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Mechanical Properties of Banana Fabric and Kenaf Fiber Reinforced Epoxy Composites: Effect of Treatment and Hybridization

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Abstract: *Nowadays, Natural Fiber Reinforced composites (NFCs) are emerging to be a good substitute for synthetic fiber reinforced composites as NFCs have many advantages such as low density, high specific strength, recyclability, low cost and good sound abatement quality etc. Among all types of NFCs, a vast study has been done on banana fiber and kenaf fiber reinforced composite. However, only limited work has been done on the banana fabric, kenaf fiber reinforced composite and the effect of their hybridization on mechanical properties.*

In this paper, an attempt has been made to study the mechanical properties of the banana fabric, kenaf fiber and hybrid banana fabric/kenaf fiber reinforced composites. Effect of alkali treatment on kenaf fiber reinforced composite is discussed in the paper. For the present work, plain-woven banana fabric and randomly oriented kenaf fiber are used as reinforcement while the epoxy resin is used as a matrix. samples are fabricated using hand lay-up and vacuum bagging method. Curing is done at ambient temperature (25^{0}C-30^{0}C) for 48h. Tensile, impact and hardness test has been performed on a specimen according to ASTM standards. Improvement in mechanical properties is observed after alkali (6% NaOH) treatment on kenaf fiber reinforced composite. Tensile testing behavior of randomly oriented kenaf fiber composite has been studied using Finite element method and results are compared with experimental investigations. This topic present big potential because it seeks to find solution for sustainable development with environmental concerns.

Index Terms*: Alkali treatment, Banana fabric, Hand Lay-up, kenaf fiber, Hand Lay-up, vacuum bagging.*

I. INTRODUCTION

In the quest of sustainability, NFCs are found to be new emerging material. An increasing amount of interest has developed over the past few years in NFCs, especially due to weight saving, low cost, and attractive look [1]. As compared to synthetic fibers, NFC has high specific strength, low density, recyclability, and good sound abatement quality. NFCs have paved its way in applications such as space research, marine, automotive industry, sport, etc. [2, 3]. Especially, Natural fibers such as Bamboo, Banana, Kenaf, Hemp, jute, flax are showing good compatibility in automotive applications. [4,5]. One of the reasons for this growing interest in natural fibers, as it has higher specific strength than glass fiber and a similar specific modulus. The energy consumption to produce natural fiber is far less than synthetic fiber. Example, for 1kg of kenaf fiber 10-15MJ/kg energy needed while for the same glass fiber, consume about 54.7MJ/kg energy [3]. The main advantage of using natural fiber is they are biodegradable and recyclable, while synthetic fiber shows poor recyclable characteristics [4].

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Natural fibers can be used in FRPs as continuous, randomly oriented or as a woven textile for reinforcement. Woven textiles are found to be more attractive as they provide excellent integrity and conformability for advanced structural applications. [6]. Banana fibers Textile is available in various types such as plain woven, twill woven, satin etc. In present work, the plain-woven banana textile is used for reinforcement. Kenaf fiber belongs to a family of bast fiber. Kenaf fiber is shown best CO_2 absorption rate as well as possesses the best nitrogen and phosphorous absorption rate which is several times higher than other fibers [5]**.** Natural fibers generally contain chain of hydroxyl (OH) group which makes them polar and hydrophilic in nature. Most plastics are hydrophobic in nature. The addition of hydrophilic fiber to hydrophobic nature plastic leads to weaker composite characteristics due to non-uniform fiber dispersion and inferior fiber-matrix interphase [3]. As the kenaf fiber forms a hydrogen bond between each other making it difficult to wet surface and form the bond with the matrix. Alkali treatment removes certain hemicellulose, lignin, wax, and oil covering the external surface of the fiber responsible for Increase in surface roughness and possible reaction sites [7].

$$\text{Fiber-OH} + \text{NaOH} \longrightarrow \text{fiber-ONa}^{+} + H_2O$$

In present work, Epoxy is used as a matrix as it offers high performance and resistance to environmental degradation [4]. Hand lay-up technique is comparatively easy for composite manufacturing, in which reinforcement and resin applied simultaneously over the mold by hand and by roller air cavities are removed. In the vacuum bagging technique, fabricated hand lay-up composite part kept in a vacuum bag and air inside is removed by using a vacuum pump. This leads to the action of atmospheric pressure over the composite in every direction and it gets compressed uniformly [7]. Finite element analysis is carried out to study tensile behavior and experimental results are verified with a numerical model. Material properties required for finite element analysis are found out by mechanical testing [8].

A vast study has been done on kenaf and banana fiber reinforced composite. However, only limited work has been done on banana fabric reinforced composite and Hybrid banana fabric/kenaf fiber-epoxy reinforced composite.

Hybridization of banana woven and kenaf fiber chosen considering its attractive look and low weight. So, an attempt has been made to study the mechanical properties of the banana fabric, kenaf fiber and hybrid banana fabric/kenaf fiber reinforced composites.

II. MATERIALS AND METHODOLOGY

A. *Materials*

For the present work, the plain-woven Banana fabric and randomly oriented kenaf fiber are used as reinforcement.

Table I Required Materials and properties

	Material	Density (g/cc)
Reinforcement 1	Kenaf fiber	1.43
Reinforcement 2	Banana Fabric	1.2
Resin	Epoxy	1.52
Releasing agent	3M Wax	
Hardener		2.1

B. *Methodology*

1. Pre-treatment on kenaf fiber

The Kenaf fiber treated with 6% NaOH for 6h and then kept in distilled water for 8h to wash out impurities and cellulose on it. Then heated in the oven for 4h at 80^{0}C. Then kept it for drying at ambient temperature for 48h.

Fig. 1. **Treatment of kenaf fiber**

2. Composite fabrication

Hand Lay-up and vacuum bagging technique are used for the fabrication of specimens. For fabrication of kenaf fiber reinforced composite, kenaf fibers are chopped about 5mm length and mat is prepared in random oriented direction. For hybrid samples, the plain-woven banana fabric was placed at top and bottom and kenaf mat placed at the core. First, a releasing agent is applied to the mold after which reinforcement placed accordingly. Epoxy resin with 50% hardener applied. Excess epoxy is removed by using a metal roller. Waxed plastic sheets are used on top and bottom of the composite plate to get the good surface finish and removed after specimen got cured. Composite plates are fabricated measuring 300mm × 300mm × 3mm. This composite plate is placed in a vacuum bag and atmospheric pressure applied on it by removing the air inside the vacuum bag using vacuum pump. samples are cut using water jet machining according to ASTM standards. After which, about 25-30 kg of dead weight placed on it to remove further epoxy. After Hand Lay-up process, composite allowed a cure for 48h at ambient temperature (25-30^{o}C). After curing is done, the specimen needed to be cut for mechanical characterization for which, water jet machining is used to cut specimen according to standards which also provide the good surface finish.

Table II Symbol for composite samples

Composite	Symbol
Kenaf Untreated	KUT
Kenaf Treated	KT
Banana plain-Woven	B
Hybrid Banana/Kenaf	HBK

3. Testing

3.1 Tensile test

One of the most important properties used in structural or semi-structural applications. Tensile strength is the ability of a material to resist breaking under tensile load. The tensile strength of the composite was measured on a universal testing machine with 10mm/min crosshead speed according to ASTM D 638-14 standards. According to it, a specimen of dimension 200mm × 19mm × 3mm fabricated and tested with feed rate 5mm/min. Tensile strength and elastic modulus are evaluated from the tensile test. 3 samples of each KUT, KT, B and HKB composite is tested.

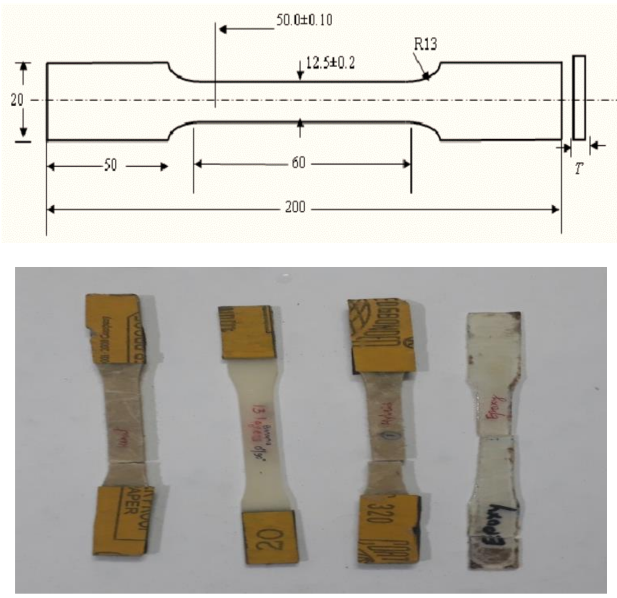
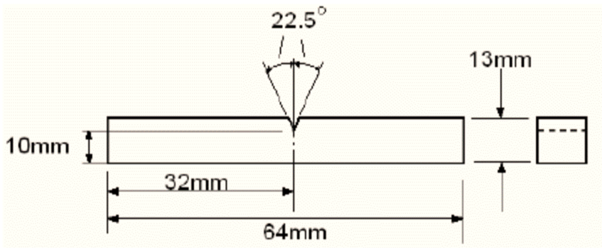


Fig. 2. Tensile testing

3.2 Impact test (Izod)

Izod test is done on the specimen with dimension 64mm × 10mm × 1.3mm by ASTM D 256-02 standards. Total 3 kenaf untreated and 3 treated samples are tested. 3 samples of each KUT, KT, B and HKB composite is tested.



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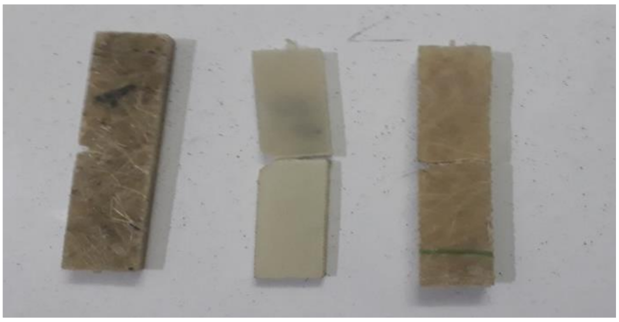


Fig. 3. Izod Impact Testing

3.3 Hardness test (Shore-D)

Hardness is characteristic of the material which defines resistance to indentation. sample of dimension 50mm × 50mm × 3mm fabricated according to ASTM D 2240-05 standards and test carried out on durometer (Shore D). 1 sample of each material is tested.

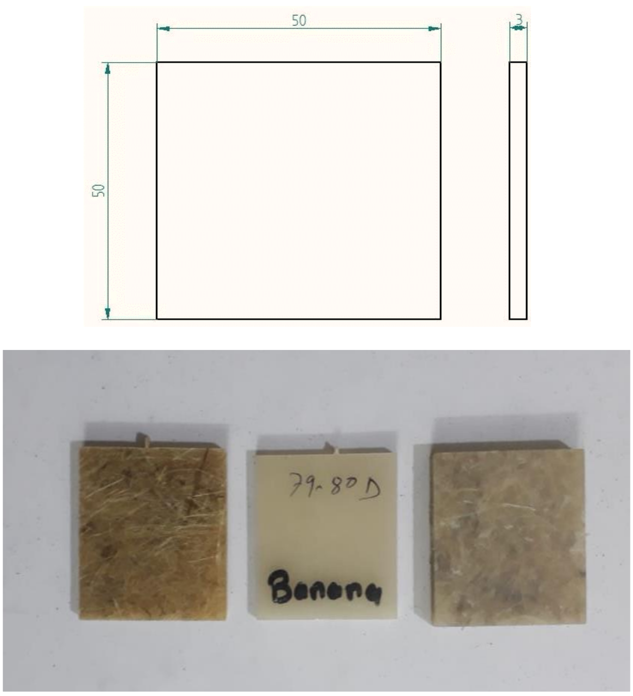


Fig. 4. Hardness shore D Testing

3.4 Finite Element Analysis

Tensile behavior of the kenaf sample is studied by using finite element analysis in ANSYS ACP. A kenaf sample model is generated in ANSYS ACP according to ASTM standards where randomly oriented kenaf fiber reinforced composite assumed to be orthotropic homogeneous core in nature and result are compared. Required input properties are taken from experimental investigations.

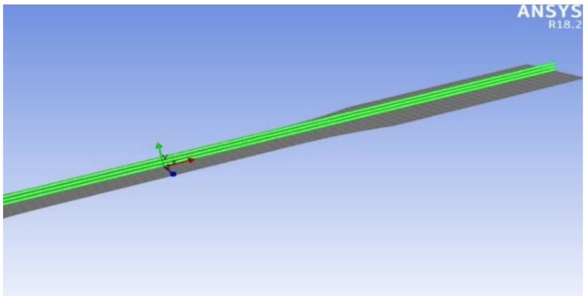


Fig. 5. Tensile testing using FEA

Rigid end support generated in the mechanical model as shown in fig. (5). Remote displacement is given to the one end about 5mm according to experimental data and one end kept fixed.

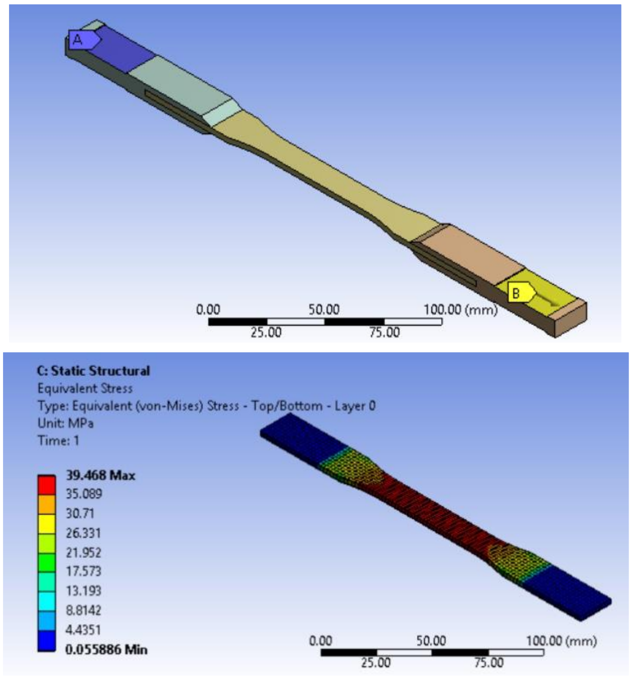
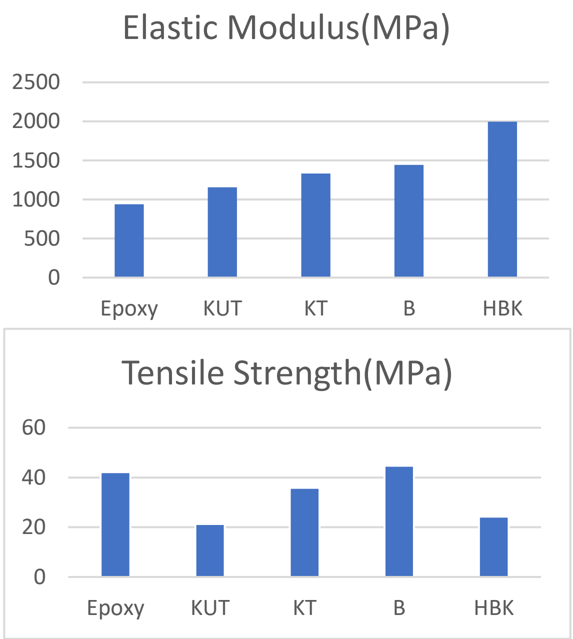


Fig. 6. Tensile testing using FEA

The Equivalent von-mises stress, equivalent strain and total deformation in the FEA model have been calculated and results were compared with experimental investigations.

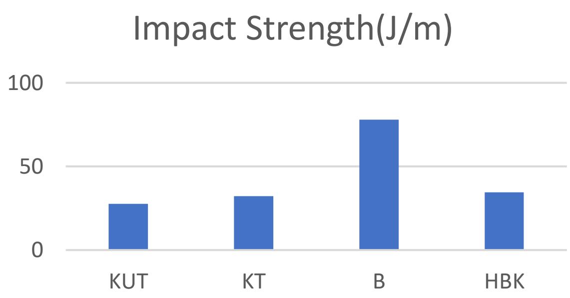
III. RESULT AND DISCUSSION

In the experimental study, Banana fabric and kenaf fiber are used as a reinforcing material with epoxy resin, the composite has been fabricated and mechanical properties are examined.



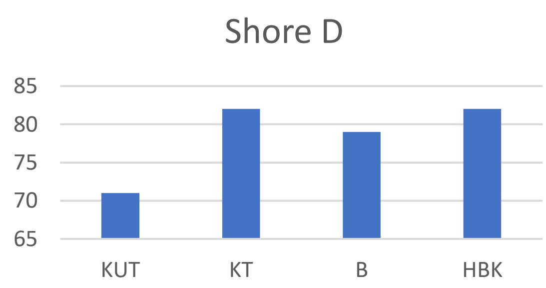
Graph 1 Tensile Test Result

By Tensile Test study, It shows that HBK has better elastic modulus, about 2GPa while B, KT shows 1.45 and 1.38 GPa while epoxy also tested to input its properties in ANSYS ACP, it has about 0.98 GPa. Kenaf sample shows improvement in its properties after treatment. Treated kenaf sample has about 35MPa tensile strength while woven Banana composite shows the best tensile strength about 45MPa. Due to some void defect, the hybrid sample shows a lower strength about 24MPa.



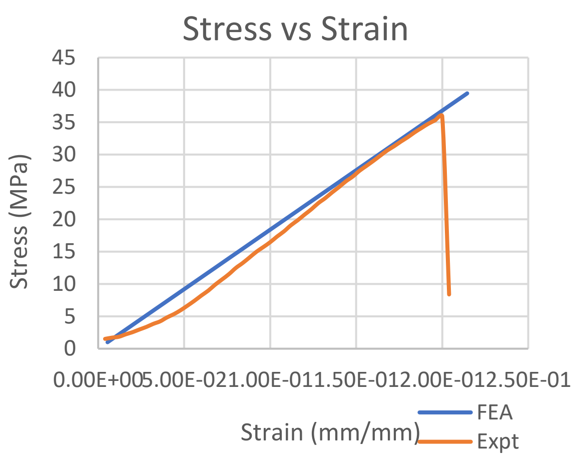
Graph 2 Impact Strength Result

Impact study shows Banana composite shows far better impact strength about 78 J/m than hybrid and kenaf sample.



Graph 3 Hardness Test Result

Impact study shows, kenaf treated and hybrid shows the same indentation resistance about 82-83 Shore While kenaf untreated poor results about 72 Shore D.



Graph 4 Stress vs Strain Curve

Comparative study of tensile behavior of kenaf fiber reinforced composite shows experimental results are in good match with FEA model. For 0.2 mm/mm strain, equivalent stress is 39.6 MPa which 91% in agreement with actual results.

IV. Conclusion

Banana fabric reinforced composite shows higher tensile strength and impact strength of about 87.5% and 122.8% more than hybrid samples. Hybrid banana/kenaf reinforced composite has higher elastic modulus about 44.2% and 42% higher than treated kenaf and banana samples. While treated kenaf and Hybrid sample has higher hardness about 82-83 shore D. Alkaline treatment shows a lot of improvement in the mechanical properties of kenaf fiber reinforced composite. Specifically, its tensile strength got improved by 54.17%. Finite element model and actual results are in 91% agreement with each other for a given strain. This study concludes that mechanical properties of kenaf fiber reinforced composites are improved after alkali treatment (6% NaOH) while hybridization of banana fabric and kenaf fiber shows mixed result, Elastic modulus of hybrid composite has improved while weaken tensile strength and impact strength properties.

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