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Improving the Mechanical Properties of Jute Fiber Mat Reinforced Epoxy Composites Using Coir Micro-Fillers

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ABSTRACT

The study investigates the effect of coir micro-filler on improving the mechanical properties of jute fiber mat-reinforced epoxy composite. Four-layer jute fiber mat-reinforced epoxy composites with different filler concentration (0-6 wt.%) were prepared and investigated for tensile and flexural properties. The findings demonstrated that the coir filler is more effective in improving the tensile behavior of the jute fiber mat reinforced epoxy composites. The tensile properties were consistently improved by the addition of coir fillers (CP) with the peak strength of 59.09 MPa at 0.5 % loading, which was 20 % greater than that of the base composite. The flexural properties did not show significant improvement, rather remained unaffected up to a CP filler content of 1 %. These results suggest that the CP-filled jute fiber mat reinforced epoxy composite can be a sustainable path to lightweight and mechanically strong composite with reduced epoxy concentration that may be used in various structural applications.

Keywords: Coir Filler, Jute-Epoxy Composite, Mechanical Properties, Waste Utilization, Plastic Reduction.

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1. Introduction

Research on natural fiber reinforced polymer composites has gained increasing attention because they are lightweight, environmentally friendly, and cost-effective compared to synthetic composites. By combining biodegradability and renewability with good mechanical performance, these materials are being explored as alternatives in automotive, aerospace, and construction applications [1], [2].

Among natural fibers, jute is notable as a bast fiber with high cellulose content (61–73%). It is strong, stiff, and biodegradable, making it suitable for composite applications [2], [3]. Previous studies have shown that the tensile and flexural properties of jute/epoxy composites improve when fillers are added to enhance adhesion between the fibers and the matrix [4]. For example, Deshpande et al. [5] demonstrated that incorporating bone and coconut shell powder into jute/epoxy composites led to performance improvements. Composites with 10% powder mixture achieved the highest ultimate tensile strength, while maximum flexural strength was obtained with 15% coconut shell powder and bone powder. Despite these advantages, the hydrophilic nature of jute leads to moisture absorption and loss of dimensional stability, reducing durability and limiting its direct application without modification [6]. Besides, jute fiber mat reinforced epoxy composites required a significant amount of epoxy to fabricate the composite due to large voids resulting from yarn weaving. So, if particulate fillers are added in the epoxy it is expected to reduce the epoxy consumption to manufacture these composites without significantly affecting the mechanical properties.

To address such limitations, coir fiber and coir powder, derived from coconut husk, have been studied as complementary reinforcements. Coir is tough, rich in lignin, and exhibits good elongation at break. These properties make it an effective counterpart to jute. In epoxy matrices, coir fillers have been reported to provide high interfacial strength and optimal tensile and flexural performance at moderate filler loadings (around 20 wt.%) [7], [8]. Sampath et al. [9] observed that composites with coir showed good energy absorption and damping characteristics, which makes them promising for impact-prone applications.

Beyond mechanical reinforcement, particulate fillers such as coir powder also contribute to functional enhancements. They are known to increase hardness, tensile strength, and wear resistance, while reducing density [10]. Moreover, the high lignin content of coir provides thermal insulation that promotes char formation in epoxy composites, thereby slowing flame propagation [11], [12]. This characteristic is critical in applications where fire safety is a design requirement. Studies have shown that composites reinforced with coir fillers are more flame retardant and thermally stable than neat epoxy systems [13], [14].

The combined use of jute fiber and particulate fillers has proven effective in overcoming individual shortcomings. For instance, the addition of silica and nanoclay significantly improved the fracture toughness and thermal resistance of jute/epoxy systems [15]. Similarly, hybrid laminates made with geotextile and coir filler achieved an optimum stiffness-to-energy absorption ratio, with tensile strength enhancements of up to 280% for the best stacking sequence [16].

In summary, the literature highlights that jute fibers provide rigidity and toughness, whereas coir micro-fillers enhance toughness, thermal stability, and flame resistance [17]. When integrated into an epoxy matrix, these materials form composites with superior mechanical performance. Such systems not only enable the value-added utilization of agricultural by-products but also meet the performance

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requirements of contemporary engineering applications [2], [8], [9], [14] .
In this work coir particles were used as a filler at various concentrations to manufacture jute fiber mat reinforced epoxy composites and their mechanical properties were evaluated and compared with the bast jute fiber reinforced epoxy composite. The utilization of waste coir particles in the jute fiber reinforced epoxy composite is expected to reduce the concentration of epoxy in the composite without affecting the mechanical properties of jute fiber reinforced epoxy composite.

2. Experimental Details

2.1 Materials

Coir particles were collected from "MyGardenBD" online shop, dried under the sunlight and then blended into powders as shown in Fig. 1(a). The powder was sieved through a 75-micron mesh to obtain uniform particle size. Bulk density of coir powder was 0.24 g/cm^3. Long-staple, untreated jute fiber mat as shown in Fig. 1(b) were procured from a local supplier. The fiber mats were manually cleaned to remove dust, cut into desired lengths (203.2*152.4 mm). The prepared powder and jute fiber were dried in the oven at 80°C for 24 hours to remove moisture. Areal density of jute fiber was 0.049 g/cm^2. LAPOX L-12 (epoxy resin) with LAPOX K-6 (hardener) was used to fabricate the composites. The LAPOX L-12 resin has a density of 1.1-1.2 g/cm^3, and the K-6 hardener has a density of about 0.95-1.10 g/cm^3. Silicone spray was used as a lubricant to facilitate the removal of the sample properly from the mold.

Fig.1: (a) Coir powder and (b) Jute fiber mat

2.2 Fabrication Process

The conventional hand layup technique was followed for the fabrication of composite in a room temperature. Coir powder fillers varying with 0%, 0.5%, 1%, 2%, 4% and 6% content which was 0, 1.05, 2.10, 4.20, 8.40, 12.60 g resepectively mixed with epoxy resin and dispersed by ultrasonic probe sonication. The mixture was kept at room temperature for 10 minutes to reduce the heat generated during sonication. Filler–matrix mixture and hardener were stirred at room temperature for 5 minutes and applied uniformly to the four layer of jute fiber mat in a silicone mold using brush and hand roller. A transparent plastic sheet was topped with a glass plate under 6 kg load and cured for 48 hours. Samples were cut according to the requirements of ASTM standards. A flow chart of the fabrication process is given in Fig. 2.

2.3 Mechanical Testing

The tension tests were performed on the universal testing machine (Shimadzu AGX 300kN) following the ASTM standards D3039. The flexural tests were conducted on the universal testing machine (Shimadzu AGX 10kN) following the ASTM standard D790. For tensile test, the gauge length was 100 mm while for flexural, the span length was 70 mm. The speed of the crosshead was 2 mm/min for both tests. For each filler content, at least three specimens were tested for reliability at room temperature.

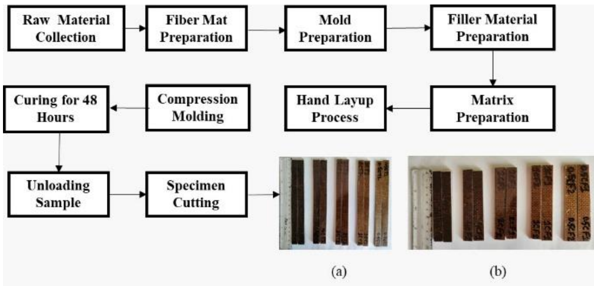

Fig.2: Fabrication process of the composite

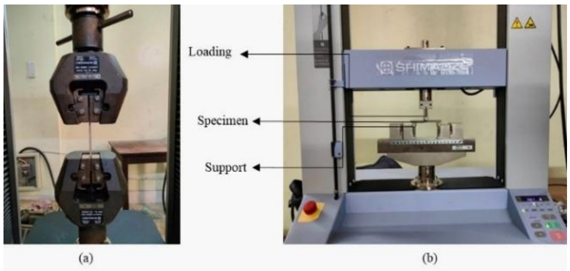

Fig.3: (a) Tensile test setup (b) Flexural test setup

3. Results and Discussion

The density of the manufactured composites is given in Fig. 4 for various filler concentrations. It is seen that the density initially decreases at lower filler levels, declining down to the lowest of 1.085 g/cm^3 at 1% Coir Powder (CP) content. However, further addition of CP increases the density gradually to 1.188 g/cm^3 at 6 % CP content. The initial drop in density results from light filler replacing resin and introducing voids, while later density rise is due to increased filler mass and reduced voids or better packing at higher CP contents.
The effect of coir filler on average tensile strength of the prepared samples is plotted in Fig. 5. The tensile strength for base composite without filler is 49.13 MPa. Adding 0.5 % CP fillers achieved the highest strength of 59.09 MPa which is around 20.27 % improvement over the base. Further addition of CP filler caused the tensile strength to drop compared to the composite with 0.5 % CP filler content but greater than the base.
At 4 % and 6 % CP content, the tensile strengths are respectively 54.21 MPa and 53.28 MPa. Again, the specific tensile strength reaches its maximum at 0.5 % CP, showing that this filler content provides the most effective reinforcement in terms of tensile properties. Sathishkumar and Ramakrishnan [18] analyzed the tensile strength of jute mat composites for varying coconut shell powder filler. They showed that the optimum filler content for a double layer composite laminate was 15 % with an improvement of 15.17 % in tensile strength. In this work a four-layer jute mat reinforced composite showed a 20 % improvement at 0.5 % coir micro filler. Although the work of Sathishkumar and Ramakrishnan are not directly comparable but this information opens up a future research direction.

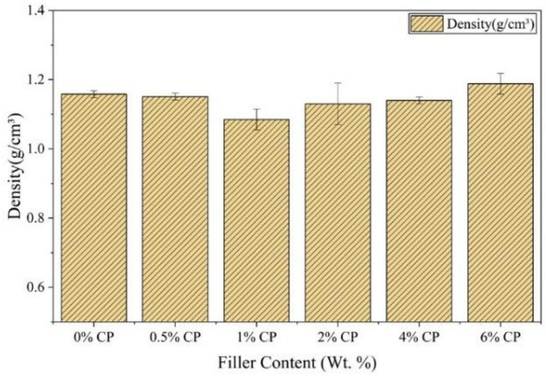

Fig.4: Density of composites for varying CP filler content

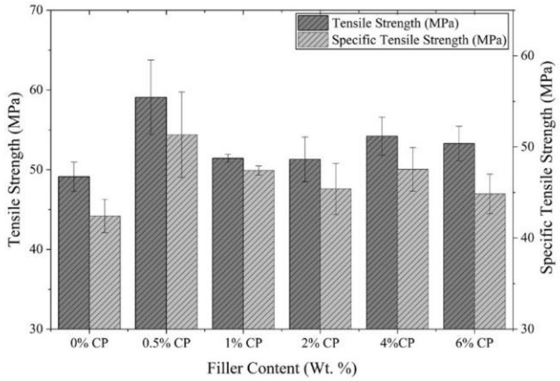

Fig.5: Tensile strength and sp. tensile strength of composites for varying CP filler content

The modulus of elasticity and specific modulus of elasticity of the composites showed a similar trend as the tensile strength and specific tensile strength as shown in Fig. 6. The maximum modulus is observed in the case of coir-based composites at 0.5 % filler i.e., 1142.48 MPa in comparison to the base (998.87 MPa) with a 14.38 % improvement. Further addition of CP in the composite caused the modulus to drop but remained similar to the base composite up to 6 % CP filler content.

Toughness of the composites reveals that the addition of CP fillers enhances the energy absorption capacity of composites for all filler content up to 6 % as shown in Fig. 7. The maximum toughness was found for the composite with 2 % CP fillers showing a 31.51 % improvement.

The flexural strength and specific flexural strength of the composites are given in Fig. 8. The base composite has a flexural strength of 86.88 MPa and the flexural strength remained similar to the base up to 1 % of CP content, but the specific flexural strength improved slightly reaching the maximum at 1 %. Increasing the filler content further causes the flexural strength and the specific flexural strength to drop below the base composite. The reason for the drop in flexural strength is that the filler is composed of short, irregular, lignocellulosic particles that more of discontinuous fillers than reinforcement. Thus, the addition of coir powder usually causes replacement of a portion of the epoxy matrix with no substantial reinforcement capacity improvement.

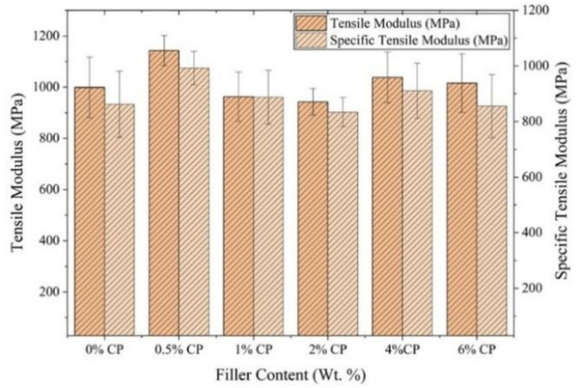

Fig.6: Tensile modulus and sp. tensile modulus of composites for varying CP filler content

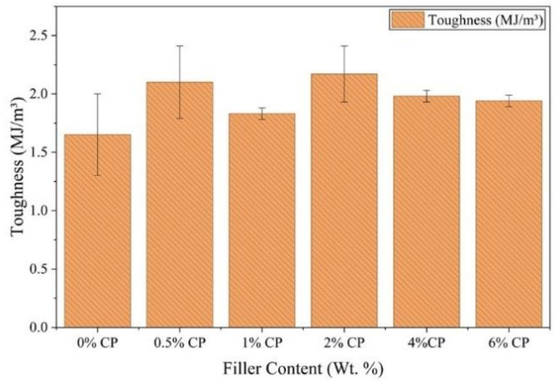

Fig.7: Toughness of composites for varying CP filler content

The flexural modulus and specific flexural modulus is given in Fig. 9. The flexural modulus of the base composite is 3141.48 MPa. It is seen that the flexural modulus and the specific flexural modulus of the composites are not significantly affected by the filler addition up to 6 %. The flexural modulus and specific flexural modulus are found to be the maximum at 6 % CP content (5.21 % increase in flexural modulus compared to the base) and 1 % CP content (7.82 % increase in specific flexural modulus compared to the base) respectively. At 4 % CP content, the flexural modulus and the specific flexural modulus are found to be the minimum, only a 8.67 % decrease compare to the base composite.

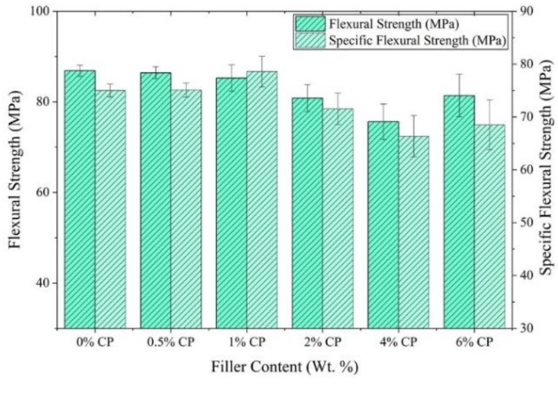

Fig.8: Flexural strength and sp. flexural strength of the composites for varying CP filler content

The flexural energy absorption is plotted in Fig. 10 for various filler contents. It is observed that the energy absorption in bending decrease gradually with increasing filler content. The decrease in energy absorption up to a CP filler content of 1 % is insignificant but a further increase in filler content in the composite results in considerable decrease in bending energy absorption.

From the stress strain curve in Fig.11, it is seen that without filler the jute-epoxy composite shows typical brittle failure with limited strain before fracture. Addition of coir fillers improve strain handling slightly at 0.5 % and 4 %, indicating better stress distribution. For 0.5 %, best tensile performance is found. In 1-2 % coir filler, cracks appear earlier but fillers help redistribute stress. In 4 % coir filler, agglomeration cause stress concentration which leads to earlier crack initiation and in the case of 6 % coir filler, less improvement in ductility but uneven distribution of fillers causes multiple micro-cracks before final rupture.

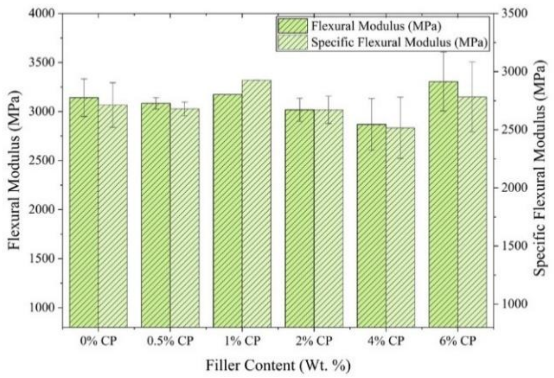

Fig.9: Flexural modulus and sp. flexural modulus of the composites for varying CP filler content

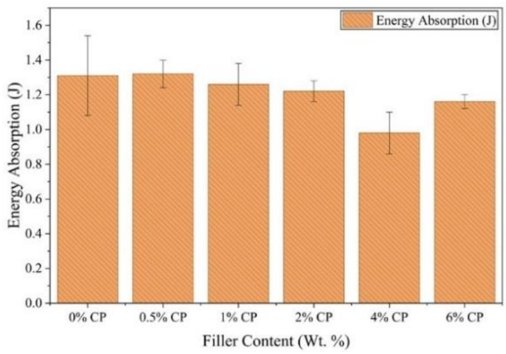

Fig.10: Energy absorption of the composites for various CP filler content

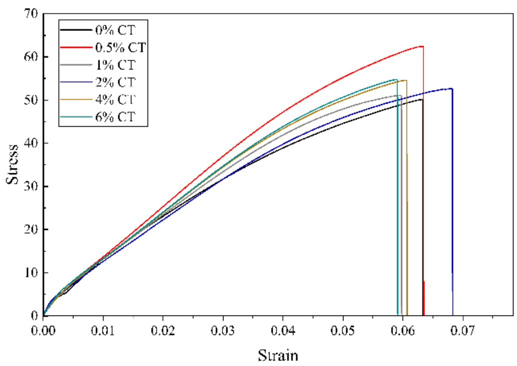

Fig. 11: Stress vs strain curve of (a) 0% CP (b) 0.5% CP (c) 1% CP (d) 2% CP (e) 4% CP (f) 6% CP

The flexural force-displacement curves in Fig. 12 reveal some significant differences as a result of filler addition. Composites made of coir shows a little more displacement and load bearing capacity at 0.5 % and 1 %, but it decreases at higher percentage.

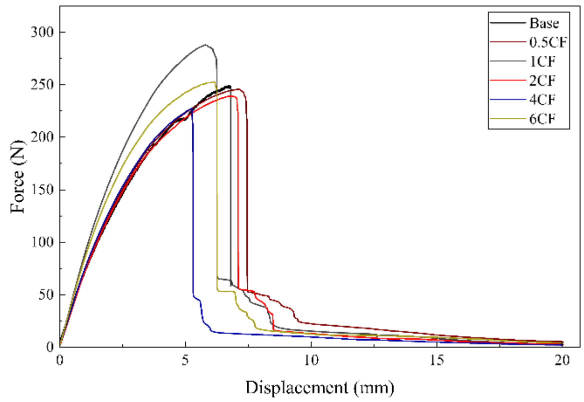

Fig. 12: Flexural load-displacement curve of (a) 0% CP (b) 0.5% CP (c) 1% CP (d) 2% CP (e) 4% CP (f) 6% CP

4. Conclusions

The impact of coir micro-filler on mechanical behavior of jute fiber reinforced epoxy composites is examined to improve their structural behavior. The results showed that filler addition substantially affected the mechanical behavior of the composites depending on the concentration of the filler. The findings of the work are summarized below:

- The composite density was not significantly affected by the filler addition up to 6 % CP content.
- The tensile strength and modulus were found to be the maximum at 0.5 % CP content and they were consistently greater than the base composite without any filler. The toughness was also found to be greater than the base composite for all CP content up to 6 %.
- The flexural properties were not considerably increased unlike tensile properties but they remained close to the base composite up to a filler content of 1 %.

Overall, it can be concluded that adding small amount of coir micro-fillers can be an effective way to improve the tensile properties of jute fiber mat reinforced epoxy composites with reduced density and unaffected flexural properties. Most importantly, addition of natural filler reduced the epoxy volume fraction in the composite without affecting mechanical behavior of the composite.

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