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Effects of Adding Natural Fillers on Textile Waste and Glass fiber Reinforced Hybrid Composite Materials

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ABSTRACT

This study explores the effects of adding natural fillers, rice husk powder (RHP) and coconut coir powder (CCP), into textile waste and glass fiber reinforced hybrid composites. Three samples were fabricated using the hand lay-up method: one without fillers and two with natural fillers. To characterize the composites, tensile, impact, hardness, water absorption and density tests were conducted. The composite with no filler showed the highest tensile (33.54 MPa) and impact strength (28,456.03 J/m²), attributed to its higher fiber content. Among the filler samples, the coconut coir powder composite outperformed the rice husk powder in mechanical properties, while the rice husk composite exhibited the highest hardness (91 HR). The coconut coir also significantly reduced water absorption by 79.06% from the composite with no filler, indicating suitability for moisture-sensitive applications. These results demonstrate the feasibility of producing functional composites from textile waste-derived materials for practical engineering applications.

Keywords: Textile Waste, Natural Fillers, Hybrid Composite, Hand Lay-up Method, Fiber Reinforced Composite

1. Introduction

The textile industry is responsible for 10% of global carbon emissions, making it the second most polluting industry in the world [1]. The increasing global consumption of fibers and the resulting waste demand focused efforts from both governments and citizens to minimize textile waste sent to landfills or incinerated and prioritize recycling. Synthetic fibers, in particular, either do not decompose or take an extended time to biodegrade. Furthermore, products derived from nonrenewable petroleum release harmful gases during decomposition, causing significant atmospheric pollution. The recycling approach lowers pollution, the demand for landfill space, and the amount of water and energy used [2]. Additionally, recycling textile waste lowers the carbon footprint of textile products along their life cycle, whereas global warming is the main consequence of these gasses [3-4]. A detailed example illustrates that, using 1 kg of an old textile product instead of producing a new one saves 6000 liters of water, 3.6 kg of carbon dioxide, 0.3 kg of chemical fertilizer, and 0.2 kg of pesticides [5]. These results show how much recycling and reuse are significant to practice in the textile industry. Reusing textile waste involves improving its usability with or without prior modification, whereas recycling means turning it into new textile or nontextile items with or without causing damage to the original. According to the products final use, recycling can be divided into two categories: recycling inside the production process, which involves making new products that are comparable to textiles, and recycling outside the production process, which includes making a different product, such as composite materials [6]. When two or more different materials are combined to develop a new substance with distinct properties from the original materials, the final output is referred to as a composite material. The popularity of composite materials is raising day by day as they offer better mechanical qualities than conventional materials in many cases. This study explores the possibilities of textile waste-based hybrid composite materials and the effect of natural fillers like rice husk powder (RHP) and coconut coir powder (CCP) in them. Epoxy resin was used as the matrix for the composite, and woven glass fiber mat and fibers extracted from textile wastes were used as reinforcement. After the fabrication of composite laminates, specimens were prepared, and their mechanical properties were tested in the laboratory. The properties of the no-filler composite and the other two filler-containing composites were compared. The hand lay-up method was used for the fabrication.

Al Mahmud et al. [7] used upcycled fabrics as reinforcement in the epoxy resin composites. As filler material, 10 wt% of coconut shell powder was used, and mechanical, thermal and morphological characteristics of the specimens were investigated. The results from SEM images depict strong binding between fabric and resin, and the results from TGA showed a significant heat absorption capability of the composites. In another study, Bodur et al. [8] reinforced glass fiber and waste cotton fibers in different ratios to fabricate polymer composite panels. Maleic anhydride was used as a coupling agent, and a custom-made single screw extruder was used for composite sample production. When compared to samples without MA, the results indicate that the addition of maleic anhydride increases torque characteristics, most likely due to strong interfacial adhesion and a lower void content. Kamble et al.

[9] employed the compression molding technique to develope four different composites by varying the volume percentage of the fibers. The resulting composites exhibited a low water diffusion coefficient, and their mechanical properties were found to be compatible with the commercial wood.

Taye Wondmagegnehu et al. [10] varied the stacking sequence of glass fiber and textile waste fiber and fabricated five samples by the hand lay-up method. Tensile, impact, flexural and water absorption tests were performed on the specimens. The flexural strength of the G/T/G sample was 95% greater than the T/T/T samples, but it had the maximum water absorption coefficient. Karahan et al. [11] developed hybrid composites by the vacuum bag moulding process and used waste cotton, jute and glass fibers as reinforcements. Composites made from waste material were found to have lower tensile and flexural properties than glass fiber composites, although hybrid composites exhibited comparable characteristics. In another study, Bodur et al. [12] fabricated glass fiber/waste cotton fabric hybrid composite specimens with and without maleic anhydride (MA) binding agent. They performed a water absorption test for different soaking times and found that MA reduced the water absorption significantly.

The overall aim of this study is to add natural fillers (rice husk powder and coconut coir powder) and find their effects on textile waste and glass fiber reinforced hybrid composites. After fabricating the composites by the hand lay-up method, characterizations like tensile strength, impact strength, hardness, density and water absorption tendency will be measured and compared these qualities among the results. By achieving this objective, the study seeks to offer a practical and efficient alternative to conventional textile waste recycling methods. The successful development of such a composite could have wide-ranging implications, providing industries with a versatile material that combines improved properties with cost-effectiveness, thereby expanding possibilities in material engineering and application design.

2. Materials and Methods

In this research, epoxy resin matrix was used to bind the glass fiber mat and recycled textile waste fibers. The epoxy resin to hardener ratio was strictly maintained at 10:1. Glass fiber mat was used instead of chopped E-glass fiber due to their superior mechanical performance and structural consistency. The continuous and oriented fibers in woven mats provide better tensile strength, improved dimensional stability, and more effective load transfer. Their uniform structure also ensures better resin distribution, stronger fiber-matrix bonding, and reduced void formation. A square feet of woven glass fiber was cut and used as the top and bottom layer of the sandwich model. The filler materials, coconut coir and rice husk, were sourced from local vendors and using a high-speed mixing machine, it was turned into powder. After the powder formation, it was sun-dried for over eight hours to reduce the moisture content in the filler material. This step is crucial to make a stronger bond and avoid void formation in the composite laminates. Fig. 1 represents the powdered filler materials and the fibers that had been used to fabricate the composites.

Textile waste, originating as pre-consumer/ post-industrial scraps or post-consumer fabrics, undergoes several steps for fiber extraction. These include manual sorting by type and color, mechanical shredding to uniform sizes, and processing through a rag-tearing machine. This transforms the waste into a fluffy, fibrous state, replicating the original raw fiber. For this experiment, the extracted fibers were collected from a reputed textile waste recycling and geo textile manufacturing company called Bang Jin (Bangladesh) Limited, located in Joydevpur, Gazipur, Bangladesh. The fiber extraction process is shown in Fig. 2.

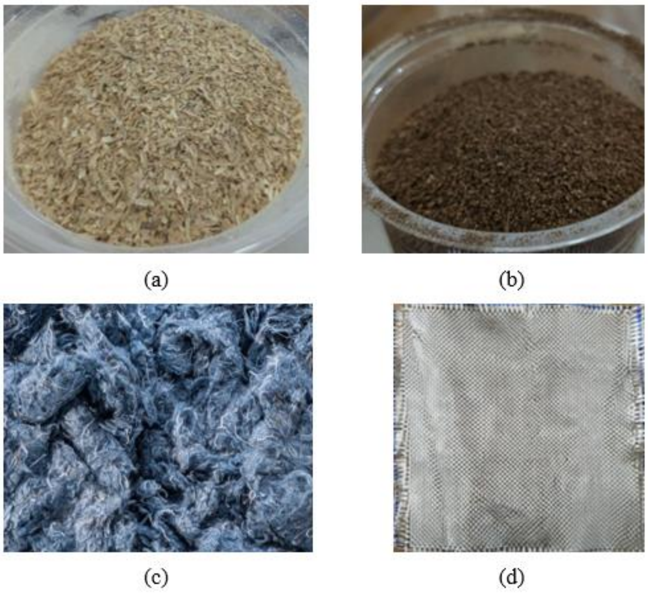

Fig. 1 (a) Rice husk powder, (b) Coconut coir powder, (c) Extracted fibers from textile wastes, (d) Woven glass fiber mat

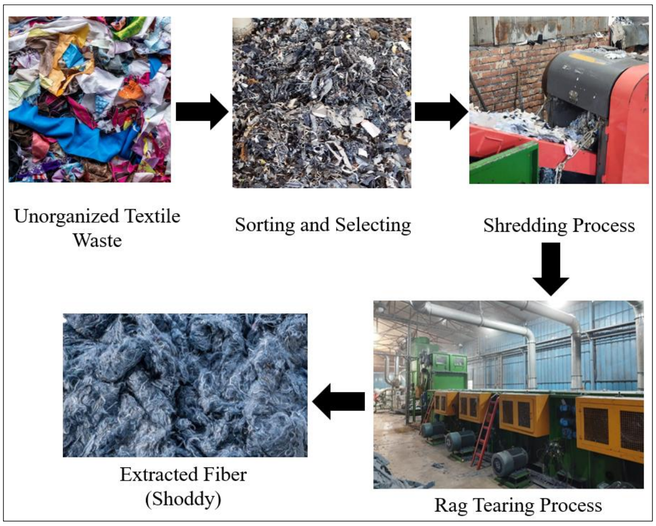

Fig. 2 Fiber extraction process

2.1 Hand Lay-up Process

There are different manufacturing techniques available for fabricating composites. The hand lay-up (Fig. 3) method is one of the simplest processes that is used in this research to develop the composite samples.

Firstly, a binder solution was prepared. Two types of filler materials, coconut coir powder and rice husk powder, were mixed with the resin and hardener to form the binder solution. The mixture was prepared by mixing 70 wt% epoxy resin and 5 wt% filler materials. The ratio between the epoxy resin and hardener was maintained at 10:1 as per the manufacturer's instructions. Three binder solutions were prepared: one without any fillers and two with coconut coir powder, rice husk powder. The sample that did not contain any natural filler had 30 wt% of fiber (glass fiber and textile waste fiber). The other two samples contain 25 wt% fiber and 5 wt% of the natural fillers. As the epoxy is a viscous fluid, the fillers were mixed into the resin by means of a stick with continuous stirring. This continuous stirring is necessary to avoid the accumulation of fillers in the epoxy resin matrix.

Secondly, a releasing agent such as wax was applied to the bottom surface of the mold. Initially, a layer of glass fiber was placed at the bottom of the layers. The prepared binder solution was gently applied over the woven glass fiber mat. Following this process, the recovered textile waste fiber was placed on top of the binder mixture. Another layer of binder mixture was placed over the fibers, and they were gently distributed throughout the fiber with the help of a soft brush. The distribution was done totally by hand, and the uniformity of this distribution was ensured throughout the process. Lastly, the final layer of woven glass fiber mat was placed, and a roller was used to minimize the bubble or void formation inside the composite. A heavy 20 kg load was placed over the mold box to compress the composite laminate for 48 hours. Fig. 4 shows the layering sequence for the composite material fabrication. After a 48-hour curing period, the composite laminates were ready (Fig. 5).

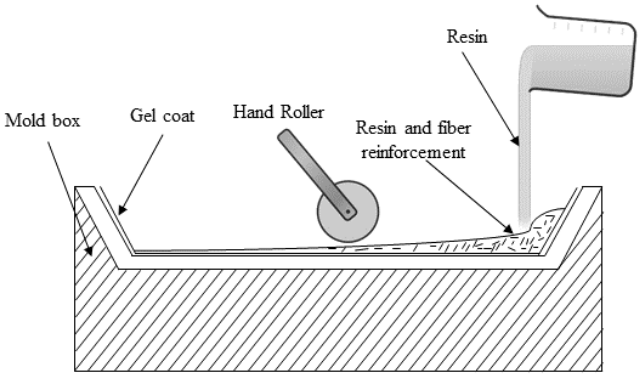

Fig. 3 Schematic diagram of the hand lay-up process

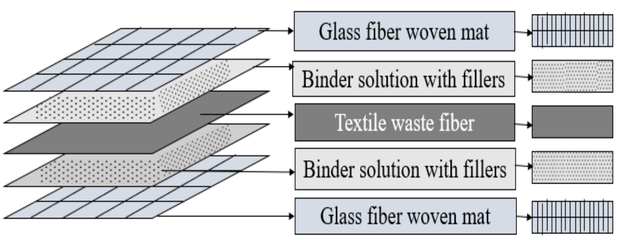

Fig. 4 Matrix and fiber layering sequence

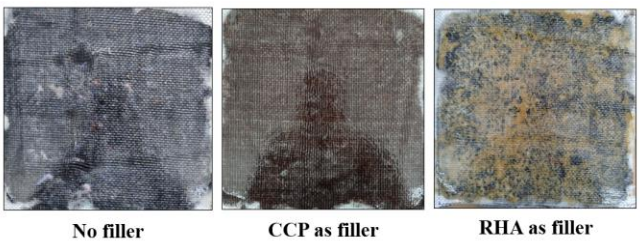

Fig. 5 Fabricated composite laminates after 48 hours

2.2 Characterization of the Composites

To characterize the properties of the composite, specimens were prepared from the solid laminates, and tensile tests, hardness tests, and impact tests were performed. In addition to these mechanical tests, the water absorption percentage and density were measured through separate tests. For the tensile test, a Controls Universal Testing Machine was used, and the specimens were prepared according to the ASTM D638 standards which is widely used for polymer and polymer-based composite materials. Fig. 6 demonstrates the specimens before and after performing the tensile test.

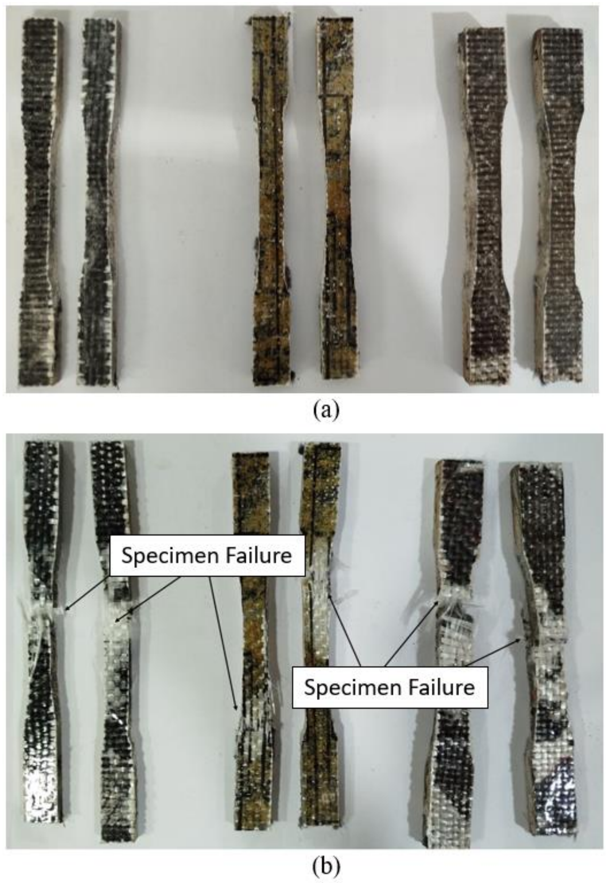

Fig. 6 (a) Specimens before tensile test, (b) Specimens after tensile test

Hardness tests were performed in a Rockwell hardness tester, and the hardness number (HRB) was measured using an indenter of 5 mm diameter and 60 Kgf load. The impact strength of the specimens was determined using the Charpy impact test method with the help of a pendulum impact tester. A hammer with a mass of 2.5kg and 0.345m arm length struck the specimens from an initial height h_1, and after striking the specimen, the hammer reached a height h_2. The impact strength was calculated using the following equation:

$$\text{Impact strength} = \frac{mg(h_1-h_2)}{A} = \frac{mgR(\cos\beta-\cos\alpha)}{A} \quad (1)$$

Two samples were taken from each panel, and the addressed mechanical tests were performed. For the water absorption test, 1-inch square specimens were prepared and they were soaked in distilled water for 24 hours. The percentage of water absorption was determined using the following equation:

$$M(t) = \left(\frac{w_t - w_0}{w_0}\right) \times 100\% \quad (2)$$

For measuring the density of the specimens, the volume of the specimens was measured using digital slide callipers, and their mass was determined using a digital precision weighing scale. For more accurate determination, the Archimedes principle-based method is recommended and will be implemented in future studies.

3. Results and Discussion

Table 1 contains a comprehensive summary of the outcomes from all the characterization tests conducted. A detailed description of these findings is discussed further in the following subsections 3.1 – 3.5.

Table 1: Average mechanical properties of the specimens

Composites	No Filler	CCP Filler	RHP Filler
Tensile Strength (MPa)	33.54	19.46	17.30
Impact Strength (J/m^2)	28456.03	17872.35	13139.76
Rockwell Hardness (HBR)	81	76	91
Water absorption (%)	3.20	0.67	6.35
Density (g/cm^3)	1.02	1.11	1.09

3.1 Tensile Strength

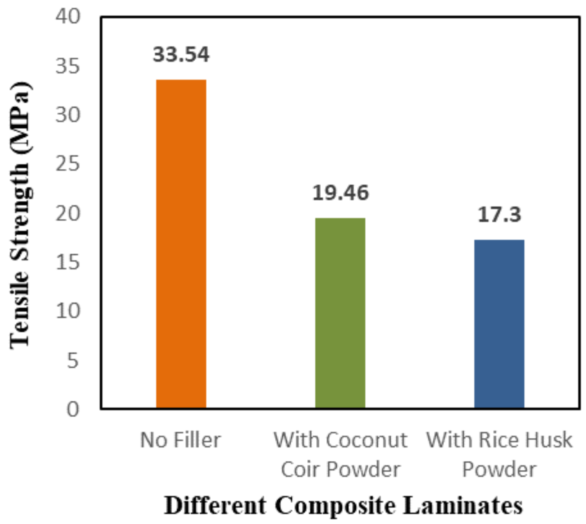

Fig. 7 Comparison of Tensile Strength

From Fig. 7, we can observe that the composite without any filler exhibited the highest tensile strength of 33.54 MPa. When coconut coir powder was added as a filler, the tensile strength decreased to 19.46 MPa, which is approximately 41.98% lower than that of the filler-free sample. The rice husk powder-filled composite showed the lowest tensile strength at 17.30 MPa, reflecting a reduction of about 48.41% compared to the composite with no filler. This indicates that the addition of natural fillers reduced the tensile performance of the composites, likely due to weak filler-matrix interfacial bonding or filler accumulation. Since the no-filler composite had 5 wt% of additional fiber in it, and fibers are the general load carriers in a composite material, this can be a possible reason for the higher tensile strength in the filler-less composite. Out of two filler materials, CCP exhibited better tensile strength when it was added to the composite.

3.2 Impact Strength

From Fig. 8, we can observe that, in terms of impact strength, the unfilled composite again outperformed the others, with a value of 28,456.03 J/m^2. The composite with coconut coir powder had a 37.19% lower impact strength, measuring 17,872.35 J/m^2. Meanwhile, the rice husk powder composite displayed the lowest impact resistance at 13,139.76 J/m^2, which is 53.82% lower than the no-filler composite. This decline suggests that the inclusion of natural fillers reduced the composite's ability to absorb and dissipate impact energy effectively.

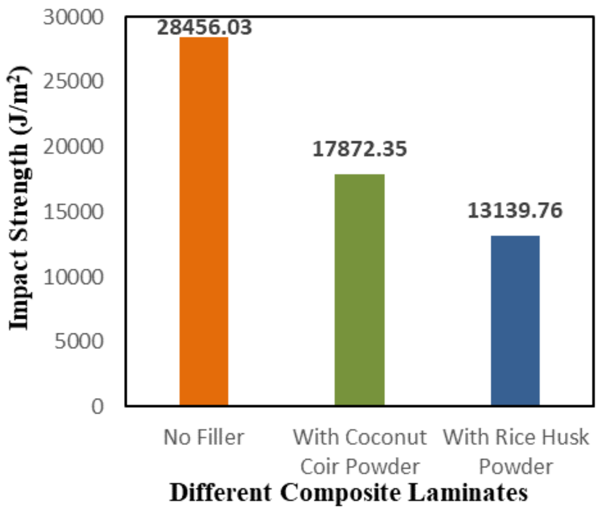

Fig. 8 Comparison of Impact Strength

3.3 Hardness

From Fig. 9, we can observe that, unlike tensile and impact strength, the hardness of the composites showed a different trend. The rice husk powder composite recorded the highest Rockwell hardness at 91, which is 12.35% higher than the 81 HR value of the no-filler composite. In contrast, the coconut coir powder composite had a hardness of 76, about 6.17% lower than the unfilled one. While higher hardness improves surface durability, it may also reduce toughness, explaining why the RHP composite exhibited lower impact strength compared to the CCP composite.

3.4 Water Absorption Coefficient

Fig. 10 shows that water absorption was significantly affected by the type of filler used. The no-filler composite absorbed 3.20% water, whereas the coconut coir powder composite exhibited a drastic reduction in water absorption, to just 0.67%, which is 79.06% lower. On the other hand, the rice husk powder composite absorbed 6.35% water, an increase of 98.44% compared to the no-filler sample. This result indicates the possibility of coconut coir powder-filled composites in moisture-sensitive applications. The maximum water absorption percentage in rice husk filler contained composites can be a result of the hydrophilic nature of RHP.

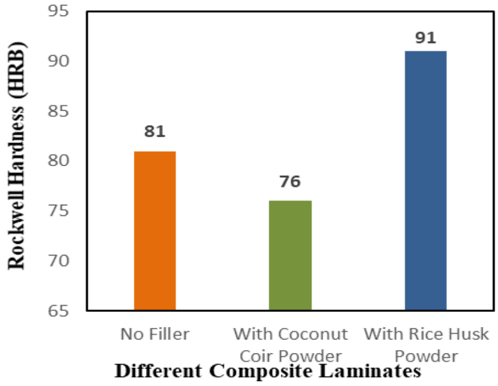

Fig. 9 Comparison of hardness

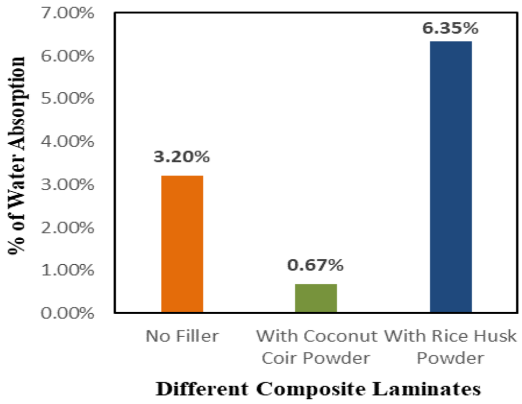

Fig. 10 Comparison of water absorption coefficient

3.5 Density

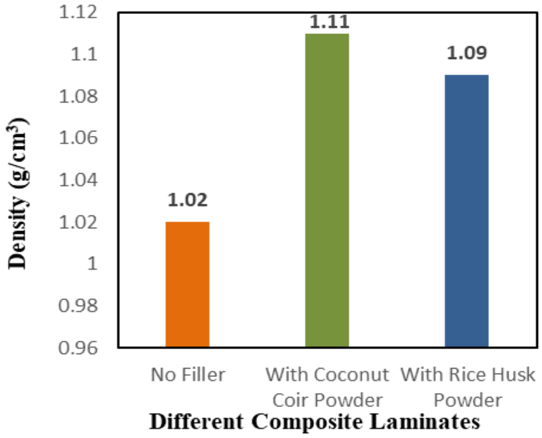

Fig. 11 Comparison of the density.

From Fig. 11, the density of the composite materials increased with the addition of natural fillers. The unfilled composite had a density of 1.02 g/cm³. This increased to 1.11 g/cm³ with coconut coir powder (8.82% higher) and to 1.09 g/cm³ with rice husk powder (6.86% higher). The rice husk composite's higher hardness might partially be explained by its increased density, as denser microstructures can resist localized deformation more effectively.

4. Conclusion

This study evaluated the effects of adding natural fillers (coconut coir powder and rice husk powder) to textile waste and glass fiber reinforced hybrid composites. Specimens were fabricated using the hand lay-up method and tested for tensile strength, impact strength, hardness, water absorption, and density. The composite with no filler showed the highest mechanical properties due to its greater fiber content. The addition of fillers reduced this fiber fraction by 5%, leading to lower load-bearing capability. Among the filler-containing samples, the coconut coir composite showed relatively better mechanical performance. Meanwhile, the rice husk filler contributed to increased hardness but compromised strength. From the study, it can be concluded that-

- This project successfully demonstrates the potential for fabricating composites from recycled textile waste and natural fillers.
- The filler-free composite demonstrates the highest tensile strength (33.54 MPa) and impact strength (28,456.03 J/m²).
- Out of two fillers, the coconut coir powder exhibited better tensile, impact, and water absorption properties.
- The rice husk powder composite had the lowest mechanical strength, with tensile strength at 17.30 MPa, and impact strength at 13,139.76 J/m².
- As a filler, the rice husk powder significantly increased the hardness of the composites.
- For its lower water absorption percentage, the coconut coir powder-based composites can be used in water-sensitive applications.
- Future studies should be focused on optimizing filler content and fiber-to-resin ratios to achieve better strength and explore other characteristics such as thermal and acoustic properties.

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Nomenclature

Symbol	Meaning	Unit
m	Mass	(Kg)
g	Gravitational acceleration	(ms^{-2})
h_1	Initial height of the hammer	(m)
h_2	Final height of the hammer	(m)
R	Length of the hammer arm	(m)
α	Initial angle of the hammer	(degree)
β	Final angle of the hammer	(degree)
A	Cross-sectional area	(m^2)
W_0	Weight of the specimen before soaking	(gm)
W_t	Weight of the specimen after soaking	(gm)