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Research Paper

Investigation of the Impact of Epoxy-based Composites Reinforced with Betel Nut and Coir Fiber on Physio-Mechanical Properties

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Natural fibers are increasingly being used in composite production due to the detrimental effects of synthetic fibers on the environment and public health. Compared to synthetic fibers, natural fibers are more easily manufactured, less expensive, and contribute significantly to the mechanical properties of composites. This study investigates the impact of natural fibers on the mechanical and physical properties of fabricated composites. The epoxy-based composite in this work was reinforced with betel nut and coir fiber, using a hand lay-up technique as the fabrication method. During the composite fabrication, resin and hardener were used at a constant weight ratio of 80%. The length of the coir fiber ranging between 15 mm to 50 mm, and the weight percentage (wt.%) of coir fiber and betel nut fiber in the composite, ranging from 5% to 15%, were used as control factors. After testing and analyzing nine different samples, it was observed that impact strength (9.5 J/cm^2), and tensile strength (4.4 MPa) were higher for 15% of coir fiber and 5% of betel nut fiber, regardless of coir fiber length. Irrespective of coir fiber length, flexural strength and hardness increased as the betel nut fiber content rose from 5% to 15%. The highest flexural strength of 1.0 MPa and hardness of 68 RHN (Rockwell hardness number) were recorded for sample 4. During the water absorption test, sample 1 with a coir fiber length of 50 mm, 5% of coir fiber and 15% of betel nut fiber showed significant performance with a 0.07% water absorption rate. These natural fiber-based composites can be utilized in the fabrication of different types of mats, bags, and clothing items.

Keywords: reinforced composite; natural fiber; mechanical properties; polymer matrix; water absorption rate; hand lay-up.

1. Introduction

The physical and chemical characteristics of the two components that make up a composite material are not the same. Their combination creates a unique material with enhanced properties, such as increased strength, reduced weight, and improved electrical resistance. These components may also contribute to making the composite more rigid and strong. Their versatility and ability to improve the properties of their underlying materials make them superior to more conventional materials [1]. For example, wood is a natural composite material that consists of long cellulose fibers bound together by lignin. It is the combined characteristics of the composite's constituent components that give the material its unique properties [2]. Additionally, the process of making bricks using mud, which dates back thousands of years old is an example of the historical use of composite materials.

Composites are becoming an integral part of our daily lives and sometimes they are referred to as composition materials Reinforcement and matrix are two main components; the former is a strong substance that bears loads, while the latter is typically weaker, helps sustain structural loads, enhancing the rigidity and strength of the composite. Although distinct, these components have attributes that contribute to the final product. Compared to the matrix, reinforcement is often more robust, hard, stiff, and powerful. Composites find use in a wide range of sectors, including transportation, aircraft, electronics, furniture, healthcare, and packaging. Because they are so resistant to chemicals and corrosion, they find usage in industrial applications as well [3]. While chemical resistance is a significant property of composite materials, it is far from the only advantage.

Fabrication of complex material bodies with composites is comparatively natural and works well for both small and large products. Tooling costs are low, and they can incorporate integral features with a satisfactory surface finish. Their low mass and weight provide unparalleled processing and manufacturing possibilities. Depending on the reinforcements used, composites can withstand four to six times the stress of metals such as steel or aluminum. When compared to metals, composites transfer less vibration and noise when operating. The impact and torsional stiffness of composites is well-documented. In addition to enhanced fatigue endurance, achieving ultimate tensile strengths of up to 60%, composites also possess high fatigue strength as well as resistance to impact and environmental factors, requiring less maintenance. Composites do not melt or corrode. With enhanced surface qualities, minimal thermal expansion, low electrical conductivity, and the ease of incorporating integrated ornamental melamine, composites are an excellent material choice. Composite components can simplify assembly design by eliminating the need for joints, unlike non-composite metallic parts. However, composites are expensive to produce and have several drawbacks, including a lengthy development period, complex manufacturing processes, low ductility, temperature limitations, susceptibility to chemical or moisture damages, hidden defects, and sensitivity to damage [4].

The matrix of composite materials degrades in nature, making analysis more challenging. Hot curing is essential in many cases, requiring the use of specialized tools: both hot and cold curing processes can be time-consuming [3].

Coconut fiber, also known as coir fiber, is one of the most readily available fibers that can be easily found in tropical regions [5]. Like jute fiber, coir fiber is extracted from coconut shells by combing and crushing the fibers after soaking them in hot water. Each of the tiny, cellulose-based fiber cells measures about 1 mm in length and 10–20 μm in diameter. The fibers are hollow, narrow, and have thick walls. The diameters of fresh coir fibers can vary between 50 to 300 μm, and their lengths vary from 15 to 35 cm. As the fibers mature, they harden and turn yellow because lignin gets embedded in their walls. Coir fiber exhibits good stiffness and is used in a variety of products, including brushes, mattresses, coarse filler material, and upholstery [6].

The construction sector is regarded as a significant economic driver in developing countries like Nigeria. Forest resources are vital to this industry, as wood is used for a wide variety of fabrication tasks, including roofing, ceiling construction, paneling, furniture production, and many more [7]. The panel and board sector has predicted a demand of 4.704 million m^3 for wood and 0.688 million m^3 for wood-derived panels and boards [8]. However, forest resources have been significantly depleted, leading to deforestation and its severe environmental impacts, and a spike in wood prices [9]. Wood shavings, flakes, wafers, chips, sawdust, strands, and other similar materials are the usual ingredients in particleboard, a type of composite panel [10]. It is a common component in many household items, including furniture, cladding, flooring, wall bracing, and partitions [11]. Composites are composed of layers of materials that are joined together by synthetic resins. To enhance the final properties of the composite, additional additives may be included. While several varieties of resins see widespread use, the most common, inexpensive, and user-friendly options are urea- and phenol-formaldehydes.

An increasing number of people are considering making particle boards from agricultural waste and byproducts instead of utilizing traditional wood or other forest resources [12]. Agricultural byproducts, including rice husks, peanut shells, coconut coir, bagasse, and stalks from various cereal crops, are plentiful and inexpensive in many developing nations, including India, Sri Lanka, Indonesia, Philippines, and Nigeria. Often, these materials are either burned or improperly disposed of, which leads to environmental contamination. Due to their appealing qualities, including cheap manufacturing costs, ease of recycling, environmental friendliness, and minimal technical requirements, bio-based composites have been proposed as an alternative to traditional composites made from wood or polymers. The use of agricultural byproducts in particle board manufacture has been the subject of many studies. For instance, Bekalo and Reinhardt [13] investigated the use of thermosetting resins in particle boards made using fibers from coffee husks and hulls. Additionally, particle boards were developed from sugarcane bagasse by Mendes *et al* [11]. The authors investigated how the loading and type of adhesive affected the particle board's quality. They claimed that urea-formaldehyde at a 6% loading of urea-formaldehyde produced the best particle board.

According to the American National Standard [14], which pertains to general-purpose particle boards, Amenaghawon *et al.* [15] optimized the manufacturing of particle boards using maize cobs and cassava stalks. Their study aimed to optimize particle board manufacturing by investigating mechanical parameters, specifically the modulus of elasticity (MOE) and modulus of rupture (MOR). Wheat straw's characteristics and its potential for use in the creation of particle boards were investigated by Boquillon *et al.* [16]. The factors influencing the manufacturing of particle boards from maize cobs were examined by Sekaluvu *et al.* [12]. Their findings demonstrated that the resin content and particle size had a significant impact on the properties of the resulting boards.

An age-old custom passed down through the generations involves chewing betel nuts with betel leaf and lime. The maturity of betel nuts can be divided into three stages: raw, ripe, and dried. The husk and nut portion of the raw fruit are soft, and it is green in color. The husk of a mature betel nut is a similar shade of golden yellow, while the nut itself is often a brighter hue. The husk is very porous and retains more juice. As the fruit ripens and dries, its husk takes on a brownish tone and its fiber becomes coarser. Approximately 2.5–2.75 grams of fiber may be extracted from the covered shell of one betel nut fruit [17]. Betel nut fiber is inexpensive and biodegradable raw material. Among the many natural fibers, betel nut fiber stands out for being both lightweight and very strong.

Cellulose makes up the bulk of the fibers, while lignin, pectin, and hemicelluloses comprise the rest in different percentages. The main goal is to remove the seeds. Crushing the betel nuts is necessary. Retting is the procedure that removes the outer layer of a nut's husk. To make the fiber extraction easier, the crushed betel nuts are soaked in water and washed twice throughout the retting process. While the betel nut fruit is still moist, its outer layers are peeled off, leaving only the husk. A fiber extractor machine or manual picking are both used to remove the fiber. To further ensure the fiber is pure, it is washed thoroughly with clean water after extraction. Sun-drying the material for one day will eliminate any excess water. Thermally setting polymers, of which epoxy resin (ER) is a prominent member, find extensive use as structural adhesives and matrices for fiber-reinforced composites. The amorphous, heavily cross-linked structure of these materials offers many advantages, including dimensional stability, high breaking strength and modulus, manufacturing simplicity, and exceptional heat and chemical resistance [18]. But, these materials exhibit reduced toughness and weakened fracture resistance, which may not be suitable for many end-use applications unless they are enhanced [19].

Epoxy, short for the epoxide functional group, is a byproduct of curing epoxy resins. Elastane is another term for a strong adhesive that is often used to bond various things. Many different types of composite materials are available, all of which have desirable properties, including resistance to corrosion, low density, low weight, and exceptionally high compressive strength. These characteristics make them suitable for making thick composite shells. Composites can be used across a wide variety of sectors due to their advantageous mechanical, electrical, and chemical qualities. Because of these suitable beneficial qualities, synthetic components produced from composite materials are used in various automotive and aeronautical components. Windows, doors, furniture, mating, civil construction, and many other household items are made from composite materials. Composite fabrics have the potential to enhance the functionality of components in the marine, chemical, and athletic industries. The use of waste such as onion shells [20], pineapple leaves, palmyra fruit fiber, coir fiber, and betel nut fiber can reduce the impact of waste substance generation. Epoxy composite materials display excellent mechanical properties, including lowering weight, specific modulus, specific strength, and specific stiffness.

This study presents the fabrication of nine samples (three specimens per sample) of distinct epoxy-reinforcement composites for each test via the application of different control factors. These factors include the resin-to-hardener ratio, the weight percentage of resin and hardener, the length of the coir fiber, and the weight percentage of coir and betel nut fiber. A variety of mechanical properties, including hardness, impact strength, tensile strength, and flexural strength, as well as the composites' capacity to absorb water, have been evaluated. The analysis of mechanical and physical properties allowed us to choose the best sample from the nine fabricated composite samples.

2. Materials and methodology

The methodology of this study is divided into two phases. In the first phase, materials were collected and prepared for fabrication. Then, nine samples were created with varying compositions: 5%, 10%, and 15% coir fiber and 15%, 10%, and 5% betel nut fiber, respectively, combined with 80% resin and hardener, maintaining a ratio of 1.25:1. The second phase involved testing the manufactured samples for various mechanical properties, including hardness, flexural strength, impact strength, and tensile strength. Additionally, the water absorption percentage of the samples was determined. After conducting the tests, the results were analyzed in relation to the fiber content of the samples.

2.1. Preparation of materials

Natural resources of coir and betel nut, shown in Figs. 1a and 2a, respectively, were selected for the reinforcement in the composite and collected from BSCIC, Tangail, Bangladesh. The epoxy resin used as a matrix material was a medium-viscosity, Di-glycidyl Bisphenol acid (LY 556), combined with the hardener tri-

FIG. 1. Preparation of coir fiber: a) dry shell; b) moist shell; c) separate fiber from shell; d) sun drying fiber; and e) processed fiber.

FIG. 2. Preparation of betel nut fiber: a) dry shell; b) moist shell; c) sun drying fiber; and d) processed fiber.

ethylene tetraamine acid (HY 951). The properties of these materials are shown in Table 1.

Table 1. Properties of matrix materials [21, 22].

Properties	Epoxy of DGEBA- LY 556	Hardener of TETA- HY 951
Appearance	Colorless	Brownish yellow
Viscosity @ ordinary temp.	9000–12 000 mPa	500–1000 mPa
Density @ ordinary temp.	1130–1160 kg/m^3	946 kg/m^3
Molecular weight (Mn)	2300 g/mol	146.23 g/mol

2.1.1. Preparation of coir fiber. The first step was to separate the coconut shell from the dry coconut. Then, the shells were soaked for 72 hours in a mixture water and 5% NaOH blend. After soaking, the moist shells were removed from the water-NaOH mixture, ensuring that there was no dust ingrained on the surface. Next, the shells were dried in the sun for two days. After drying the shells, the best fibers were extracted from the shells.

2.1.2. Preparation of betel-nut fiber. The extraction technique for betel nut fiber was the same as that for coir fiber extraction. The process involved separating the dry betel nut from the betel nutshell. The shell was then soaked in a mixture of in NaOH and water for 72 hours. After 72 hours, it was removed from the solution and checked to see if there was any surface dust. Then, the shells underwent a drying process in the sun for two days. Once dried, the coir fiber was extracted from the shells.

2.2. Fabrication of specimens

Composites of coconut and betel nut fibers were manufactured in accordance with ASTM standards. Each of the nine samples had dimensions of 250 mm × 130 mm × 5 mm. Composites were made using the hand lay-up procedure, an easy and straightforward method for making composites. Initially, composites were made using the manual lay-up method involving pouring a mixture of fibers and resins into a prefabricated mold designed to the exact dimensions and shape needed. The hand lay-up technique was revolutionary, as it reduced complexity and time due to its low-cost and easy-to-use equipment. The first mold was a wooden one with dimensions of 250 mm × 130 mm × 5 mm. To facilitate the removal of the composite from the mold, the interior was wrapped in polythene. Pulses of chemically treated fibers, resin, and hardener were mass-tested, maintaining A consistent ratio of hardener to resin at 1.25 : 1.

The bucket was then filled with epoxy resin as well as the hardener mixture. For the samples, a combination of 5% coir fiber and 10% betel nut fiber was added to 80% of the hardener and resin mixture, while 5% betel nut fiber was added to 15% of the mixture (Fig. 3a). All percentages were calculated based on weight. Molds were filled with the epoxy resin mixture after it had been mixed with natural fibers (Fig. 3b). The resin was applied uniformly throughout the fibers using a manual roller and brush, which helped to eliminate voids in the fiber structure. The last step involved covering the resin and fibers with glass, and then to ensure there were no air spaces, the glass sheet was placed on the top The next step was to let it set for at least two days. Once the composite material had set, it was removed from the mold, and its rough edges were neatly cut. Based on the components of the control variables listed in Table 2, nine samples were created.

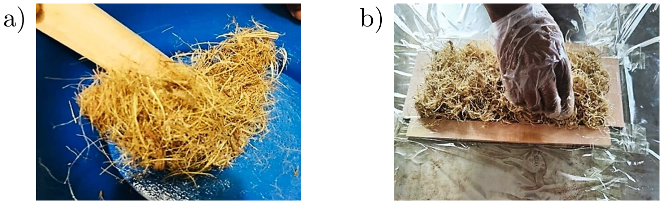

FIG. 3. (a) Mixing of fibers, resin and hardener; (b) pre-molding stage of composites.

Table 2. Experimental design using different control variables.

Sample No.	Ratio of resin and hardener [wt. %]	Resin and hardener in composite [wt. %]	Length of coir fiber [mm]	Coir fiber in composite [wt. %]	Betel nut fiber in composite [wt. %]
1	1.25:1	80	50	5	15
2				10	10
3				15	5
4			30	5	15
5				10	10
6				15	5
7			15	5	15
8				10	10
9				15	5

3. MECHANICAL CHARACTERIZATION

3.1. Impact test

The composite of coir fiber and betel nut fiber in different ratios was tested in a universal impact testing machine. The dimensions of the specimen were prepared according to ASTM D256 standards [23] (see Table 3 and Fig. 4).

Table 3. Data used for impact test.

Machine	Method	V-notch	Specimen dimension
Universal impact tester	Charpy impact test	45°	55 mm × 10 mm × 5 mm

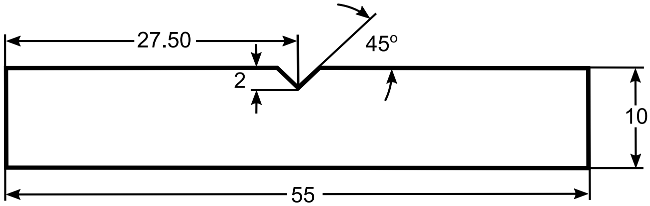

FIG. 4. Specimen geometry for the impact test.

Figure 5a shows the impact tester equipment used to place a Charpy V-notch sample between the equal jaws. At its highest setting, the pointer was 300 J. In Fig. 5b, the hammer is shown lowered toward the specimen from a predetermined height. The absorbed energy during the test was documented and organized as shown in Fig. 5c.

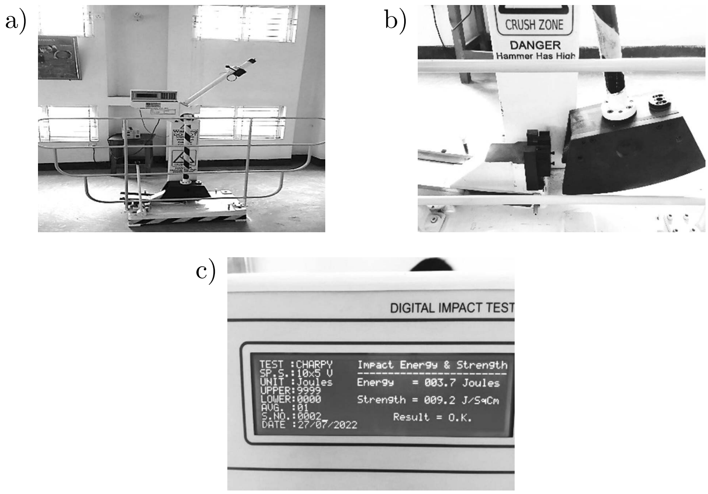

FIG. 5. Digital impact tester machine: a) all setup; b) hammer striking the sample; c) display.

3.2. Tensile test

Composites of coir fiber and betel nut fiber in different ratios were tested in a universal testing machine (UTM) shown in Fig. 7. The dimensions (all in mm) of the specimens were prepared according to ASTM D3039/3039M standards [24], as shown in Fig. 6.

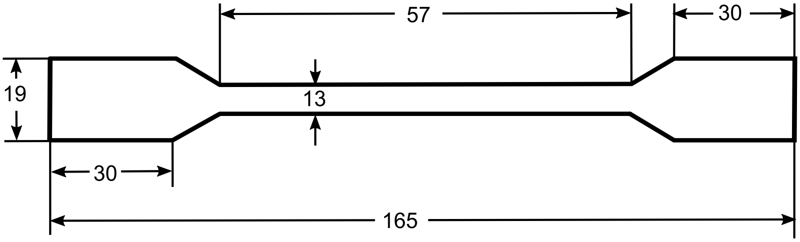

FIG. 6. Specimen geometry for the tensile test.

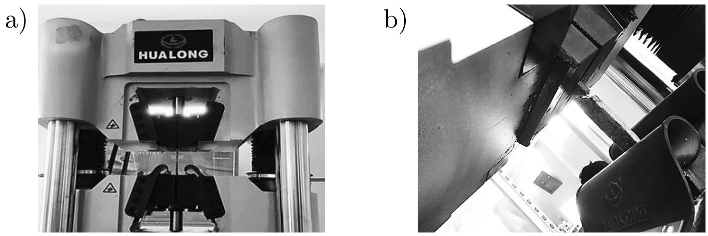

FIG. 7. Tensile strength test: a) universal testing machine (UTM);
b) fractures on the sample.

A tensile test for the coir fiber and betel nut fiber-reinforced composite was performed using the universal testing machine (UTM). The UTM had some limitations in performing the tensile test of the composite, as the specimen had to be around 250 mm long with a radial thickness of 5 mm. However, the grip of the UTM was very strong, as it was specifically designed for testing rod-shaped materials, making it suitable for the composite material as well.

By adjusting the underlying adjustment knob, the workload pointer was set to zero. To determine the elongation of small amounts, a dial gauge was fixed and a sample was used. The length of the sample to be tested was determined by taking three measurements of its diameter using a Vernier caliper, and then calculating the mean value. The specimen was then clamped between the machine's upper and center crosshead jaws. It was configured to record data. As the equipment was turned on, the reading was recorded. Gradually loading the specimen while monitoring its elongation led to its eventual failure.

3.3. Flexural test

Composites of coir fiber and betel nut fiber of various ratios were examined using a standard flexural testing machine. The dimensions for the flexure test were prepared in accordance with ASTM D790 standards [25] (Table 4, Fig. 8).

The UTM had some limitations in performing a flexural test of the composite, as the specimen had to be around 250 mm long with a width of 19 mm. A clamp

Table 4. Data used for the flexural test.

Machine	Method
Universal testing machine (UTM)	Two-point flexural bending test

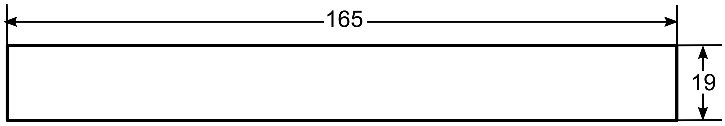

FIG. 8. Specimen geometry for the flexural test.

was designed to allow fora single-point load to be applied to the specimen during the test. The two-point flexure bending test method was used to perform the flexural test.

The specimen was measured using a Vernier caliper to determine its length, breadth, and thickness. The testing machine's bottom crosshead was used to mount the bending fixture. The bending fixture's rollers were used to hold the specimens. The dial gauge was adjusted using its spindle knobs while the specimen was loaded onto the stand. A mechanism was put in place to automatically record the graphs during the test. Once the machine was started, the readings were taken. The specimen was gradually loaded while its bending stress was monitored until it ultimately failed (Fig. 9).

a) b)

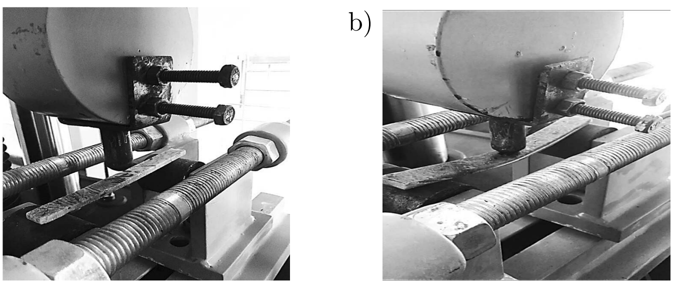

FIG. 9. Flexural test by UTM: a) before loading; b) after loading.

3.4. Hardness test

Composites of coir fiber and betel nut fiber in different ratios were tested in a hardness testing machine shown in Fig. 10 (see also Table 5). The tests were conducted using the C scale.

By turning the knob, the desired load could be chosen, and the appropriate diamond indenter (120°) was set in place. After the sample was cleaned, the machine's work surface was setup. The indenter tip was brought into contact with

a) b)

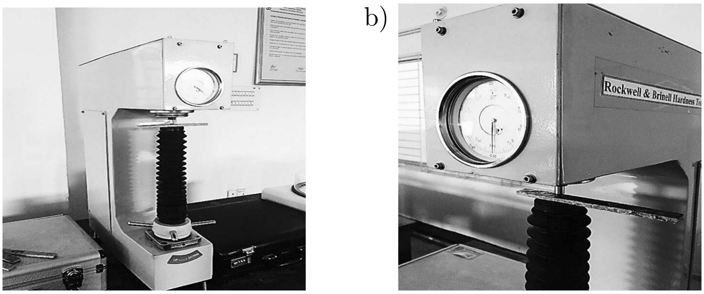

Fig. 10. Rockwell (C scale) hardness tester machine:
a) all setup; b) sample with reading display.

Table 5. Data used for Rockwell hardness test.

Machine	Method	Specimen dimension [mm]	Diamond indenter [°]	Load [kg]
Hardness testing machine	Rockwell C scale hardness test	$30 \times 15 \times 5$	120	150

the test specimen by turning the capstan wheel. In addition, the specimen was subjected to pressure from the indenter while the wheel was rotated three times, ensuring that a small load of 150 N had been applied. The scale dial's pointer was set to the correct position. To apply the main force, the lever was pulled. The loading system included a dashpot to make sure the weight was applied gently. When the pointer stopped moving, the handle was gradually yanked in the opposite direction. After that, the pointer moved 32° in the opposite direction When the pointer stopped moving, the Rockwell hardness could be read from the corresponding scale on the dial.

3.5. Water absorption test

A cloth's water absorption rate refers to its capacity to soak up liquids; this rate is determined by dividing the weight of the dry material by the weight of the water absorbed. This test that measures the soil's moisture level relative to its dry weight, as stated in British Standard [26]. After the design has been dried in an oven, it is weighed again under normal conditions. The formula for determining the moisture content of a material is as follows: the weight of the box with wet soil that is wet minus the weight of the box with dry soil, divided by the weight of the box with sandy soil minus the weight of the empty box, and then multiplied by 100 to provide the percentage. The samples were dried under natural light for a set amount of time and temperature before the absorption test. Then, the dry specimen's weight was recorded. The specimens were subsequently submerged three times, as shown in Fig. 11a. There were three intervals of time: 24, 48, and 72 hours, as marked in Fig. 11b.

a) b)

Fig. 11. Water absorption test: a) samples submerged in water; b) sample time interval marking.

Coir and betel nut fibers were manually collected, and the mold was prepared by hand to create the composite plate. When preparing the form, the hand lay-up method was used, which limited the precision of the fabrication and resulted in a slightly higher costs than anticipated. Additionally, this research was completed during a pandemic, which constrained the availability of raw materials and resources.

4. Results and discussion

Table 6 presents the detailed results of impact strength, tensile strength, flexural strength, hardness and water absorption rate for nine different samples. For each test, three specimens were prepared as per ASTM standards from the nine corresponding samples, and the mean values were taken as the result. From the table, it is evident that the variations in length of the coir fiber and the ratios of coir to betel nut fibers were examined to assess the mechanical properties of the fabricated composite materials.

A graphical representation of different mechanical and physical properties, i.e., impact strength, tensile strength, flexural strength, hardness, and water absorption rate, is shown in Fig. 12, using the data provided in Table 6.

Figure 12a illustrates the variation in impact strength of the fabricated composites. It is evident from experiments 2, 5, and 8 that increasing the length of coir fiber also increases the impact strength of fabricated composite materials containing 10% (wt.) coir fiber and 10% (wt.) betel nut fiber. The highest impact strength, i.e., 9.5 J/cm^2, is observed for 30 mm coir fiber at a ratio of 15% (wt.) coir fiber and 5% (wt.) betel nut fiber. Similar to the impact strength, the tensile strength of the fabricated composites increases from 3.3 MPa to 4.4 MPa, as the length of the coir fiber increases from 15 mm to 50 mm, as indicated in Fig. 12b.

Table 6. Experimental results of samples for different control factors.

Experiment number	Ratio of resin and hardener	Resin and hardener in composite [wt. %]	Length of coir fiber [mm]	Coir fiber in composite w [wt. %]	Betel Nut fiber in composite [wt. %]	Impact strength [J/cm^2]	Tensile strength [MPa]	Flexural strength [MPa]	Hardness [Rockwell C scale]	Water absorption [%]
1	1.25:1	80	50	5	15	7.9	1.1	0.95	65.00	0.07
2				10	10	8.2	4.2	0.85	62.33	0.11
3				15	5	8.4	4.4	0.55	53.66	0.11
4			30	5	15	8.0	2.6	1.00	68.00	0.14
5				10	10	8.1	3.9	0.80	61.33	0.14
6				15	5	9.5	4.2	0.75	53.33	0.08
7			15	5	15	7.5	2.5	0.95	62.33	0.08
8				10	10	7.7	3.2	0.70	57.33	0.11
9				15	5	8.1	3.3	0.65	53.00	0.20

It is also noted that as the percentage of betel nut in the composites increases, the tensile strength decreases to 1.1 MPa. In the case of flexural strength, shown in Fig. 12c, it is found that regardless of the coir fiber length, flexural strength has downfall ranges of 0.25–0.40 MPa each time due to the increase in coir fiber percentage in the composites, or, in other words, due to the decrease of betel nut fiber. A similar trend is observed in the Rockwell hardness test. Figure 12d shows that the Rockwell hardness values decrease, ranging from 9.33 to 14.67, as the percentage of coir fiber increases. This suggests that betel nut fiber has a stronger influence on toughness and flexural strength. It can be observed from Fig. 12e that, for a given length of coconut fiber, water absorption increases as the weight percentage of coir fiber in the composite increases or decreases, except for experiment 6. The maximum water absorption is found in sample 9, which contains 15 mm coir fiber, 15% coir fiber, and 5% betel nut fiber. Therefore, it can be said that coir fiber has a higher impact on water absorption.

Finally, from the above graphical and descriptive analysis, experiment 6 is the best choice for achieving higher impact and tensile strength. On the other

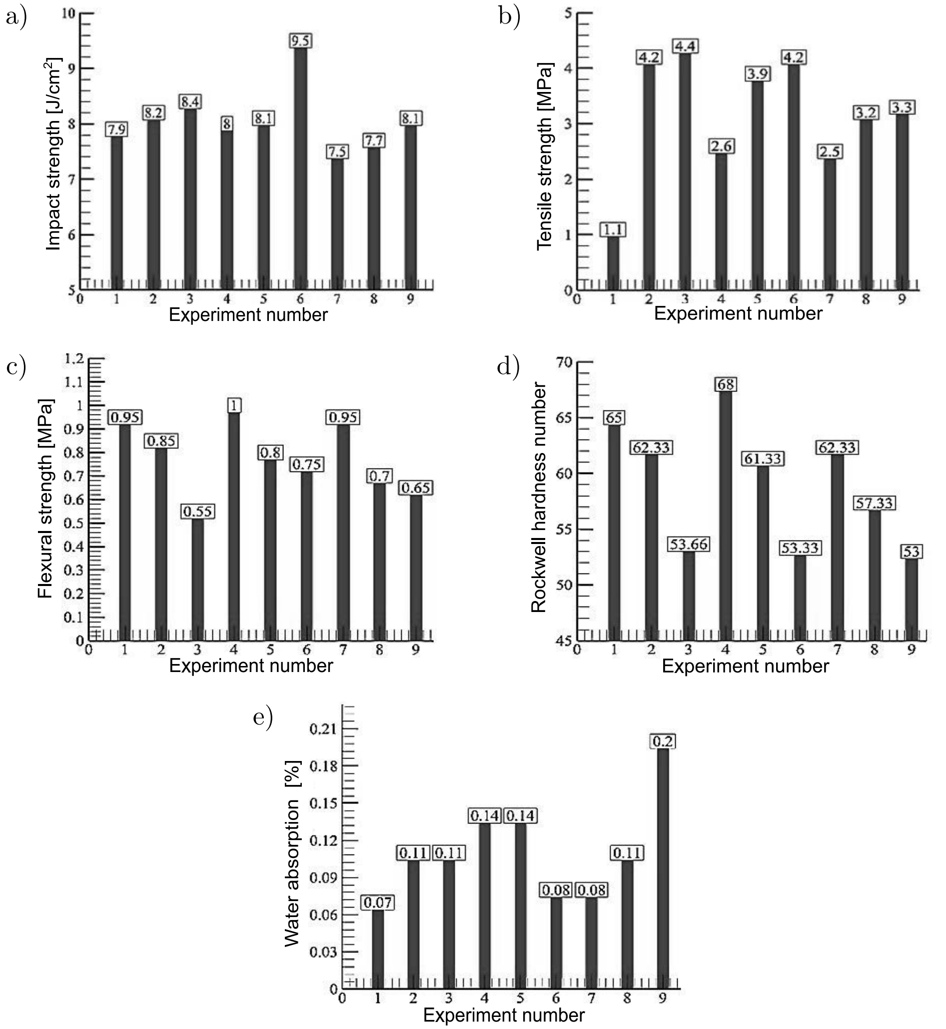

FIG. 12. Comparison of mechanical properties of different samples; a) impact strength; b) tensile strength; c) flexural strength; d) Rockwell hardness; e) water absorption rate.

hand, for greater flexural and Rockwell hardness, experiment 4 is the best one. Furthermore, experiment 1 exhibits the best performance in the water absorption test.

4.1. Cost analysis

The preparation of composite specimens, which involved collecting coir and betel nut fibers and preparing molds, was completed through the hand lay-up method. During the fabrication of composites, great attention was given to precision, resulting in costs that were slightly higher than expected (see Table 7). Besides, this experiment was conducted during the pandemic, which further limited the availability of raw materials and resources.

Table 7. Estimated cost analysis of composites fabrication.

Items	Quantity	Cost (USD*)
Epoxy resin and hardener	4 kg	33.5
Coir fiber	3 kg	0.34
Betel nut fiber	4 kg	0.34
NaOH	250 gm	2.93
Total cost		57.61

*1 USD = 119.40 Bangladeshi Taka (conversion on: 01-10-2024).

5. Future recommendation

In this work, different mechanical properties of the fabricated composite materials using coir fiber and betel fiber were examined by varying the length of coir fiber and the weight percentage of these fibers, while maintaining a constant ratio of resin and hardener. However, in the future,

1) The research work can be extended further by considering other composite fabrication methods such as compression or vacuum molding technique.
2) As natural fibers were dried in sunlight after chemical treatment in this work, the humidity of these fibers was not controlled. A dryer can be used to improve the quality of the composite by controlling the humidity of the fibers.
3) In this work, the fibers were mixed with epoxy and hardener by a hand stirrer. A mixing machine could be used to produce a more homogeneous mixture.
4) In this study, 80% of the compositions consisted of a mixture of resin and hardener (by wt.%), but this ratio can be varied in further research to compare with the current study.
5) Additional control factors can be considered, such as the size of the fibers, the length of the betel nut fiber, the duration of chemical treatment of the fibers, mixing temperature, molding pressure, and curing time.

6. Conclusion

From the analysis of physio-mechanical properties of different samples, the following findings were derived:

1) The impact strength and tensile strength were higher for samples containing 15% coir fiber and 5% betel nut fiber, regardless of the length of the coir fiber.
2) In the case of flexural strength and hardness, a reciprocal relationship was observed between the weight percentages of coir fiber and betel nut fiber in contrast to the impact and tensile strength. Irrespective of the coir fiber length, flexural strength and hardness increased due to the increase of betel nut fiber from 5% to 15%.
3) During the test of physical property, i.e., water absorption, sample 1, which had a coir fiber length of 50 mm with 5% coir fiber and 15% betel nut fiber showed significant characteristics with a 0.07% water absorption rate.
4) Due to the biodegradability, recyclability, eco-friendliness, and economical materials, different types of mats, bags, and clothing items can be fabricated from these composite materials.

Author contributions

All the authors of this research significantly contributed to the work presented. Conceptualization was conducted by M.F. Kabir; the original draft writing and preparation were conducted collectively by M.F. Kabir, M.A. Hossain, M.S. Tamanna, G.M.U. Kader, and S.S. Sakib; the review and editing were carried out by M.F. Kabir and M.A. Hossain.

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Data availability statement

All data are included in the paper.

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Conflicts of interest

The authors declare that there no conflicts of interest.

References

1. TWI Ltd, *What is a composite material?* (A definitive guide), https://www.twi-global.com/technical-knowledge/faqs/what-is-a-composite-material (retrieved on 30.08.23).

2. Ngo T.-D., *Composite and Nanocomposite Materials: From Knowledge to Industrial Applications*, IntechOpen Limited, London, UK, 2020, doi: 10.5772/intechopen.80186 (retrieved https://www.intechopen.com/books/8768).

3. Gupta G., Kumar A., Tyagi R., Kumar S., Application and future of composite materials: A review, *International Journal of Innovative Research in Science, Engineering and Technology*, **5**(5): 6907–6911, 2016, doi: 10.15680/IJIRSET.2016.0505041.

4. Boda M.A., Phand R.V., Kotali A.C., Metal and non-metal composite materials a new alternative for materials: Review, *International Journal of Scientific Development and Research*, **2**(4): 236–239, 2017, https://ijsdr.org/papers/IJSDR1704040.pdf.

5. Huzaifa W., Coconut/Coir Fiber: Properties, Manufacturing Process and Uses, *Textile Learner*, 2020, https://textilelearner.net/coconut-coir-fiber-properties-manufacturing/ (retrieved on 03.09.23).

6. Yan Y., Developments in fibers for technical nonwovens, [in:] *2-Advances in Technical Nonwovens*, Kellie G. [Ed.], pp. 19–96, Woodhead Publishing Series in Textiles, 2016, doi: 10.1016/B978-0-08-100575-0.00002-4.

7. Boopalan M., Niranjanaa M., Umapathy M.J., Study on the mechanical properties and thermal properties ofjute and banana fiber reinforced epoxy hybrid composites, *Composites Part B: Engineering*, **51**: 54–57, 2013, doi: 10.1016/j.compositesb.2013.02.033.

8. Sotannde O.A., Oluwadare A.O., Ogedoh O., Adeogun P.F., Evaluation of cement-bonded particle board produced from afzelia Africana wood residues, *Journal of Engineering Science and Technology*, **7**(6): 732–743, 2012.

9. Kayode J., Conservation implications of timber supply pattern in Ekiti State, Nigeria, *Research Journal of Forestry*, **1**(2): 86–90, 2007, doi: 10.3923/rjf.2007.86.90.

10. Erakhrumen A.A., Areghan S.E., Ogunleye M.B., Larinde S.L., Odeyale O.O., Selected physico- mechanical properties of cement-bonded particleboard made from pine (*Pinus caribaea M.*) sawdust-coir (*Cocos nucifera L.*) mixture, *Scientific Research and Essay*, **3**(5): 197–203, 2008.

11. Mendes R.F., Mendes L.M., Guimarães J.B., Jr., dos Santos Cavalcante R., Bufalino L., The adhesive effect on the properties of particleboards made from sugar cane bagasse generated in the distiller. *Revista de Ciências Agrárias*, **32**(2): 209–218, 2009, doi: 10.19084/rca.15739.

12. Sekaluvu L., Tumutegyereize P., Kiggundu N., Investigation of factors affecting the production and properties of maize cob-particleboards, *Waste and Biomass Valorization*, **5**: 27–32, 2014, doi: 10.1007/s12649-013-9228-9.

13. Bekalo S.A., Reinhardt H.W., Fibers of coffee husk and hulls for the production of particleboard, *Materials and Structures*, **43**(8): 1049–1060, 2010, doi: 10.1617/s11527-009-9565-0.

14. American National Standard for Particleboard. ANSI/A208.1. Composite Panel Association, Gaithersburg, 1999, https://www.scribd.com/doc/286962476/ANSI-A208-1-1999-PB.

15. Amenaghawon N.A., Osayuki-Aguebor W., Okieimen C.O., Production of particle boards from corn cobs and cassava stalks: Optimisation of mechanical properties using response surface methodology, *Journal of Materials and Environmental Science*, **7**(4): 1236–1244, 2016.

16. Boquillon N., Elbez G., Schönfeld U., Properties of wheat straw particleboards bonded with different types of resin, *Journal of Wood Science*, **50**: 230–235, 2004, doi: 10.1007/s10086-003-0551-9.

17. Chakrabarty J., Hassan M.M., Khan M.A., Effect of surface treatment on betel nut (*Areca catechu*) fiber in polypropylene composite, *Journal of Polymers and the Environment*, **20**: 501–506, 2012, doi: 10.1007/s10924-011-0405-2.

18. Song M., Yu H., Gu J., Ye S., Zhou Y., Chemical cross-linked polyvinyl alcohol/cellulose nanocrystal composite films with high structural stability by spraying Fenton reagent as initiator, *International Journal of Biological Macromolecules*, **113**: 171–178, 2018, doi: 10.1016/j.ijbiomac.2018.02.117.

19. Prabhu R., Joel C., Bhat T., Development and characterization of low-cost bamboo fibre reinforced polymer composites, *American Journal of Materials Science*, **7**(5): 130–134, 2017, doi: 10.5923/j.materials.20170705.02.

20. Hossain M.A., Rashid F., Akhter M.S., Aziz M., Hoque M.E., Liquid fuel generation from onion shell: an experimental approach of pyrolysis process, *Energies*, **17**(9): 2171, 2024, doi: 10.3390/en17092171.

21. Mittal M., Chaudhary R., Biodegradability and mechanical properties of pineapple leaf/coir fiber reinforced hybrid epoxy composites, *Materials Research Express*, **6**(4): 045301, 2019, doi: 10.1088/2053-1591/aaf8d6.

22. Naik A.B., Reddy A.C., Optimization of tensile strength in TIG welding using the Taguchi method and analysis of variance (ANOVA), *Thermal Science and Engineering Progress*, **8**: 327–339, 2018, doi: 10.1016/j.tsep.2018.08.005.

23. Dahal R.K., Acharya B., Dony B., Dutta A., Biocarbon filled hemp-epoxy composite: its physical, mechanical, and thermal properties, *Applied Composite Materials*, **29**(6): 2185–2202, 2022, doi: 10.1007/s10443-022-10059-8.

24. Li H., Wang T., Sun J., Yu Z., The effect of process parameters in fused deposition modelling on bonding degree and mechanical properties, *Rapid Prototyping Journal*, **24**(1): 80–92, 2018, doi: 10.1108/RPJ-06-2016-0090.

25. Gowda R.B.S., Udayagiri C.S., Narendra D.D., Studies on the process parameters of rapid prototyping technique (Stereolithography) for the betterment of part quality, *International Journal of Manufacturing Engineering*, **2014**(1): 804705, 2014, doi: 10.1155/2014/804705.

26. Foley M.E., Hart D.C., Guidelines for developing and inserting material properties into the code 65 composite material database, *West Bethesda, MD: Naval Surface Warfare Center, Carderock Division*, 2011, https://apps.dtic.mil/sti/citations/ADA579199.

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