INVESTIGATION MECHANICAL PROPERTIES OF RAW BANANA FIBRE HYBRID BIOCOMPOSITE

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ABSTRACT

In this paper, the mechanical properties like Tensile Strength, Flexural Strength and Impact Strength of Raw Banana-Kenaf fibers Hybrid Epoxy Biocomposite are investigated experimentally as well as theoretically. Banana fibers and Kenaf fibers are natural ecofriendly fibers. They can be used along with Epoxy resin Matrix to prepare composite material. In this work, three different kinds of Laminates were prepared. One laminate is 30% Banana fiber epoxy Biocomposite, the second laminate is Hybrid 15% Banana-15% Kenaf alternate layers epoxy Biocomposite and the third laminate is Hybrid 15% Banana-15%Kenaf cumulative layers epoxy Biocomposite Epoxy Resin LY556 is used as a matrix material. Tensile test specimen is prepared as per ASTM D3039 standards. Flexural Test specimen is prepared as per ASTM D 790 and Izod impact test is specimen is prepared as per ISO 180 Standards. All specimens are prepared by Hand Layup process. For Finite Element Analysis, Theoretical values of Young’s Modulus, Poisson’s ratio and Shear Modulus were used. FE Analysis is done on ANSYS APDL 14 Software. The results show that such hybrid Biocomposite can be used as an alternate material for plastics.

Keywords— Banana Composite, Biocomposite, Kenaf Composite, Banana-Kenaf Hybrid Biocomposite, Epoxy Biocomposite

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1. INTRODUCTION

Composite material can be defined as the material which is composed of two or more distinct material on macro scale with different properties to form a new material with a property that is entirely different from the individual constituents. The primary phase of a composite material is called a matrix having a continuous character. In other words, matrix is a material which acts as a binder and holds the fibers in the desired position thereby transferring the external load to reinforcement. These matrixes are considered to be less hard and more ductile. The composite material consists of a matrix along with a fiber with some filler material.

Based on the matrix used, composite material can be divided into three types i.e. Metal Matrix Composite (MMC), Polymer Matrix Composite (PMC) and Ceramic Matrix Composite (CMC). The selection of any of the above composite material depends upon the type of application. The most commonly used composites are polymer matrix composite.

Composite materials have a long history of usage. For example, straw was used by Mesopotamians to strengthen mud bricks. Plywood was used by ancient Egyptians when they realized that wood could be rearrange to achieve superior strength, resistance to thermal expansion as well as swelling due to the presence of moisture. Medieval swords and armors were made by using layers of different materials. Composite materials are formed by combining two or more dissimilar materials that have quite different properties.

Although natural resins (resins derived from bio materials) and green composites (natural resins reinforced with natural fibers), which are biodegradable, are being developed, at present, only natural fibers reinforced plastics are the best possible solution for reducing the dependency on petroleum based products.

![Composite Material](image)

Fig. 1 – Composite Material

2. LITERATURE REVIEW

V.P. Arthanarieswaran, A. Kumaravel, M. Kathirselvam [1] evaluated mechanical properties of Banana- Sisal-Glass fiber epoxy composites. They have compared mechanical properties like

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Tensile Strength, Flexural Strength, Impact Strength of different kinds of stacking sequences of Banana, Glass and Sisal fibers. Experimentally they found Tensile Strength of Banana and Sisal composites 21MPa & 23MPa respectively; (Banana + Sisal) Hybrid composite 25MPa; (Banana + Sisal + Glass) composite as 104 MPa. Whereas flexural Strength of Banana and Sisal composites 56 & 62MPa respectively followed by (Banana + Sisal) Hybrid composite as 61MPa and (Banana + Sisal + Glass) hybrid composite as 192 MPa. Izod Impact test had given results as Banana and Sisal composites 7.6 J & 8.4 J respectively; followed by (Banana + Sisal) Hybrid composite 7.4 J and (Banana + Sisal + Glass) hybrid composite as 13.3 J.

V.S. Srinivasan, S. Rajendra Boopathy, D. Sangeetha, B. Vijaya Ramnath [2] evaluated mechanical properties of Banana-Flax-Glass fiber based hybrid Biocomposite. They have prepared Hybrid Epoxy Biocomposite specimens with different layers of Banana, Flax and Glass fiber for Tensile, Flexural and Impact Test. They concluded that hybrid composite has far better properties than single fibre reinforced composite under impact and flexural loads.

R. Bhoopathia, M. Ramesha, C. Deepa [3] evaluated properties of Banana-Hemp-Glass Fiber Reinforced Composites. Tensile, Flexural and Impact Testing of fabricated specimens were carried out. Banana with Glass fiber composite has highest tensile strength of 39.5MPa followed by Hemp with Glass fiber composite with 37.5MPa and (Banana + Hemp + Glass fiber) composite has 28 MPa. Flexural load for all is near to 0.5 kN. Impact strength of (Banana + Glass Fiber) composite was 5.5 J on the other hand (Banana + Hemp + Glass fiber) composite has 8.3 J.

R. Badrinath and T. Senthilvelan [4] compared mechanical properties of Banana and Sisal epoxy composites. They had manufactured unidirectional (UD) as well as bidirectional (BD) three layered composites by Hand Lay-up technique. UD sisal fiber composite has tensile strength of 56.5 MPa, Flexural strength of 26.4MPa and Impact strength of 1.3 kJ/m2 whereas UD Banana fiber composite has tensile strength of 20 MPa, Flexural strength of 33.5 MPa, and Impact strength of 2.5 kJ/m2. BD sisal fiber composite has tensile strength of 16 MPa, Flexural strength of 96.375 MPa and Impact strength of 1.35 kJ/m2 whereas BD Banana fiber composite has tensile strength of 32.5 MPa, Flexural strength of 33.49 MPa, and Impact strength of 2.8 kJ/m2.

N. Venkateshwaran, A. Elaya Perumal and D. Arunsundaranayagam [5] investigated effect of surface treatment on mechanical properties of Banana/Epoxy composite. They had treated banana fibers with different percentages varied from 0.5% to 20% NaOH solution for surface modification. They concluded that 1% NaOH treated banana fibers provides better mechanical properties, but increasing the alkali concentration results in fiber surface damage, and decreases the mechanical properties.

Paul, K. Kanny, G.G. Redhi [6] studied mechanical properties of Banana Fiber and novel Banana Sap based resin. They found Tensile strength of Banana Sap based composite as 26.5 MPa and flexural strength of 32.3 MPa. While Tensile strength of Banana fibers with normal polymer resin composite we 22.2 MPa, but there was no any significance change in Flexural strength.

Toshihiko HOJO, Zhilan XU, Yuqiu YANG, Hiroyuki HAMADA [7] compared Tensile Properties of Bamboo, Jute and Kenaf Mat-Reinforced Composite. Tensile testing specimens of
Bamboo, Jute and Kenaf Biocomposite were fabricated. Tensile test of all specimens is done to obtain stress-strain curves. Kenaf fiber composite has highest tensile strength of 27.9 MPa then Jute composite has 23 MPa followed by Bamboo composite which has 22.4 MPa. There were no considerable changes in Tensile Strengths after Low Cycle Fatigue (LCF) of specimens.

2.1 Problem Statement

- Fabrication and Strength Analysis Banana-Kenaf fibers Hybrid Biocomposite.
- Experimentation and Theoretical study of effect of hybridization, layering pattern

2.2 Objectives

- Study of Natural Fibers and Biocomposite from Literature Survey
- Fabrication of Epoxy based Banana-Kenaf fiber Hybrid Biocomposite specimens
- Finite Element Analysis of Biocomposite
- Evaluation of Mechanical behavior (Tensile, Flexural and Impact) of Fabricated testing specimens by Experimentation and Finite Element Analysis
- Investigation of effect of Hybridization and layering pattern of fibers on strength
- Eco-Friendly low cost preparation of New Hybrid Natural Fiber Biocomposite Material useful for Society.

3. METHODOLOGY

A. Materials

i. Banana Fibers-

The banana fibers are 3 to 4 feet long and they are extracted from the pseudo stem of the banana plant (Musa species). The stalk of banana plant is cut and its outer sheath is removed. Then these stalks are crushed in Banana Extractor Machine. This machine removes the pulpy material between the fibers.

Extracted fibers are washed by water and dried in sunshine to remove the moisture content.

ii. Kenaf Fibers [8]-

Kenaf fibers are 4 to 5 feet long and they are extracted from Bark and core of kenaf tree. Kenaf fibers are used to make ropes, canvas, and sacking. Kenaf now days used as an alternative raw material in place of wood used in pulp and paper industries to avoid the destruction of forests. It has also been used to make non-woven mats in the automotive industry and textiles.

iii. Epoxy resin and Hardener-

Mixture of Epoxy resin LY 556 (diglycidyl ether of biphenyl- A) and Hardener HY 951 are used in 9:1 by weight ratio [2]. This acts as a matrix material for composite. This resin has good binding properties [2].
Properties of Banana Fibers and Kenaf Fibers [1, 12] are explained in Table 1.

Table 1- Properties of Banana and Kenaf Fiber

<table>
<thead>
<tr>
<th>Properties</th>
<th>Banana Fiber</th>
<th>Kenaf Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>1350</td>
<td>1400</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>56</td>
<td>350</td>
</tr>
<tr>
<td>Young’s Modulus (GPa)</td>
<td>3.5</td>
<td>40</td>
</tr>
</tbody>
</table>

Fig. 2 – Banana Fiber

Fig. 3 – Kenaf Fiber

B. Manufacturing

The weighted quantity of banana and Kenaf fibers are taken. Epoxy resin and hardener are mixed in 9:1 ratio by weight. In this work three different composite laminated plates were fabricated. For all composite plates total fibers content is kept 30% and Matrix material is kept 70% by weight fraction. One plate is 4 layer bi-directional 30% Banana Fiber composite (BD B-B-B-B). Second Plate is 4 layer unidirectional 15% Banana + 15% Kenaf fibers alternate layers composite (UD B-K-B-K). Third Plate is 4 layer 15% Banana + 15% Kenaf fibers cumulative layers composite (UD B-B-K-K) [11]. Firstly all fibers are washed with 6% NaOH solution [9] to remove lignin and other impurities from fibers. Then they are dried in sunlight to remove all moisture. All fibers are combed and arranged in one direction. Plain uniform layer of fibers is skillfully prepared. A mold of 200 X 100 X 4 mm is prepared for Hand lay-up process. Good quality polythene sheet was used as a barrier between mold and epoxy resin so that after curing of resin, it should not stick into the mold. Weighed quantity of we stirred mixture of Epoxy resin is spread uniformly on each layer of fibers by brush as shown in fig. 4.
Hand- Gloves were necessary to avoid contact with resin. Finally weight of 100N is put on laminated plate and allowed this to get cured for 8 to 10 hours.

Once this plate is formed, it is cut to prepare testing specimens. Tensile testing specimen is prepared as per ASTM D3039 standard in the form of Dumb-bell shape with overall dimensions 200mm length, 20 mm width and 4 mm thick. In dumbbell shape gauge length kept for testing is 100mm and 50 mm on both sides is kept for mounting on UTM. In the testing area width of dumbbell was 12mm. Flexural test specimen is prepared as per ASTM D 790 Standard with dimension 127 mm in length, 13mm width, 4 mm thick. Distance between supports at the time of testing was 64mm. Izod impact test specimen is prepared as per ISO 180 standard with dimensions 80mm length, 10mm width and 4mm thick with small 2mm deep 45° V-Notch. All specimens are shown in Figure 5.
4. THEORETICAL CALCULATIONS

Composite material can be considered as orthotropic material. Theoretically we can calculate Elastic Constants in X and Y directions (E1 and E2) by considering this as a plain stress case. For simplicity we can assume E2 = E3.

If Ef is Elastic Constant of Fiber and Em is Elastic Constant of matrix [15] then, for given volume fraction Vf,

\[ E1 = Ef \cdot Vf + Em \cdot (1 - Vf) \]

As per Halphin–Tsai equation

For this analysis, Poisson’s ration is assumed to be 0.35.

If we know Young’s Modulus and Poisson’s ratio (ν) then we can easily find Shear Moduli, G1 and G2 by formula.

With the help of above formulae all theoretical constants are calculated as given in Table 2

Table 2- Calculated Material Properties for FE Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Banana</th>
<th>Kenaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume Fraction</td>
<td>Vf</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Young’s Modulus of Fiber</td>
<td>Ef (GPa)</td>
<td>3.5</td>
<td>53</td>
</tr>
<tr>
<td>Young’s Modulus of Matrix</td>
<td>Em (GPa)</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>ν</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Longitudinal Young’s Modulus</td>
<td>E1 (GPa)</td>
<td>2.94</td>
<td>17.79</td>
</tr>
<tr>
<td>Halphin–Tsai Factor</td>
<td>β</td>
<td>0.089</td>
<td>0.86</td>
</tr>
<tr>
<td>Transverse Young’s Modulus</td>
<td>E2 (GPa)</td>
<td>1.08</td>
<td>2.04</td>
</tr>
<tr>
<td>Longitudinal Shear Modulus</td>
<td>G1 (GPa)</td>
<td>1.08</td>
<td>6.58</td>
</tr>
<tr>
<td>Transverse Shear Modulus</td>
<td>G2 (GPa)</td>
<td>0.4</td>
<td>0.75</td>
</tr>
</tbody>
</table>

5. FINITE ELEMENT ANALYSIS (FEA)

FEA is done on ANSYS APDL 14.0 Software. In FE analysis, from the experimental values of deflection, Stress values are plotted. For composite material Shell 181 element type is selected [14]. The element has four nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y and z axes. Thus each element has 24 degrees of freedom in total. In this work FE analysis is done for Tensile and Flexural Behaviour. Material properties are defined from Table 2. For Tensile testing dumbbell shape specimen is modeled using proper key-points. Then its one side is fixed and displacement is applied on other side. The value of displacement is equal to experimental value of elongations. From applied displacement we can get von-mises stress values. Figures 5 and 6 show FE Analysis of Tensile Test. Similarly flexural test specimen is also modeled and its two ends are fixed. Then Experimental value of displacement is applied on middle of specimen. In the result, von-mises stress is plotted.
6. EXPERIMENTATION

1. Tensile Test - Tensile test is done to determine tensile strength. Tensile strength is an ability of substance to stretch without breaking under tension. For epoxy composites, tensile test is done as per ASTM D 3039 standards [1]. It is done on Universal Testing Machine (UTM). The specimen is held on UTM Jaws and allowed to stretch with rate of 5mm/min. From this test Tensile Strength, Young’s Modulus, can be determined.

2. Flexural Test - This is also called as three point bending test. Flexural tests were performed on an UTM, using the three-point bending fixture according to ASTM D 790-10 standard [1]. Crosshead speed is 5 mm/min. The distance between supports was kept at 16 times thickness of Specimen. From this test, Flexural Strength is determined. Maximum load at failure was used to determine flexural strength.

3. Impact Test - Izod Impact test is carried out as per ISO 180 standards [10]. Notched specimens were fixed in Izod Impact Test machine and broken by single shot of Pendulum. Velocity of pendulum was 6m/s. This test determines amount of energy required to break under impact which is related to toughness of material.

7. RESULTS AND DISCUSSION

1) Tensile Strength
Elongation is directly proportional to the load applied till the specimen breaks. It was found that tensile strength of unidirectional hybrid composite is more than that of Bidirectional composite. Tensile Properties of Laminates are explained in Table 3. Tensile Strength of UD BBKK is 72.35 MPa which more than that of UD BKBK which is 64.46 MPa. Tensile Strength of BD BBBB composite is 43MPa which is lowest. Figure 10 shows Load Vs Elongation graph of tensile tests.

Fig. 11 Load Vs Elongation graph of Tensile Tests
Table 3 Tensile Behavior

<table>
<thead>
<tr>
<th>No.</th>
<th>Specimen Type</th>
<th>Tensile Load (N)</th>
<th>Deflection (mm)</th>
<th>Tensile Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BD B-B-B-B</td>
<td>1580</td>
<td>4</td>
<td>43.07</td>
</tr>
<tr>
<td>2</td>
<td>UD B-K-B-K</td>
<td>3430</td>
<td>7.69</td>
<td>64.46</td>
</tr>
<tr>
<td>3</td>
<td>UD B-B-K-K</td>
<td>3816</td>
<td>8.7</td>
<td>72.35</td>
</tr>
</tbody>
</table>

2) Flexural Strength
Flexural test also shows similar trend as tensile behavior. In flexural strength top layers get under compression whereas bottom layers get under tension. Flexural strength of BD BBBB is 60MPa whereas those of UD BKBK and UD BBKK are 131.74 MPa and 144.1 MPa respectively. Table 4 and Fig. 6 show flexural analysis.

Table 4 Flexural Behavior

<table>
<thead>
<tr>
<th>No.</th>
<th>Specimen Type</th>
<th>Flexural Strength (MPa)</th>
<th>Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BD B-B-B-B</td>
<td>60</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>UD B-K-B-K</td>
<td>131.74</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>UD B-B-K-K</td>
<td>144.1</td>
<td>10</td>
</tr>
</tbody>
</table>

Fig. 12 Flexural Tests Results

3) Impact Strength
Impact strength of UD BKBK is found to be highest then followed by UD BBKK and that of BD BBBB is lowest. Table 5 shows impact strength of specimens.
4) Comparison of FEA and Experimental Results

Values of FE analysis are more than Experimental results, because of defects in manufacturing. These defects are Presence of Voids in composite, Moisture content in fiber etc. Comparison of FE results and Experimental Results and deviation is given in table 6 and 7.

<table>
<thead>
<tr>
<th>No.</th>
<th>Specimen Type</th>
<th>Impact Strength(KJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BD B-B-B-B</td>
<td>1.85</td>
</tr>
<tr>
<td>2</td>
<td>UD B-K-B-K</td>
<td>15.9</td>
</tr>
<tr>
<td>3</td>
<td>UD B-B-K-K</td>
<td>8.93</td>
</tr>
</tbody>
</table>

8. CONCLUSION

1. There is difference in FEA results and Experimental results due to manufacturing defects in Hand lay-up process. While doing hand lay-up, many air bubbles get trapped in the laminate. Being project of composite material design and characterization, FE analysis is just done for the sake of showing how we can apply material properties to analyze composite laminates using ANSYS APDL. So experimental results are more considerable than FEA results.
2. Tensile, Flexural and Impact properties of Unidirectional Hybrid Banana + Kenaf fibers Biocomposite are more than Bi-Directional Banana Biocomposite.
3. Layering sequence also plays important role in Biocomposite. In this work it is found that cumulative staking i.e. B-B-K-K has more Tensile and Flexural strength than alternate staking i.e. B-K-B-K. On the other hand Cumulative staking (B-B-K-K) has less impact strength than alternate staking (B-K-B-K).
4. Hybrid Banana- Kenaf Epoxy Biocomposite can be used in various decorative automotive interior parts like door panel parts, instrument panel parts etc., and also it can be used for domestic furniture applications.

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REFERENCES


