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Studies on fracture toughness of Banana-Glass fibre hybrid composite

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ABSTRACT
Composite materials, especially fibre reinforced plastics are widely used in industrial, automotive and household applications. Environmental impact of synthetic fibres forces us to investigate alternate means in the form of natural fibres. The use of natural fibre reinforced plastics represents attractive and suitable methods for replacing the synthetic fibres like glass fibre and carbon fibre. Among various natural fibres, banana fibre is of particular interest in that, its composites has high tensile strength, high tensile modulus, and low elongation at break beside its low cost and eases of availability. This paper concentrates on reinforcement of polymer (Epoxy resin) with different lengths of banana and glass fibre to form hybrid composites. Hybrid composites are prepared using hand layup technique. Tests were conducted to calculate fracture toughness (Mode I, Mode II and Mixed mode) of these composites. The experiments were carried out to investigate the effect of fibre length on the fracture toughness of the hybrid composite. As epoxy is a brittle material, stress intensity factor is used to assess the fracture toughness of the composites. From the experimental results it is found that the increase in fibre length increased the fracture toughness value of the banana/glass fibre hybrid composite.

Keywords: Natural Fibre, Fracture Toughness, Polymer Composites, banana fibre composites, Hybrid composites, Epoxy composites.

Abbreviations: LEFM- Linear Elastic Fracture Mechanics, CTS- compact tensile specimen, ENF- End Notched Flexure, ASTM- American Society for Testing and Materials, MMF- Mixed Mode Flexure, SEM- Scanning Electron Microscope.

1. INTRODUCTION

In the past decade composite materials promise a good future for many of the engineering applications due to their low cost and high strength to weight ratio. The advantages of two or more materials can be combined to give better desirable properties in composites. Fibre reinforced polymers find wide applications in transporting, industrial and construction applications. But the adverse impact of these synthetic fibres such as glass fibre, carbon fibre on environment, poses a threat for the future. Hence extensive research has been done on the natural fibres as an alternative for the synthetic fibres (Paul Wambua et al., 2003). Several natural fibres such as bamboo, jute, coconut, hemp, flax and banana fibres got the attention of many researchers due to their better mechanical properties. But the mechanical properties of natural fibres are inferior to that of synthetic fibres. Natural fibres are hydrophilic in nature; the fibres contain cellulose, ligninand moisture. Proper extraction and processing can ensure that the moisture content is fully removed from the fibre. To overcome these properties of natural fibres they can be hybridized with synthetic fibres such as glass fibre to give better mechanical properties (Velmurugan et al., 2009).

Lot of research has been done on the hybrid composites (Kasama Jarukumjorn et al., 2009). Hybridization of cellulosic fibre with synthetic fibre was studied (Mishra et al., 2003). It was observed that the hybridisation will bring the balance between cost and performance along with environmental friendly composites. Mechanical behaviours of sisal/carbon fibre reinforced hybrid composites were reported (Noorunnisa Khannam et al., 2010). The properties and performances of various hybrid glass / natural fibre composites was also reported (Cicala et al., 2009). Glass fibre was hybridized with several natural fibre and they were used for fabrication of curved pipes to be used for the industries. Effects of Moisture absorption of sisal hybrid composites were also studied (venkateshwaran et al., 2011). Lot of research is being done on the mechanical properties of hybrid composites (Maries Idicula et al., 2010; Sreekalaa et al., 2002; Vijaya Ramnath B et al., 2013). It is evident from the literature that the hybridization gave better mechanical properties at the same time natural resources were effectively used. Among several natural fibres, banana fibre is less reported on the literature. Hence Banana fibre is considered for hybridizing with glass fibre. Also banana fibre has better mechanical properties among the natural fibres (Kulkarni et al., 1982). Hence banana fibre was hybridised with glass fibre for the present study.

Fracture toughness
Hybrid composites were prepared using hand layup method. The composites were subjected to mode I, Mode II and mixed mode testing. A basic knowledge on fracture behaviour will enable us to have suitable applications.

Tensile test gives the strength of the material to withstand the direct load. Whereas most of the engineering composites are subjected to fatigue loading, this initiates fracture failure. Fracture is a main criterion for the failure of composite materials. Transverse loads acting on the composite materials gives rise for the interlaminar shear which is mode II fracture failure. Chopped short fibre composites are subjected to fracture by crack formation at the weaker point in the composite. Fracture toughness is a measure of resistance for crack growth; hence the study of fracture toughness is evident. In general the composite materials are assumed to be orthotropic in nature. But in case of short fibre composites the material can be assumed as homogeneous; hence the testing method which is used for isotropic materials can be used to determine fracture behaviour of short fibre composites (Silva et al., 2006). Fracture toughness is a measure of energy absorbed during fracture failure. Shamprasad et al. (2011) studied various aspects of fracture toughness measurement for polymer composite materials. Different Methods were given for interlaminar and intralaminar fracture.

Mode I Fracture
Mode I fracture is the tension mode fracture, in which crack originates and propagates in the opening mode.

This paper concentrates on fracture behaviour of short banana/ glass fibre hybrid composite by varying the fibre length. Epoxy resin was used as matrix material. Since epoxy is brittle material, critical stress intensity factor is used to evaluate the fracture toughness of hybrid composite. Linear Elastic Fracture Mechanics (LEFM) theory can be satisfactorily applied to the materials with less plastic deformation like epoxy resin. Mode I fracture toughness was determined by compact tensile specimen (CTS). End Notched Flexure Specimen (ENF) is used to predict the fracture behaviour of composite material. Experiments on mode II and mixed mode fracture toughness were reported by several researchers (Compston et al., 2001; Pereira et al., 2006). Extensive research was reported on woven fibre composite materials and laminates (de Morais et al., 2003). The fracture toughness of composite material is attributed to the matrix shear strength, bonding strength between the fibre and matrix and fibre strength. The effect of loading rate on the fracture toughness was also reported by several researchers. George C.Jacob et al. (2004) reported the mixed response for the loading rate. Some of the composites exhibited no change in fracture toughness with change of loading rate. This review clearly shows that less has been reported on the fracture behaviour of random oriented short fibre composites.

2. MATERIALS AND METHODS

2.1. Materials

Epoxy is a thermosetting polymer that cures (polymerizes and cross links) when mixed with a hardener. Epoxy resin of the grade LM-556 with a density of 1.1–1.5 g/cm3 was used. The hardener used was HY-951. The matrix material was prepared with a mixture of epoxy and hardener HY-951 at a ratio of 10:1.The system is easy to process, has good fibre impregnation properties and exhibits excellent mechanical, dynamic and thermal properties. It has an excellent chemical resistance especially to acids at temperatures up to 80°C. This epoxy system fulfils MIL specifications R 9300.The processed banana fibre was obtained from ROPE Internationals Chennai. Since the moisture was removed from the banana fibres there was no formation of fungi during the storage. The banana fibres used in the study were chopped to different lengths of 5mm, 10mm, 15mm and 20mm.The glass fibre used in this study is circular cross-section E-glass obtained from Sakthi glass fibre, Chennai. Chopped fibre glass strands at different lengths of 5mm, 10mm, 15mm and 20mm were mixed with banana fibre. The mixture of glass/banana fibre was used for hand lay-up moulding and provides equal properties in all of the in-plane directions of the structure. Different samples were prepared for each fibre length of the composite with the same procedure. The samples were identified as BGE5, BGE10, BGE15 and BGE20 corresponding to 5mm,10mm,15mm and 20mm fibre length respectively.

2.2. Fabrication of Composites

Initially the chopped glass fibre and Banana fibre were mixed in a volumetric ratio of 50:50. The total fibre volume fraction was kept at 20%, the remaining is filled by epoxy resin. The calculated weight of fibre mixture was taken and it was thoroughly mixed with the epoxy resin. Extra care has been taken to ensure homogeneous mixing of the fibre in the matrix. Then hardener is added to the mixture as per the requirements. Then immediately the entire mixture was poured into the cavity which is formed by a wooden mould of dimensions 300mm x 300mm. Then pressure was applied on the composite and it was cured for about 24 hrs at room temperature. The test specimens (Figure 1) were cut from the fabricated composite plate as per the ASTM standards.

Mode II fracture

This is the in plane shear fracture. In this the adjacent layers slide one over another. This mode of fracture can be initiated by bending type of loads.

Mode III fracture

This type of fracture is known as out of plane shear. This is also known as tear mode fracture. This type of fracture in very less observed.

Mixed Mode Fracture

This is a combination of mode I and Mode II fracture.

2.3. Testing methods

2.3.1. Mode I fracture testing

The fracture toughness was determined using Instron type universal Testing machine as per ASTM D 5045 method. Compact Tensile Specimen (CTS) was used for Mode I fracture testing (Figure 2). The testing of the specimen was done with the help of Instron 4204 Universal Testing Machine. Two bolts were inserted in the 8mm diameter hole, which was drilled on the CT specimen. Those 2 bolts were fixed in the testing machine. Thus the specimen was fixed in the testing machine for conducting CT test. A uniform head speed of 3mm/min was given and the results were digitally recorded. Load vs. displacement was given as output.

2.3.2. Mode II fracture testing

End Notched Flexure (ENF) specimen (Figure 3) was used to evaluate the mode II fracture toughness. The end notch was introduced in the composite material by careful cutting by a continuous thin band cutter. Then the specimens were subjected to three point bend test to evaluate the mode II fracture behaviour. ENF specimens were fabricated by placing an adhesive tape during the hand layup process. These tapes will act as initial crack on the specimen. The ENF specimen was subjected to three point bending test, in which the specimen undergoes mode II fracture.

2.3.3. Mixed mode fracture testing

Mixed mode fracture test was done as per ASTM D6671 standard. The testing was conducted at MetMech Labs Chennai. The testing method suggested by Andras Szekrenyes (2002) is used for mixed mode bending test The ENF specimen itself was used for the MMB test. Mixed Mode Flexure (MMF) specimen (Figure 4) was prepared by cutting a small portion of material from the bottom layer of ENF specimen.

3. RESULTS AND DISCUSSION

The average values of the load vs. displacement output was calculated and tabulated as shown in table 1. Stress intensity factor K can be considered as an estimate of fracture toughness. It depends on Load, Flow depth and geometry and load displacement curve. Critical stress intensity factor for mode I is given by,

$$K_{ic} = \frac{P}{B\sqrt{W}}\left\{F\left(\frac{A}{W}\right)\right\}$$

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Where

P- Load at which crack propagate, B- Thickness of the test specimen, w- Length of the specimen

$\left\{F\left(\frac{A}{W}\right)\right\} = \frac{2+\left(\frac{A}{W}\right)}{\left(1-\frac{A}{W}\right)^{1.5}}\left\{0.866 + 4.66\left(\frac{A}{W}\right) - 13.32\left(\frac{A}{W}\right)^2 + 14.72\left(\frac{A}{W}\right)^3 - 5.6\left(\frac{A}{W}\right)^4\right\}$ a - crack length, $F\left(\frac{A}{W}\right)$-geometry factor

Stress intensity factor for mode II is given by,

$$Kii = \left[\frac{9xPx\alpha^2 x\delta x1000}{\left[2xB(L^3/4+3\alpha^3)\right]}\right]$$

Stress intensity factor for mixed mode I + II is given by,

$K_{I+II} =$ 21a²pδ/ 2W (7a³+L³)

The values of stress intensity factor were calculated from above formula and are tabulated in table 2.

It can be observed from the results that the increase in fibre length attributes toward the increase in fracture toughness value of the composite. A close observation of the composite has shown that the increase in fracture toughness is due to the brittle epoxy matrix is reinforced with glass and banana fibres. Hence it may be concluded that increasing the fibre length increases fracture toughness. Also, it was observed that there is an increase of 40% value of Critical stress intensity factor (Kic) when the fibre length is increased from 5mm to 15mm. But it may be noted that the increase in Kic value is only 2.35% between 15mm fibre and 20mm fibre. Hence, increasing beyond this length may not greatly affect the fracture toughness in chopped fibres. When the fibre length is increased beyond its critical length the fibre acts as continuous fibre. At small fibre lengths the fracture occurs due to the shear failure of the matrix, and fibre pull out from the matrix. The friction between the fibre and matrix attributes to the fracture toughness. But when the fibre length is increased, the energy is dissipated due to fibre breakage. For relatively long fibre the adhesion shear strength is higher than the fibre shear strength. Apart from the fibre breakage, the matrix also deforms elastically. Due to the high difference of fibre strength between glass and banana fibre the initial fibre breakage occurs for the banana fibre. Figure 5 shows Scanning Electron Microscope (SEM) image for mode I fracture specimen. It was evident that the fracture occurs mainly due to the fibre breakage and fibre pullout from the matrix. Also the random orientation of the fibre attributes to the longitudinal fracture of the fibre. The SEM image of mode II fracture specimen (Figure 6) shows the fracture in transverse direction. Similarly SEM image of mixed mode fracture specimen (Figure 7) shows the fracture of matrix in longitudinal direction due to shear failure. The co-existence of fibre pullout and shear failure in the image confirms to the mixed mode failure of the specimen. Also it may be noted that the loading rate may be changed and its effect on the fracture toughness value can be further analysed.

4. CONCLUSION

The fracture characterization of the continuous fibres was studied extensively, but very less work is reported on the fracture toughness of chopped fibres. Hence, in this study, the effects of fibre length of chopped Banana/Glass fibre hybrid composites were investigated on fracture toughness values. Tests were performed on Hybrid composites with the fibre length of 5mm, 10mm, 15mm and 20mm respectively. From the experiments, it was observed that the fibre length of 20 mm possess the maximum fracture toughness. It is due to the energy dissipation by fibre breakage and matrix shear, which was apparent from SEM images of the test specimens. Further, studies on the effect of strain rate on the fracture toughness can be done. Thus, it is conclude that the systematic and persistent research in the future will increase the scope and better future for banana fibre and it composites.

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Table 1

Average value of load and displacement of all the specimens

Specimen	Mode I		Mode II		Mixed Mode I+II	
	Load (kN)	Displacement (mm)	Load (kN)	Displacement (mm)	Load (kN)	Displacement (mm)
BGE5	0.856	2.5	1.53	1.5	0.634	3.0
BGE10	0.935	3.0	1.64	1.0	0.706	3.6
BGE15	1.035	3.5	1.82	2.0	0.835	4.0
BGE20	1.23	4.5	1.81	2.5	0.634	4.9

Table 2

Fracture toughness of Hybrid fibre composite at different fibre lengths

Specimen	Fracture toughness (Stress Intensity Factor) (MPa. $m^{1/2}$)		
	Mode 1	Mode 2	Mixed Mode 1+2
BGE5	1.51	0.243	0.092
BGE10	1.93	0.585	0.0325
BGE15	2.55	0.798	0.0453
BGE20	2.61	0.9855	0.0502

Figure 1

Banana/Glassfibre hybrid composite specimens as per ASTM standards

Figure 2

Compact Tensile Specimen (CTS) as per ASTM Standards

Figure 3

ENF specimen under Mode II fracture test

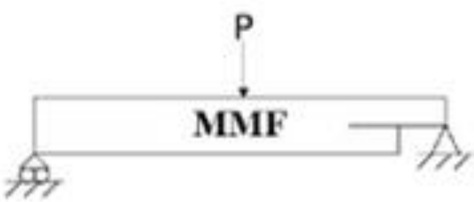

Figure 4

Mixed Mode Flexure specimen

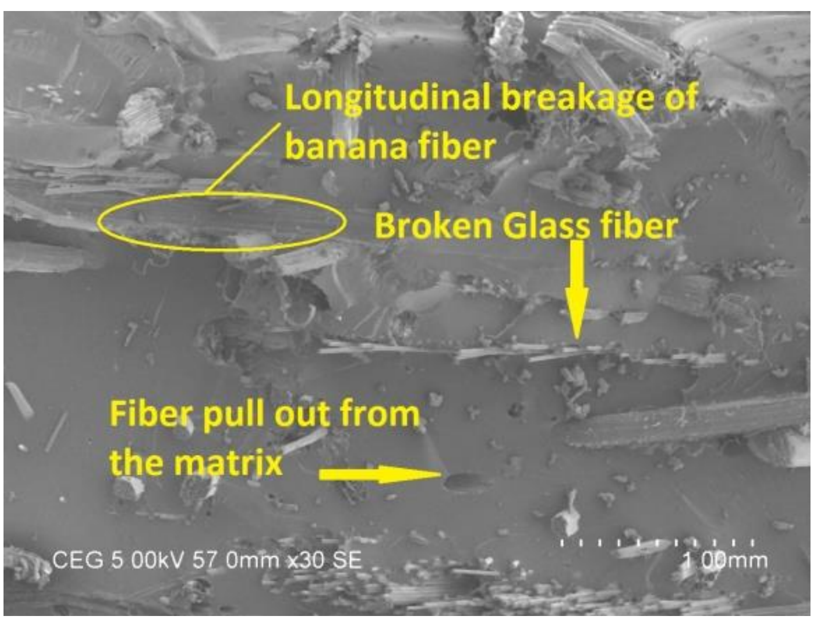

Figure 5

Sem image of Mode I fracture specimen

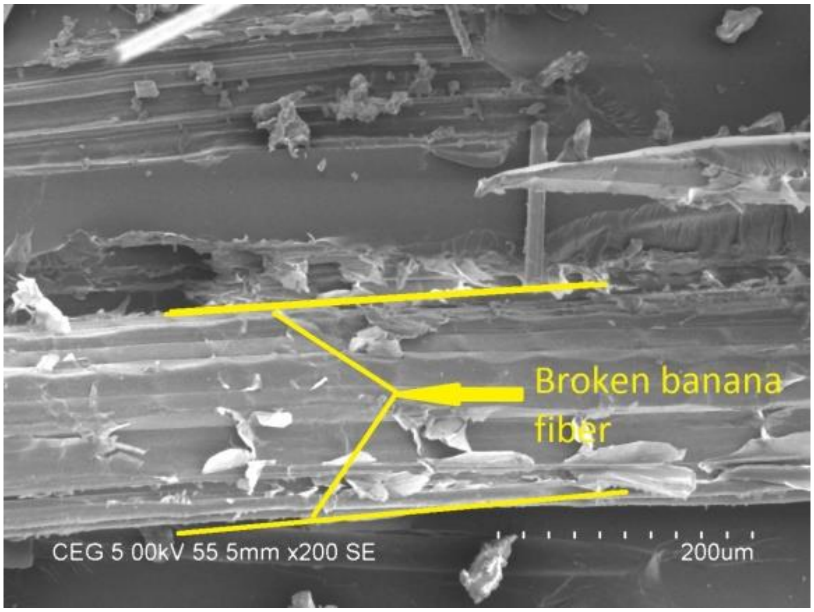

Figure 6

Sem image of Mode II fracture specimen

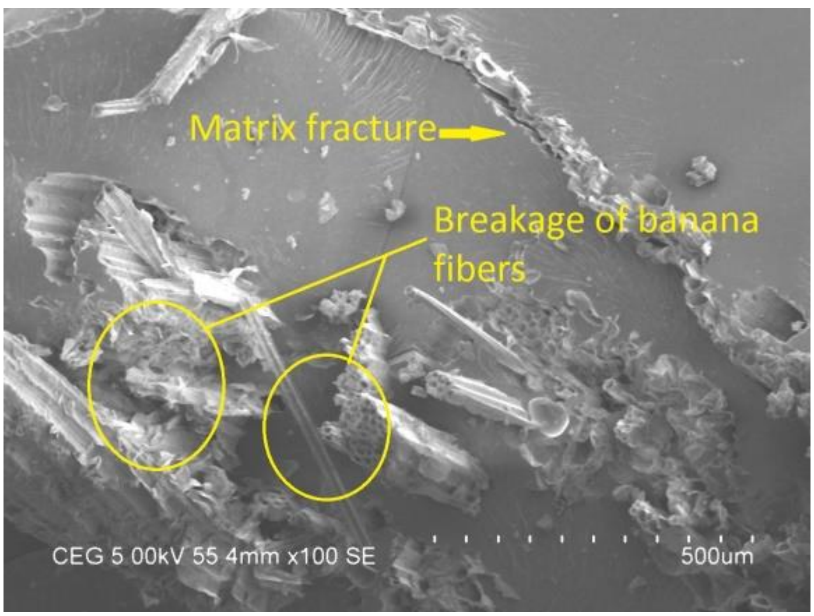

Figure 7

Sem image of Mixed Mode (I+II) fracture specimen