

Mechanical properties of bamboo-epoxy composites a structural application

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Abstract. In this study, the physical and mechanical properties of bamboo fiber reinforced epoxy composites were studied. Composites were fabricated using short bamboo fiber at four different fiber loading (0 wt%, 15 wt%, 30 wt% and 45 wt%). It has been observed that few properties increases significantly with respect to fiber loading, however properties like void fraction increases from 1.71% to 5.69% with the increase in fiber loading. Hence, in order to reduce the void fraction, improve hardness and other mechanical properties silicon carbide (SiC) filler is added in bamboo fiber reinforced epoxy composites at four different weight percentages (0 wt%, 5 wt%, 10 wt% and 15 wt%) by keeping fiber loading constant (45 wt%). The significant improvement of hardness (from 46 to 57 Hv) at 15 wt%SiC, tensile strength (from 10.48 to 13.44 MPa) at 10 wt% SiC, flexural strength (from 19.93 to 29.53 MPa) at 5 wt%SiC and reduction of void fraction (from 5.69 to 3.91%) at 5 wt%SiC is observed. The results of this study indicate that using particulate filled bamboo fiber reinforced epoxy composites could successfully develop a composite material in terms of high strength and rigidity for light weight applications compared to conventional bamboo composites. Finally, SEM studies were carried out to evaluate fibre/matrix interactions.

Keywords: composites; bamboo fiber; SiC; epoxy; mechanical testing

1. Introduction

Mechanical properties of natural fiber based polymer composites are influenced by many factors such as fibers volume fraction, fiber length, fiber aspect ratio, fiber-matrix adhesion, fiber orientation, etc. (Kahraman *et al.* 2005). A great deal of work has already been done on the effect of various factors on mechanical behavior of natural fiber reinforced polymer composites. The mechanical behaviour of jute and kenaf fiber reinforced polypropylene composites has been studied by Schneider and Karmaker (1996). It is concluded from their study that jute fiber based composites provides better mechanical properties than kenaf fiber based composites. A systematic study on the properties of henequen fiber has made by Cazaurang *et al.* (1991) and reported that fibers have mechanical properties suitable for reinforcement in thermoplastic resins. The effect of various loading rate on mechanical properties of jute/glass reinforced epoxy based hybrid composites has studied by Srivastav *et al.* (2007). The mechanical properties of jute fiber reinforced polyester composites were evaluated by Gowda *et al.* (1999). It is reported from their study that they have

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better strengths as comparison to wood based composites. Bamboo fiber reinforced composites with different polymers have been reported including epoxy resin (Gupta *et al.* 2011a, Gupta *et al.* 2011b), polypropylene (PP) (Mi *et al.* 1997, Chen *et al.* 1998), poly(butylene succinate) (PBS) (Kori *et al.* 2005) and polylactic acid (PLA) (Lee *et al.* 2006). Thwe and Liao (2000) studied the effects of fiber content, fiber length, bamboo to glass fiber ratio and MAPP content on mechanical properties of bamboo fiber reinforced plastics and bamboo-glass fiber reinforced plastics. Okubo *et al.* (2004) studied the tensile strength and modulus of bamboo fiber reinforced polypropylene based composites. The effect of bonding agent on mechanical properties of bamboo fiber reinforced natural rubber composites was studied by Ismail *et al.* (2002). In another investigation, Chen (1996) studied the structure, morphology and properties of bamboo fiber reinforced polypropylene composites in details. The effect of environmental aging on mechanical properties of bamboo-glass fiber reinforced polymer hybrid composites was studied by Thwe and Liao (2002). In polymers, fillers are used for a variety of reasons such as cost reduction, density control, improved processing, control of thermal expansion, optical effects, magnetic properties, thermal conductivity, electrical properties, improved hardness and wear resistance, flame retardancy etc. A great deal of work has been made on the effect of fillers on polymer composites. The effect of various filler parameters on mechanical properties of composites is studied by many investigators. The structure and shape of silica particle have significant influence on the mechanical properties of composites (Yamamoto *et al.* 2003). The effect of filler size and shape on the mechanical properties of composites was studied (Nakamura *et al.* 1991a, Nakamura *et al.* 1991b). The effect of filler type and content on the performance of polymer based hybrid composites were studied by few investigators (Patnaik *et al.* 2009, Biswas *et al.* 2011).

Though much work has been done on a wide variety of natural fibers for polymer composites, very less has been reported on the reinforcing potential of short bamboo fiber in spite of its several advantages over others. A number of research efforts have been devoted to the mechanical and wear characteristics of either fiber reinforced composites or particulate filled composites. However, a possibility that the incorporation of both particulates and fibers in polymer could provide a synergism in terms of improved performance has not been adequately addressed so far. To this end, the present work is undertaken to study the effect of fiber and filler on physical and mechanical properties of bamboo fiber reinforced epoxy composites.

2. Experimental details

2.1 Composite fabrication

In this study, short bamboo fiber is taken as reinforcement material which is collected from local sources. The epoxy resin (LY 556) and the hardener are supplied by Ciba Geigy India Ltd. As epoxy resins are being widely used for many advanced composites due to their many advantages such as excellent adhesion to wide variety of fibers, good performance at elevated temperatures and superior mechanical and electrical properties. Silicon carbide (SiC) is collected from the local supplier in a range of 80 μm . A stainless steel mould having dimensions of 210 \times 210 \times 40 mm³ is used for composite fabrication.

The short bamboo fiber and SiC particulates are mixed with epoxy resin by the simple mechanical stirring and the mixture is poured into various moulds conforming to the requirements of various testing conditions and characterization standards. The composite samples of different compositions

Table 1 Density and void fraction of unfilled short bamboo epoxy composites

Designation	Composition	Theoretical density (gm/cc)	Experimental density (gm/cc)	Voids fraction (%)
EB-1	Epoxy + 0 wt.-% Bamboo fiber	1.17	1.15	1.71
EB-2	Epoxy + 15 wt.-% Bamboo fiber	1.2	1.16	3.33
EB-3	Epoxy + 30 wt.-% Bamboo fiber	1.21	1.15	4.96
EB-4	Epoxy + 45 wt.-% Bamboo fiber	1.23	1.16	5.69

Note: EB: Bamboo fiber reinforced epoxy composites

Table 2 Density and void fraction of SiC filled short bamboo epoxy composites

Designation	Composition	Theoretical density (gm/cc)	Experimental density (gm/cc)	Voids fraction (%)
EBS-1	Epoxy + 45 wt.-% Bamboo fiber + 0 wt.-%SiC	1.23	1.16	5.69
EBS-2	Epoxy + 45 wt.-% Bamboo fiber + 5 wt.-%SiC	1.28	1.23	3.91
EBS-3	Epoxy + 45 wt.-% Bamboo fiber + 10 wt.-%SiC	1.38	1.32	4.35
EBS-4	Epoxy + 45 wt.-% Bamboo fiber + 15 wt.-%SiC	1.51	1.39	7.95

Note: EBS: SiC filled Bamboo fiber reinforced epoxy composites

are prepared with and without particulate filler. The detail composition and designation of the composites prepared for this study are listed in Table 1 and Table 2. A releasing agent is used to facilitate easy removal of the composite from the mould after curing. The entrapped air bubbles (if any) are removed carefully with a sliding roller and the mould is closed for curing at a temperature of 30°C for 24 h at a constant pressure of 10 kg/cm². After curing, the specimens of suitable dimension are cut for mechanical tests.

2.2 Physical and mechanical testing of composites

The theoretical density of composite materials in terms of weight fraction can easily be obtained as per standard model. Leitz micro-hardness tester is used for micro-hardness measurement on composite samples. A diamond indenter in the form of a right pyramid of a square base of an angle 136° between opposite faces is forced under a load 20 N into the sample. The tension test is performed on the samples as per ASTM D3039-76 test standards. To find out the flexural strength of the composites, a three point bend test is performed using Instron 1195. The cross head speed is taken as 10 mm/min and a span of 30 mm is maintained. The strength of a material in bending is expressed as the stress on the outermost fibers of a bent test specimen, at the instant of failure. Finally, impact tests are carried out on composite specimens as per ASTM D 256 using an impact tester. The pendulum impact testing machine ascertains the notch impact strength of the material by shattering the V-notched specimen with a pendulum hammer, measuring the spent energy and relating it to the cross section of the specimen. The standard specimen for ASTM D 256 is 64 × 12.7 × 3.2 mm and the depth of the notch is 10.2 mm.

2.3 Scanning electron microscopy (SEM)

Scanning electron microscope of Model JEOL JSM-6480LV is used for the morphological characterization of the composite surface. The samples are cleaned thoroughly, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. To enhance the conductivity of the composite samples a thin film of platinum is vacuum evaporated onto them.

3. Results and discussion

3.1 Effect of fiber loading on void content of composites

The experimental and theoretical densities of all the unfilled and particulate filled bamboo epoxy composites are calculated and developed relationship between fiber/filler loading with void fraction as shown in Table 1 and Table 2 respectively. The void fractions of the unfilled composites are increases with the increase in fiber loading as presented in Table 1. However, with the addition of SiC filler in bamboo epoxy composites, the void fraction show reverse trend as shown in Table 2. The reduction in void fraction may improve the hardness and mechanical properties of the composites and can be used for structural and other wear analysis of the composites successfully.

3.2 Effect of fiber loading on hardness of composites

Fig. 1(a) shows the effect of fiber loading on hardness of composites. The test results show that with the increase in fiber loading, hardness value of the short bamboo fiber reinforced epoxy composites is significantly increasing. However, with the addition of SiC in the bamboo epoxy composites, the hardness of the composites further increases as compared with unfilled composites (Fig. 1b).

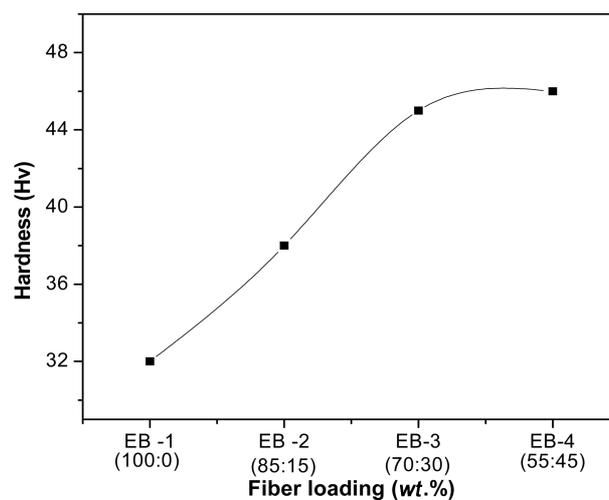


Fig. 1(a) Effect of fiber loading on hardness of composites

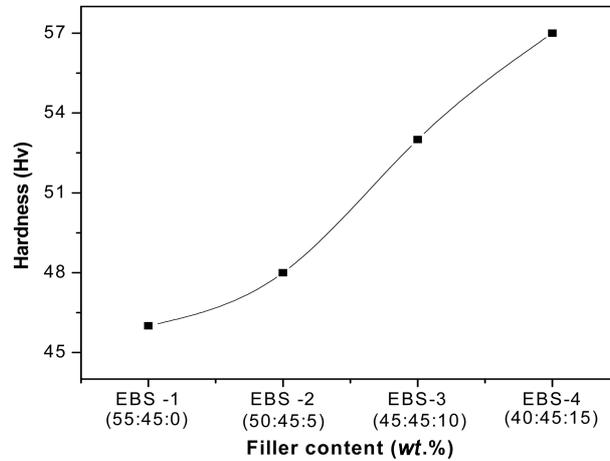


Fig. 1(b) Effect of filler content on hardness of composites

An increase in hardness is evident as the content of the ceramic filler increases. As far as hardness is concerned, this is an expected fact, since bamboo fiber display considerably higher hardness than that of the soft polymer matrix. This should be of importance when the wear properties of such systems are evaluated. As a matter of fact, the hardness values are a measure of the better wear resistance, since hard materials better resist friction and wear.

3.3 Effect of fiber loading on tensile strength of composites

The effect of weight fraction of fiber on the tensile strength of the composite is shown in Fig. 2(a). As the weight fraction of fiber increases in the composites up to 45 wt%, the tensile strength of composite is increases up to 10.48 MPa. The tensile properties measured in the present work are

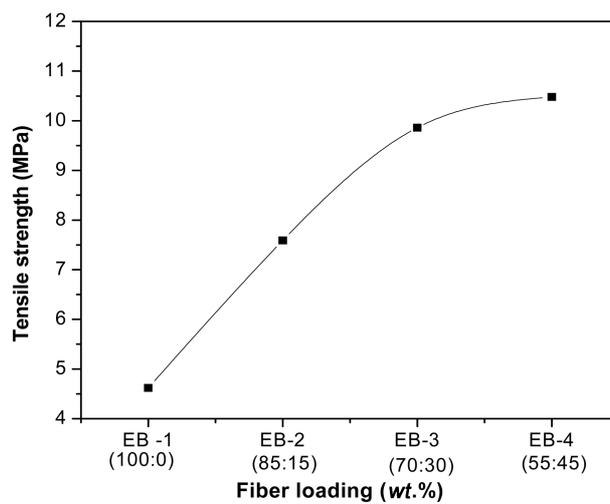


Fig. 2(a) Effect of fiber loading on tensile strength of composites

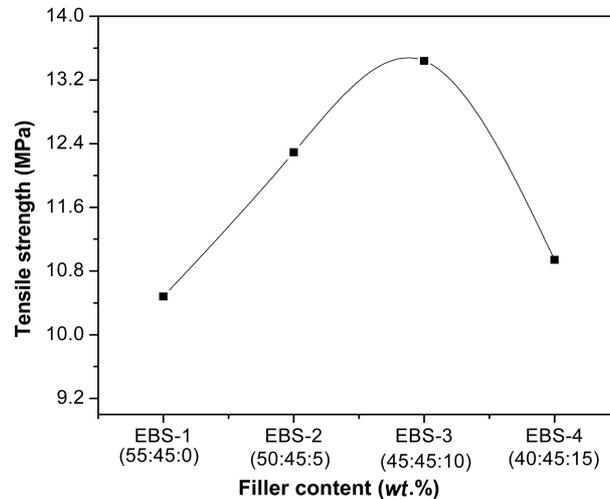


Fig. 2(b) Effect of filler content on tensile strength of composites

well compared with various earlier investigators (Nakamura *et al.* 1991a, Nakamura *et al.* 1991b), though the method of extraction of bamboo fiber is different. The influence of filler content on tensile strength of bamboo epoxy composites is shown in Fig. 2(b). It can be seen that the tensile properties have become distinctly improved with the incorporation of SiC particles in the bamboo epoxy composites. The significant improvement of tensile strength is observed up to 10 wt% SiC content and on further addition of SiC the strength starts decreasing as shown in Fig. 2(b).

This is due to the fact that the epoxy resin transmits and distributes the applied stress to the bamboo fibers resulting in higher tensile strength. Therefore, the composite can sustain higher load before failure compared to the unfilled composites. The increase in tensile strength is due to the cross-linking network formation between the fibers and the filler filled polymer matrix. However, with increase in filler content above 10 wt.% the tensile strength starts decreasing irrespective of filler content.

3.4 Effect of fiber loading on flexural strength of composites

Fig. 3a shows the effect of fiber loading on flexural strength of composites. Adversely, as shown in Fig. 3a, the flexural strength increased with the increase of fiber loading up to 30 wt%. For instance, flexural strength of bamboo-epoxy composite is increased from 16.41 MPa to 31.27 MPa i.e., up to 30 wt% and then decreased from 31.27 MPa to 19.93 MPa i.e., up to 45 wt% respectively (Fig. 3a).

It is also observed from Fig. 3a that a linearly increasing trend up to a certain value of fiber loading (30 wt%) and suddenly drops due to failure of specimens and the arrest points correspond to breakage and pull out of individual fibers from the resin matrix. This is due to higher flexural stiffness of bamboo composite and the improved adhesion between the matrix and the fiber.

The effect of weight fraction of fiber on mean flexural strength for other fiber reinforced composites in comparison to bamboo composites are more. According to Ismail *et al.* (2002) and Yao and Li (2003), this decrease is attributed to the inability of the fiber, irregularly shaped, to support stresses transferred from the polymer matrix and poor interfacial bonding generates partially spaces between fiber and matrix material and as a result generates weak structure. However, on

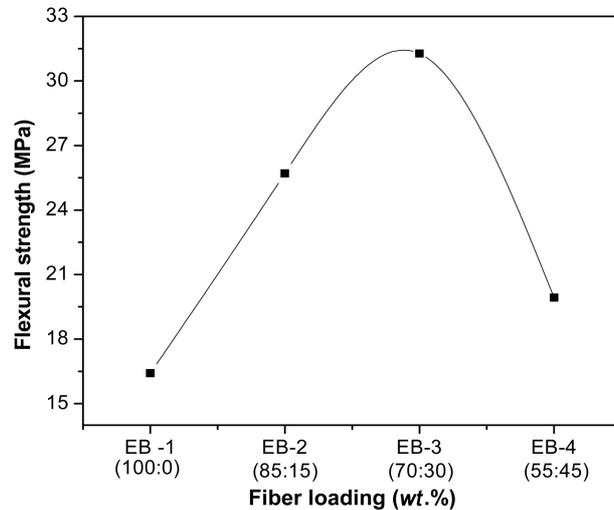


Fig. 3a Effect of fiber loading on flexural strength of composites

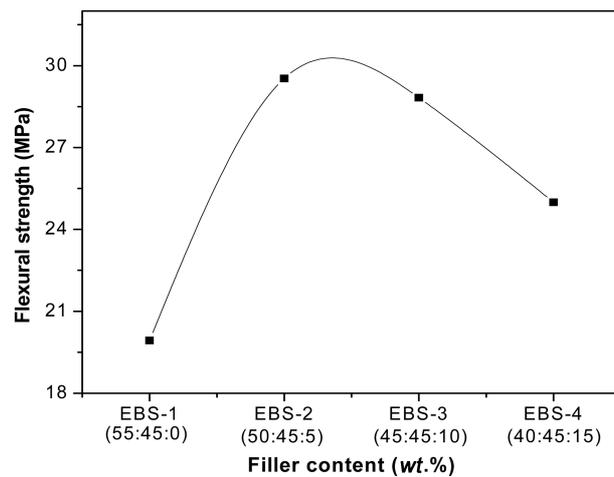


Fig. 3b Effect of filler content on flexural strength of composites

addition of SiC on the bamboo epoxy composites the bending strength increases only up to 15 wt% and then decreases but more than the unfilled one (See Fig. 3b). The decreases in mechanical strengths of the composites are probably caused by an incompatibility of the SiC particles and the epoxy matrix with bamboo fiber, leading to poor interfacial bonding. However, it also depends on other factors such as the size and shape of the filler taken in the composites.

3.5 Effect of fiber loading on impact strength of composites

As impact strength is the ability of a material to resist the fracture under stress applied at high speed. The impact properties of composite materials are directly related to its overall toughness.

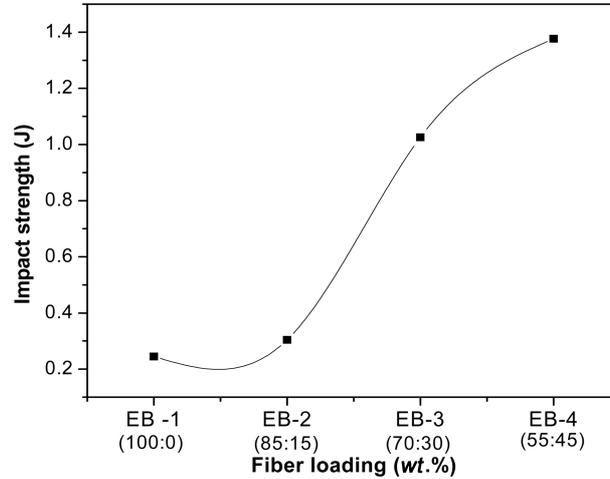


Fig. 4a Effect of fiber loading on impact strength of composites

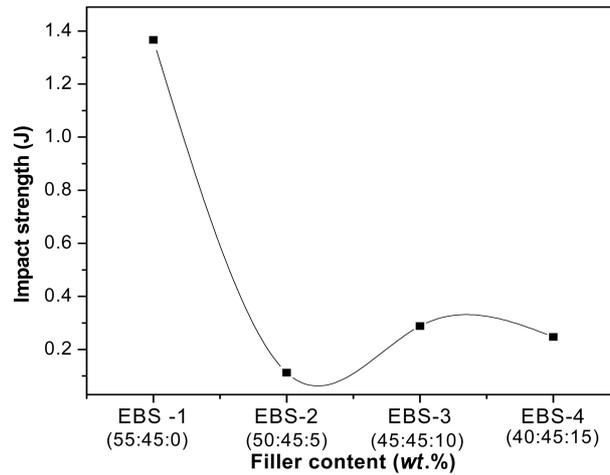


Fig. 4b Effect of filler content on impact strength of composites

Composite fracture toughness is affected by inter-facial strength parameters. Fiber reinforced polymer composites are mainly used in structural applications and therefore their impact resistance is also one of the important concerns. The improvement in impact strength of composites with respect to fiber loading is shown in Fig. 4a.

The impact strength of the composites increases nominally with increase of fiber loading up to 15 wt% and on further increase of fiber loading the strength increases drastically. Similarly, for particulate filled bamboo epoxy composites the impact strength drastically decreases up to certain filler percentage and then increases but comparatively less than unfilled bamboo epoxy composites (See Fig. 4b). The decrease in impact strength or smaller variation in strength may be due to induce micro-spaces between the fiber and matrix polymer, and as a result causes numerous micro-cracks when impact occurs, which induce crack propagation easily and decrease the impact strength of the composites (Zhao *et al.* 2008, Yang *et al.* 2004).

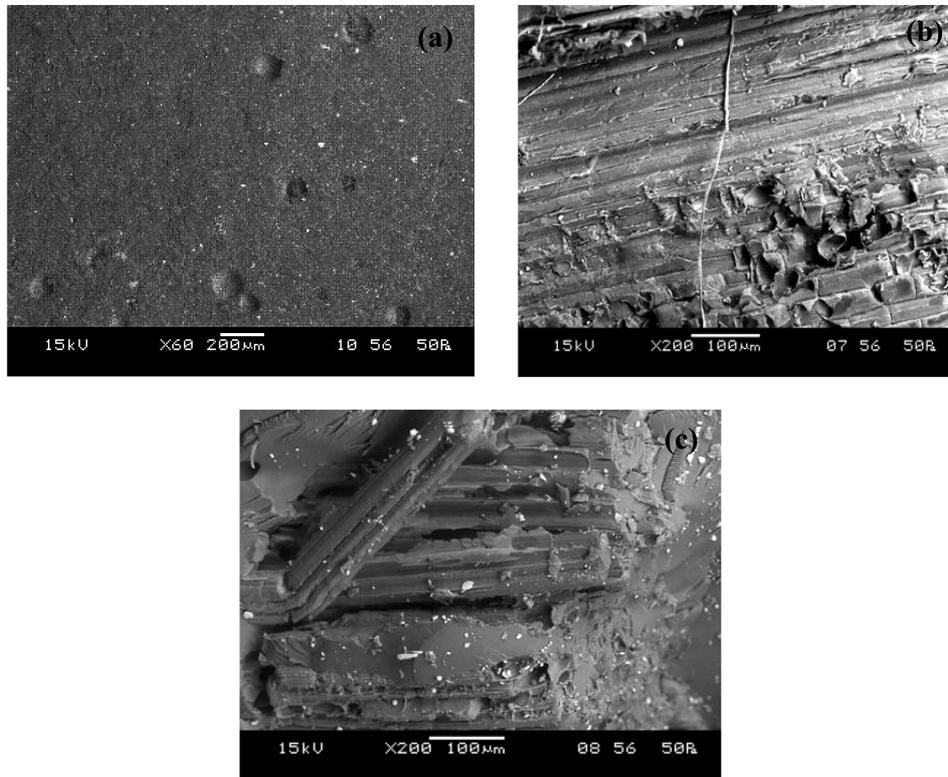


Fig. 5 Scanning electron micrographs of bamboo fiber reinforced epoxy composite specimens before and after tensile testing

3.6 Surface morphology

The fracture surfaces study of short bamboo fiber reinforced epoxy composite before and after the tensile test has shown in Fig. 5. Fig. 5a shows the fiber reinforced epoxy composite without tensile test sample. It is observed from the figure that the surface looks very smooth and lesser void content as shown on the upper surface of the composite sample. On applying tensile load on the 45 wt% of bamboo epoxy composite the fractured surface of composite shows breaking of matrix material under initial loading condition (Fig. 5b).

This is because without fibers to retard the crack growth upon external loading, the crack would propagate in an unstable manner. Besides, it is also observed that there is matrix plastic deformation near the crack tip, which contributes to plastic zone generation in the material. However, with the increase in tensile load up to yield point relatively long extruding fibers can be observed, which is depicted by fiber pullout as shown in Fig. 5c. It is an indication of crack deflection, where the crack path is changed by the fiber and directed along the fiber surface. This leads to fiber de-bonding, which is an indication of matrix separation around the fibers as crack front intersects the fiber/matrix interface and subsequently, it causes fiber pull-out. In this case, energy is dissipated by shear. At higher fiber loading, there are more fiber surfaces in contributing to energy dissipation, thus further improving the fracture resistance.

4. Conclusions

The experimental investigation on the effect of fiber loading (bamboo fiber) on physical and mechanical behavior of short fiber reinforced epoxy composites leads to the following conclusions obtained from this study are as follows:

1. The successful fabrications of a new class of epoxy based hybrid composites reinforced with short bamboo fibers have been done.
2. It has been observed that the properties like void fraction increases from 1.71% to 5.69% with the increase in fiber loading. However, in order to reduce the void fraction, improve the hardness and other mechanical properties silicon carbide (SiC) filler is added in bamboo fiber reinforced epoxy composites at four different weight percentages (0 wt%, 5 wt%, 10 wt% and 15 wt%) by keeping fiber loading constant (45 wt%).
3. The significant improvement in hardness from 46 to 57 Hv at 15 wt%SiC filled, tensile strength from 10.48 to 13.44 MPa for 10 wt%SiC, flexural strength improves from 19.93 to 29.53 MPa at 5 wt%SiC and finally the reduction of void fraction reduced from 5.69 to 3.91% at 5 wt%SiC is observed.
4. The fracture surfaces study of short bamboo fiber reinforced epoxy composite after the tensile test has been done. From this study it is concluded that the poor interfacial bonding is responsible for low mechanical properties.

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