

# Development and Evaluation of Hybrid Natural Fiber Composites

Sagar Yanda<sup>1</sup>, Jagadish<sup>2</sup>, Venkata Swamy Naidu Neigapula<sup>3</sup> \*

## Abstract

Natural fiber based polymer composites are becoming more common because they are cheap, sustainable, and operate effectively across mechanical and environmental settings. Natural fibers (NFs) like bamboo and roselle are being used to strengthen polymer composites. They are being used in textiles, medical equipment construction, and car making. People are becoming more interested in these fibers because of the unique properties. Bamboo fiber is an effective option for reinforcement in composite materials because it is strong, stiff, flexible, and easy to find. The roselle fiber is also unique because it has a low density, is biodegradable, and has mechanical characteristics that are similar to those of other natural fibers. This property makes it a good choice for making composites that are environmentally friendly. The current study concentrates on the development and mechanical assessment of innovative hybrid composites fortified with short bamboo and roselle fibers, each chopped to lengths between 2 and 4 mm. Five unique composite samples were fabricated using different fiber weight fractions, employing the traditional hand lay-up technique. The binding agent was epoxy resin (LY556), and the hardening agent for the matrix was HY951. To assess the performance of the manufactured composites, extensive mechanical testing was conducted, including tensile and flexural evaluations. The experimental findings indicated that the hybridization of bamboo and roselle fibers within the epoxy matrix led to significant enhancements in mechanical properties compared to composites reinforced by a single fiber type. The hybrid composites had an ultimate tensile strength of 70.115 MPa, maximum flexural strength of 1747.66 MPa, maximum tensile stress 70.10 Mpa, maximum flexural stress 27.24 Mpa and a maximum elongation 1.57 mm, which was better than the single-fiber composites. These results show that combining bamboo and roselle fibers has a synergistic effect, which could lead to the creation of highly effective, eco-friendly composite materials. The results of this study offer significant insights into the enhancement of natural fiber-reinforced polymer composites for various engineering applications, fostering a sustainable environment and material innovation.

**Keywords:** Bamboo fiber, roselle fiber, areca powder, epoxy resin, tensile strength and flexural strength

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## INTRODUCTION

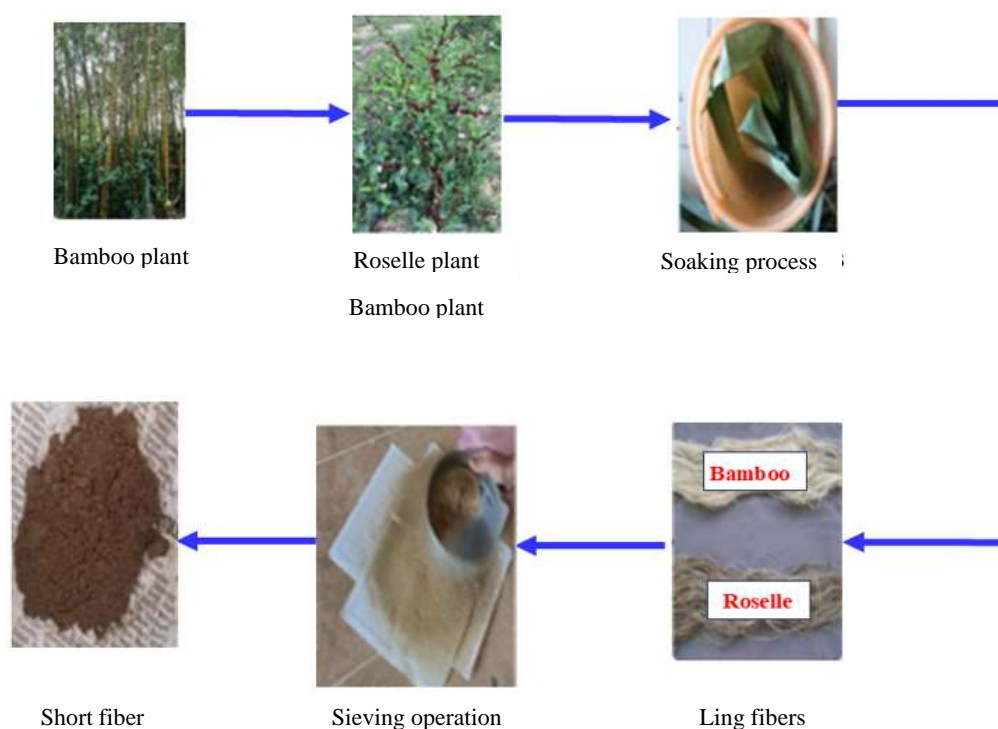
Due to their low cost, biodegradability, renewability, and favourable mechanical properties, natural fiber-reinforced polymer composites have found widespread application in the automotive, aerospace, machining, and packaging industries [1]. Bamboo, roselle, jute, hemp, and sisal are the most widely used NFs, and they are mostly derived from plants [2–3]. In contrast to roselle, which has low density, hydrophilicity, and good tensile performance, bamboo is widely prized for its high tensile strength, toughness, flexibility, and abundance. Fibers that are widely grown in Andhra Pradesh, Kerala, Kashmir, and northeastern India [4–5]. Bamboo's composition is comparable to that of

wood, consisting of 65.49% cellulose, 20.46% hemicellulose, 5.41% lignin, and 0.53% ash [6–8]. components such as salts, tannins, and waxes [9–10], as well as organic substances such proteins (0.8–6%), lipids (2–4%), sugars (2%), and carbohydrates (2–6%) [11–12]. The durability and hardness of composites are significantly impacted by these components, especially carbohydrates [13–24]. A lot of study has been done on how to make and describe natural filler mixed polymer composites. However, there is limited study into hybrid natural filler-based polymer composites. The current research investigation examined the development and mechanical performance of a hybrid polymer composite reinforced with Roselle (R) and bamboo (B) fibers. Bamboo and Roselle fibers of 2–4 mm length, along with areca (A) powder (prepared using a 2.36 mm sieve), were employed to develop the hybrid composites. The matrix system was made up of a mixture of epoxy resin (LY556) and a harder component (HY951). Five composite formulations were made: B (30 wt. %) + E (70 wt. %), R (30 wt. %) + E (70 wt. %), B + R (15 wt. % + 15 wt. %) + E (70 wt. %), B + R (15 wt. % + 15 wt. %) + A (3 wt. %) + E (67 wt. %), and B + R (15 wt. % + 15 wt. %) + A (6 wt. %) + E (64 wt. %). After that, the created samples were tested for their mechanical behavior, particularly their tensile and flexural strengths.

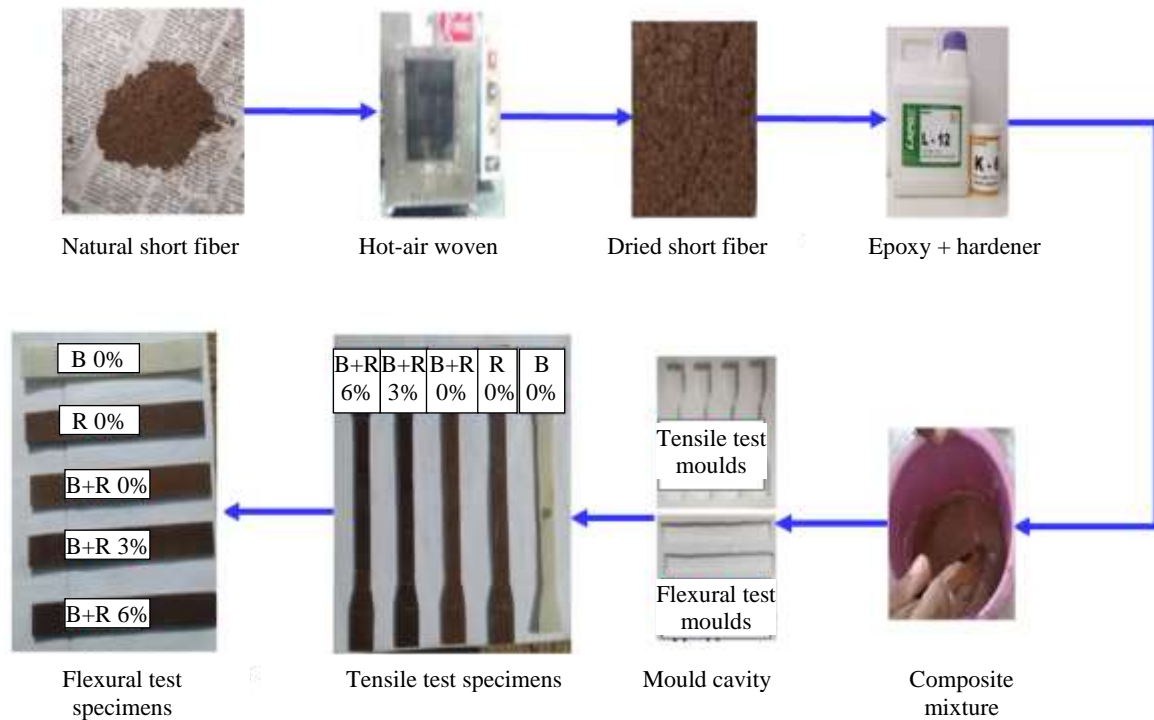
## MATERIALS AND METHODS

### Fabrication of Hybrid Composites

Bamboo fibers extracted from the stems of bamboo (*Bambusa*) and roselle fibers taken from the stems of *Hibiscus sabdariffa* were used to make a hybrid fiber-reinforced polymers composite, as illustrated in Figure 1. The isolated long fibers further cut to small lengths (2–3 mm) and treated with NaOH, ethanol and acetone solutions to remove soluble contaminants. To eliminate moisture, the fibers heated in a furnace at 100°C to eliminate moisture before being used composite fabrication. After brief fiber extraction, a hybrid composite of polymers was made by hand laying it up. Five different composite formulations were made: B (30%) + E (70 wt. %) R (30 wt. %) + E (70 wt. %) B + R (15 wt. % + 15 wt. %) + E (70 wt. %) B + R (15 wt. % + 15 wt. %) + A (3 wt. %) + E (67 wt. %), and B + R (15 wt. % + 15 wt. %) + A (6 wt. %) + E (64 wt. %). For the best drying, the hybrid fiber blend (B + R + A) was mixed with resin made from epoxy (LY556) and the hardening factor (HY951) in a weight proportion of 10:1.



**Figure 1.** Bamboo and roselle fiber extraction process.



**Figure 2.** Fabrication process of hybrid composite specimens for mechanical testing.

The filler components were mechanically blended with epoxy resin for one hour to ensure uniformity. Molds constructed in conformance with ASTM norms, and a release gel used to prevent polymer adherence [14–16]. The epoxy-fiber combination was then poured into the molds and distributed uniformly with a brush. A second coat applied, and trapped air and excess glue removed with a roller using light pressure. ASTM criteria followed for developing hybrid composite specimens of various sizes [21, 23, 25].

## MECHANICAL TESTING

### Tensile Test

The tensile strength amid of bamboo and roselle filler based composite samples containing areca powder and polymer was evaluated at the AITAM, Srikakulam, India, utilizing a universal testing machine (UTM). Figure 2. illustrates that the samples were invented in conformance with ASTM D638-03 norms and were 40×10×6 mm. The machine grips held each specimen tightly, and a tensile load that increased stronger over time was put on them. We tested the tensile strength of each composite composition twice and reported the average result [18].

### Flexural Test

UTM is utilized to assess the flexural strength of composite samples in conformance with ASTM D790-03. The test samples were 125×12.7×3.2 mm. Every sample was held up by two points that were 50 mm apart during testing. A load was imposed on it at a travel rate of 5 mm.min<sup>-1</sup> until it broke. Each test was performed twice, and the average value was used for analysis [6, 17].

## RESULTS AND DISCUSSION

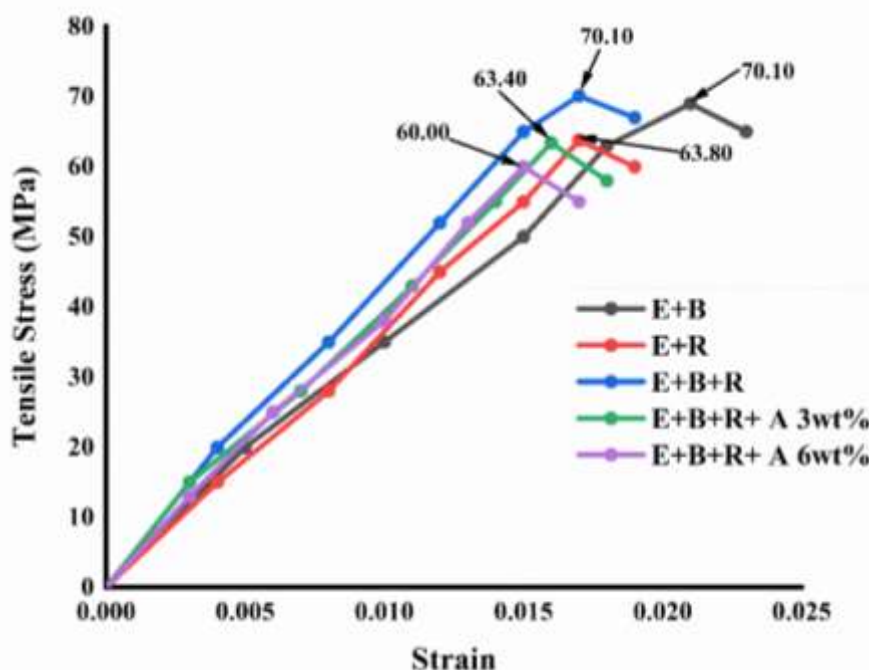
### Tensile Properties of Mixed Polymer Composites

The tensile aspects of the B, R, and A hybrid composite specimens—B (30 wt. %) + E (70% wt. %), R (30 wt. %) + E (70 wt. %), B + R (15 wt. % + 15 wt. %) + E (70 wt. %), B + R (15 wt. % + 15 wt. %) + A (3 wt. %) + E (67 wt. %), and B + R (15 wt. % + 15 wt. %) + A (6 wt. %) + E (64 wt. %)—

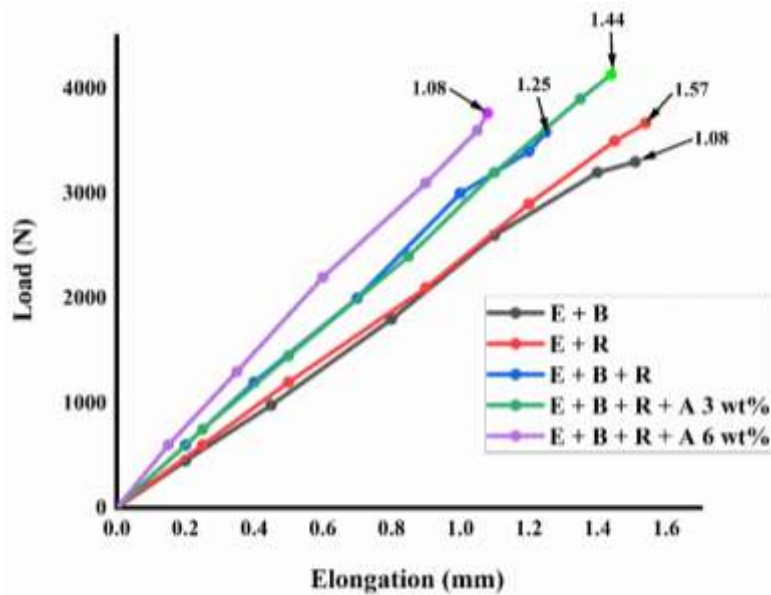
were evaluated based on the peak load and appropriate cross-sectional area. Table 1 shows a summary of the outcomes. Figure 3 and 4, based on stress vs. strain and load vs. elongation plots, provide a thorough comparison of how the different natural fiber-reinforced composites behave mechanically. The materials investigated include BFC (Bamboo Fiber Composites), RFRC (Roselle Fiber-Reinforced Composites), and their hybrids with and without areca powder as an additional filler. BFC shows a normal stress-strain response, with an initial linear elastic region, a peak, and a smooth decline that is linked to yielding and progressive failure [6–7]. BFC has an adequate tensile strength because its peak stress is about 22 MPa. The fibers might be weaker, or the bond across each fiber and the matrix might not be as strong, which could explain this drop in performance [8–9].

Figure 3 and 4 show a hybrid composite that combines BFC and RFRC in a way that works together. The load–strain curve shows that the two fibers work well together, and the stress–strain curve achieves a maximum of 16 MPa, which shows that the mechanical performance is well-balanced [18]. The hybridization that we saw improved ductility and energy absorption by spreading the stress more evenly. We also looked at how adding areca powder filler at different amounts affected the results. When the load is 3 wt.% of areca powder, the elongation vs. load curve remains strong, indicating that the load-bearing capacity has not changed significantly. However, when the areca concentrations are increased to 6 wt.%, the stress-strain curve demonstrates that the peak stress decreases significantly to approximately 15 MPa. This decrease indicates that an excessive amount of filler may disrupt the interaction between the fibers and the matrix, thereby diminishing the composite mechanical strength [19]. Prior research indicates that the BFC exhibits greater strength than individual fibers, despite the RFRC possessing beneficial reinforcing properties. The combination of BFC and RFRC produces a balanced performance, and the addition of areca powder increases the characteristics to an optimal level beyond which the mechanical performance degrades. These findings indicate that optimizing fiber composition and filler content is crucial for producing durable, high-performance natural fiber composites for applications in buildings and vehicles [25].

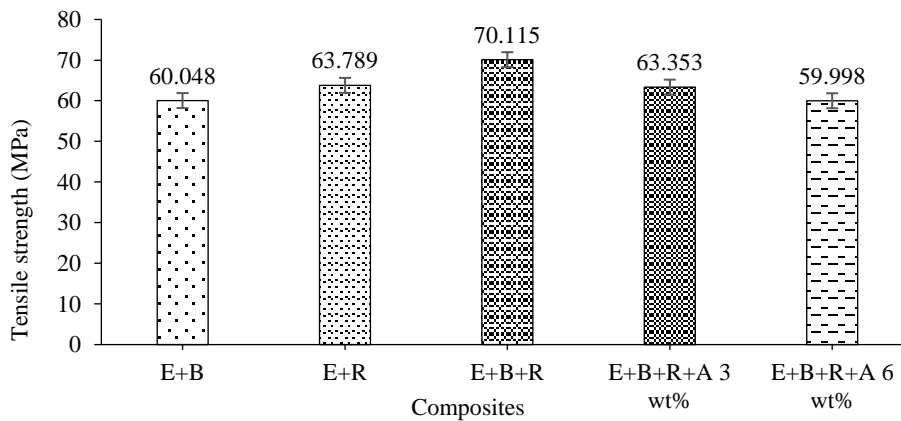
Figure 5. illustrates the tensile strength of various composite compositions. The E + B + R composite has the greatest tensile strength (70.115 MPa), however adding areca concentrate (A) at 3 wt.% and 6 wt.% lowers the tensile strength.



**Figure 3.** Stress vs. strain Curves of epoxy reinforced natural composites.



**Figure 4.** Elongation vs. load curves of epoxy reinforced natural composites.



**Figure 5.** Tensile strength of epoxy reinforced natural composites.

**Table 1.** Tensile and flexural qualities of hybridized polymer composite with different wt. %

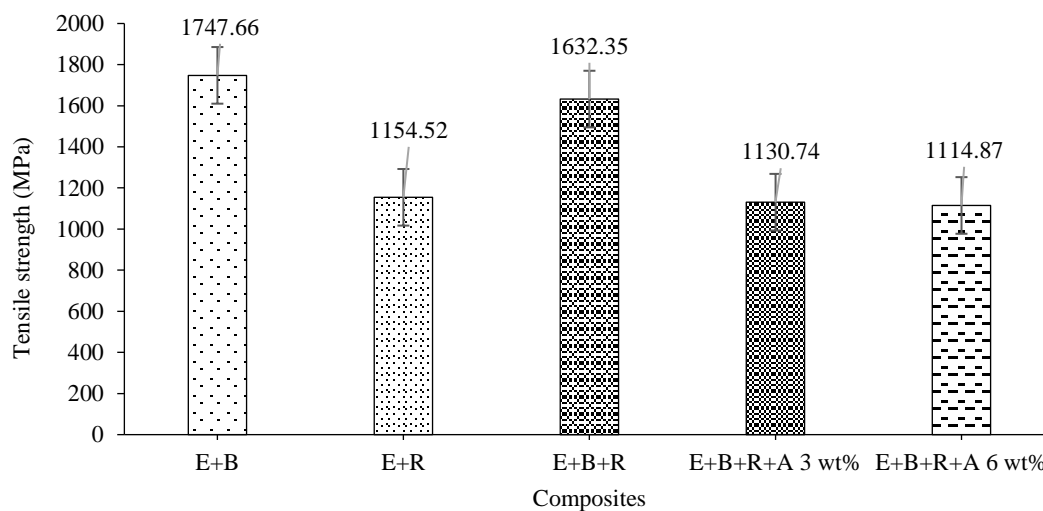
| Fiber | Wt. % | E  | Areca | TS (MPa) | Load (N) | Area (mm <sup>2</sup> ) | $\Delta$ (%) | TSt (MPa) | FS (MPa) | FL (N) | FA (mm <sup>2</sup> ) | FSt (MPa) |
|-------|-------|----|-------|----------|----------|-------------------------|--------------|-----------|----------|--------|-----------------------|-----------|
| B     | 30    | 70 | 0     | 69.04    | 3300     | 47.79                   | 1.51         | 69.04     | 1747.66  | 2330   | 85.21                 | 27.34     |
| R     | 30    | 70 | 0     | 63.78    | 3670     | 61.65                   | 1.54         | 63.78     | 1154.52  | 2370   | 107.41                | 22.06     |
| B+R   | 15+15 | 70 | 0     | 70.11    | 3585     | 49.88                   | 1.25         | 70.11     | 1632.35  | 2355   | 86.98                 | 27.07     |
| B+R   | 15+15 | 67 | 3     | 63.35    | 4135     | 65.07                   | 1.44         | 63.35     | 1130.74  | 2365   | 108.68                | 21.76     |
| B+R   | 15+15 | 64 | 6     | 59.99    | 3765     | 62.26                   | 1.08         | 60.46     | 1114.87  | 2340   | 110.08                | 21.25     |

E: Epoxy, TS: Tensile Strength,  $\Delta$ = Elongation, Tst: Tensile Stress, FS: Flexural Strength, FL: Flexural Load, FA: Flexural area, Fst: Flexural stress

### Flexural Properties of Mixed Polymer Composites

The term "flexural strength" means how well a composite can handle bending or flexural loads. The flexible characteristics of the B, R, and hybrid composite specimens were determined by putting a load on the center point and looking at the cross-sectional area at failure [19]. Table 1 depict the flexural aspects of the mixed composites, while Figure 6 illustrates the variation of flexural strength with differing fiber content.

The flexural potential of mixed composite specimens with altering fiber weight percentages indicates that bamboo fiber composites indicated the highest flexural potential at 1747.6 MPa among all formulations. The B + R composite has a better flexural performance (1632.35 MPa) than R (1154.52 MPa), B + R + A (3%) (1130.74 MPa), and B + R + A (6 wt. %) (1114.87 MPa). The improved performance is due to the fact that the pure bamboo filler and epoxy matrix can spread the load evenly and gradually before it fails. Bamboo fiber-reinforced composites are widely recommended for practical uses because they bend very well, unlike other fiber combinations [22, 23].



**Figure 6.** Flexural strength of epoxy reinforced natural composites.

## CONCLUSION

This research examines the mechanical behaviour of hybridized polymer mixtures with dissimilar fiber weight proportions. Bamboo (B) and roselle (R) fibers from their plant stems were turned into short fibers. Five different hybrid compositions, such as B (30 wt. %) + E (70 wt. %), R (30 wt. %) + E (70 wt. %), B + R (15 wt. % + 15 wt. %) + E (70 wt. %), B + R (15 wt. % + 15 wt. %) + A (3 wt. %) + E (67 wt. %), and B + R (15 wt. % + 15 wt. %) + A (6 wt. %) + E (64 wt. %), were fabricated in accordance with ASTM standards to evaluate their mechanical performance. The B + R (30 wt. %) + E (70 wt. %) composite had the greatest tensile strength of all the formulations, at 70.115 MPa. The examination of flexural strength showed that the pure B (30 wt. %) + E (70 wt. %) combination had the highest value (1747.66 MPa), which was higher than any of the other hybrid combinations. Furthermore, the B (15 wt. %) + R (15 wt. %) + E (70 wt. %) composite exhibited greater flexural strength (1632.35 MPa) than R (30 wt. %) + E (70 wt. %), B + R + A (3 wt. %) + E (67 wt. %), and B + R + A (6 wt. %) + E (64 wt. %). These results show that bamboo fiber-reinforced composites have better mechanical performance, making them a good choice for structural uses that need strong tensile and flexural strength.

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