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코코넛 꽃자루 섬유의 기계적 특성에 대한 연구

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Studies on Mechanical Behaviour of Coconut Peduncle Fibers

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Abstract: Natural fibers have gained popularity as reinforcements in composite materials owing to their renewable and sustainable characteristics. In this study, the mechanical behaviour of coconut peduncle fiber with epoxy resin was investigated through four types of mechanical tests with four different weight percentages. The coconut peduncle fiber was extracted from the coconut tree. Mechanical testing revealed that adding coconut peduncle fiber to the epoxy resin increased the mechanical qualities of the composite material. The composite material's tensile strength was determined to be 2042 N, while its compressive value was 1383.81 N. The flexibility and elasticity of the composite material are both measured to be 170.69 N. The impact strength of the composite material was discovered to be 47 kJ/mm^2. The study discovered that coconut peduncle fiber composite has good mechanical properties, making it an excellent choice for use in a range of industries, including construction, automotive, and aerospace.

Keywords: polymer composite, epoxy resin, coconut peduncle fiber, mechanical properties.

Introduction

Materials made of composites, plastics as a ceramic have dominated the expanding material environment during the previous thirty years. Alongside new products, composite materials have steadily increased. Modern composite materials have contributed significantly to the development of engineered materials, from simple everyday items to advanced components. Although composites have already demonstrated their value as lightweight materials, the present challenge is to make them affordable and advantageous to everyone. Some cutting-edge techniques widely used in the composites sector were developed to make economically viable composite components. Composites can be divided into two categories: Artificial and natural fiber-reinforced composites and organic composites. Natural fibers[1] including hemp, flax, and abaca are commonly utilised. Synthetic fibers[2] include carbon, glass, and kevlar. Natural fiber-reinforced composites employ the husk of rice, coir fibers, cotton fibers, bagasse from sugarcane, jute fiber, wool, hemp, and other natural fibers as reinforcement. Biodegradable natural fibers are widely available on the earth. Natural fibers are widespread on the earth, but synthetic fibers are produced by humans and manufacturing. The main objective of fiber strengthening is to improve tensile, impact strength, flexural strength, hardness, compression strength, and other attributes of the resin so that it may be used in manufacturing and heavy industries.[3-7] To distinguish them from filled polymeric composites, these materials are referred to as advanced matrix composites. In this type of composite, the reinforced fibers are primarily responsible for carrying extremely light external loads. Since both the mechan-

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ical and physical attributes of these composite are so important in their widespread application, it is necessary to explore their properties in a range of conditions and orientations. Delamination, matrix cracking, fiber fracture, and fiber debonding/pulling are the most common types of composite damage. Understanding the damage process is crucial for improving the composite framework and picking a strategy that reduces the expenses of all operations. Damage caused by impact occurrences is one of the most crucial results in composite constructions. Understanding the damage and failure in the composite is crucial to producing a fiber-reinforced material that is both inexpensive and durable.

Mohan Prasad *et al*.[8] studied the maximum fiber strength by analyzing the characteristics of fibers from coconut peduncle fibers. Vineet Nair *et al.*[9] analyzed the mechanical features of natural fiber reinforcement composites and organic FFRP (Flax Fiber-Reinforced Polymer) fiber, which are utilized to substitute synthetic glass or carbon fiber with environmental and financial benefits. Zhijian Li *et al*.[10] studied methods to improve the flexural strength, ductility, toughness of conventional cementitious materials, the alkali treated coir fibers and other chemical agents were poured into the mixer. The alkali treatment of coir fiber results in the elimination of lignin and an increase in tensile strength. Al-Mosawi *et al*.[11] used ansys modelling to estimate both the flexural and tensile strength of green materials. Under varying loading, the flexural and tensile properties of a green composite consisting of a substance called poly and Ramie's fibers having (twenty percent, forty percent, sixty percent) reinforcements were calculated using the Ansys programme version. Using a new fiber architecture (NFA) that significantly enhances mechanical characteristics and performance, Forkan Sarker *et al*.[12] explored nano-engineered graphene-based organic jute fiber preforms. Vishnu Prasad *et al.*[13] says that the coating nano titanium dioxide (TiO_2) particles on flax Fibers is used in this work as a Fiber modification approach. Venkatasubramanian *et al*.[14] examined the mechanical properties of composites made of abaca, glass, and banana fiber. This research focuses on the production and mechanical characteristics of natural fibers such as the abaca and glass fibers. Abaca polymer reinforced composites' tensile, moisture absorption, and impact characteristics were studied by Prakash *et al*.[15] Results of tests conducted on the abaca natural fiber's elastic, impact, and hardness were obtained. Using experimental and computational modelling, Najim A Saad *et al*.[16] evaluated the influence on the resistance to fracture of a polyphenylene sulphide base material composite. The project's major purpose is to quantify the impact fracture resistance of composite components and compare it to numerical modelling. Experimental and numerical research were used by Satnam singh *et al*.[17] to examine the mechanical properties of epoxy composites reinforced with glass fiber. Naveen[18] conducted study on finite element analysis for natural fiber reinforced composite. Three stages are usually employed to examine the interfacial damages assessment for fiber reinforced polymer composites, and basic FEA methodologies were applied throughout the entire process. The mechanical characteristics and evaluation of Kevlar-49 composite components based on modern polymers were studied by Narayanaswamy *et al*.[19] With dimensions of 230 and a thickness of 3 mm, this fiberglass is set up with the hand-up layering and hoover bag method. Mouritz *et al*.[20] examined over fifty publications to investigate the effect of stitching on the in plane mechanical characteristics for fiber reinforced composites made of polymers. Tensile and flexural tests are, according to Mohammad ZR Khan *et al*.,[21] the most important studies to predict the applications of materials. Ganesh R Kalagia *et al*.[22] describes that the study shows that the modern wind turbine plants have the estimated life span of 20 years, after their life span, they need mass structure needed to dispose it in future. Siva *et al*.[23] investigated the effectiveness of evaluation of the stitching and unstitching of a fiber from bamboo laminate, as well as the de-lamination resistance of laminates. It has numerous advantages over other kinds of fibers. The fiber is environmentally friendly, sustainable, and highly renewable, as it is biodegradable. It has high tensile strength and durability for different purposes. Furthermore, the cost of material is lower owing to the fact that it is a readily available waste product from coconut processing. The fiber is light in weight and gives an excellent strength-to-weight ratio, which is very useful in lightweight composites. This is because the fiber has natural insulation properties and is also resistant to moisture and pests. With all these properties, coconut peduncle fiber becomes one of the more interesting eco-friendly alternatives to traditional fibers, combining environmental benefits with practical performance.

From the literature study, relatively fewer researches are available in relation to polymer composites reinforced with coconut fibers. In the present research paper, discussed with the development of polymer composites reinforced with coconut peduncle fiber and studied their mechanical properties.

Experimental

Materials. Coconut peduncle fiber: The peduncle of a coco-

Table 1. Mechanical Properties of Coconut Peduncle Fiber

Properties	Unit	Value
Average Diameter	μm	300-320
Density	g/cm^3	1.2
Cellulose	%	28.29
Hemicellulose	%	20.14
Lignin	%	13.48
Wax	%	0.35

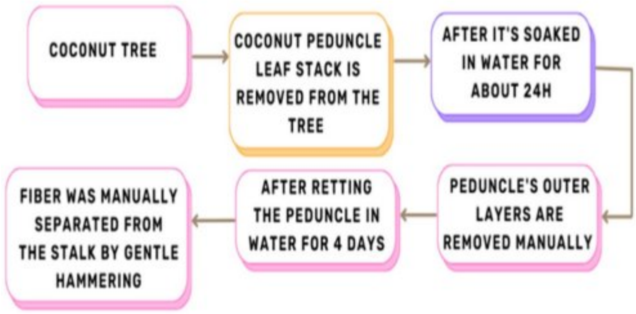

Figure 1. Preparation of fiber from coconut peduncle.

nut tree, which is left over after the coconuts are harvested as agricultural waste, is what is known as coconut tree peduncle fiber (CTPF). The coconut tree's scientific name is cocos nucifera, and it is a monocotyledon that belongs to the Arecaceae family. Table 1 lists the mechanical characteristics of the fiber made from coconut peduncles, and Figure 1 displays a production of such fiber.

Epoxy Resin: Epoxies are widely used to manufacture higher-performance composite substances with superior mechanical capabilities, resistance to corrosive substances and conditions, better electrical characteristics, high temperature performance, adhesion to a the substrate, or any number of these advantages. The epoxy resin matrix was used to create the composite. A hardener (HY-951) and epoxy resin (LY-556) were used. At 250 ℃, resin has a weight per cubic centimeter and viscosity that are dynamic of 1.109 g/cm^3 and 11789 MPa respectively. Table 2 summarizes the properties of epoxy resin.

Table 2. Properties of the Epoxy Resin

Properties	Epoxy Resin
Density	1.2-1.4 g/cm^3
Melting Point	177 ℃
Tensile Strength	50-110 Mpa
Elongation	1-6%
Impact Strength	0.3 J/m

Methods: The graphical representation of this research is represented in Figure 2.

Fiber Arrangement for Polymer Composite Making: Coconut peduncle fiber was employed as the reinforcing material in this investigation, while epoxy resin was used as the composite matrix. Various fiber lengths, fiber orientations, and fibers (treated and untreated fibers) have been employed and analyzed in prior studies. We took raw fibers that ranged in length from 200 to 350 mm. In our research, we employed several fiber orientations and fiber compositions. In our research, we did not utilize any stitching. As different fiber compositions, we uti-

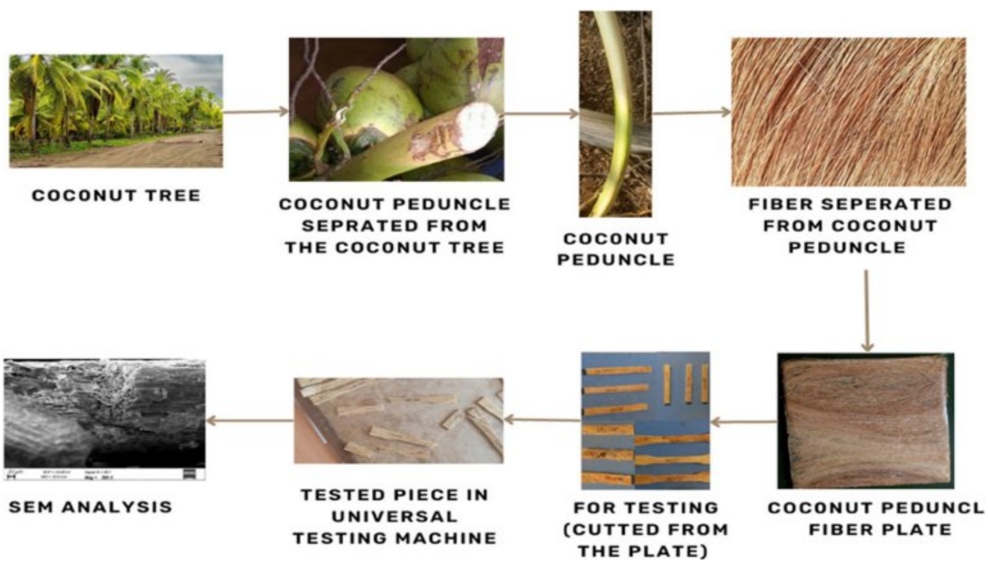

Figure 2. Pictorial flowchart.

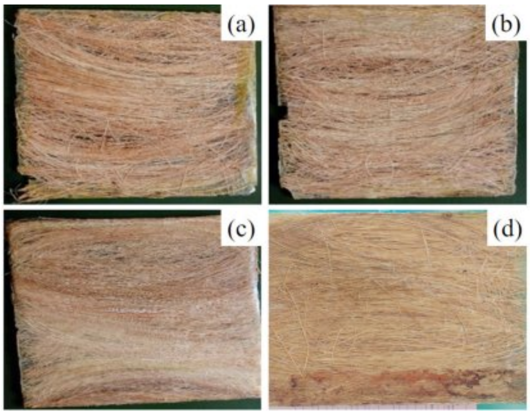

Figure 3. Coconut peduncle fiber (CPF) composite plate: (a) 10; (b) 20; (c) 30; (d) 40 wt%

lized 10, 20, 30, and 40%. Selection of 10, 20, 30, and 40% fiber content in natural fiber-reinforced composites provides an optimum compromise between desired mechanical properties, processing difficulties, and cost control. Each of the selection percentages largely depends on the application requirements and characteristics of the fiber/matrix. Figure 3 demonstrate the many forms of fiber arrangement.

Tensile Strength Testing: A tensile examination is a basic mechanical testing in which the specimen is carefully loaded as the force that is applied and sample extension over a given distance are measured. The breaking point, strength of yield, strength of tensile, and other tensile characteristics are calculated. The American Society of Testing and Materials (ASTM) D638 tensile strength technique, which describes the dog-bone structure, is used. Figure 4 shows the prepared Peduncle fiber composite for tensile test and Figure 5 shows the various setup for testing the Peduncle fiber composite.

Flexural Strength Testing: Flexural strength is measured at the convex or stress side surface of the specimen. The angle at which a slope of a stress vs. deflection curve is used to compute flexural modulus. The sample to be tested undergoes exposure

Figure 4. Peduncle fiber composite for tensile test.

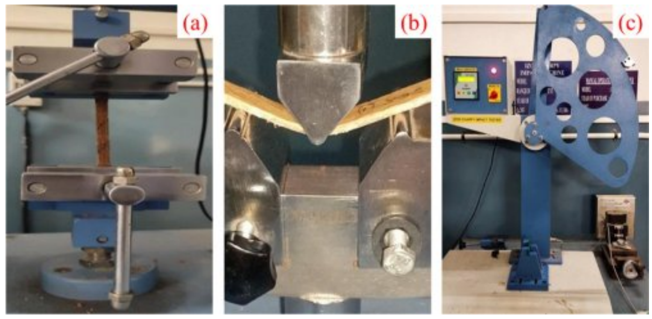

Figure 5. Setup for (a) tensile & compressive test; (b) flexural test; (c) Izod charpy impact tester.

to a force at its midpoint in its support structure until it fractures and breaks in this test. The three-point flexure test is the most often used polymer flexure test. The ASTM D790 technique was used to calculate the flexural strength.

Compressive Strength Testing: The test for compressive strength is a mechanical test that evaluates the greatest amount of compressive stress that a material can sustain before breaking. A progressively applied load compresses the test component, which is normally in the shape of a rectangle, between the plates of a compression-testing machine.

Impact Strength Testing: The impact test, which may also be used to measure the substance's toughness and yield strength, can simply quantify the energy required to shatter the material. The impact test can be used to investigate the effect of strain rate on material strength and flexibility. The ASTM D370 charpy test was used to determine the impact hardness of the composite samples. The amount of energy will be expressed in Joules.

Results and Discussion

Physical Properties. The Archimedes' principle was used to derive the density of the raw fiber, as prescribed in ASTM D 3800-9. This involved placing a known weight of the raw fiber into the water and calculating the volume of water displaced. Then, the equation was applied, where fiber density was equal to fiber weight and the volume of water displaced.[24] In addition, the measuring of the diameter of the raw fibers was carried out with the use of a profile projector. CPF physical properties are tabulated in Table 3.

Chemical Properties. A known quantity of raw fiber was subjected to steeping in a diluted solution made from 1.72% sodium hypochlorite and a few drops of sulfuric acid. The residue was collected after which it left in air, weighed, was then used to calculate the percentage content of cellulose in the raw

Table 3. Physical Properties of the CPF

Property	Specification
Density (g/cc)	1.42
Length (inch)	5-8 inch
Diameter (mm)	0.2-0.5
Swelling in water (%)	30

Table 4. Chemical Properties of the CPF

Component	Percentage
Cellulose	44.21
Lignin	45.52
Moisture	5.4

fiber. The lignin in CPF, was determined using the Klason lignin method, which is based on APPITA P11s-78 standard. Raw fibre samples were hydrolysed in a 72% sulfuric acid solution in an ultrasonic bath for an hour under 30 ℃. The extract was then mixed with methylene chloride and transferred to a stirred autoclave for an hour under 125 ℃. The moisture content of the CPF was determined by weight loss method. A known weight of the fibre was placed in a hot air oven at 105±5 ℃ for 4 hours. Weight of the dried fibre was then taken, and the moisture content calculated.[24] All the values are tabulated in Table 4.

FTIR Analysis. Figure 6 illustrates the FTIR spectrum of peduncle fiber, which was characterized by typical absorption bands that could be assigned to cellulose, lignin, and hemicellulose. The strong peak at 3327 cm^{-1} was ascribed to the hydroxyl

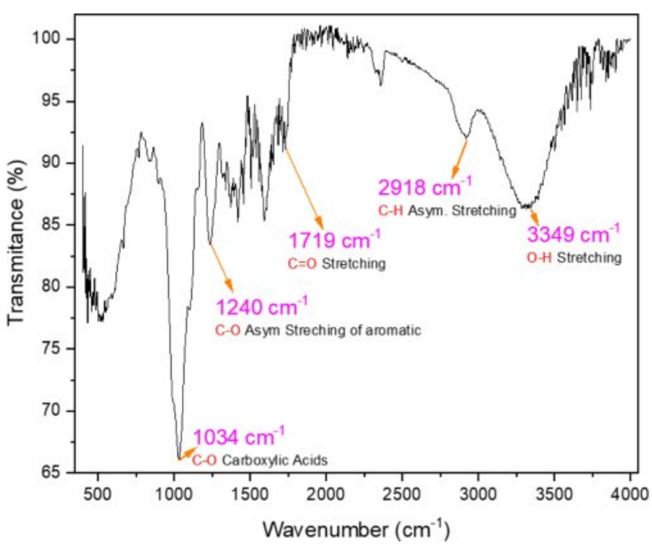

Figure 6. FTIR analysis of coconut peduncle fiber.

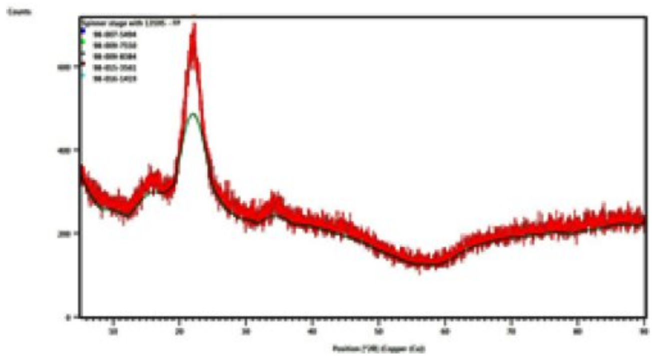

Figure 7. XRD analysis of CPF.

groups of cellulose, lignin, and water.[25] This band corresponds to the C-H stretching vibration of both cellulose and hemicellulose at 2917 cm^{-1}.[26] The band at 1593 cm^{-1} can reflect the presence of water in fibers.[27] The absorption band at 1420 cm^{-1} corresponds to symmetric CH_2 bending in the cellulose, while the band at 1374 cm^{-1} corresponds to the bending vibrations of the groups C-H and C-O in the aromatic rings of cellulose polysaccharides. The intense band at 1032 cm^{-1} is assigned to the stretching of the C-O and O-H groups of the polysaccharides in cellulose. The band located at 898 cm^{-1} is attributed to the β-glycosidic linkages between monosaccharide.[28]

X-ray Diffraction (XRD) Analysis. XRD analysis with identified phases of peduncle fiber is shown in Figure 7. The analysis was conducted in the angular range of 5° to 90° with the highest diffraction peak at 22° corresponding to Quartz.[29] XRD is a crucial tool in materials science and crystallography for identifying the crystalline phases present in a sample. The graph displays the intensity of diffracted X-rays, measured in counts, against the position in degrees 2θ using copper (Cu) radiation as the x-axis. This setup is typical for XRD measurements, where the angle of diffraction (2θ) is directly related to the interplanar spacing of the crystal lattice, allowing for the identification of specific crystalline structures. The graph features multiple data series, each represented by a different color, which likely correspond to different reference patterns or phases being compared to the experimental data. The most prominent feature is the sharp peak around 23°, which suggests the presence of a dominant crystalline phase in the sample. This peak is characteristic of a well-ordered crystalline structure, indicating that the sample has a significant degree of crystallinity.

The experimental data, represented by the red line, exhibits high variability, which is typical of raw XRD data. This variability can be attributed to factors such as instrumental noise, sample preparation, and the inherent properties of the material being analyzed. In contrast, the smoother underlying curves, particularly the green line, may represent fitted or reference patterns that have been used to model the experimental data.

The overall shape of the graph, with its initial high peak followed by smaller peaks and a general decrease in intensity, is characteristic of XRD patterns for many materials. This pattern can be used to identify the crystalline phases present in the sample by comparing the peak positions and intensities to known reference patterns. The presence of multiple peaks suggests that the sample may contain multiple crystalline phases or impurities, which can be further analyzed to determine the sample's composition and structure.

XPS Analysis. A systematic X-ray photoelectron spectroscopy (XPS) data shown in the picture includes images which provide information about the elemental composition and chemical states of the sample surface. Figure 8(a) considers C1s XPS spectrum having a single sharp peak at a binding energy range of about 284.8 eV and intense chromatographic peak. Most probably that indicates the presence of certain carbon material in the sample that is mainly due to carbon or its organic compounds. Since carbon seems to dominate as indicated by the high factor of the peak above that was obtained shrinks.

Figure 8(b) contains the O1s XPS spectrum that demonstrates the most intensive peak at the binding energies of about 532.4 eV. The peak confirms the present of oxygen in the sample where it could occur in metal oxides, organic materials or as adsorbed species. Other smaller features at higher binding energies may represent different states or sites or attachment of different molecules containing oxygen in them. Figure 8(c) is a survey or wide scan XPS spectrum, which presents the presence of peaks at different binding energy ranges (about 0-1000 eV).

Table 5. Tensile Strength of Various Peduncle Samples

Composite Sample	Trial 1 (N/mm^2)	Trail 2 (N/mm^2)	Trial 3 (N/mm^2)	Average (N/mm^2)
10 wt%	7.50	8.70	7.44	7.88
20 wt%	9.42	10.56	9.30	9.76
30 wt%	10.53	10.88	10.65	10.70
40 wt%	9.80	10.44	9.45	9.89

Tensile Strength Test Analysis. When comparing to other composites reinforced with CPF (10, 20, and 40 wt%), the findings of tensile force for a sample 30 wt% of composite are greater. The tensile test results of different samples are tabulated in Table 5 and can be seen in Figure 9 shows the tensile strength results graph of different samples.

The Figure 9 illustrates how tensile strength varies with increasing fiber volume fraction in fiber reinforcements. An increase in tensile strength was observed with increasing fiber content up to 30 wt%. This addition of filler material to the matrix improved stress transfer between the fibers and the matrix.[30]

The maximum tensile strength, 10.7 MPa, was observed at a fiber volume fraction of 30 wt%, while the minimum tensile strength, 7.99 MPa occurred at 10 wt%. These results indicate that the stress transfer capacity between the fiber and matrix is influenced by the amount of matrix present in the composites, with the maximum tensile strength observed at 30%. The sudden drop in tensile strength at 40 wt% is attributed to insufficient matrix in the composite, which is compounded by the increased fiber length in these composites.[31] Consequently, the stress transfer between the fiber and matrix diminishes, resulting in decreased tensile strength.

Flexural Strength Test Analysis. The flexural strength results

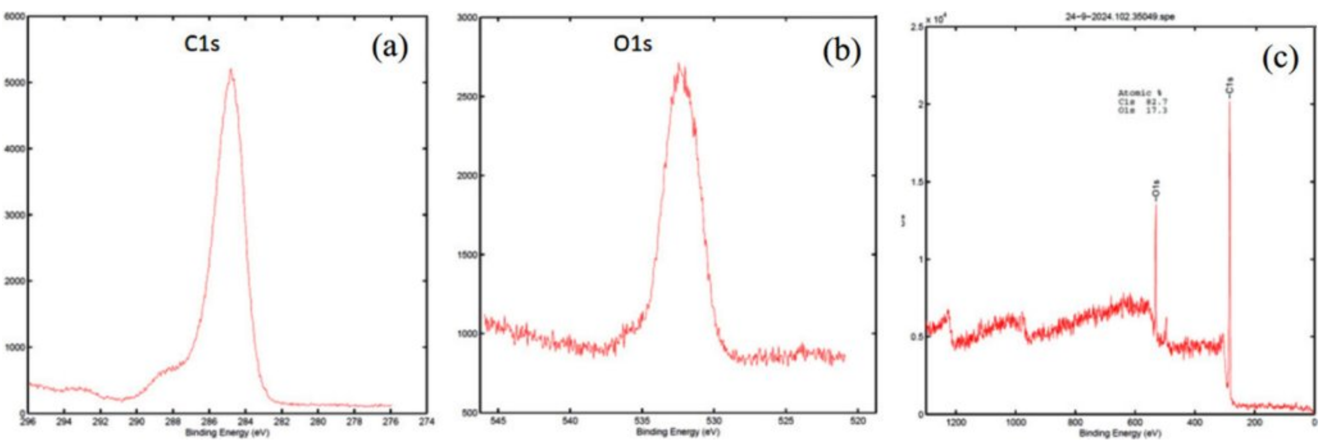

Figure 8. XPS analysis of CPF: (a) C1s binding energy; (b) O1s binding energy; (c) survey of the presence elements.

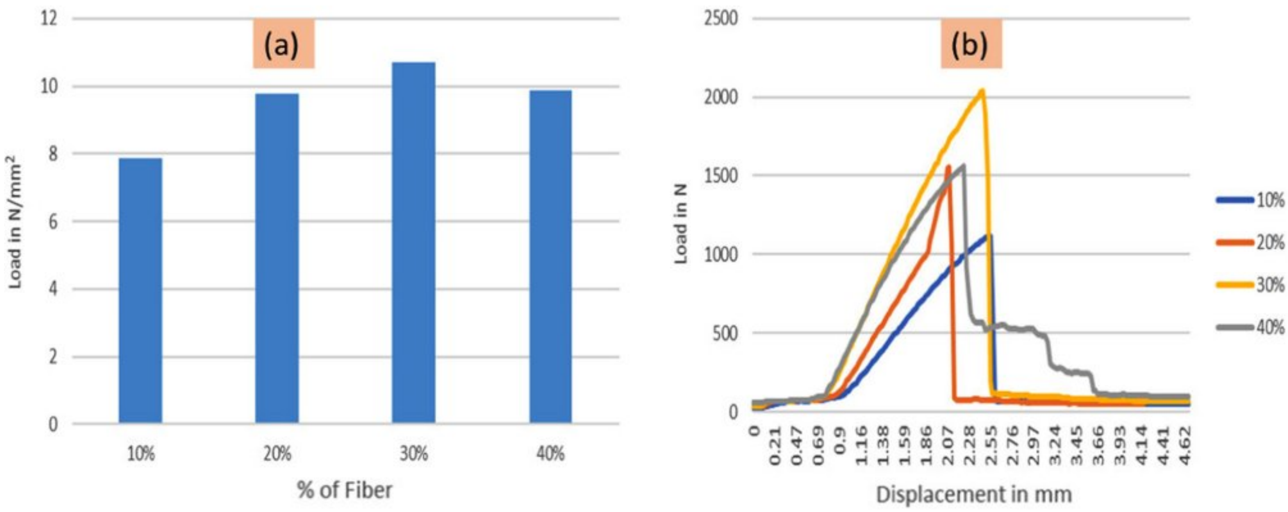

Figure 9. (a) tensile strength of various coconut peduncle fiber; (b) load *vs*. displacement of tensile test.

Table 6. Flexural Strength of Various Peduncle Samples

Composite Sample	Trial 1 (N/mm^2)	Trail 2 (N/mm^2)	Trial 3 (N/mm^2)	Average (N/mm^2)
10 wt%	39.42	0.516	28.33	39.42
20 wt%	56.67	98.56	60.50	77.62
30 wt%	107.19	73.92	80.55	90.56
40 wt%	96.10	51.74	60.47	73.92

indicate that the composite reinforced with 30 wt% CPF exhibits higher flexural strength compared to composites reinforced with other weight percentages of CPF (10, 20, and 40 wt%). The flexural test results of different samples are tabulated in Table 6. Figure 10(a) presents the flexural test data for the various samples, illustrating how the flexural strength varies with different weight percentages of CPF reinforcement. Figure 10(b) further details these results with a graphical representation of the flexural strength for each sample.

The higher flexural strength observed in the 30 wt% CPF composite suggests that this particular composition achieves optimal reinforcement characteristics, likely due to an effective balance between fiber content and matrix properties. This balance enhances the composite's ability to withstand bending forces, indicating improved mechanical performance compared to samples with lower or higher CPF content. These findings underscore the importance of fiber volume fraction in composite materials, as they directly influence mechanical properties such as flexural strength. The graphical representation in Figure 10(b)

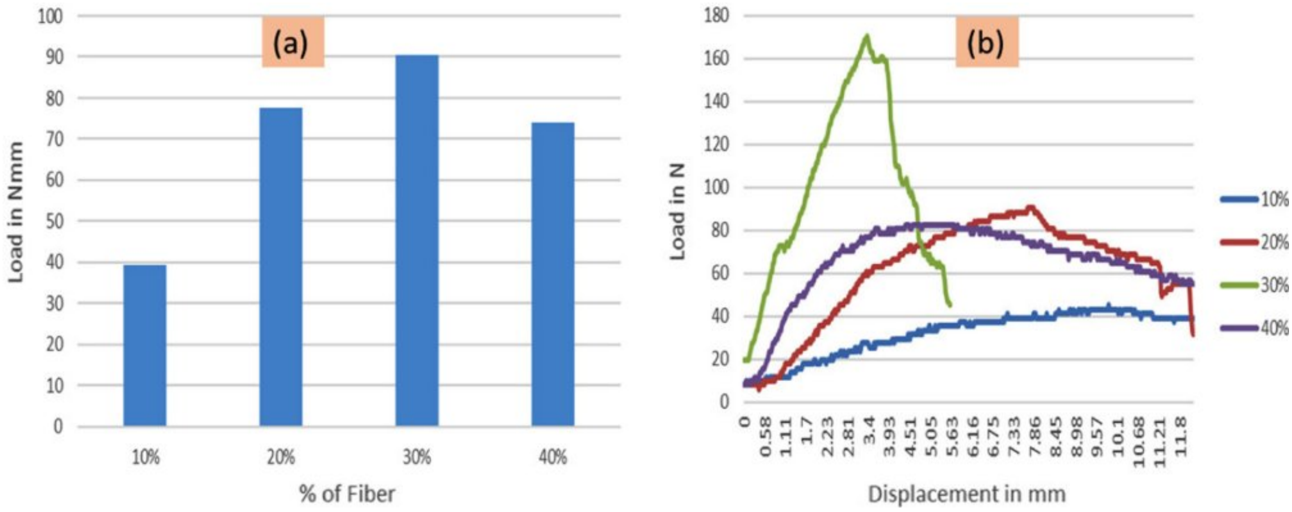

Figure 10. (a) flexural strength of various coconut peduncle fiber; (b) load *vs*. displacement of flexural test.

visually confirms the trend observed in the flexural test data, highlighting the superior performance of the 30 wt% CPF composite in terms of flexural strength compared to other compositions tested.

Compressive Strength Test Analysis. The results of Compressive strength for a sample 30 wt% of composite reinforced with Coconut Peduncle Fiber are higher when compared to other composite reinforced with Coconut Peduncle Fiber (10, 20, and 40 wt%). The compression strength results graph for several samples is displayed in Figure 11.

Impact Strength Test Analysis. The Pendulum Impact test is commonly used to assess material strength. It involves cutting composite materials into fibers in accordance with ASTM standards, and then testing them as illustrated in Figure 12. The impact test results of different samples are tabulated in Table 7. This method is compliant with the required ASTM standards. The sample 30 wt% have a higher value of impact strength rather than other coconut peduncle Fiber composite (10, 20,

Table 7. Impact Strength of Various Peduncle Samples

Composite Sample	Trial 1 (N/mm^2)	Trail 2 (N/mm^2)	Average (J)	Impact Strength (KJ/mm^2)
10 wt%	1.214	0.508	0.595	19.76
20 wt%	0.945	1.103	1.0020	26.00
30 wt%	1.530	2.175	1.805	47.00
40 wt%	1.530	1.337	1.105	33.79

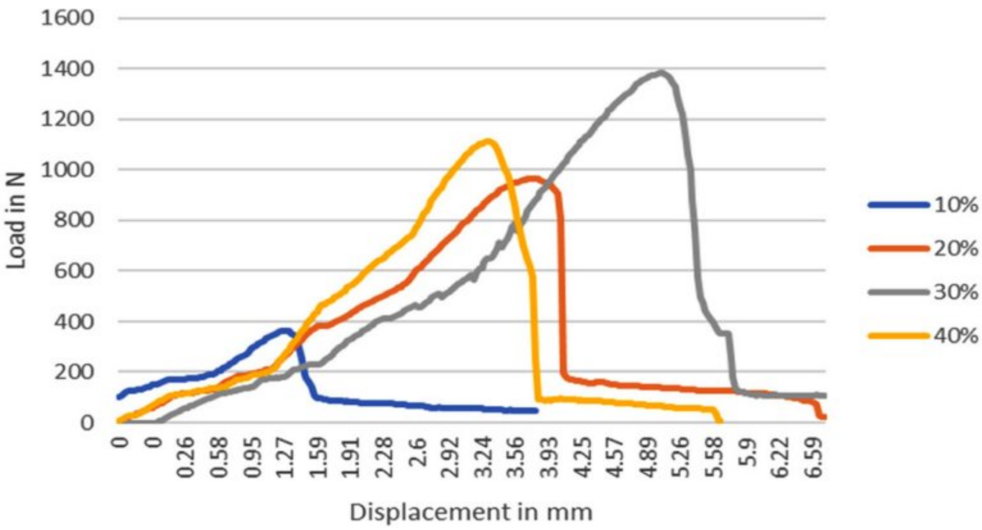

Figure 11. Load vs displacement of compressive strength.

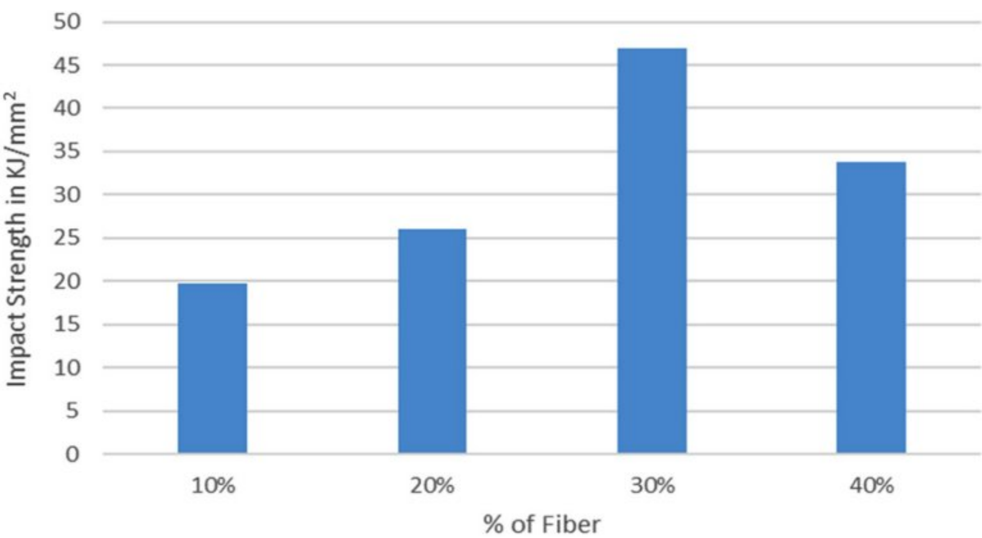

Figure 12. Load *vs*. displacement of impact test.

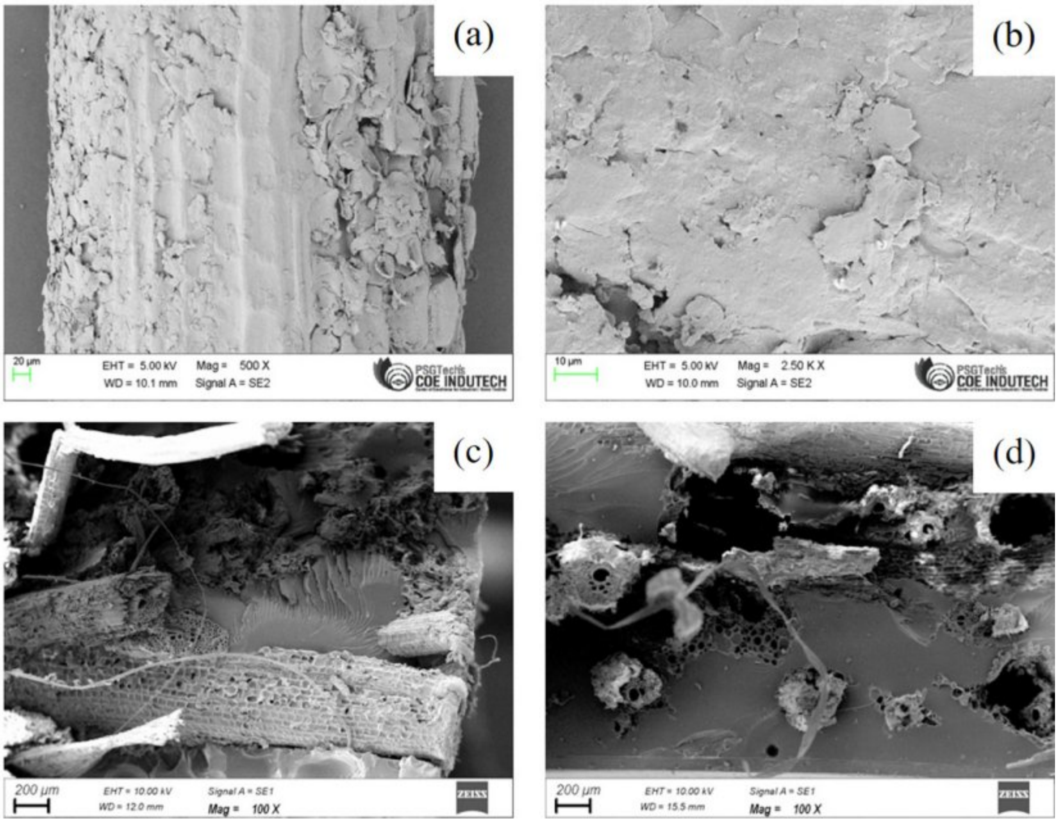

Figure 13. SEM images of (a), (b) CP Fiber and composite with (c) 20 wt%; (d) 30 wt% of CPF.

and 40 wt%). Impact strength is higher, indicating good binding and interfacial adhesion between the matrix and Fiber, allowing for increased interfacial stress to form, minimizing fracture work and making the fracture more brittle.

SEM Analysis. The peduncle fiber surface scanning electron micrographs (Figure 13(a), (b)) exhibit cracks, voids, and parallel ridges. Intermediately placed perpendicular to the fiber length, the nodes of the ridges work to connect them with square-shaped indentations. The observed non-uniformity in the fiber is probably due to the nonuniform distribution of impurities, fats, waxy substances, and globular protrusions.

The tensile strength, compressive and impact strength are increasing up to 30 wt% and it decreases after that. So the SEM image was taken for 20 and 30 wt%. SEM analysis was conducted to examine the surface morphology of fractured CPF/polyester composites. Figure 13(c) illustrates the interface bonding between the fiber and matrix, revealing minimal voids within the composites. This absence of voids can be attributed to the compressive forces applied during composite manufacturing. The analysis also highlights a strong interfacial bonding between CPF and the polyester matrix, which correlates with the observed maximum flexural strength of 90.56 MPa achieved at 30 wt% CPF content.

The curing process of the polyester matrix led to a cater-like structure, influenced by the catalyst and accelerator reactions. In contrast, Figure 13(d) depicts the fracture surface of the 30 wt% CPF/polyester composites, where fiber pull-outs were observed. These pull-outs indicate poor interfacial bonding between CPF and polyester, which is a significant factor contributing to the decrease in flexural strength observed as the fiber content exceeds 30 wt%. Thus, the SEM analysis provides insights into both the effective and problematic aspects of CPF/polyester composites, emphasizing the critical role of interfacial bonding in determining mechanical properties.

Conclusions

Result from the test showed that coconut peduncle fiber has high strength and mechanical properties such that it promises to be an excellent material for its applications. The tensile strength increased by 30 wt% CPF, which reached 2042 N with a displacement of 2.49 mm, where the 10, 20, and 40 wt% fiber samples were inferior. The flexural strength at 3.26 mm displacement was recorded to be 170.69 N for 30 wt%, but this value surpasses the other fiber concentrations. The compressive strength maximum at 30 wt% CPF was also recorded as 1383.81 N with a displacement of 5.12 mm. The impact strength at 30 wt% was measured as 47.00 KJ/mm²; it showed that the fibers have high resistance to a sudden impact.

These findings suggest that CPF may potentially be an alternative to the traditional materials in the fabrication of high-performance polymer composites. Using CPF within polymer composites not only contributes to reduced impact on the environment but also provides a highly cost-effective option for the widest possible spectrum of industrial applications.

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Conflict of Interest: The authors declare that there is no conflict of interest.

References

1. Dewangan, R. K.; Singh, S.; Das, B.; Bhaskar, M.; Patanwar, P.; Gupta, P. K.; Han, S. S.; Bhaskar, R. Influence of Stacking Sequence and Orientation on Tensile and Flexural Properties of Jute/glass/carbon Fiber Epoxy-based Hybrid Composites. *Polymer* **2023**, 47, 574-581.
2. Khalid, M. Y.; Al Rashid, A.; Abbas, Z.; Akram, N.; Arif, Z. U.; Márquez, F. P. G. Evaluation of Tensile Properties of Glass/sisal and Glass/jute Fibers Reinforced Hybrid Composites at Different Stacking Sequences. *Polymer* **2021**, 45, 390-397.
3. Lee, S. W.; Kang, J.-S.; Kim, M. J.; Yoon, K.-B. The Effect of rGO on the Electromagnetic Interference Shielding Performance of Epoxy Composites Incorporating MXene/rGO Fillers. *Polymer* **2024**, 48, 403-412.
4. Arul, M.; Sasikumar, K.; Sambathkumar, M.; Gukendran, R.; Saravanan, N. Mechanical and Fracture Study of Hybrid Natural Fiber Reinforced Composite–coir and Sugarcane Leaf Sheath. *Mater. Today. Proc.* **2020**, 33, 2795-2797.
5. Arul, M.; Sasikumar, K.; Sambathkumar, M.; Dineshkumar, K. Enhancement of Fracture Toughness Characteristics of Woven Jute Fabric Mat Reinforced Epoxy Composites with SiC Fillers. *J. Nat. Fibers* **2023**, 20, 2144979.
6. Gukendran, R.; Sambathkumar, M.; Raj, T. P.; Nalinkumar, S.; Nivaas, B.; Kumar, B. S. P. Effect of Various Stitching Patterns on Mechanical Properties of Jute Fiber Reinforced Composite. *Mater. Today. Proc.* **2023**, 80, 882-887.
7. Rangasamy, G.; Mani, S.; Kolandavelu, S. K. S.; Alsoufi, M. S.; Ibrahim, A. M. M.; Muthusamy, S.; Panchal, H.; Sadasivuni, K. K.; Elsheikh, A. H. An Extensive Analysis of Mechanical, Thermal and Physical Properties of Jute Fiber Composites with Different Fiber Orientations. *Case Stud. Therm. Eng.* **2021**, 28, 101612.
8. Prasad, M. M.; Padmavathy, S.; Gowshick, P.; Kavinkumar, P.; Kishore, O. Characterization of Cellulosic Fibres from Coconut Peduncle Leaf Stalk Fibres (CPLSF). *Alinteri J. Agriculture Sci.* **2021**, 36, 204-208.
9. Nair, V.; Khosla, P.; Ramachandran, M. Review on Mechanical Properties of Various Natural Fibers Reinforced Composites. *Res. J. Pharm. Biolog. Chem. Sci.* **2016**, 7, 2001-2004.
10. Li, Z.; Wang, L.; Wang, X. Flexural Characteristics of Coir Fiber Reinforced Cementitious Composites. *Fibers Polym.* **2006**, 7, 286-294.
11. Al-Mosawi, A. I.; Abdulsada, S. A.; Ali, M. M. Ansys Modeling for Estimation Tensile and Flexural Strength of Green Composite. *Adv. Chem. Mater. Sci.* **2016**, 2, 1-7.
12. Sarker, F.; Potluri, P.; Afroj, S.; Koncherry, V.; Novoselov, K. S.; Karim, N. Ultrahigh Performance of Nanoengineered Graphene-based Natural Jute Fiber Composites. *ACS Appl. Mater. Interfaces* **2019**, 11, 21166-21176.
13. Prasad, V.; Sekar, K.; Varghese, S.; Joseph, M. Evaluation of Interlaminar Fracture Toughness and Dynamic Mechanical Properties of Nano TiO_2 Coated Flax Fibre Epoxy Composites. *Polym. Test.* **2020**, 91, 106784.
14. Venkatasubramanian, H.; Chaithanyan, C.; Raghuraman, S.; Panneerselvam, T. Evaluation of Mechanical Properties of Abaca-glass-banana Fiber Reinforced Hybrid Composites. *Int. J. Innovative Res. Sci., Eng. Technol.* **2014**, 3, 8169-8177.
15. Prakash, K.; Manjunath, K.; Achutananda, K.; Chandru, B. Investigation of Tensile, Impact and Moisture Properties of Abaca Natural Polymer Reinforced Composites. *Int. J. Eng. Res. Technol.* **2017**, 8, 799-805.
16. Saad, N. A.; Hamzah, M. S.; Hamzah, A. F. Study of Fatigue Behavior of Composite Materials with the Basis of Polyphenylene Sulfide (PPS) Reinforced with Glass Fiber and Carbon. *Int. J. Eng. Technol.* **2013**, 3, 467-475.
17. Singh, S.; SK Jain, P. An Experimental and Numerical Investigation of Mechanical Properties of Glass Fiber Reinforced Epoxy Composites. *Adv. Mater. Lett.* **2013**, 4, 567-572.
18. Naveen, J.; Jawaid, M.; Vasanthanathan, A.; Chandrasekar, M. Finite Element Analysis of Natural Fiber-reinforced Polymer Composites. In *Modelling of Damage Processes in Biocomposites, Fibre-reinforced Composites and Hybrid Composites*, Elsevier, 2019; pp 153-170.
19. Kaliraj, M.; Narayanasamy, P.; Balasundar, P.; Rajkumar, M. Mechanical Behaviour and Analysis of Advanced Polymer-based Kevlar-49 Composite Material. *Int. J. Computer Aided Eng. Technol.* **2017**, 9, 251-260.
20. Mouritz, A.; Leong, K.; Herszberg, I. A Review of the Effect of Stitching on the in-plane Mechanical Properties of Fibre-reinforced Polymer Composites. *Compos. Part A: Appl. Sci. Manuf.* **1997**,

28, 979-991.
21. Khan, M. Z.; Srivastava, S. K.; Gupta, M. Tensile and Flexural Properties of Natural Fiber Reinforced Polymer Composites: A Review. *J. Reinf. Plastics Compos.* **2018**, 37, 1435-1455.
22. Kalagi, G. R.; Patil, R.; Nayak, N. Experimental Study on Mechanical Properties of Natural Fiber Reinforced Polymer Composite Materials for Wind Turbine Blades. *Mater. Today. Proceed.* **2018**, 5, 2588-2596.
23. Siva, R.; Anish, M.; Yuvaraja, S.; Mathiselvan, G. Experimental Investigation of Stitched and Unstitched Bamboo Fiber Using Sugarcane Powder. *Int. J. Mech. Prod. Eng. Res. Development* **2018**, 8, 1095-1104.
24. Rajeshkumar, G.; Hariharan, V.; Sathishkumar, T. Characterization of *Phoenix* sp. Natural Fiber as Potential Reinforcement of Polymer Composites. *J. Ind. Textiles* **2016**, 46, 667-683.
25. Hwang, I.-T.; Kim, T.-Y.; Sohn, J.-Y.; Shin, K.; Shin, J.; Jung, C.-H. Reproducible Green Radiation-based Synthesis of Poly(glycidyl methacrylate)-Grafted Non-woven Polypropylene Adsorbent for Removal of a Heavy Metal Ion. *Polymer* **2021**, 45, 764-774.
26. Satyanarayana, K.; Guimarães, J.; Wypych, F. Studies on Lignocellulosic Fibers of Brazil. Part I: Source, Production, Morphology, Properties and Applications. *Compos. Part A: Appl. Sci. Manuf.* **2007**, 38, 1694-1709.
27. De Rosa, I. M.; Kenny, J. M.; Puglia, D.; Santulli, C.; Sarasini, F. Morphological, Thermal and Mechanical Characterization of Okra (Abelmoschus esculentus) Fibres as Potential Reinforcement in Polymer Composites. *Compos. Sci. Technol.* **2010**, 70, 116-122.
28. Portella, E. H.; Romanzini, D.; Angrizani, C. C.; Amico, S. C.; Zattera, A. J. Influence of Stacking Sequence on the Mechanical and Dynamic Mechanical Properties of Cotton/glass Fiber Reinforced Polyester Composites. *Mater. Res.* **2016**, 19, 542-547.
29. Jahan, M.; Feni, F. Environmentally Friendly Bifunctional Catalyst for ORR and OER from Coconut Shell Particles. *Adv. Mater. Phys. Chem.* **2022**, 12, 106-123.
30. May-Pat, A.; Valadez-González, A.; Herrera-Franco, P. J. Effect of Fiber Surface Treatments on the Essential Work of Fracture of HDPE-continuous Henequen Fiber-reinforced Composites. *Polym. Test.* **2013**, 32, 1114-1122.
31. Son, S. Y.; Kim, Y.; Lee, J.; Lee, G.-Y.; Park, W.-T.; Noh, Y.-Y.; Park, C. E.; Park, T. High-field-effect Mobility of Low-crystallinity Conjugated Polymers with Localized Aggregates. *J. Am. Chem. Soc.* **2016**, 138, 8096-8103.