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Chopped Areca Nut Fibers as Filler in Epoxy Matrix: Mechanical and Tribological Studies

Aju Jo Sankarathil[1,*], Raja Rosari[1], Vijay Santhiyagu Joseph[1], Sabitha Jannet[1] and Aswathy Ann Mathew[2]

[1]Department of Mechanical Engineering, Karunya Institute of Technology and Sciences, Coimbatore 641114, India
[2]Department of Civil Engineering, National Institute of Technology, Calicut 673601, India

([*]Corresponding author's e-mail: aju.js@saintgits.org)

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Abstract

In the current investigation, fibers extracted from the areca nut tree husk were either used unprocessed or processed with an alkaline treatment by being submerged in a 5 % sodium hydroxide solution. The average length of the areca fibers used in this work is 30 mm. Compression molding is used to create the composite out of an epoxy matrix with fibers added at 10, 15, 20 and 25 weight percent. The composites were tested for tensile strength, flexural modulus, Charpy impact, and shore D hardness, all of which showed the significant advantage acquired with quantity of fibers and fiber treatment. Pin on disc tribometer was used to conduct tribological tests on the treated fiber composites to analyse how the fiber-matrix bonding improved with an increase in fiber content. The primary shortcoming of the fibers is their relatively low elongation, which, even after treatment, hardly approaches 4 %. This indicates that the fibers are not uniform in length and prevents direct comparison to comparable composites containing a similar volume and length of natural fibers. The mechanical qualities of materials made with alkali treated chopped areca fibers where found to be enhanced when it was at 20 % volume fraction. A linear increment in values where observed in samples till 20 % volume fraction and a decrement with further increase in volume fraction. In the case of tribological evaluations, lesser values or wears were obtained at combination III for all the 3 loads, 10N, 15N and 20N.

Keywords: Tribological, Bonding, Areca fiber, Resin, Epoxy, Chopped, Treatment, Flexural

Introduction

With the lowering of oil supplies diurnal, associates throughout the world are getting more interested in biomass resources. It is advantageous to choose natural fibers because they are both light and affordable. Different types of naturally available fibers namely hemp, flax, coconut, jute, abaca, bamboo and sisal are commonly used as a material for reinforcement in different types of composites [1]. Composite materials with particle reinforcement have better performance characteristics because of the particles. Spherical, cubical, or tetragonal particles make up the majority of the known particle types [2]. Continuous fibers and discontinuous fibers are the 2 primary types of fibers used in fiber-based composite materials. These are further split into bidirectional reinforcements and unidirectional reinforcements, respectively [3]. Using particle filled bamboo fiber reinforced epoxy composites, Biswas [4], suggested that a composite material with high strength and stiffness for light weight applications might be effectively developed as an alternative to traditional bamboo composites, as opposed to conventional bamboo composites. Because they contain a mixture of fibers, hybrid composites have superior qualities than single fiber composites [5]. Nano fibrillated cellulose, natural fibers, cellulose nanocrystals are increasingly being investigated as polymer reinforcements in composites for the automobile sector [6]. Natural fiber-based composite materials have seen a surge in use across a wide range of industries due to their long-term viability [7]. Idicula *et al.* [8], explored that sisal fibers reinforced with epoxy which were small and randomly oriented of 15 mm length improved its mechanical characteristics. After a certain point, Vaghasia and Rachchh [9], discovered that adding bamboo fiber to epoxy resin causes a resin deficit and a loss in its mechanical characteristics. Fibers including sisal, abaca, areca, hemp, jute and coir are employed well as thermosetting and thermoplastic reinforcements of resins. Composites reinforced with natural fibers are often used in different industries, including building, packaging and automobiles [10].

There is much more to be explored regarding areca nut fibers. This plant's botanical name is *Areca Catechu* Linnaeus, a member of the *Arecaceae (Palmae)* plant family and the *Arecoideae* subgroup [11]. Its origins can be traced back to the Malaya peninsula in East India. India is expanding areca nut agriculture on a massive scale to achieve self-sufficiency in medicine, chocolate, paint and other products. Around 6 lakh tonnes of areca nut husk are expected to be available in South West India [12]. Furthermore, the impact strength values were found to be increasing upto 60 % fiber loading in the case of treated and neat areca fiber reinforced epoxy polymer composites but then decreased in a wide range of alkali treated and untreated epoxy composites. As a result of alkali treatment, it was possible to minimize the wettability [13] and specific surface area of the fiber networking structure [14].

Areca fiber reinforced epoxy polymer composites have received less attention in the literature than other natural fibers reinforced with epoxy composites [15]. Mechanical evaluation of epoxy polymer composites is done to demonstrate the properties of the same and enable them to be used in different applications [16]. There are several ways to make polymer composites, including using sludge, slugs, red dirt, and so on as matrix materials and the polymer's desirable properties as a matrix. It is possible to use these composites in commercial and industrial applications because of their particular mechanical features, such as flexural strength and tensile strength [17,18]. In addition, most of the data on their tribological behaviour comes from observation, and their precognitive abilities are minimal [19,20]. According to the tribological analysis, the wear resistance for alkali and untreated fiber composites peaks at 50 % fiber fraction. As more load was applied to the samples, their wear rate increased [21]. Additional research is needed into Areca fiber reinforced composites because they have yet to be thoroughly tested like other fibers. Various studies are being conducted to explore the benefits of incorporating areca nut husk and sheath fibers in composite fabrication to identify the best composition for future work [22]. Instead of using long or continuous areca nut husk fibers, this study used 30 mm long chopped NaOH-treated areca nut husk fibers as a substitute. Intricate pieces can be made with ease by using chopped fibers. Using chopped fibers delays the onset of fracture, making this material the strongest. The primary focus of this novel research study is to synthesize the chopped areca nut fiber reinforced epoxy polymer composites and subsequently evaluate their mechanical and tribological evaluations.

Materials and methods

A hardening agent and a resin are combined in a precise ratio to create epoxy. The hardener used in this research work is HY 951. The Araldite HY 951 Epoxy Hardener is admired for good resistivity against chemical & atmospheric conditions, excellent mechanical strength and better electrical properties. The epoxy resin used in this research work is LY 556. This particular resin possesses excellent mechanical properties and resistance to chemicals, which can be modified within wide limits by using different hardeners and fillers. Furthermore, it has a low tendency to crystallize. Resin to hardener ratio was finalized to 10:1 after refering with the available literatures and data sheets. Vruksha Composites & Services, Andhra Pradesh, supplied the fibers used in this study. Areca fiber's primary desired properties are mentioned in detail in **Table 1**.

Areca nut fibers require extraction from the nut before being treated with alkali. For this goal, numerous fiber remotion techniques are employed. Mechanical extraction and retting are included in this category. Retting is typically done with water, dew, chemicals, or enzymes. Water retting is the most common technique used for obtaining superior fibers among these. In this investigation, we are using this strategy.

Table 1 Major characteristics of areca fiber [23].

Property	Values
Density (g/cm^3)	1.05
Youngs modulus (GPa)	8.8 - 34.5
Hemicellulose (wt%)	35 - 64.8
Lignin (wt%)	13 - 24.6
Ash content (%)	4.4
Water content (%)	8 - 25
Elongation (%)	3.1 - 10.5
Tensile strength (MPa)	20 - 250

Alkali treatment on areca fibers

When areca fiber is treated with an alkaline chemical, the link between the fiber and the epoxy resin is strengthened [24]. Alkaline treatment increases surface roughness and the amount of exposed cellulose on the fiber surface by eliminating cellulosic content that covers the external surface of the fiber cell wall [25], resulting in better mechanical interlocking. Furthermore, alkali treatment improved the thermal resistance of date palm fibers due to the removal of the waxy layers and other impurities from the surface [26]. Also, alkali fiber surface treatment is considered as an effective treatment amongst all the other available chemical treatments [27, 28]. Compared to untreated fibers, abaca fibers demonstrated higher crystallinity, tensile strength, and Young's modulus [29]. They also showed improved interfacial strength with epoxy.

The treatment technique implemented in this investigation is continuously soaking areca nut fiber for 2 h in a 5 % NaOH solution. The areca nut fibers have been cut into the chopped form before synthesising the composites. **Figure 1(a)** depicts the untreated fibers, while **Figure 1(b)** displays the treated fibers used in the experiment. In the research that was done to evaluate the improvement in the properties of the composites, both sets of fibers (treated and untreated) were used.

(a) (b)

Figure 1 (a) Untreated areca nut husk fibers and (b) chemically treated areca nut husk fibers.

Synthesis of composites

About 30 g of hardener and 300 g of epoxy were required for each composite. Compression moulding was recently the most extensively used and straightforward technology available for composite fabrication**.** **Table 2** lists the chemical proportions of the composite specimens developed. The chopped NaOH-treated areca fibers were soaked in the liquid before it was poured over them. Afterwards, the metal mould was removed from the mixture, which had been squeezed and allowed to harden for 3 h. A maximum thickness of 6 mm is imposed on the composite, which cannot be larger than 200×200 mm^2. These test pieces were cured and then cut into the standard ASTM dimensions. **Figure 2** depicts the selection of the composite samples created through the above-mentioned manufacturing process.

Table 2 List depicting the codes of the present study's composite laminates.

Sample code	Amount of epoxy added	Amount of hardener added	Areca fiber volume fraction
I	300 g	30 g	10 %
II	300 g	30 g	15 %
III	300 g	30 g	20 %
IV	300 g	30 g	25 %
V	300 g	30 g	30 %

Figure 2 Laminates prepared for doing the mechanical interpretation.

Mechanical evaluation

Mechanical testing is needed to interpret fibre-reinforced epoxy polymer composites based on their strength. From this testing process, we could see their ability to deal with dynamic and static forces. This study described flexural, impact, hardness, and tensile tests. Error results are produced for all trials. Three samples were used to investigate each test's effects, and the average value was calculated for each shot. **Tables 3** and **4** display the results obtained after mechanical testing over untreated and treated areca nut fibre-reinforced epoxy polymer composites. It is found from the table that the mechanical properties were increased up to 20 wt% fiber composition, and the trend is found to be decreasing afterwards. The hardness values achieved are significantly greater than those obtained for other epoxy composites reinforced with the same number of different kinds of natural fibers, such as Typha Angustifolia [30]. This is because as the concentration of fiber increases, there is no effective binding between fiber and resin, because of which effective transfer of load from fiber to matrix does not occur [31]. Furthermore, in the case of polypropylene composite reinforced with *Luffa cylindrica*, the decreased thermal stability of the composite was able to be brought about as a result of the higher fiber concentration in the composition [32].

Table 3 Mechanical properties of epoxy/untreated areca fiber reinforced composites.

Composition	Tensile Strength (MPa)	Elongation (%)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Impact Strength (KJ/m^2)	Hardness
Epoxy/10 % UT areca fiber	10.10	0.24	2913.33	31.76	2490.0	2.18	80
Epoxy/15 % UT areca fiber	12.31	0.33	3680.0	37.96	3243.33	2.48	80
Epoxy/20 % UT areca fiber	14.12	0.30	4903.33	41.12	4303.33	2.64	84
Epoxy/25 % UT areca fiber	10.87	0.34	3300.0	36.03	2936.66	3.82	81
Epoxy/30 % UT areca fiber	9.78	0.28	2840.0	34.96	2733.3	3.58	82

Table 4 Mechanical Properties of alkali treated areca/epoxy fiber reinforced composites.

Composition	Tensile Strength (MPa)	Elongation (%)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Impact Strength (KJ/m^2)	Hardness
Epoxy/10 % Treated areca fiber	20.20	3.21	3356.2	42.35	2590.0	2.36	82
Epoxy/15 % Treated areca fiber	24.62	3.13	4235.1	48.68	3363.33	2.98	82
Epoxy/20 % Treated areca fiber	28.24	3.30	5012.2	52.11	4878.32	3.34	86
Epoxy/25 % Treated areca fiber	21.74	3.24	3523.4	47.23	3012.23	4.12	83
Epoxy/30 % Treated areca fiber	18.20	3.32	3012.7	43.60	2989.45	3.90	84

Tensile testing

The tensile specimens were prepared according to ASTM D638-14 standard, following the parameters indicated in it, as regards gauge length, crosshead speed etc., therefore using a gauge length of 50 mm and performing the tests in displacement control mode using a crosshead speed of 5 mm/min.

Flexural testing

The flexural specimens were prepared according to ASTM D790-17 standards. The bending strength of the samples was evaluated using the 3-point test in a UTM machine. The models were held on 2 supports in a flat-wise position, and a load was applied to the center of the specimen. The supports' length was fixed at a span-to-depth ratio of 16:1. Load was applied to the samples using a crosshead speed of 2 mm/min. In this test, constant Load was applied to the specimens throughout the testing process until they broke or fractured.

Impact evaluations

The specimens for the impact test were produced with reference to the ASTM D256 standards. It is permissible for the impact testing machine's pendulum to strike the sample multiple times throughout the testing process until it breaks. Each specimen had a notch with a depth of 2.5 mm carved into it to carry out the operation.

Hardness testing

The shore D testing machine performed the hardness tests on the prepared specimens. Samples were fabricated and evaluated with reference to ASTM D2240 standards. Specimens were pierced with the durometer indenter's foot to obtain the hardness values.

Evaluation of tribological characteristics

Tests for identifying dry sliding wear were done on a tribometer, particularly pin-on-disc type (Ducom, TR-20 LE). An ASTM G99-05 compliant specimen was created. There were 30 mm long square pins used in the experiment, with linear specifications of 5×5 mm^2. Loads of 10N, 20N and 15N were applied while the disc slid at 3 m/s. The tribometer disc used in this work measured 24 mm in diameter and 7.9 mm in thickness and was made of carburized steel. Samples were polished with abrasive (SiC) paper with 800 grid size before the tests were carried out in a laboratory (SiC paper with a grid size of 1,200). The test specimens were then cleaned well enough in acetone and dried afterwards. After that, the dry sliding test is weighted both before and after. Samples were weighed using a computerized device (Shimadzu, Japan, AUW. 220D). The minimum readability of the weighing scale used in this work is 0.001 g. Errors were analysed before the measurements in every experiment. Three tests were done for all tribological evaluations, and the average value was taken. Samples prepared for tribological assessment are presented in **Figure 3**, and the machinery used for the review is displayed in **Figure 4**.

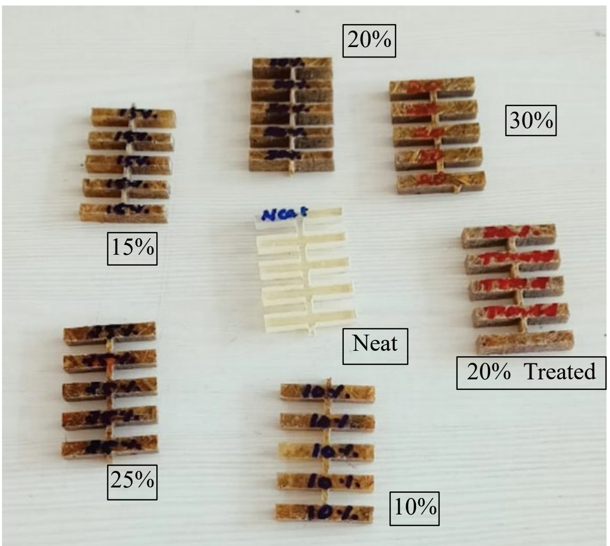

Figure 3 Samples prepared for tribological property evaluation.

Figure 4 Tribometer with computer assistance used for the evaluation of tribological properties.

Results and discussion

Evaluation of tensile characteristics

Tensile modulus and tensile strength values for areca fibre-reinforced epoxy polymer composites are enlisted in the following figures, say **Figures 5** and **6**. The tensile modulus and tensile strength of combination III (which contains 20 % areca fiber) are higher than those of the other combinations, registering 28.24 and 5012.2 MPa, respectively. This can be stated as continuing the behaviour seen during the impact testing process.

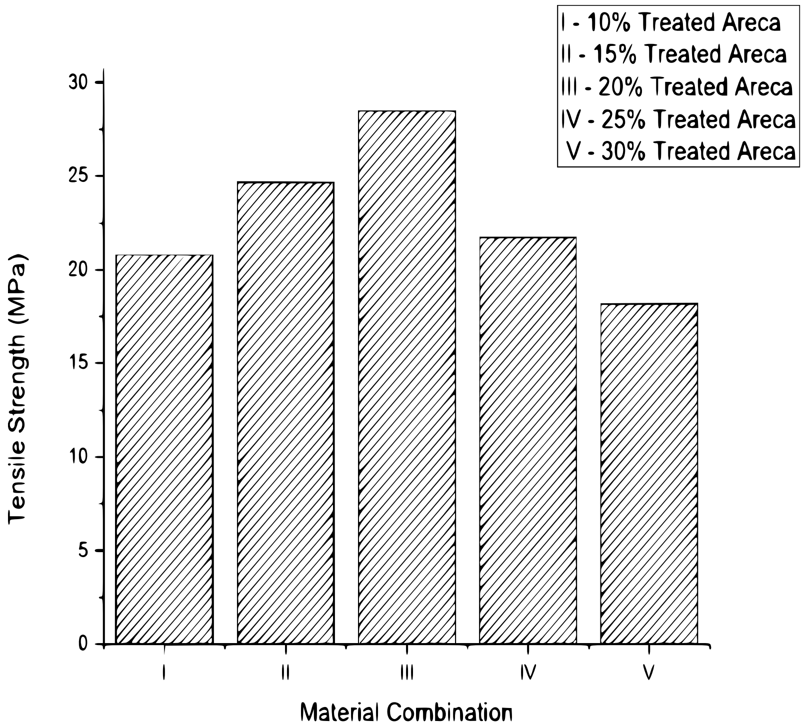

Figure 5 Tensile strength evaluation.

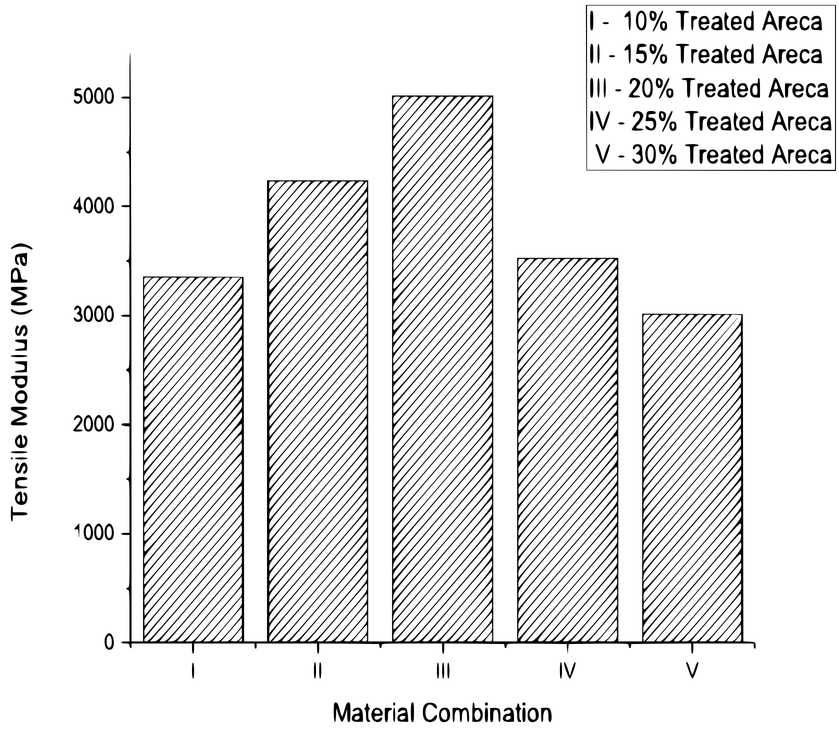

Figure 6 Evaluation of tensile modulus.

Evaluation of flexural characteristics

Figures 7 and **8** illustrate the observations after the tests conducted to find the flexural modulus and strength of the areca fiber reinforced epoxy polymer composites. Flexural modulus and flexural strength are higher in combination III (which contains 20 % areca fiber) than in the other 2 combinations, with values of 52.11 and 4878.32 MPa, respectively.

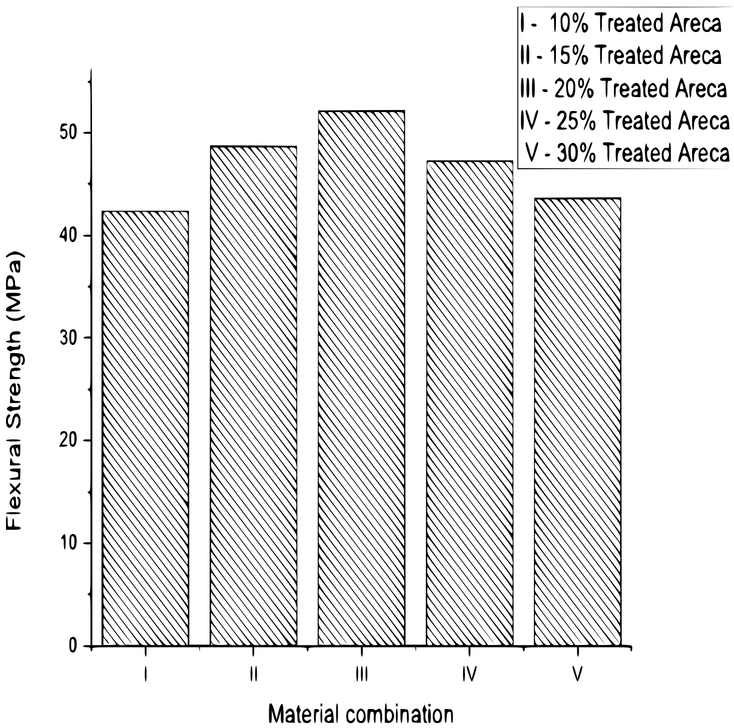

Figure 7 Flexural strength evaluation.

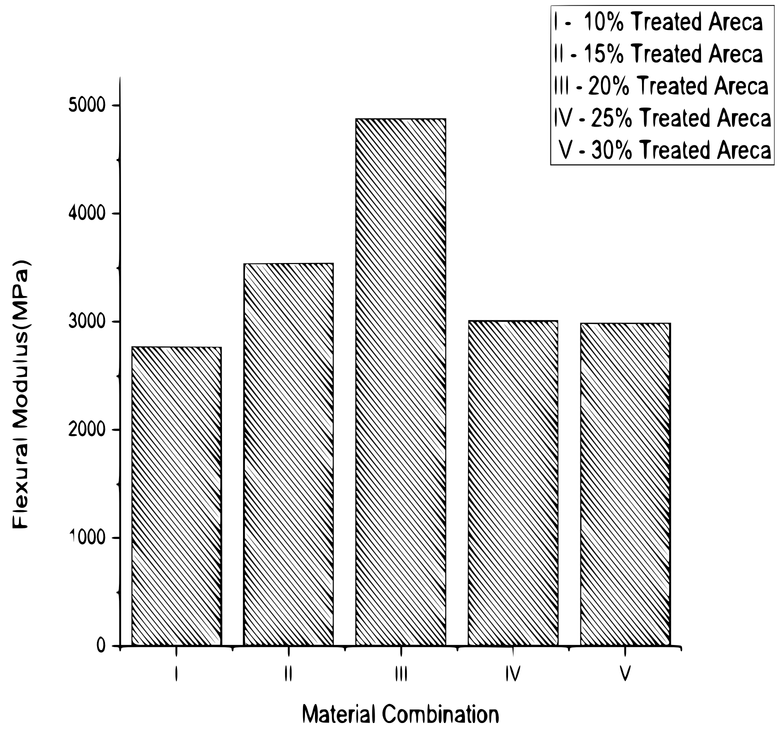

Figure 8 Evaluation of flexural modulus.

Evaluation of impact characteristics

Specimen toughness of areca fiber reinforced epoxy polymer composites was evaluated using an impact test. The outcome of the impact test is depicted in **Figure 9**. From the result obtained, it is evident that composite III (with 20 % areca nut fiber) performs better impact strength of 3.34 KJ/m^2 when compared with other combinations.

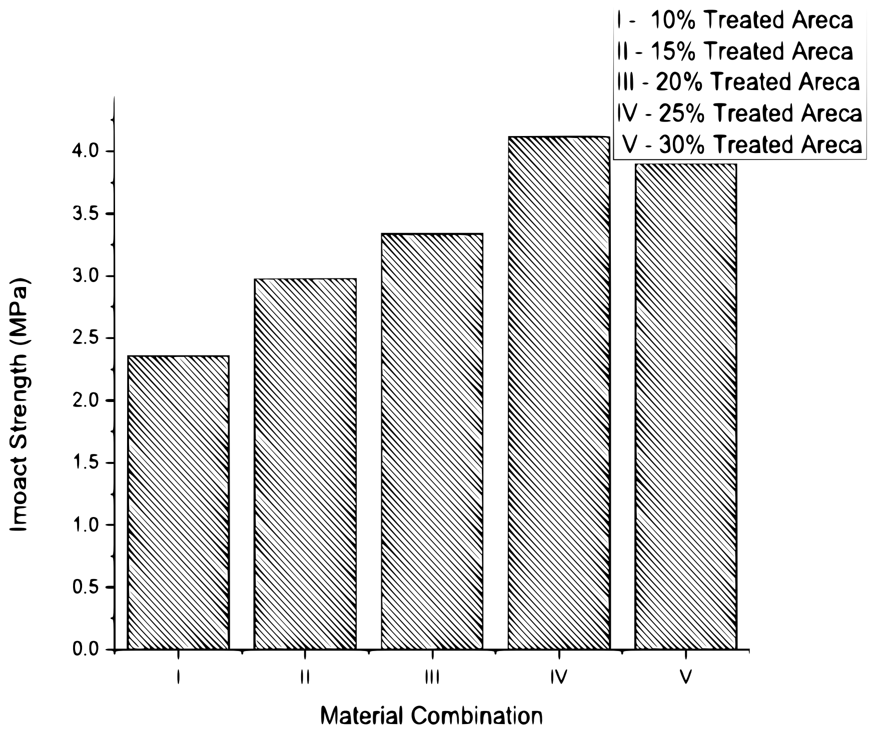

Figure 9 Impact strength evaluation.

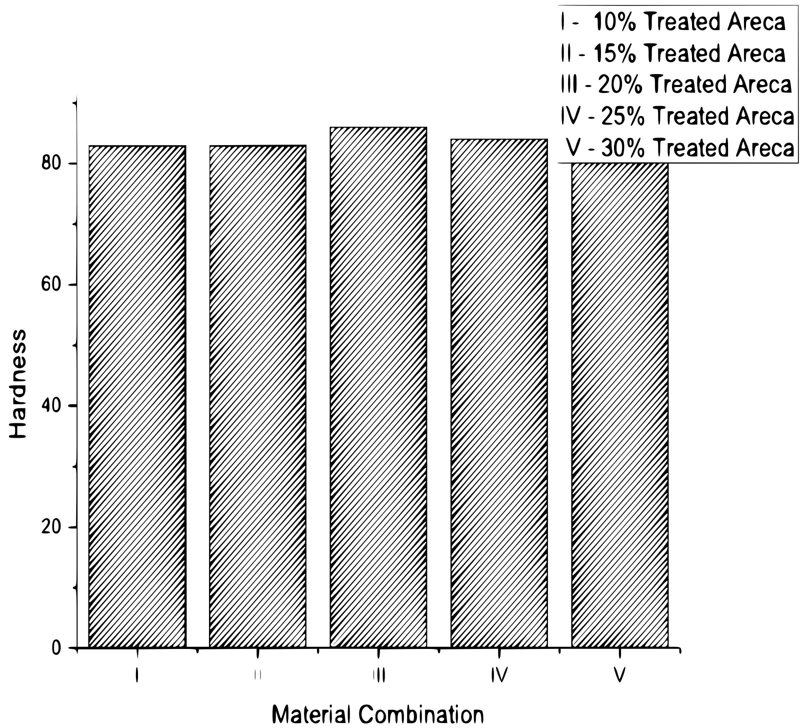

Figure 10 Hardness property evaluation.

Evaluation of hardness characteristics

Hardness is a composite material's resistance to various form changes when subjected to a force. The outcome of the hardness test is depicted in **Figure 10**. The third combination comprising 20 % areca fiber has a greater hardness grade of 86 shores D. Compared with the flexural and impact properties, the trend is not substantially repeated when the hardness test is conducted on a Shore D Hardness tester. There was less uniformity in the outcomes of the influence of the several added components on Shore D hardness.

Testing of wear resistance

Material wear happens when 2 or more surfaces of the same material come into contact, resulting in material loss from one or both of these surfaces. During the POD test, a sample with a length of 30 mm and thickness and breadth of 5 mm is subjected to a wear test. Three samples were analyzed for this discussion, and an average of those data was used. A variety of loads are shown in **Table 5** to illustrate wear.

Table 5 Values of wear obtained corresponding to varying loads.

Fiber weight %	Load of 10N	Load of 15N	Load of 20N
10 %	3.7×10^{-3} g	3.8×10^{-3} g	4.4×10^{-3} g
15 %	2.7×10^{-3} g	3.1×10^{-3} g	3.5×10^{-3} g
20 %	1.5×10^{-3} g	1.5×10^{-3} g	1.9×10^{-3} g
25 %	2.8×10^{-3} g	3.4×10^{-3} g	3.5×10^{-3} g
30 %	3.9×10^{-3} g	4.6×10^{-3} g	4.9×10^{-3} g

The revolving counter face presses the sample perpendicularly against it. Data in **Figure 11** shows the weight loss in grams when subjected to 3 different loads. Adding 20 % more fiber slows weight loss dramatically; however, this is only true for a short period. Epoxy's material loss can be reduced by increasing the adhesion between the fiber and epoxy by adding the aforementioned fibers. Up to a fiber volume of 20 wt%, the pattern seems to be increasing and later it starts decreasing.

Increased tensile, hardness, toughness, and fibre-matrix adhesion were the key governing factors for these improved tribological properties. The chopped areca fibre reduced wear by minimizing the proximity between the revolving disc and the epoxy composite. Composites containing 20 % fiber reinforcement have improved wear resistance in all evaluated conditions. In addition, it has been found that alkali-treated chopped areca nut fibers are found to be the best material which can be used as reinforcement for friction components. A good tribological performance is demonstrated by combination III (with a 20 percent areca fiber content). Fiber addition until 20 weight percentage follows Archard's Law in most areas, but the values begin to fall as the percentage of fiber increases.

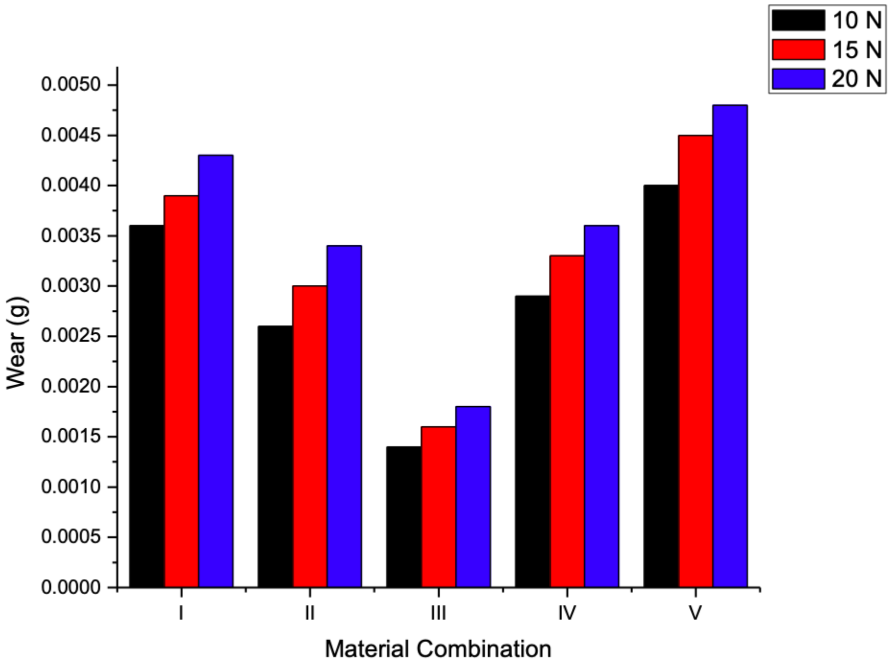

Figure 11 Values of Wear obtained at 10N, 15N and 20N.

Table 6 gives a brief detail about the various instruments used in this research work. By referring to this table, an idea about the machineries, its manufacturer, measurement parameter and accuracy/error can be identified and utilised in the upcoming works.

Table 6 Instrumentation details used for carrying out various tests.

Instrument	Manufacturer	Measurement parameter	Accuracy/error
Universal Testing Machine	Tinius Olsen, USA	Tensile strength & modulus, Flexural strength & modulus	± 1 %
Charpy Impact testing machine, Instron 9400	Instron, United Kingdom	Impact strength	± 1 %
Shore D hardness tester	Hans Schmidt, Germany	Hardness	0.1
Computerised weighing device, AUW. 220D	Shimadzu, Japan	Weight	0.01 mg
Pin on disc tribometer (POD), Ducom, TR-20 LE	Ducom, USA	Wear	1 micron

Areca nut husk fiber based composites and many other green composites are often used in a wide range of automotive applications [33]. To enable better putting into context the results obtained, some tensile data (**Table 7**) is reported on natural fibers of the same length i.e., 30 mm, and introduced in an amount of 20 wt% into a polymer matrix, are compared to the present data. In that respect, areca nut husk composites appear strongly penalized by their limited elongation and possibly not regular geometry, which results in a relatively precocious failure, which may limit its application. However, the introduction of larger amounts of fibers would possibly need to be attempted, which would hypothetically also improve the effect of treatment.

Table 7 Tensile performance on areca nut husk fiber/epoxy composites against composites with the same amount of fiber (20 wt%) and with the same length (30 mm).

Fiber	Matrix	Tensile strength (MPa)	Tensile modulus (GPa)	Ref
Areca nut husk	Epoxy	28.5	5.01	Here
Cissus quadrangularis	Unsaturated polyester	42	1.17	[34]
Banana	Epoxy	68	-	[35]
Indian mallow	Unsaturated polyester	26.7	3.25	[36]
Jute	Epoxy	78	0.8	[37]

Conclusions

The application of NaOH treatment on areca nut husk fibers allows these being effectively used on composites: On the other side, this treatment does decrease the temperature for their degradation and possibly a less aggressive process might be proposed either chemical or not. From the results on composites testing, it is evident that the areca nut husk fiber/epoxy polymer composites with an amount of short (30 mm length) random reinforcement introduced of 20 wt%, exhibits the highest peak mechanical properties among all the calculated properties. The possible increase over that level do not appear conversely to bring additional benefits. It has been indicated that raising the fiber weight ratio up to a specific proportion, which is bonded with the resin matrix and has a sufficient adhesive strength, would result in more efficient strength outcomes. Tensile strength has dropped when the fiber weight ratio has been increased further. Critical fiber length is a major parameter that affects the strength of the fiber reinforced composites. The fibers with 30 mm length were used in this study to evaluate the mechanical and tribological properties of the composite samples. Chopped fibers delay the onset of fracture, making this material appropriate for different varieties of applications. This material offers the maximum impact strength when compared with that of the long areca nut fiber reinforced epoxy polymer composites. In addition, the tribological behavior of these composites indicates that the introduction of more number of fibers also offers the most limited wear. In general terms, it appears that the production of areca nut husk fiber composites in this configuration does hardly compare with other more diffuse fibers, and further work on the possible introduction of more fibers or on the improvement of process production, may be fabricating hybrids with other fibers, needs to be investigated. Areca fiber reinforced epoxy polymer composites are used in aircraft and spacecraft structures, missile components, automobile components like body panels, engine components, suspension parts, marine components like boat hulls and decks, construction industries like building facades, bridges, sports equipment like tennis rackets, golf clubs, bicycles, medical devices like prosthetics and implants, and electronic devices like printed circuit boards.

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