Investigation of Mechanical Properties of Epoxy Resin Based E-Glass and Banana/Kenaf Hybrid Composite Materials.

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ABSTRACT

In this project we study the mechanical properties of natural composite materials like banana and kenaf fibers reinforced with E-glass fiber materials. The objectives of the natural fiber composite to develop a sustainable, high-performance composite by combining the strength of synthetic fibers with the environmental benefits of hybrid composite materials. The E-glass fiber provides the structural integrity and durability, while banana and kenaf fibers contribute biodegradability, low density and cost-effectiveness. The hybrid laminates were fabricated using hand lay-up and compression molding techniques with various stacking sequences. The hybrid composites exhibit a balanced combination of stiffness, strength, and thermal resistance, with certain stacking configurations outperforming results. The incorporation of natural fibers reduced overall weight and improved environmental sustainability without significantly compromising performance and making these composites suitable for applications in automotive, construction, and consumer products.

INTRODUCTION

The Natural fiber-reinforced composites have gained significant importance in modern engineering due to their lightweight nature, high strength-to-weight ratio, and environmental advantages [1]. The E-glass fiber combined with epoxy resin is widely recognized for delivering excellent thermal and mechanical properties, making it suitable for high-performance applications such as aerospace, automotive, and marine components [2]. The growing need for sustainable and eco-friendly alternatives has led to increased interest in natural fibers like banana and kenaf. Banana fiber, sourced from the plant's pseudostem, and kenaf fiber, known for its rapid growth and high cellulose content, both offer good mechanical properties and low environmental impact, when they are used either alone or in hybrid form with E-glass, these fibers can enhance the tensile, flexural, and impact strengths of composite materials [3-4].The integration of natural fibers in composites offers a promising route toward greener, cost-effective materials, and further research on fiber treatment, hybrid configurations, and material optimization could expand their application across industries [5].

The Banana and kenaf fibers are two promising natural reinforcements increasingly used in the development of sustainable composite materials [7]. Banana fiber is lightweight, biodegradable, and exhibits good tensile strength and stiffness due to its high cellulose content [8-9]. Its availability as agricultural waste makes it an environmentally and economically attractive option**.** The Kenaf fiber plant is also known for its high tensile strength, low density, and fast growth rate [10]. It contains cellulose, hemi-cellulose, and lignin, which contribute to its mechanical integrity and biodegradability [11]. These fibers are used in hybrid composites with synthetic fibers like **E-**glass and embedded in epoxy resin, both banana and kenaf fibers enhance mechanical performance, including tensile, flexural, and impact strength [12]. The combination of these natural fibers not only improves load-bearing capabilities but also supports the development of lightweight, cost-effective, and eco-friendly materials suitable for structural and automotive applications [13].

The epoxy resin is a widely used thermosetting polymer known for its excellent mechanical strength, chemical resistance, and strong adhesion to various materials [14]. Its rigid molecular structure provides high dimensional stability, making it an ideal matrix material for composite applications [15]. In the development of hybrid composites, epoxy resin acts as a binder that holds reinforcing fibers—such as E-glass, banana, and kenaf—together, effectively transferring loads between the fibers and distributing stress throughout the material, this enhances the overall performance of the composite under tensile, flexural, and impact conditions [16-17]. Due to its low shrinkage, good thermal resistance, and ease of processing, epoxy resin is extensively used in high-performance sectors such as aerospace, automotive, marine, and structural engineering [18]. The natural fibers like banana and kenaf are incorporated into an epoxy matrix alongside synthetic fibers like E-glass, the resulting hybrid composite benefits from a balance of strength, stiffness, and environmental sustainability [19].

sisal and **banana fibers** focuses on enhancing strength, stiffness, and durability using natural materials. Combining sisal and banana fibers offers a balance of mechanical performance, as sisal provides good tensile strength and rigidity, while banana fibers contribute flexibility and impact resistance [20]. Then used together in an epoxy matrix, these fibers can create lightweight, eco-friendly composites with improved tensile, flexural, and impact properties compared to single-fiber composites [21]. jute are natural lingo-cellulosic fibers commonly used in composite materials due to their mechanical strength and environmental advantages [22]. Sisal, derived from Agave sisalana leaves, offers high tensile strength and moisture resistance, making it suitable for durable composites [23]. These fibers are combined with synthetic materials like E-glass in an epoxy resin matrix, they improve properties such as impact resistance and flexural strength [24]. These hybrid composites are ideal for sustainable and economical use in automotive parts, construction, and consumer products [25].

The hand lay-up technique is one of the simplest and most cost-effective fabrication methods used to produce fiber-reinforced composite materials. In this process, fibers such as E-glass**,** banana and kenaf fibers are manually arranged in layers within a mold, and epoxy resin is applied over them to ensure proper impregnation [26].The tensile strength of the material, increasing it from 37.2 MPa to 84 MPa. This improvement was achieved through hybridization, where the strategic arrangement of natural and synthetic fibers played a key role. While different stacking sequences had minimal effect on tensile strength.

METHODOLOGY

FORMULAS FOR CALCULATION :

$$E_x = E_f V_f + E_m V_m$$

Where,

E_f is the fiber modulus of elasticity, N/mm2
E_m is the matrix (resin) modulus o f elasticity, N/mm2
V_f is the fiber volume ratio
V_m is the matrix volume ratio
Vf + Vm = 1 with zero voids
The fibre ratio can be derived from the fibre / resin volume ratio.
We have,

$$V_f = 1 - V_r - V_{voids}$$

$V_f = 1 - V_r$ Where,

V_f = fiber volume

V_r = matrix or resin volume

Determine the fiber matrix volume ratio :

And we have,

$$\frac{V_f}{V_r} = \frac{1}{1+(\frac{V_f}{V_r})}$$

From the above equation we can find the fiber/resin weight ratio.

We have,

$$\frac{V_f}{V_r} = (\frac{W_f}{W_r})(\frac{\rho_r}{\rho_f})$$

From the above equation we can get $(\frac{W_f}{W_r})$

The resin weight is the difference between the composite and fiber weights.

Wmatrix = Wcomposite – Wfibre

Substitute the determined values in above equation we can find the W matrix and W fibre.

Density of Epoxy Resin = 1.15g/cm3

Banana fibre =1.35g/cm3

Glass fibre =2.62g/cm3

Kenaf fibre = 1.5g/cm3

Weight of resin (W*m*) = (1.15) x (20x20x0.8) x (0.738) = 271.58gm

Weight of fibre (*Wf*) = (2.26) x (20x20x0.8) x (0.262) = 189.47gm

1: Preparation of Composites:

Composites	**Compositions**
S1	Epoxy (75wt %) +Glass Fibre (20wt.%)+banana Fibre (Fibre length 10 mm) (5wt %)
S2	Epoxy (75wt %) +Glass Fibre (20wt.%)+banana Fibre (Fibre length 15 mm) (5wt %)
S3	Epoxy (75wt %) +Glass Fibre (20wt.%)+banana Fibre (Fibre length 10mm) (5wt %)
S4	Epoxy (75wt %) +Glass Fibre (20wt.%)+banana Fibre (Fibre length 15 mm) (5wt%)

The two composite formulations were developed using epoxy resin as the matrix material with identical weight fractions of reinforcing fibers but varying fiber lengths. Both compositions contained 75% epoxy resin, 10% banana fiber, 10% kenaf fiber, and 10% E-glass fiber by weight. In the first formulation, the natural fibers—banana and kenaf—were cut to a length of 10 mm, while in the second formulation, these fibers were increased to 15 mm in length. The E-glass content and resin percentage remained constant in both cases. This variation in fiber length aims to assess the influence of fiber size on the mechanical and structural performance of the composite materials.

Figure 1: Banana Fibre

Figure 2: Kenaf Fibre

Figure 3: E-Glass Fiber

Figure 4: Epoxy Resin

Figure 5: Sample Of Epoxy Resin

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TESTING METHODS:

TENSILE TEST:

The tensile test was conducted in Universal testing machine .The test specimen was cut according to the ASTM D-638 standard. The test specimen of dimension 20x20x0.8 mm is prepared as in figure. The test specimen is enclosed between the grippers of the Universal testing machine. The load is applied gradually until the deformation of the specimen is observed. The corresponding value of the load is noted down for the deformation of the specimen. The stress for the corresponding load is calculated. Figure 6 shows the experimental set up for tensile test, Figure 7 shows the before tensile test, Figure. 8 shows the after tensile test.

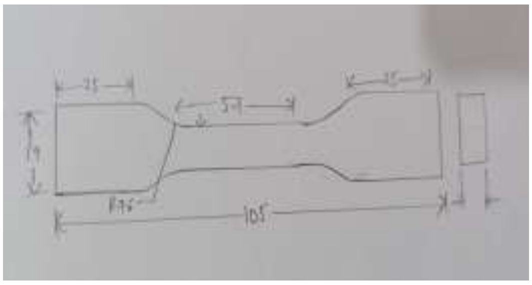
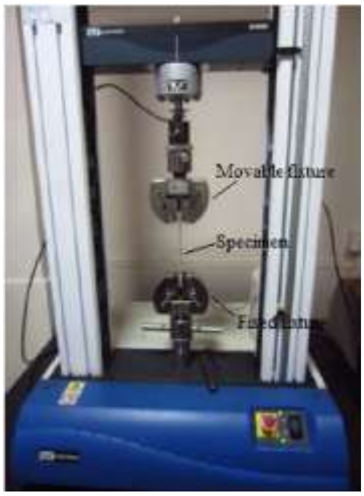


Figure 6: Tensile Test Specimen (ASTM D–638)



UTM Machine testing

Figure7:Tensile Test

(Before Tensile Test)

Fig:8 Tensile Test

(After Tensile Test)

FLEXURAL TEST:

Flexural test was conducted in the three point bending test arrangement in a MCS 60UTE -60.specimen is cut according to ASTM D-790 standard. The test specimen of the dimension 20X20X0.8 mm is prepared. The test specimen is placed on the roller support at both the ends. The load is gradually applied from the top roller until the deformation is observed. The load value at the maximum deformation is noted down. Figure 9 shows the before flexural test. Figure 10 shows after flexural test. Figure 11 shows the experimental set up for flexural test

Figure 9: Flexural Test
(Before Testing)

Figure10: Flexural Test
(After Testing)

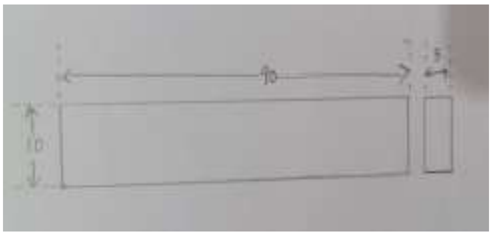


Figure 11: Flexural Test Specimen(ASTM D – 790)

IMPACT TEST:

An impact test is a mechanical test used to determine a material's ability to absorb energy and resist sudden shocks or impacts .The test specimenwas cut according to the ASTM D-256 standards. The test specimen of the dimension 20x20x0.8 mm is prepared.It involves striking a notched sample with a swinging pendulum and measuring the energy absorbed during fracture. This test helps assess the toughness and brittleness of materials, especially under rapid loading conditions. Common types of impact tests include the Charpy and Izod tests, and they are widely used in quality control and material selection for applications where impact resistance is critical. Figure 12 shows the experimental set up for impact test, Figure 13 shows the before impact test ,Figure 14 shows the after impact test.

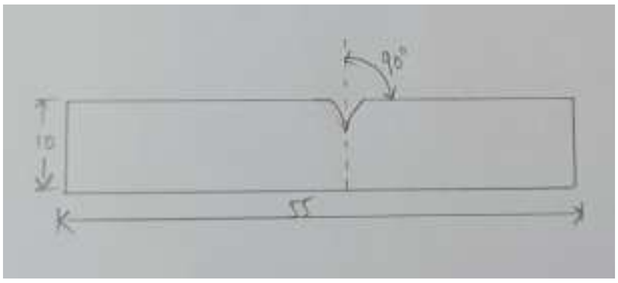


Figure12: Impact test specimen(ASTM D-256)

Figure13: impact test

(Before Testing)

Fig : 14 impact test

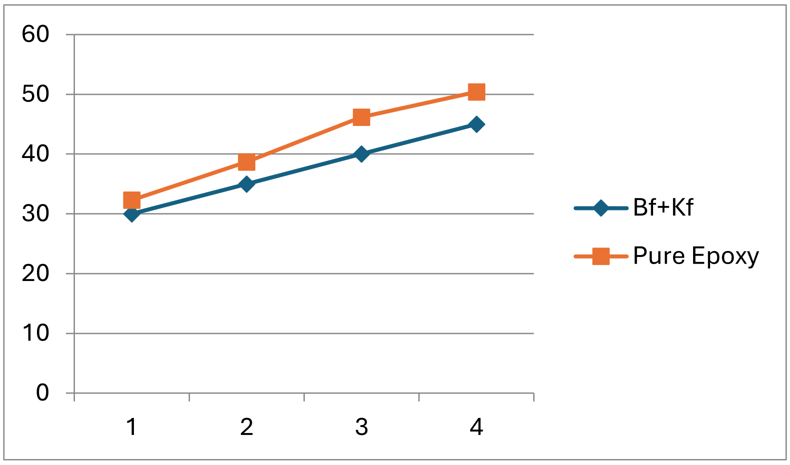
(After testing)

RESULTS AND DISCUSSION

Table 2: Short banana and glass fiber and Epoxy resin of composite materials for different volume fraction of fiber and resin

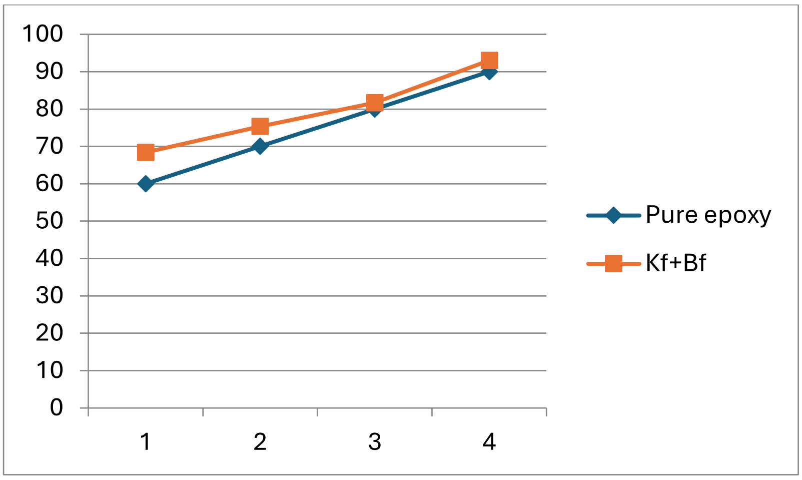
COMPOSITES	TENSILE STRENGTH MPa	FLEXURAL STRENGTH MPa	IMPACT STRENGTH MPa
S1	32.3	68.4	38.2
S2	38.7	75.3	42.7
S3	46.2	81.7	51.5
S4	50.4	93	65.7

Figure6. The effect of fiber loading and length on the tensile strength of composites.



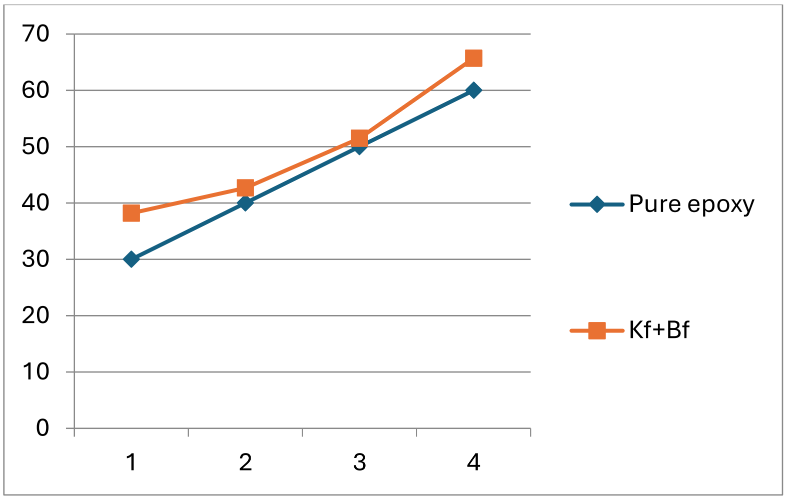
The graph illustrates the tensile strength comparison between banana fibe and kenaf hybrid composite materials composite and Pure Epoxy across four samples. The horizontal axis represents the sample sequence, while the vertical axis indicates the tensile strength values. Both materials exhibit a steady rise in tensile strength with increasing sample numbers. However, the pure Epoxy line (red) consistently shows higher tensile strength than the kenaf and banana fibers composite line (blue). Although the composite demonstrates gradual improvement, it remains slightly lower in strength compared to pure epoxy throughout the range. This indicates that while the composite has notable strength characteristics, pure epoxy retains superior tensile performance under similar testing conditions.

Figure7. The effect of fiber loading and length on the tensile strength of composites.



This graph represents the flexural strength comparison between pure epoxy and kenaf and banana fibers composite. The blue line corresponds to pure epoxy, while the red line represents the kenaf and banana fibers composite. It is observed that both materials exhibit a steady rise in flexural strength with increasing intervals along the x-axis. However, the kenaf and banana fibers composite consistently show slightly higher values than pure epoxy at each point, indicating improved load-bearing capability and enhanced resistance to bending. The overall trend suggests that the inclusion of keanf and banana fibers strengthens the epoxy matrix, leading to better flexural performance compared to the unreinforced epoxy.

Figure8. Effect of Fibre Loading and Length on the Impact Strength of Composites.



The graph illustrates the variation in impact strength for pure epoxy and a composite material containing kenaf and banana fibers .The horizontal axis represents the sample numbers, while the vertical axis shows the impact strength values. Both materials demonstrate a positive trend, indicating an increase in impact strength with each successive sample. Pure epoxy starts at a lower value compared to the kenaf and banana fibers composite but gradually rises as the sample number increases. The kenaf and banana composite consistently exhibits higher impact strength across all samples, with a more significant improvement at higher sample numbers. This suggests that incorporating kenaf and banana fibers enhances the material's ability to absorb energy upon impact compared to pure epoxy.

CONCLUSION

The investigation into epoxy resin–based hybrid composites reinforced with E-glass and natural fibers such as banana and kenaf fiber has shown that hybridization significantly enhances mechanical performance compared to composites reinforced with only natural fibers. By combining the high strength of synthetic E-glass fiber with the lightweight and sustainable nature of banana and kenaf fibers, these hybrids offer improved tensile strength, flexural strength, and impact resistance.

Among the tested configurations, composites with a balanced ratio of natural and synthetic fibers particularly those using 10–20% banana or kenaf fiber combined with 20–30% E-glass—tended to deliver optimal performance. The inclusion of E-glass enhances structural stiffness and load-bearing capacity, while banana and kenaf fibers contribute to weight reduction and better impact absorption.

The natural fiber composite materials are used in various applications, such as interior panels (door panels, dashboards and trunk liners), insulation materials, sound proofing components and in aerospace wings.

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