Effects of Incorporation of Fine Particles Made from the Banana Fibers on the Mechanical Properties of Epoxy Composites

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Abstract:

The effects of fine particles made from banana fibers on the mechanical properties of epoxy resin composites were investigated in this work as a function of fine particle weight percentages. Composites were prepared using the compression molding technique, and mechanical properties such as tensile, flexural, and impact were measured at four different particle loadings. When compared to the other particle loadings, the composite with 30 wt% particle loading has the highest tensile strength (30.19 MPa) and flexural strength (51.89 MPa). However, the composite with the highest impact strength (0.41J) was found to have a particle loading of 35wt %. The surface analysis with a scanning electron microscope reveals the reasons for composite failure.

Keywords**:** *Fine particles, Epoxy, Polymer composite, Mechanical properties, Scanning electron microscope*

Introduction

Natural cellulose fiber has a distinct advantage over synthetic fiber in the recent development of composites due to advantages such as biodegradability, low cost, lightweight, high stiffness, and strength [1-4]. Natural cellulose fibers such as sisal, jute, coir, flax, banana fibers, Roselle, and others are now commonly used as reinforcing agents in polymer matrix composites [5-9].Natural cellulose fibers have more advantages than synthetic fibers, but they also have some disadvantages, such as low impact strength, a high moisture absorption tendency, incompatibility with the polymer matrix due to their hydrophilic nature, and making them critical for certain applications [9-12]. Fiber aspect ratio and loading, orientation, and interfacial adhesion between the fiber and the matrix are the main parameters that affect the mechanical properties of natural cellulose fiber-reinforced polymer composites [13-15].

Banana fibers, among other natural cellulose fibers, have been used as a potential reinforcement for polymer composites for decades. Banana plant cultivation has increased dramatically in India's southern region, particularly in Tamil Nadu. As a result, fibers from the various branches of the banana plant can be obtained cheaply for commercial purposes. However, these fibers can also be purchased from various fiber industries for use as reinforcement in polymer composites. In this paper, an effort was made to examine the mechanical properties of an epoxy composite reinforced with fine banana fiber particles. Compression molding is used to produce composite materials, and mechanical properties are evaluated based on banana fiber particle loadings. For investigation and to determine the reasons for the failure, scanning electron microscopy (SEM) images are taken from the fractured surfaces of the composite specimens.

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Experimental details

Materials

Banana fibers are extracted mechanically from the pseudo-stem of the banana plant (*Musa Sepientum*) and cleaned by hand. The fibers are then crushed as fine particles by a crushing machine with a density of 1.35 g/cm^3, a tensile strength of 54 MPa, and Young's modulus of 3.49 GPa. Following that, fine particles with an average size of 1-10 microns are manually separated using a sieving machine. In this study, an epoxy resin (LY 556) with a hardener (HY 951) is used as a polymer matrix. All chemicals used in this study were obtained from GVR Enterprises in Madurai, Tamil Nadu, India. Table 1 lists the typical properties of the epoxy resin ($C_{18}H_{21}ClO_3$) used in this study.

Table 1. The typical properties of the epoxy resin ($C_{18}H_{21}ClO_3$)

Preparation of banana fibers in particle form

Banana fibers are mechanically extracted from the banana plant's pseudo-stem sheath. They are then manually chopped with a chisel before being crushed with a mixture grinder. Finally, the crushed particles are sieved with micron holes for use in composite preparation.

Fabrication procedures of composite

The compression molding machine in our composite laboratory was used for composite fabrication. The machine has a metal mold that measures 290 × 290 ×3 mm. A releasing agent is sprayed into the mold box prior to the process to ensure that the cured composites can be easily removed. A mechanical stirrer is used to mix the epoxy resin and hardener with the particulates. The mixture was then poured into the mold and compressed for 45 minutes at 103bars at 80oC. The composites are removed from the mold after curing and cut into specimen size according to the ASTM standard for mechanical tests.

Testing of composites

In accordance with ASTM D3039, the tensile tests were carried out on the composite specimens using a universal testing machine (DTRX-30KN DEEPAK POLY PLAST PVT LTD) at a crosshead speed of 2 mm/min. On the same machine, the flexural tests were performed according to ASTM D790 at a crosshead speed of 2 mm/min. According to ASTM D256, the impact strength of composite specimens was assessed on the Izod impact testing machine. At ambient pressure and temperature, all tests were carried out. Each test uses a total of five samples, and the average value is recorded for the analysis.

Following the tests, the fracture specimen was examined using a scanning electron microscope (SEM). For examination, composite specimens are cut and uniformly coated with gold on the surface. In this study, the accelerating voltage was 10kV.

Results and Discussion

Tensile properties

Figure 1 depicts the variations in tensile properties of fine particulate reinforced epoxy composites prepared for varying fine particle weight percentages (20 to 35 wt%). It can be seen that the composite with 30 wt% particle content has a 66.61 % higher tensile strength than the composite with 20 wt% particle content. The neat resin sample had tensile strength and modulus values of 28.57 MPa and 3.15 GPa, respectively. The reinforced composite achieves the tensile strength of the neat resin sample at 30 wt%, and beyond this, the particle reinforcement (35 wt%) reduces the composite's tensile strength. A strong interfacial region may be developed by the proper (optimal) level concentration (volume or weight percentages)

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of reinforcements, which results in a higher level of applied load (stress) transfer from the matrix to the reinforcements. Due to their geometry, particles used to strengthen polymer composites operate as a bridge in the interfacial region and raise the level of stress transmission [16]. When compared to the neat resin sample, the 30wt% composite showed an improvement of 5.67 %. The 35 wt% composite has a lower tensile strength than the 30 wt% composite. This could be due to the formation of voids and poor particle dispersion, i.e. particle dumping at a specific location [17]. When comparing 30 wt% composite to 35 wt% composite, a 21.88% improvement was observed. Furthermore, the tensile strength of the 35 wt% composite is lower than that of the neat resin sample. Figure 1 also shows the fine particle reinforced epoxy composite's tensile modulus values. It is obvious that the modulus values rose linearly when particles were added to the epoxy resin matrix. The modulus of the composite is decreased as a result of the early inclusion of fine particles. The correct stress transmission between the reinforcements and the matrix may not be achieved due to improper distribution and dispersion of insufficient filler material [18]. At 35 wt% composite, which is 31.11% and 17.66% greater than the clean resin sample and 30 wt% composite, respectively, the maximum tensile modulus value of 4.13 GPa was found. It is clear that adding more particles could increase the toughness of epoxy composites.

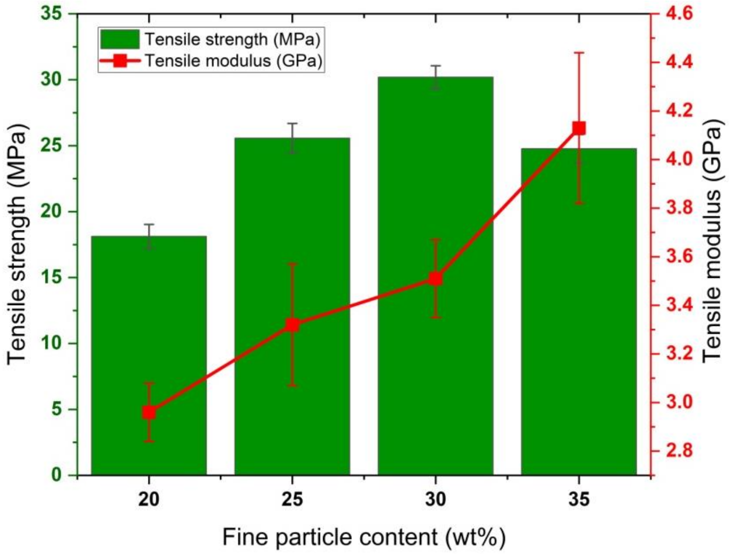

Figure 1: Variation in tensile strength and modulus of fine particle/epoxy composites for varying particle loading

Flexural properties

Figure 2 shows the flexural properties of fine particle reinforced epoxy composite for various particle loadings, including flexural strength and flexural modulus. The neat resin sample had a flexural strength and modulus of 33.58 MPa and 3.37 GPa, respectively. At 25 wt%, the composite reaches the neat resin sample's flexural properties. Figure 2 shows that the composites' flexural strength improves up to 30 wt% before decreasing. In comparison to the neat resin sample, the maximum flexural strength was found at 30% composite, which is higher by 54.53 %. The 30 wt% composite showed an improvement of 68.80% over the 20 wt% composite. This effect of particle addition on epoxy composites could be attributed to improved interfacial adhesion between the particle and matrix. Better interfacial adhesion can be achieved through proper particle-matrix interaction and increasing the effective surface area of the particles for contact with the polymer matrix [19]. Flexural modulus values, on the other hand, increased linearly from 20% to 35%, as shown in Figure 2. At 35 wt%, the maximum flexural modulus value of 4.55 GPa was obtained, which is 35.01% higher than the neat resin

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sample. The flexural modulus of the 30 wt% composite was 3.92 GPa, which is 16.07% lower than the flexural modulus of the 35 wt% composite.

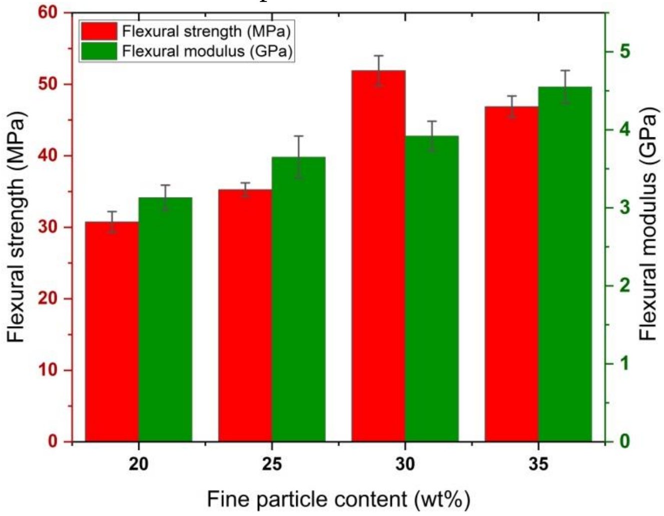

Figure 2: Variation in flexural strength and modulus fine particle reinforced epoxy composite for varying particle loading

Impact energy

Figure 3 depicts the energy absorbed by the composite specimen during impact tests. It was noted that there is a linear increase in impact strength values with the addition of particle loading. The neat resin sample had an impact strength of 0.25 J. The composite achieved the impact strength of the neat resin sample at a weight percentage of 25%. The composite with a particle loading of 35% absorbs more energy than the other weight percentage composites. When compared to the neat resin sample, a 64% improvement was obtained at 35 wt%.This is due to the particles' effective interaction with the matrix. Higher loading of fine particles increases the effective surface area for contact with the matrix, which increases the interfacial bonding strength between the particles and the matrix. As a result, the 35 wt% composite has a higher impact strength value than both the unreinforced and reinforced composites [20].

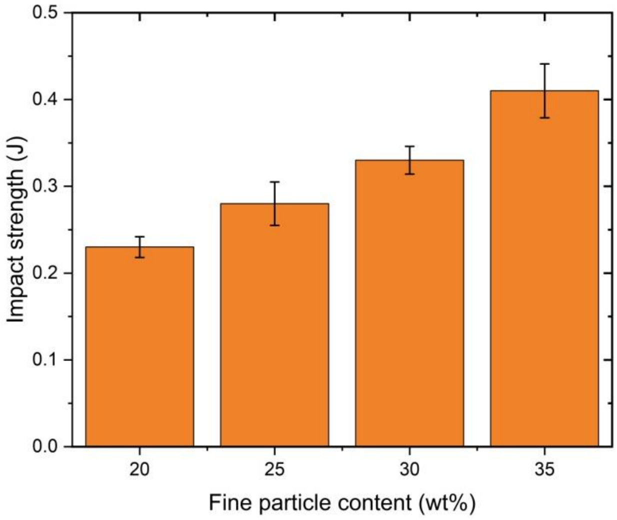

Figure 3: Variation in impact strength of fine particle reinforced epoxy composite for varying particle loading

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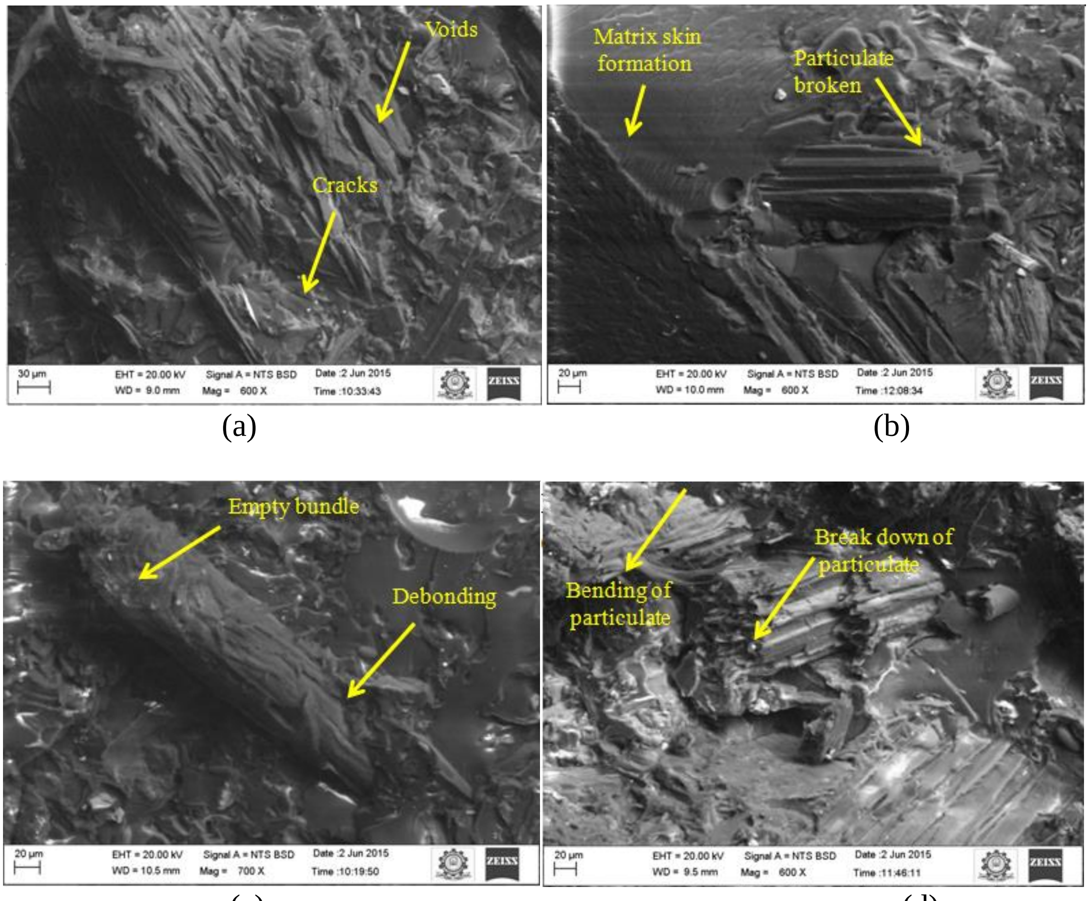
SEM microstructure analysis

The SEM analysis was performed to examine the failure mechanism on the fracture surface of mechanically tested composites. Figure 4a depicts an SEM image of a fractured surface of composite with a tensile strength of 35%. It is clear that the formation cracks as a result of poor adhesion between the particle and the epoxy resin. As a consequence, the stress transfer between the particle and the matrix is non-uniform, resulting in composite failure. Figure 4b depicts an SEM image of a fractured surface of the composite with a tensile strength of 30%.It suggests that even if some matrixes are disrupted in some locations, other locations have matrix skin development. As a result, it is observed that there is a better overall bond between the particle and epoxy matrix, which improves the tensile property. The SEM image of a fractured surface of the flexural test specimen (35 wt%) shown in Figure 4c clearly indicates that particle de-bonding causes the weak interfacial region between the particles and the epoxy resin matrix. Figure 4c also depicts an empty particle in which the resin does not penetrate the particle's bundle, possibly due to de-bonding. Figure 4d depicts the fractured surface of the composite (30 wt%) after the flexural test. It demonstrates a strong bond between the particle and the epoxy matrix. Figure 4d depicts the pull-out of particles as a result of matrix de-bonding. The SEM analysis (35 wt%) in Figure 4e shows that there are no voids or tearing due to the improved interfacial strength between the particle and the matrix, resulting in an increase in impact strength. Figure 4f depicts the fractured surface of 30 wt% composite specimens following impact tests. It has cracks and voids. As a result, the composite specimens absorb less impact energy.



(a) (b)

(c) (d)

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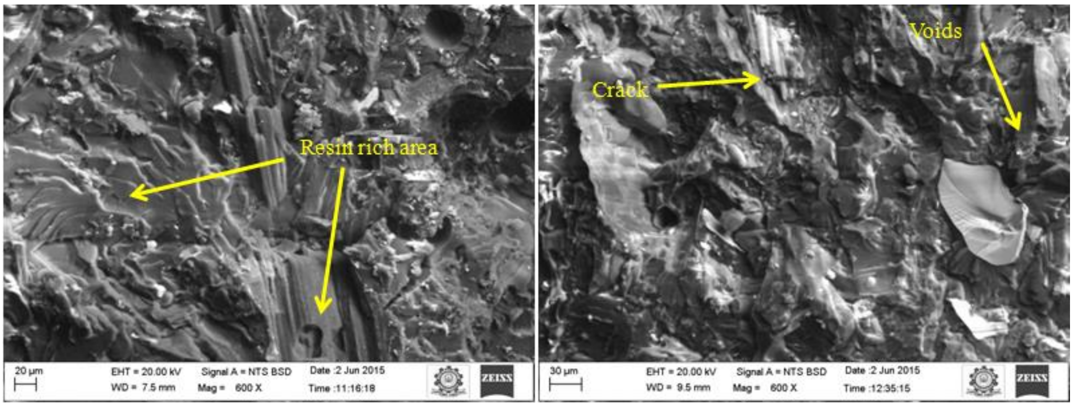

(e) (f)

Figure 4: SEM images of banana fine particle/epoxy composites: (a) 25 wt% composite after tensile test, (b) 35 wt% composite after tensile test, (c) 25 wt% composite after flexural test, (d) 35 wt% composite after flexural test, (e) 25 wt% composite after impact test, and (f) 35 wt% composite after impact test

Conclusions

Based on the loading of fine particles, the mechanical properties of an epoxy composite reinforced with fine particles made from banana fiber were evaluated. When compared to other particle loading composites, the composite with a particle loading of 30% has the highest tensile and flexural strength values. Because of the improved interfacial adhesion between the particle and the matrix, 30 wt% composite has a 21.88 % improvement in tensile strength over 35 wt% composite. Furthermore, the composite with a particle loading of 35% absorbs 0.41 J of impact energy, which is higher than the other composites. The results of the mechanical tests show that the mechanical properties of the epoxy composite have been greatly impacted by the addition of fine particles. The scanning electron microscope, however, allowed for the observation of matrix cracks, voids, and locations where the particle and matrix had de-bonded

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