possessions of banana fiber-reinforced epoxy composite and compare experimental outcomes by means of numerical~analysis at different orientations of fibers. Tensile, flexural, and compressive strengths of laminates prepared by bidirectional banana fiber fabric (0°–90°) were tested. The experimental tensile strength was determined to be 34.37 N/mm² with 5.32% variation with numerical analysis. The recorded flexural strength was 85.21 N/mm², which only had a 2.69% deviation from the numeric values. For compressive strength, the laminate had 22.49 N/mm², a 9.46% deviation being noted in the numeric.

Additionally, the numerical simulations were conducted at fiber orientations of 0°, 30°, 45°, 60°, and 90°. Of these, the 90° orientation provided the highest strength, followed by that of 0°, agreeing with these as the best angle(s) for mechanical properties. Results prove that either the use of 0°, 90°, or a bidirectional fabric made from both (as indicated above) greatly improves the mechanical belongings of BFRC.

According to this, it is concluded that 0° and 90° oriented banana fiber composites are the most suitable for uses demanding superior tensile strength, flexural strength, lightweight structure, and heat stability, and hence they can be used for any number of industrial and structural applications.

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