Comparative Investigation of Mechanical Properties of Epoxy Composites Reinforced with Short Fibers, Macro Particles, and Micro Particles

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The present investigation reports the mechanical properties of banana short fiber, macro particle, and micro particle reinforced epoxy composites. Mechanical properties, such as tensile, flexural, and impact strength, of three different composites were studied and compared based on the three different fiber contents (25 wt%, 30 wt%, and 35 wt%). The composites were prepared by a compression moulding method for which the mixture containing the reinforcing agents and resin matrix was prepare dusing a mechanical stirrer. The scanning electron microscopy (SEM) analysis revealed the failure mechanism and the resulting damage that occurred in the composites. The short fiber composite with 35 wt% content showed the highest tensile strength (35.59 MPa), whereas the macro particle composite with 35 wt% content showed the highest flexural strength (67.16 MPa). In the case of the impact strength, both the short fiber and macro particle composites showed the highest impact strength (0.32 J). The mechanical properties of epoxy composites increased substantially with increase of content of reinforcing agents (short fiber, macro particle, and micro particle).

Keywords: *Short fiber; Macro particle; Micro particle; Composites; Mechanical properties; SEM*

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INTRODUCTION

Natural cellulose fibers, which are procured from renewable natural resources, act as biodegradable reinforcing materials and an alternative for the man-made synthetic fibers. The most commonly used natural cellulose fibers are banana, sisal, jute, bamboo, roselle, kenaf, rice husk, coir, and flax, which are used as reinforcing agents and filler for polymer matrix composites. These fibers enhance the mechanical properties of the polymers, *i.e.*, tensile, flexural, and impact properties (Chin and Yousif 2009). Many researchers have reported that the mechanical properties of the natural fiber reinforced composites, highly depend on the interfacial adhesion property between the fibers and the polymer matrix (Herrera-Franco and Valadez-González 2004).

Natural fiber-reinforced polymer composite materials can be used for many applications such as automotive, aerospace, construction, sports, and packing due to their high specific properties. The properties of natural cellulose fiber and particle reinforced polymer composites mainly depend upon the fiber geometry (length and content) and particle geometry (shape and size) (John 2004; Goulart *et al.* 2011). The properties of cellulose reinforced polymer composites have been studied by Dufresne and Belgacem (2013). The suitable cellulose in the micro and nano scale for the preparation of composites was reported. The particle reinforcement improves the mechanical and tribological performances of polymer composites, and they are widely used as biomaterials in various applications such as dental and bone cements. The effect of particle fraction and size on the mechanical and wear behaviours of polymeric composites were studied and it was reported that the composite abrasion resistance decreases with the increase of the volume percentage of the particle, instead of an accompanying rise in hardness and elastic modulus (Antunes *et al.* 2014). The particle-reinforced polymer composites can be used in many applications due to their low cost, isotropic properties, and easy manufacturing process (Oréfice *et al.* 2001). The objective of this study was to compare the mechanical properties of banana short fiber, macro particle, and micro particle reinforced epoxy composites. For this study, three types of composites were fabricated separately. The fractured surface of the composite specimens after testing was examined using SEM.

EXPERIMENTAL

Materials

Banana fibers were purchased from the Sozhavanthan Village, Madurai, Tamilandu, India and used in three different forms,such as banana short fiber, banana macro particle, and banana micro particles, to fabricate the composites. Initially the fiber was dried under direct sunlight to remove the moisture. Then, it was chopped and crushed using a mixture grinder into banana macro particles and banana micro particles. The crushed particles were sieved to obtain particles in the size ranges 1 to 10 μm and 10 to 100 μm for the preparation of composites. Table 1 indicates the mechanical properties of the banana fiber. Epoxy resin (LY 556) was used as the polymer matrix and was procured with hardener (HY 951) from the GVR Enterprise, Madurai, Tamilnadu, India.

Table 1. Mechanical Properties of Banana Fiber

Mechanical Properties of Banana Fiber	
Density (kg/m^3)	1350
Flexural Modulus (GPa)	2 to 5
Tensile Strength (MPa)	54
Young's Modulus (GPa)	3.4878

Fabrication of Composites

Composite plates were prepared using a compression-moulding machine with the mould size of 290 mm ×290 mm ×3 mm. The mould was cleaned before applying the releasing agent. The top and bottom surfaces of the mould were coated with wax for the easy removal of the cured composite plate. The epoxy resin and the hardener were mixed in the ratio of 10:1 by weight as recommended. The different weight ratios of the banana short fiber, macro particle, and micro particle (25 wt%, 30 wt% and 35 wt%) were used to prepare the composite. After pouring the mixture containing the reinforcing agents and resin matrix, the mould was closed and allowed to cure at the temperature of 80 ºC in the pressure of 103 bars for 45 min in a compression moulding machine. Once the composite was cured, it was removed from the mould and cut into the specimen size according to the ASTM standards for tensile, flexural, and impact tests.

Mechanical Testing

The mechanical properties such as tensile, flexural, and impact test analyses were performed by various machines.

Tensile test

The tensile properties of the composites were tested by using the universal tensile tester (DTRX-30KN) (Deepak Poly Plast Pvt. Ltd., Ahmedabad, India) according to ASTM D-3039 (2000). The gauge length was set at 80 mm, with a constant crosshead speed of 2mm/min.

Flexural test

The flexural test was performed in a three-point flexural setup Kalpauk universal testing machine (KIC-2-1000-C, capacity 100KN) (Kalpak Instruments and Controls, Maharashtra, India) according to ASTM D-790 (2003) at a rate of 2 mm/min until the specimen fractured and broke.

Impact test

The impact strength of the specimen was tested in the Izod impact test rig (Deepak Poly Plast Pvt. Ltd., Ahmedabad, India) according to ASTM D-256 (2005).

SEM Analysis

A Scanning Electron Microscope (SEM) (ZEISS, Oberkochen, Germany) was used for failure analysis of the tested specimens after tensile, flexural, and impact testing. The fracture surface, which has to be scanned, is coated with a layer of gold before inspection. The images of the fracture specimens are taken by subjecting them to a voltage of 10 KV.

RESULTS AND DISCUSSION

Tensile Properties

The tensile strength capabilities of the three different forms of banana fiber-filled epoxy composites with different wt% were determined *via* a universal testing machine. The tensile properties of the composites are listed in Table 2. The tensile strength of the 35wt% composite with the short fiber exhibited higher tensile strength than the macro particle and the micro particle composites at 35wt%. It was clear that the tensile strength was increased with the fiber length and fiber content in the composites. When the length and the fiber content was increased, the tensile strength of the composite also increased (Athijayamani *et al.* 2009). The tensile strength of the short fiber composite at 35 wt% was 46.1% and 63.48% higher than the macro particle and micro particle composites, respectively. The macro particle composite at 35 wt% showed 11.89% of improvement in the tensile strength, when compared with the micro particle composite at 35 wt%. In the case of the macro particle and micro particle composites also, the maximum tensile strength was obtained at 35 wt%. Tensile modulus of the composites was obtained by measuring the corresponding value of the stress-strain graph. It was observed that the micro particle with 35wt% gave the higher tensile modulus than the short banana fiber and macro particle composites because of their fiber loading.

Table 2. Tensile Properties of Composites

Properties	NRS	Short Fiber (wt%)			Macro Particle (wt%)			Micro Particle (wt%)		
		25	30	35	25	30	35	25	30	35
Tensile Strength (MPa)	29.6	25.23	33.77	35.59	19.73	21.20	24.36	18.12	18.07	21.77
Tensile Modulus (GPa)	2.51	2.94	3.85	3.64	2.81	3.16	3.69	3.32	3.51	4.43

NRS: Neat resin sample

Flexural Properties

The flexural properties of the composites were analyzed using a three point flexural test. Table 3 gives the flexural properties of the three different epoxy composites. It revealed that the macro particle composite with 35wt% showed the maximum flexural strength (67.16 MPa) compared to the short fiber and micro particle composites at 35wt%. Flexural strength was the lowest in the short fiber composites (54.34 MPa). It is observed from Table 3 that the macro particle composite with 35wt% was 23.6% and 18.24% higher than the short fiber and micro particle composite with 35 wt%. The short fiber composite was unable to withstand a heavy flexural load, which led to the failure of the fiber, and resulted in a decrease in the flexural strength. The increased flexural strength in the macro particle composites may have been due to the better interfacial adhesion within the composites. The flexural modulus was highest at 35 wt% of the short fiber composite compared to the macro and micro particle composites. It was observed that the size of the fiber gave a sufficient flexural modulus in the short fiber composite with 35 wt%. The flexural modulus of composites is also shown in Table 3. The micro particles were unable to bear higher tensile and compressive strengths because of the size of the particle. Hence,they would undergo severe deformation, which would lead to a low flexural modulus of the composites.

Table 3. Flexural Properties of Composites

Property	Short Fiber (wt%)			Macro Particle (wt%)			Micro Particle (wt%)		
	25	30	35	25	30	35	25	30	35
Flexural Strength (MPa)	39.79	40.73	54.34	43.25	51.96	67.16	35.25	51.89	56.80
Flexural Modulus (GPa)	2.41	1.72	1.83	2.15	2.32	1.69	1.55	2.11	1.35

Impact strength

The impact test was performed to predict the impact capability of different composites. The loss of energy during impact is the energy absorbed by the specimen during impact. The impact strength values of composites after testing are listed in Fig. 1. The short fiber and macro particle composites showed almost the same impact values at

35 wt%. In the case of the micro particle composites, the 25 wt% composite showed the maximum impact strength value compared to the 30 wt% and 35 wt% composites. Generally, the natural cellulose fibers have lower impact strengths. The breakage of the specimen started with the crack propagation, due to the weak interfacial strength (bonding strength) between fibers or particles and the matrix. The impact strength of the micro particle composites showed less value than the other two composites. The banana fiber was made into a particle, and it did not have a positive trend in the impact strength. From the above result, it was clear that the sharp increase in the impact properties also depended on the particle size.

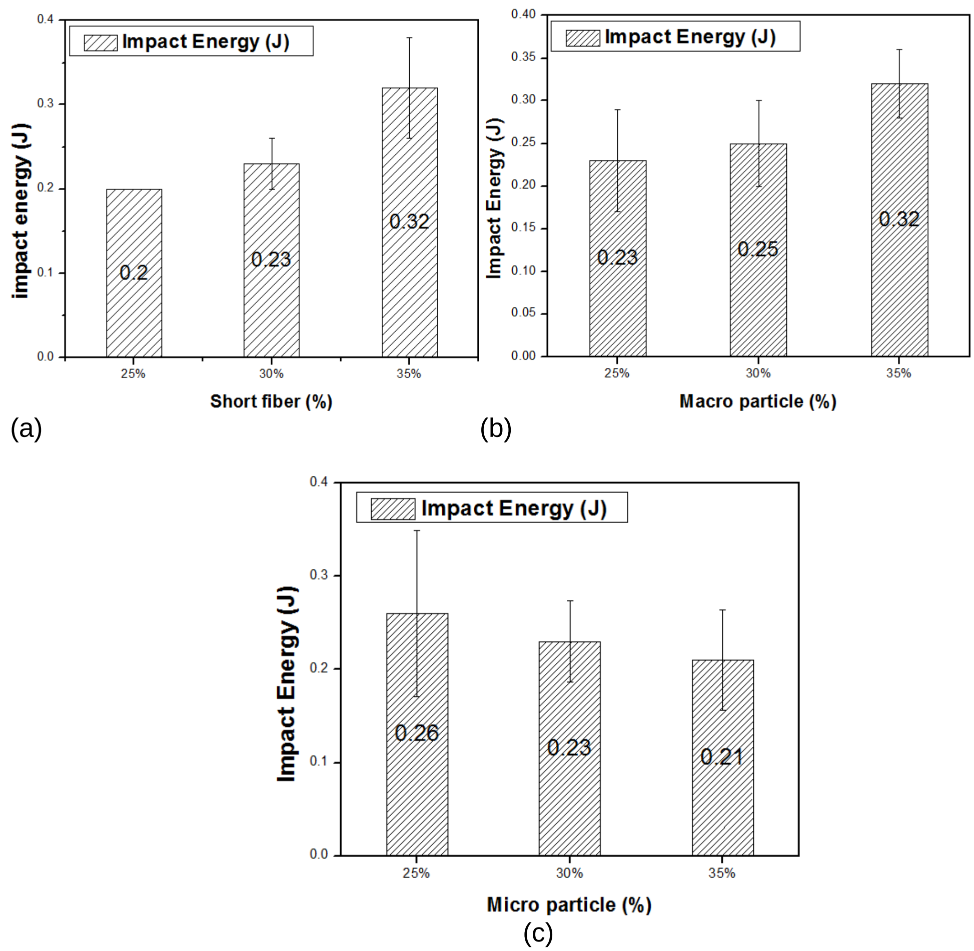

Fig. 1. Impact strength values of three different composites: (a) short fiber, (b) macro particle, and (c) micro particle

SEM Analysis

The SEM analysis was used to predict the morphological changes on the fracture surfaces in the tensile tested composite specimen of 35wt% of banana short fiber, macro particle, and micro particle reinforced composites. The 35wt% banana short fiber composite showed a higher tensile strength. Figure 2 shows the SEM image of the fractured surface of the 35wt% short fiber composite after the tensile test. This clearly illustrates the better fiber matrix interaction between the short fiber and the matrix. Further more, the fiber breakage can be seen in the fracture surface and it was the evidence of an effective stress transfer between the fiber and the matrix.

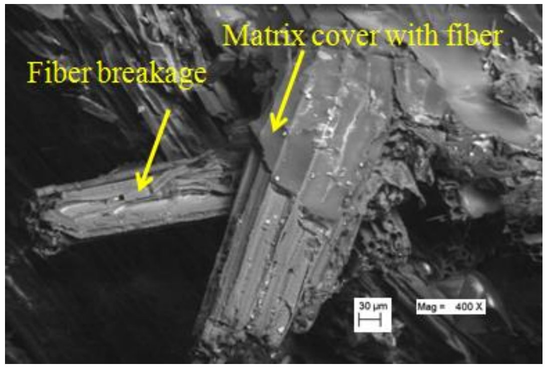

Fig. 2. SEM image of fractured surface of banana short fiber composite (35 wt%) after tensile test

Figure 3 shows the SEM image of a fractured surface of the 35 wt% macro particle composite after the flexural test. As can be seen in Fig. 3, there was a good bonding area between the macro particle and epoxy matrix, and there was almost no sign of fiber de-bonding and detachment. This result suggested that the interfacial adhesion between the macro particle and epoxy matrix had become stronger. Thus, the 35wt% macro particle composite showed a high flexural strength. The SEM image of a fractured surface of the 35 wt% short fiber composites after impact testing is shown in Fig. 4. It shows good bonding between the fiber and the matrix. From the above studies, it was established that the presence of micro cracks, voids, and poor adhesion between the fiber and the matrix were the major causes for the composite failure.

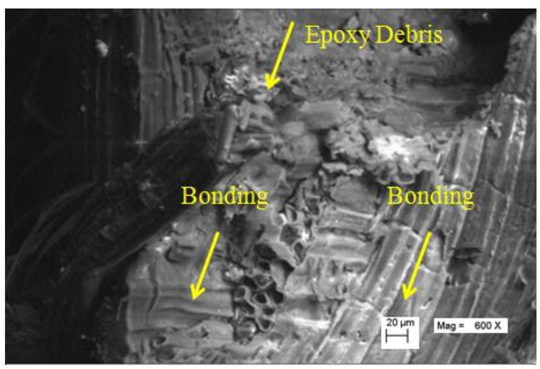

Fig. 3. SEM image of fractured surface of banana macro particle composite (35 wt%) after flexural test

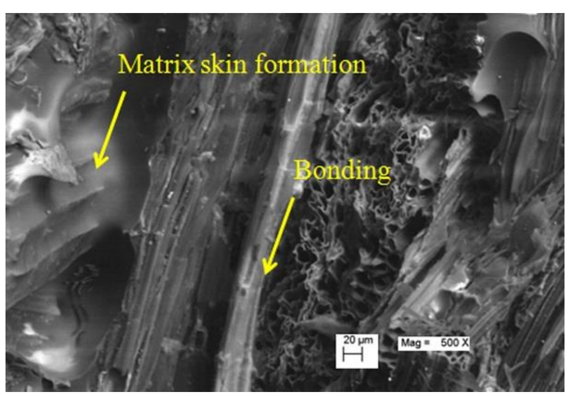

Fig. 4. SEM image of fractured surface of banana short fiber composite (35 wt%) after impact test

CONCLUSIONS

The mechanical properties of epoxy composites reinforced with the three different forms of banana fiber-reinforced epoxy composites (short fiber/epoxy composite, macro particle/epoxy composite, and micro particle/epoxy composite) were studied.

1. The short fiber-reinforced epoxy composites showed the greater values of tensile strength as compared to the other composites. The tensile strength values increased with the increase of the fiber content from 25 wt% to 35 wt%. The maximum tensile strength of 35.6 MPa was observed for the composite with 35 wt% short fibers.
2. The flexural strength values of the composites were higher for macro particle reinforced epoxy composites. The flexural strength values increased with the continuous addition of the particles from 25 wt% to 35 wt%. Composites having the macro particle content of 35 wt% acheived the highest value of flexural strength.
3. The short fiber and macro particle reinforced epoxy composites showed an increasing trend with the addition of the fibers and particles from 25 wt% to 35 wt%. On the other hand, the micro particle reinforced epoxy composites showed a decreasing trend with the addition of the particles. The short fiber and macro particle reinforced epoxy composites exhibited almost the same impact energy at 35 wt%, which was higher than that of micro particle reinforced epoxy composite.
4. The SEM analysis revealed that the tensile, flexural, and impact performances were affected by factors, such as poor adhesion between fiber and matrix, formation of micro cracks, presence of voids, and fiber pull out.

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