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Research Article

Investigation of Weight Fraction and Alkaline Treatment on *Catechu Linnaeus*/*Hibiscus cannabinus*/*Sansevieria Ehrenbergii* Plant Fibers-Reinforced Epoxy Hybrid Composites

R. Rangaraj,[1] **S. Sathish**,[2] **T. L. D. Mansadevi**,[1] **R. Supriya**,[1] **Raviteja Surakasi**,[3] **M. Aravindh**,[2] **Alagar Karthick**,[4,5] **V. Mohanavel**,[6] **M. Ravichandran**,[7] **M. Muhibbullah**,[8] **and Sameh M. Osman**[9]

[1]*Department of Aeronautical Engineering, Sri Ramakrishna Engineering College, Coimbatore 641 022, Tamil Nadu, India*
[2]*Centre for Machining and Material Testing, KPR Institute of Engineering and Technology, Coimbatore 641407, Tamil Nadu, India*
[3]*Department of Mechanical Engineering, Lendi Institute of Engineering and Technology, Vizianagaram 535005, Andhra Pradesh, India*
[4]*Renewable Energy Lab, Department of Electrical and Electronics Engineering, KPR Institute of Engineering and Technology, Coimbatore 641407, Tamil Nadu, India*
[5]*Departamento de Quimica Organica, Universidad de Cordoba, Edificio Marie Curie (C-3), Ctra Nnal IV-A, Km 396, Cordoba E14014, Spain*
[6]*Centre for Materials Engineering and Regenerative Medicine, Bharath Institute of Higher Education and Research, Chennai 600073, Tamil Nadu, India*
[7]*Department of Mechanical Engineering, K. Ramakrishnan College of Engineering, Tamil Nadu, Trichy 621112, India*
[8]*Department of Electrical and Electronic Engineering, Bangladesh University, Dhaka 1207, Bangladesh*
[9]*Chemistry Department, College of Science, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia*

Correspondence should be addressed to M. Muhibbullah; m.muhibbullah@bu.edu.bd

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The aim of the present work is to develop novel hybrid composites using areca, kenaf, and snake grass fibers as reinforcement and epoxy as the matrix. The areca, kenaf, and snake grass fibers were extracted from *Catechu Linnaeus*, *Hibiscus cannabinus*, and *Sansevieria Ehrenbergii* plants, respectively, and treated with 5% NaOH to improve the interfacial adhesion between the hydrophilic fiber and the hydrophobic matrix. Hybrid composites were developed by the compression molding technique and formulated based on the weight fraction of fibers. Tensile, flexural, and impact strength and hardness samples were prepared as per ASTM *D* 3039, ASTM *D* 790, ASTM *D* 256, and ASTM *D* 2240, respectively. The effects of alkaline treatment on developed hybrid composites were investigated. The developed hybrid composites with 20% wt. snake grass and 10% wt. areca fiber present interesting mechanical properties with a tensile strength of 58 MPa, flexural strength of 124 MPa, impact strength of 5.24 kJ/m^2, and hardness of 88. The results indicate that maximum mechanical properties were obtained for alkaline-treated fiber composites with 20% wt. snake grass fiber compared to untreated fiber composites owing to better adhesion between the treated fiber and the matrix. The effect of alkaline treatment was analyzed by Fourier transform infrared. The fractured surfaces of tested samples were analyzed by scanning electron microscopy.

1. Introduction

The role of natural fibers has been increasing in this world due to their outstanding properties, such as light weight, low energy consumption, renewability, worldwide availability, biodegradability, cost-effectiveness. Regardless of their properties, there are some limitations to natural fibers, such as high moisture content, low thermal stability, and incompatibility with the matrix. Reinforcement of natural fibers along with the polymer matrix has been emerging in this world due to its extended applications and higher specific properties [1]. Natural fibers are used in automobile structures because of their moderate tensile strength, better stiffness, and high damping capability. When natural fiber-reinforced composites are used in vehicles, it is expected that not only the weight of the component will be decreased, but also noise and vibration will be reduced. In addition to these, composites have high resistance to fatigue and corrosion [2]. The properties of natural fibers depend on the age, nature of soil, and environmental conditions [3]. Kenaf fiber (*Hibiscus cannabinus*) has been chosen for this work because it can grow under different climatic conditions. It shows properties such as low density, nonabrasiveness during processing, and high specific mechanical properties [4]. Lee reported that the tensile strength and modulus of both kenaf and jute-reinforced polypropylene composites strengthened with higher fiber loading, achieving maximum strength of 39 MPa and 1300 MPa, respectively, at 40% fiber weight fraction before declining at higher fiber weight fractions [5]. Singh stated that kenaf fibers assisted in enhancing the wear and frictional performance of the polyurethane thermoplastic composite by about 59 and 90% [6]. Areca (*Catechu Linnaeus*) and Snake fiber (*Sansevieria Ehrenbergii*) along with the kenaf fiber have been taken for this experimental work due to their attracting nature. Areca fiber is inexpensive, and it is used in medicine, paints, chocolates, etc. [7]. The areca evergreen tree grows linearly, reaching a height of 10 m to 20 m, and its stem is straight and slender, with a diameter of less than 15 cm. The leaves are 1.5 to 2 m long and have a large number of pinnately shaped leaves, with the upper part usually displaying 9 to 12 fronds. However, soil conditions have a large impact on the growth of these trees [8]. The areca husk accounts for roughly 60–80% of the overall weight and volume of the fresh fruit. The husk fiber is made up of cellulose with different amounts of hemicelluloses, 35–64.8%, lignin 14.0–26.0%, and pectin [9]. Snake grass-reinforced polymer composites may supplant sal wood and other wood species and save trees, which helps in diminishing environmental damage [10]. Besides their scope, there are some limitations to reinforcing natural fibers along with the polymer matrix, like low processing temperatures, high water intake, and improper stress transfer. Cellulosic fibers absorb more moisture content because of their hydrophilic nature. This nature of cellulosic fibers results in protrusion. When this fiber gets reinforced with the hydrophobic matrix, it results in improper bonding and poor interfacial shear strength [11, 12]. If fibers are not treated and if they are embedded in a polymeric matrix, it results in generating unstable interfaces and, therefore, the stress applied to the fiber/polymer composite is not efficiently transferred from the matrix to the fiber. These issues can be diminished by various treatment processes, thereby increasing the mechanical properties of the natural fiber-reinforced composites. Alkali treatment is a suitable method for enhancing the mechanical properties of natural fibers [13, 14]. This treatment will modify the surface by removing hemicellulose, lignin, pectin, and wax, thereby increasing the aspect ratio. A higher concentration of NaOH results in damage to the fiber and hence decreases the mechanical properties. So, optimum treatment percentage plays a crucial role in the modification of the fiber surface [15, 16].

Karsli and Aytac et al. [17] studied the tensile properties of flax fibers-reinforced PLA polycarbonate composites as function of 5% NaOH alkaline treatment for 20 min. The authors observed that 5% NaOH-treated flax fibers-reinforced PLA polycarbonate composites increases the flexural strength and flexural modulus by 9.1% and 62.5%, respectively, compared to untreated fiber composites. The maximum tensile strength, flexural strength, and modulus of the chopped snake grass fiber-reinforced polyester composite are achieved at 25% volume fraction for 30 mm of fiber length. The result indicates that, overall, 25% of the fiber fraction showed better mechanical properties [18]. Mazuki [19] conducted a study on kenaf fiber and highlighted its potential use in verities of applications such as panels of doors, seats, armrests, and dashboards. The potential of using kenaf-reinforced composite materials as sound barriers and acoustic absorbers was also indicated in the article. The tensile, flexural, impact, and interlaminar shear strength (ILSS) of 5% NaOH-treated kenaf and tea leaf fibers-reinforced composites were improved by 33.32%, 25%, 20.48%, and 35.16%, respectively, when compared with untreated composites due to removal of hemicellulose, lignin, pectin, and waxy elements which resulted in better interactions between hydrophilic fiber and hydrophobic matrix [20]. The treated surface of the fiber becomes rough, thereby enhancing the interfacial bonding and mechanical properties [21]. The tensile strength of randomly distributed snake grass fiber-reinforced composites was found to be lower than the tensile strength of longitudinal direction oriented composite material [22]. Satyanarayana et al. [23] investigated the chemical and physical characteristics of natural fibers. Jayabal et al. [24] studied randomly oriented coir fiber-reinforced polyester composites manufactured by hand layup technique for different fiber lengths of 20, 100, and 150 mm. The mechanical strength of polyester composites varies depending on the weight and length of the fibers. The findings revealed that fiber content had quite a greater impact on mechanical characteristics than fiber length [25]. Usually, the weight of the fiber content improves the tensile properties, and this is dependent on the type of matrix used [26]. A prolonged literature review has led to the selection of the optimum alkali treatment process. The experimental work emphasizes the importance of alkali treatment on the mechanical properties of snake grass, areca, and kenaf fiber-reinforced hybridized epoxy composites. No literature has reported data on kenaf-, snake grass-, and areca-reinforced hybridized epoxy composites. So, this hybridization combination was chosen and the main objectives of the paper were carried out as follows: (i) effect of alkaline treatment on kenaf, snake grass, and areca fiber and (ii) effect of weight fraction of snake grass fiber on mechanical properties of hybrid composites.

2. Experimental Work

2.1. Materials. Areca, kenaf, and snake grass fibers were collected from KCT, Tifac core, Coimbatore, India. For the preparation of composites, a widely available epoxy resin

(LY 556) and an amine-based hardener, triethylenetetramine (HY 951), were used. The hardener is used to enhance bonding between the fibers and the matrix. They were used in the mixing ratio of 10 : 1 as recommended by the supplier. The epoxy and hardener were purchased from Covai Seenu and Company, Coimbatore, Tamil Nadu. Epoxy resins (LY556) have prominent advantages over thermoplastic and other thermoset resins such as minimum shrinkage rate, excellent moisture and chemical resistance, and better damage tolerance [27]. Properties of epoxy resin (LY556) are presented in Table 1. The hardener (HY951) is made from polyamine monomers, such as triethylenetetramine. When these compounds are combined, the amine groups react with the epoxide groups to form a covalent connection. Amine hardeners react with epoxy resins and contribute to the ultimate properties of the epoxy resin treatment system.

Table 1: Properties of epoxy resin (LY556) (27).

Property	Epoxy resin
Density (g/cm^3)	1.1 to 1.4
Elastic modulus (GPa)	3 to 6
Tensile strength (MPa)	35 to 100
Compressive strength (MPa)	100 to 200
Elongation (%)	1 to 6
Cure shrinkage (%)	1 to 2
Water absorption (%)	0.1 to 0.4
Impact strength (J/m)	0.3

2.2. Process of Alkali Treatment. The alkaline treatment is also referred to as mercerization. This causes fibrillation, which leads to the breakdown of fiber bundles into smaller ones. The fiber surface becomes rough and the diameter of the fiber decreases, increasing aspect ratio and mechanical properties [28]. It breaks the hydrogen bond in the cellulose fibers and increases the number of reaction sites, which promotes better interfacial shear strength and stress transfer. Mercerization removes the noncellulosic contents like hemicellulose, lignin, and wax from the surface of the fiber and enhances the properties of the composite [29]. Hemicellulose in plant fiber has a more hydrophilic part, so alkali treatment decreases the moisture absorption of water. The reaction that occurred during the treatment is as follows:

$$\text{fiber} - \text{OH} + \text{NaOH} \longrightarrow \text{fiber} - \text{O} - \text{Na} + \text{H}_2\text{O}. \tag{1}$$

The hydrophilic nature of the fiber is reduced and the resistance to moisture increases. The amount of hemicellulose, pectin, lignin, and wax will be removed depending upon the concentration of treatment [16, 30, 31]. Among the various chemical treatments, alkali treatment has been identified as one of the best and most effective for removing impurities from the surface of the fibers. Reduction of the hydrophilic nature of the fibers has been carried out in this work by chemically treating the surface using NaOH. The fibers of areca, kenaf, and snake grass were soaked in 10 liters of distilled water for 24 hours to remove dusty layers and then hung to dry for 24 hours. For 3 hours, dust-free fibers were immersed in a 5% NaOH concentration solution (50 ml of NaOH in 10 liters of water). The fibers were then removed and washed several times in distilled water to remove the excess accumulation of NaOH solution on the surface of the fibers. The fibers were then air dried for 24 hours.

2.3. Fabrication of Hybrid Composites. Initially, treated fibers were cut into 28 cm lengths as per mold requirement with the help of a cutter. For preparing the epoxy matrix, both the epoxy resin and epoxy hardener (LY 556 and HY 951) were mixed with the aid of a stick in the ratio of 10 : 1. Following the preparation of matrix materials and reinforcement, the composites were manufactured using the compression molding technique (Supplier: Modern Plastics Pvt Ltd., Coimbatore, India). In the fabrication process, 300 * 300 mm aluminum plates were used. Aluminum plates and frames are first cleaned, and then white grease is applied to the aluminum plates to reduce the friction between them. Then the epoxy resin is poured onto the aluminum plate, and the fibers are arranged on the plate bidirectionally, with the areca fiber placed on the bottom surface, the middle layer of the laminate is occupied by kenaf fiber, and the top layer is occupied by snake grass fiber. The epoxy matrix is poured between each layer of fiber in order to achieve uniform dispersion [32]. Five samples were prepared in the same order using different fiber content. Then the completed laminates were placed inside the modern compression molding machine and maintained at a temperature and pressure of 120 °C and 35 bar for 45 minutes and the laminates were cured for another 45 minutes. After solidification, the final dimension of the composite is 280 mm × 280 mm *x* 5 mm, obtained from the mold cavity. The diamond cutter was used to cut the samples for mechanical characterization tests as per ASTM Standard. Table 2 presents the designation of hybrid composites. Figure 1 shows graphical procedure of composite fabrication process.

2.4. Mechanical and Morphological Analysis. It is one of the simplest and most commonly used mechanical tests. The samples were tested on a computerized universal testing machine (UTM) (Supplier: Aimil Ltd., India) with a crosshead speed of 2 mm/min. The tests were carried out in accordance with ASTM *D* 3039 standards with a specimen size of 250 × 25 × 5 mm [33]. Each composite was tested with five specimens, and their values are noted. Figure 2 shows tensile gripper and tested samples. Flexure tests are generally used to determine the flexural modulus or bending of a material. The samples were tested using a three-point bending test on a computerized UTM with a crosshead speed of 2 mm/min. The tests were carried out in accordance with ASTM *D* 790 standards with a specimen size of 125 × 12.7 × 6.5 mm [33]. Each composite was tested with five specimens, and their values are noted. This test is used to determine a material's impact resistance. In this experiment, a hybrid combination was examined for the ability to absorb energy without breaking. The samples were tested on a digitalized Izod impact tester.

The tests were carried out in accordance with ASTM *D* 256 standards with a specimen dimension of

Table 2: Designation of hybrid composites.

Sample designation	Kenaf fiber (% wt.)	Snake grass fiber (% wt.)	Areca fiber (% wt.)	Epoxy resin (% wt.)
A	10	5	25	60
B	10	10	20	60
C	10	15	15	60
D	10	20	10	60
E	10	25	5	60

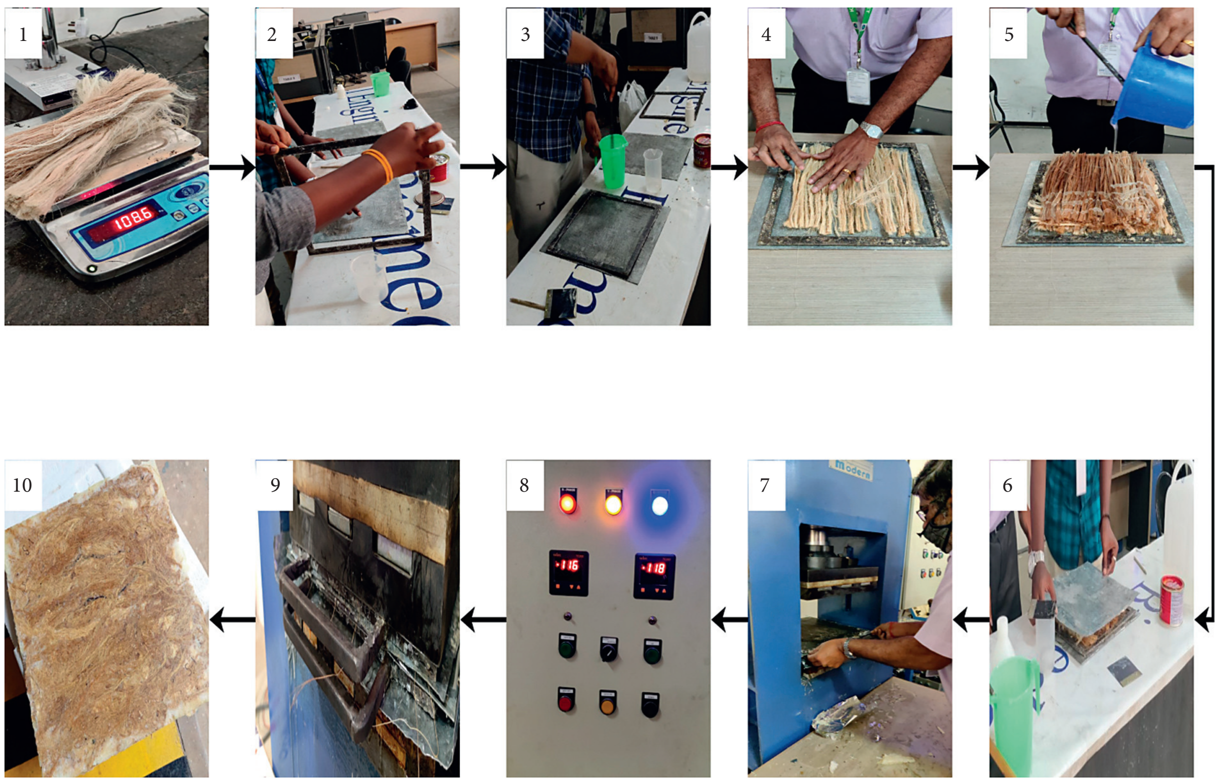


Figure 1: Graphical procedure of fabrication process.

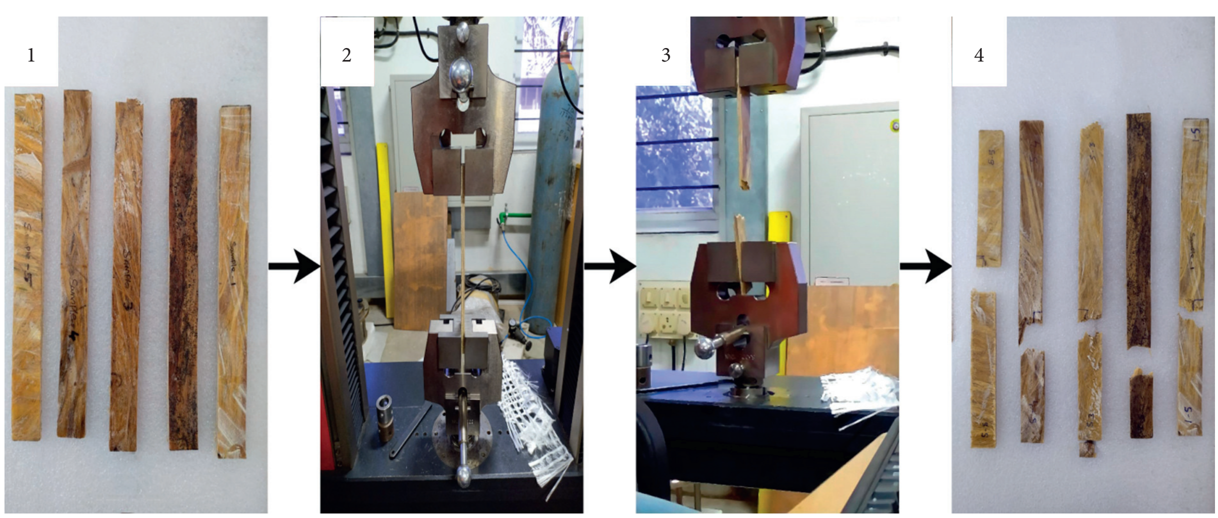


Figure 2: Tensile setup and fractured samples.

$65 \times 12.7 \times 6.5$ mm [33]. Each composite was tested with five specimens, and their values are noted. Hardness is determined by how little deformation it offers under localized mechanical or abrasive pressure. The samples were tested on a Shore *D* Durometer. The tests were carried out in accordance with ASTM *D* 2240 standards with a specimen dimension of $20 \times 20 \times 6.5$ mm. Five specimens were tested, and six readings at different points were taken. A mean value was determined for the specimens. A scanning electron microscope was used to examine the morphology of the modified fibers using (SEM JEOL JSM-6510LA). After fabrication, the surfaces characteristics of the composite materials are investigated using SEM. Scanning electron micrographs clearly show the interfacial adhesion between the matrix and the fiber. The SEM operates at an accelerating voltage of 25 kV.

3. Results and Discussion

3.1. Mechanical Characterization. Fiber content and strength are influencing parameters in determining the properties of the composites. Specimen *D* gave a higher tensile strength of 58 MPa, followed by specimen *E* (44 MPa), specimen C (37 MPa), specimen B (21 MPa), and specimen A (21 MPa). Figure 3(a) shows the tensile strength of treated and untreated composites. Among the hybrid composites, specimen *D* has 20% wt. snake grass fiber which showed enhanced tensile strength and further increase in snake grass fiber led to a sudden decrease in tensile strength. From the results, it can be inferred that the alkali treatment increases the elastic behavior and makes it able to withstand failure. At a lower strain rate, the stress increases linearly, forming the elastic region, and above this zone, the specimen exhibits plastic deformation. This behavior is due to the reason that resin in the region starts to deform plastically, and it leads to the formation of minor cracks in the resin [33]. When the fibers propagate through these cracks, it leads to a decrease in tensile strength. The tensile strength of specimen A is much lower than specimen D. This is due to the reason that the 20% wt. snake grass fiber in specimen A bonded strongly with the epoxy matrix, thereby enhancing the tensile properties and interfacial shear strength, whereas specimen A has 25% wt. of areca fiber which does not properly interact with the matrix when compared to other composites. According to Maslinda et al. [34], the tensile strength of the hybrid composites extremely weakened and their results showed that mechanical properties of the hybrid composites were influenced by weight fraction of cellulosic fiber. With the increase of cellulosic fiber beyond 40% wt. in composites, the adhesion between the hydrophilic fibers and the hydrophobic matrix deteriorated leading to poor strength. The improper bonding is due to the higher amount of hemicellulose percentage, which is responsible for moisture content. 5% alkali treatment on areca is not efficient enough to remove the noncellulosic contents to a better extent. The tensile strength of all untreated fiber composites is lower as compared to alkaline-treated fiber composites. This indicates that 5% NaOH reagent increases the roughness of fibers and decreases the fiber diameter, resulting in greater tensile properties.

Flexural strength determines how the material will resist bending force. Specimen *D* shows a higher flexural value of 124 MPa when compared to other specimens. The causes of the higher flexural strength of the specimen *D* are stated as follows: (i) 20% wt. snake grass fiber is properly bonded with the matrix, which means that 5% NaOH has effectively removed the hydrophilic nature of the fiber. (ii) The diameter of the fiber decreases so that crack generation will not occur. (iii) Due to this, the interfacial bond between the fiber and the matrix becomes strong and fiber pullout will not be generated on the surface. (iv) Enhanced interfacial bonding leads to proper stress distribution. Specimen *E* has the highest flexural strength of 96 MPa, followed by specimen C (91 MPa), specimen B (78 MPa), and specimen A (62 MPa). Figure 3(b) shows the flexural strength of treated and untreated composites. The decrease in flexural strength can be due to the presence of voids in the surface [33]. Specimen A has more holes on the surface. That is why the flexural strength is less when compared to other specimens. Delamination of specimen A occurs at a faster rate when compared to other specimens. The weaker fiber/matrix adhesion could not offer adequate stress transport; thus, the flexural strength of the hybrid composites reduced considerably [35]. Alkaline-treated fiber-reinforced composites display the highest flexural strength, while untreated fiber composites reveal a marginal loss in flexural strength due to poor adhesion between fiber and matrix.

Impact strength determines how much energy the material can withstand when a load is applied to it. Specimen *D* has the highest impact strength of 5.24 kJ/m^2 because of its low brittleness. This is so because the stress distribution between each lamina has been distributed equally. The reasons are stated as follows: (i) proper alkali treatment reduces the diameter and makes the surface rough. (ii) In addition to that, all the noncellulosic components are removed to an optimum extent. (iii) Due to this, the material's ductile-brittle transformation will not happen soon [36]. The brittle behavior in all other specimens will occur soon. Figure 3(c) shows impact strength of treated and untreated composites. From the results, it can be concluded that other specimens will not absorb much energy when compared to specimen D. At higher luffa cylindrica fiber volume fraction, the accretion of reinforcement in the composites causes poor matrix regions leading to inadequate adhesion between the luffa cylindrica fiber and epoxy matrix and results in reduced impact strength [37].

Low energy absorption of the specimen is due to protrusion of the fiber surface, which leads to the onset of brittle behavior [36]. As a result of the impact test, it can be indicated that 5% NaOH solution is optimum for enhancing the impact strength of the composites compared to untreated fiber composites owing to minimized voids, formation of pores, and removal of moisture content, hemicellulose, lignin, and wax.

The hardness test was done using the Shore *D* Durometer. The ability of a material to resist deformation is referred to as hardness. Among those five specimens, specimen *D* has the highest hardness value of 88. This is because the interlaminar strength between the fibers and the matrix is strong [33]. As a result, the composite becomes finer and more capable of resisting applied force, so the highest value is obtained for specimen *D*, followed by specimen *E* with a hardness value of 76, specimen C with a hardness value of 68, and specimen B with a hardness value

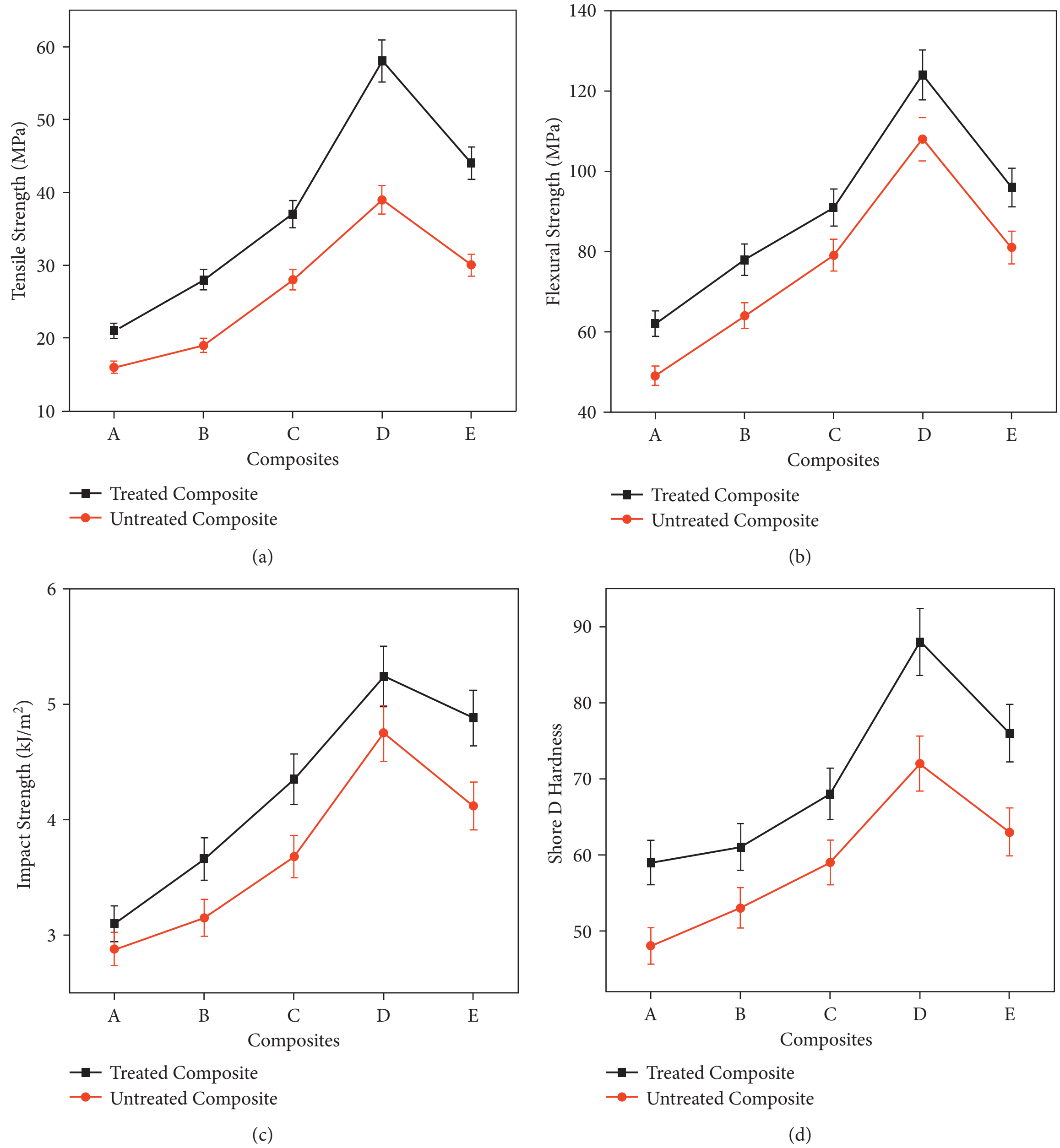
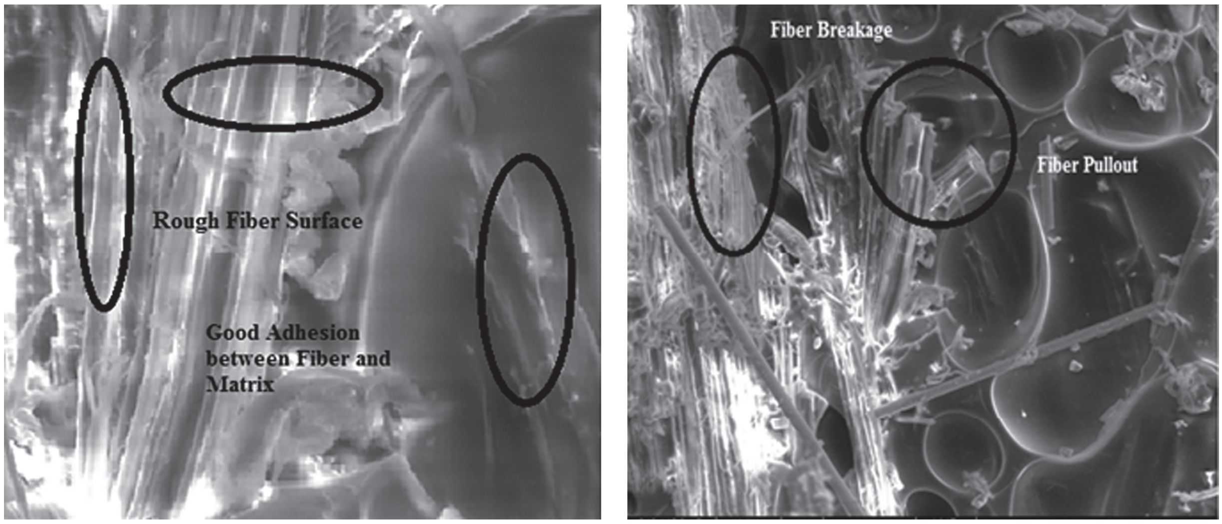


Figure 3: Alkaline-treated and untreated composites: (a) tensile strength, (b) flexural strength, (c) impact strength, and (d) shore D hardness.

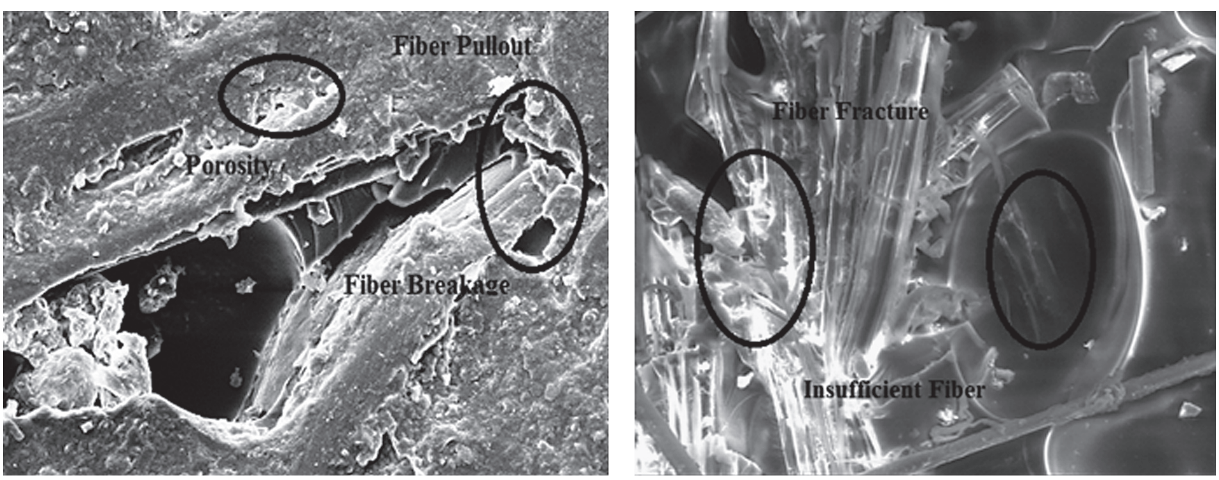
of 61. Specimen A has the lowest hardness value among the five specimens, which is due to improper fiber-matrix adhesion (Figure 3(d)). Because 25% wt. of the areca fiber did not remove the noncellulose compound more effectively, the fiber-matrix adhesion was poor, resulting in a lower hardness value. When there are fewer fibers in the region, the hardness value is low. When there are more fibers focused on a specific location, then the hardness value is high. The hardness values are influenced by the strong fiber-matrix bonding. The hardness of alkaline-treated composites indicates noticeably better interaction between fibers and matrix which resists indentation or penetration as compared to untreated fiber composites [20].

3.2. SEM Analysis. Among the various hybrid composite specimens, specimen *D* has 20% wt. of snake grass fiber, 10% wt. of kenaf fiber, 10% wt. of areca fiber, and 60% wt. of resin showing improvement in fiber-matrix adhesion. The surface of specimen *D* has no fiber pullout and, from this, it can be concluded that specimen *D* has bonded properly with the epoxy matrix and the surface of the composite produced a rough nature (Figure 4(a)). The rough nature is due to the removal of hemicellulose, which is responsible for moisture content. Due to this, there is no generation of microcracks and this leads to proper stress distribution by carrying the loads efficiently [36]. In Figure 4(b), specimen *E* showed some microcracks in the surface of the fiber, which is due to



(a) (b)

Figure 4: SEM images: (a) 20% wt. of snake grass fiber-reinforced composite; (b) 25% wt. of snake grass fiber-reinforced composite.



(a) (b)

Figure 5: SEM images: (a) 5% wt. of snake grass fiber-reinforced composite; (b) 10% wt. of snake grass fiber-reinforced composite.

the fact that 25% wt. of the snake grass fiber did not bond properly with the epoxy matrix. Figures 5(a) and 5(b) show the SEM images of specimens A and B which depict more fiber breakage, fiber pullout, and insufficient distribution of fiber in the matrix leading to failure of composite under minimum load.

4. Conclusion

This paper investigated and reported the effect of alkali treatment on hybridized areca, kenaf, and snake grass fiber-reinforced epoxy composites. Fibers were treated with 5% NaOH to improve the interfacial adhesion between the fiber and the epoxy matrix. The compression molding technique was used to fabricate hybridized fiber-reinforced epoxy composites by keeping the weight percent of kenaf fiber content constant at 10% wt. and changing the weight percent of areca and snake grass fiber to 25A-5SG, 20A-10SG, 15A-15SG, 10A-20SG, and 5A-25SG. The mechanical properties of 5% NaOH treated areca, kenaf, and snake grass fibers-reinforced composites with varying fiber content were tested. The results of the tests lead to the subsequent conclusions:

(i) The composite containing 10% wt. areca, 10% wt. kenaf, and 20% wt. snake grass fibers had the highest tensile, flexural, impact, and hardness values. This is due to the fact that 20% of alkaline-treated SG fibers remove hemicellulose more effectively, improving fiber-matrix adhesion compared to untreated fiber composites.

(ii) 5% NaOH alkaline treatment of fibers reduced their hydrophilic nature, which improved fiber-matrix adhesion and resulted in good mechanical properties.

(iii) The SEM micrograph of (10% wt. A–10% wt. K–20% wt. SG fibers) clearly shows no fiber pullout, indicating that the fiber and matrix were well bonded.

(iv) Based on the mechanical properties, it was concluded that the areca, kenaf, and snake grass fibers are alternative reinforcements for the development of hybrid composites for production of less weight products used in aircraft, automobile, building and constructions, sports and home appliances, etc.

Data Availability

The data used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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