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Processing and Mechanical Property Evaluation of Banana Fiber Reinforced Polymer Composites

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Abstract

In the fast developing world, the concern for the environmental pollution and the prevention of non-renewable and non-biodegradable resources has attracted researchers seeking to develop new eco-friendly materials and products based on sustainability principles. The fibers from the natural sources provide indisputable advantages over synthetic reinforcement materials such as low cost, low density, non-toxicity, comparable strength, and minimum waste disposal problems. In the present experiment, banana fiber reinforced epoxy composites are prepared and the mechanical properties of these composites are evaluated. The composite samples with different fiber volume fractions were prepared by using the hand lay-up process and apply pressure at room temperature. The samples were subjected to the mechanical testing such as tensile, flexural and impact loading. Scanning electron microscope (SEM) analysis is carried out to evaluate fiber matrix interfaces and analyze the structure of the fractured surfaces.

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Keywords: Sustainability, Natural fibers, Banana fibers, Mechanical testing, Scanning electron microscope.

1. Introduction

The natural fibers are renewable, non-abrasive, bio-degradable, possess a good calorific value, exhibit excellent mechanical properties and can be incinerated for energy recovery have low density and are inexpensive. This good environmental friendly feature makes the materials very popular in engineering markets such as the automotive and construction industry [1, 2]. The incorporation of natural fibers with glass fiber improve the tensile and flexural strength and these composites can be used for medium strength applications [3].At present the banana fiber is a

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waste product of banana cultivation, therefore without any additional cost these fibers can be obtained for industrial purposes [4]. Pothan et al [5] studied the dynamic mechanical behavior of banana fiber reinforced polyester composites and found that the volume fraction of the fiber has great influence on the mechanical properties of the composites. The maximum strength is observed for composites with 40% fiber loading, which is chosen as the critical fiber loading. Idicula et al. [6] investigated the mechanical properties of short banana/sisal fiber reinforced with random orientation mixed hybrid polyester composites. The results shows that, the fiber/matrix adhesion and stress transfer was found to be good in composite with relative volume fraction of banana and sisal 3:1, which shown the highest tensile strength and flexural modulus. The chemically treated banana fibers reinforced composites exhibited superior mechanical properties than untreated fiber reinforced composites [7-12]. The improvement in the properties was found mainly due to the better packing of the cellulose chains, after the dissolution of lignin, which is the cementing material [12].

Zainudin et al. [13] experimented on the thermal degradation of banana pseudo-stem (BPS) filled un-plasticized polyvinyl chloride (UPVC) composites. The results indicated that the thermal stability of acrylic modified BPS/UPVC composites was greater than that of unmodified BPS/UPVC composites. Samal et al. [14] fabricated and evaluated the properties of banana and glass fiber reinforced polypropylene (BSGRP) composites. From the results, it is known that the BSGRP composites in the presence of MAPP is cost effective had improved storage modulus, crystallization and thermal degradation temperature, enhancement in melting point, and optimum viscosity. The degradation studies of the polycaprolactone banana fiber reinforced composites has been conducted and concluded that the banana fibers treated with alkali solution resulted in an increase in surface roughness, and increase in density [15, 16]. The mechanical properties of thermoplastic matrix material (HDPE/PCL 80:20 blend and LDPE/PCL 70:30 blend) were improved by introducing untreated or alkali-treated short banana fibers [16]. Shaktawat et al. [17] investigated the temperature dependence of thermo-mechanical properties of banana fiber reinforced polyester composites and found the alkali treated composites had the maximum phase transition temperatures.

Zaman et al. [18] investigated the influence of acrylic monomer and starch on the fiber/low density polyethylene (LDPE) composites. They prepared banana fiber-reinforced low density polyethylene composites by using the fibers treated with monomer solution along with 2% Darocur-1173 photo initiator and cured under UV radiation. They found that there was a remarkable improvement on properties of the composites after monomer treatment. Aseer et al. [19] prepared chemically treated banana fiber composites and evaluated the physical, thermal and morphological properties. The results indicated that, the NaClO treated banana fibers showed good physical properties and low moisture absorption characteristics with respect to untreated raw banana fiber. Chemically treated fibers have good adhesion with hydrophobic resins and improved crystallinity index of 71%. It was revealed that the percentage of weight loss in treated fibers is less compared with raw fiber which may be attributed to the removal of cellulose and hemicellulose while treating. The surface treatment results indicated that treated banana fibers can be a good choice as reinforcement in the manufacture of bio-composites.

Sathasivam et al. [20] prepared the banana trunk fibers and polyvinyl alcohol blended composite films and examined their physical characteristics. They found that the increase in the fiber content improved the physical characteristics and decreased the degree of swelling when compared to unblended films. They suggested that these films can be used as an alternate replacing material for food packaging materials. Biswal et al. [21] examined the mechanical and morphological properties of polypropylene modified banana fiber nano-composites and observed that the improved mechanical properties by treating the mercerized banana fibers with NaOH solution. Addition of 30 weight % mercerized banana fibers to polypropylene nano-composites improves the tensile strength up to 79.9% and the flexural strength by 68.8%. Morphological observations confirmed that the removal of cementing agents from raw banana fibers enhanced the fiber adhesion properties with matrix. Naik and Mishra [22] studied the electrical properties of natural fiber reinforced high density polyethylene composites and found that the untreated banana fiber showed better resistivity and volume resistivity while maleic anhydride-treated agave fiber composites showed minimum surface resistivity and volume resistivity.

2. Experimental

2.1. Materials

The materials used in this experiment for fabrication are banana fibers, epoxy resin, catalyst methyl ethyl ketone peroxide (MEKP) and acetone thinner. The banana fibers are collected in the form of residues from Coimbatore district, Tamil Nadu, India. The epoxy resin, Methyl Ethyl Ketone Peroxide (MEKP) and the acetone thinner are purchased from a local dealer in Chennai. The physical properties of the banana fibers are presented in Table.1.

Table 1. Physical properties of banana fiber [4, 6, 7]

Property	Range
Cellulose (%)	63- 64
Hemi cellulose (%)	19
Lignin (%)	5
Moisture (%)	10-11
Density (g/cm^3)	1-1.5
Elongation at break (%)	4.5- 6.5
Young's modulus (GPa)	20
Microfibrillar angle (deg.)	11
Lumen size (mm)	5

2.2. Preparation of composites

The preparation process adopted here is hand lay-up process followed by applying pressure using compression moulding. The fiber mats of uniform thickness were prepared from banana fibers of particular length. The composite consists of 3 layers. The mats were impregnated with epoxy resin. MEKP is the catalyst mixed with epoxy resin to give effective binding. Initially the banana fibers are dried under the hot sun to remove the moisture for more than 24 hours. The fiber layers are washed in the acetone thinner before they are fabricated. This removes the impurities on them and makes them ready for binding with the resin. The banana fibers are mounted on the base plate which is placed on the table, and then it is completely filled with the epoxy resin. The resin gets mixed with the fiber and may tend to dried up in the open atmosphere under hot sun for 48 hours. Before the resin gets dried up the second layer must be mounted on it. The process is repeated for another layer also. The epoxy resin applied is distributed to the entire surface by means of a roller and the air gaps formed between layers during fabrication are removed by gently squeezing. The specimen is then pressed at a temperature of 32°C, under the pressure of 6MPa, and the average relative humidity of 65%. Three such samples were prepared with different lengths and volume fractions, tested and the average values are used for detailed analysis.

3. Mechanical testing

3.1. Tensile strength

The specimen prepared is shaped into required dimension using a hand cutter and the edges are polished using an salt paper. It is prepared according to the ASTM D638 standard. The dimensions, gauge length and cross head speeds are chosen according to the ASTM D638 standard. The tensile test is performed on the Universal Testing Machine (UTM) Make FIE (Model: UTN 40, S. No. 11/98-2450).

The process involves placing the test sample in the UTM and applying tension to it until the fracture of the material. Then the force is recorded as a function of the increase in gauge length. During the application of tension, the elongation of the gauge section is recorded against the applied force. There are three different types of samples prepared according to the ASTM standards and the experiments are repeated for several times and the average values are used for discussion.

Table. 2 Experimental tensile strength of the composite samples

Samples	Trial 1	Trial 2	Trial 3	Average(MPa)
40% banana fiber + 60% Epoxy resin	101.35	114.24	109.69	108.42
50% banana fiber + 50% Epoxy resin	110.56	116.48	114.70	112.58
60% banana fiber + 40% Epoxy resin	89.18	104.82	101.02	98.34

3.2. Flexural strength

The flexural specimens are prepared as per the ASTM D790 standards and the test has been carried out using the same UTM. The 3-point flexural test is the most common flexural test and used in this experiment for checking the bending strength of the composite materials. The testing process involves placing the test specimen in the UTM and applying force to it until it fractures and breaks.

Table. 3 Experimental flexural strength of the composite samples

Samples	Trial 1	Trial 2	Trial 3	Average (MPa)
40% banana fiber + 60% Epoxy resin	74.02	68.94	74.06	72.34
50% banana fiber + 50% Epoxy resin	65.44	57.53	71.27	64.68
60% banana fiber + 40% Epoxy resin	80.28	78.21	73.32	77.21

3.3. Impact test

The impact test specimens are prepared according to the required dimension following the ASTM-A370 standard. During the testing process, the specimen must be loaded in the testing machine and allows the pendulum until it fractures or breaks. Using the impact test, the energy needed to break the material can be measured easily and can be used to measure the toughness of the material and the yield strength. The effect of strain rate on fracture and ductility of the material can be analyzed by using the impact test.

Table. 4 Experimental impact strength of the composite samples

Samples	Trial 1	Trial 2	Trial 3	Average (Joules)
40% banana fiber + 60% Epoxy resin	10.43	8.15	7.28	8.62
50% banana fiber + 50% Epoxy resin	12.82	6.77	8.85	9.48
60% banana fiber + 40% Epoxy resin	9.08	13.11	11.47	11.22

4. Results and discussion

The samples are tested in their corresponding testing machines and the tensile, flexural and impact properties are determined. Each type of sample is tested three times and the average values are found. The sample graphs generated with respect to load for banana fiber is presented below. The results indicated that the banana fibers exhibited excellent mechanical properties and the maximum values obtained are 112.58 MPa as tensile strength, 77.21 MPa as flexural strength and 11.22 Joules as impact strength.

Table. 5 Experimental findings of the composite samples

Samples	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (Joules)
40% banana fiber + 60% Epoxy resin	108.42	71.28	8.62
50% banana fiber + 50% Epoxy resin	112.58	76.53	9.48
60% banana fiber + 40% Epoxy resin	98.3	66.18	11.22

4.1. Tensile strength analysis

The banana fiber reinforced composite specimen are prepared with different volume fractions and tested in the universal testing machine (UTM). The typical load versus displacement graph generated directly from the machine for tensile test is presented in Fig. 1. From the figure it can be observed that, the load is gradually increasing upto the maximum load carrying capacity of the material and then decreasing. The tensile strength comparison of the different combinations of the banana fiber epoxy composites are presented in Fig.2. From the figure it has been clearly indicated that the 50% banana fiber and 50% epoxy resin polymer composites are performing better than the other composite combinations tested.

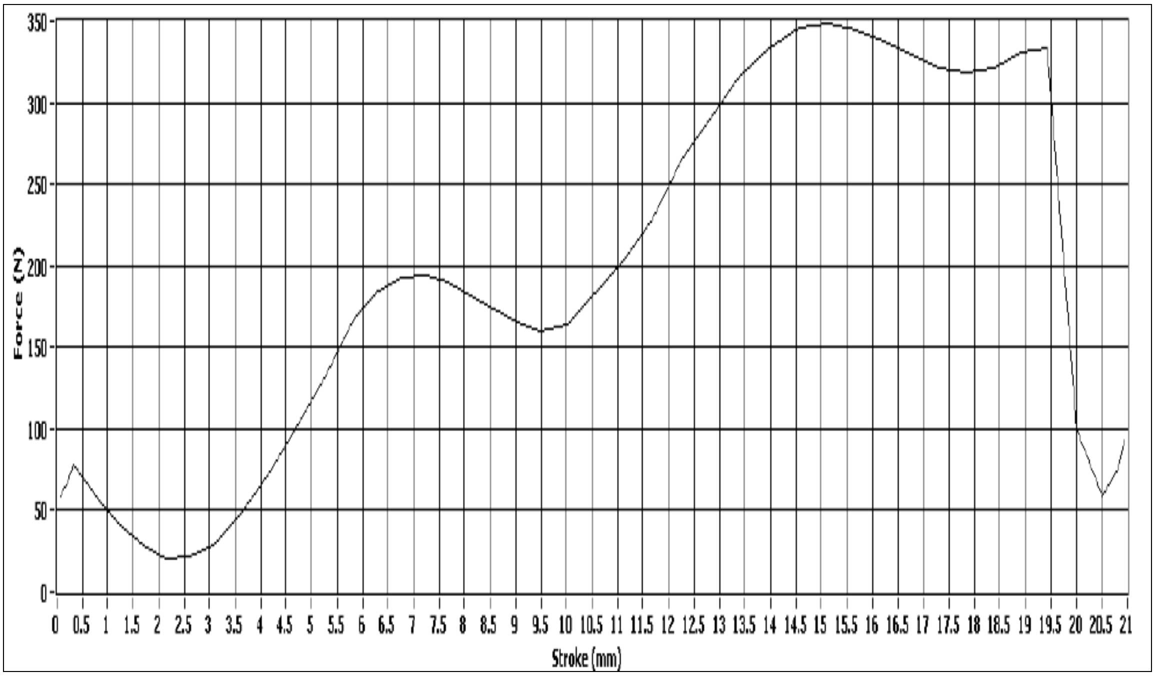


Fig.1 Typical force vs. stroke graph developed from the UTM during tensile testing

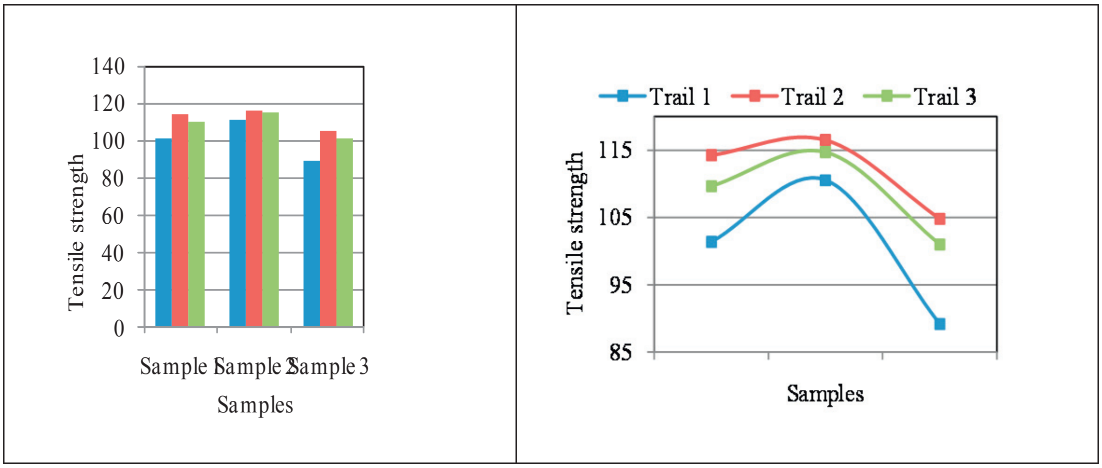


Fig. 2 Tensile strength comparison of the banana fiber composite samples

4.2. Flexural strength analysis

The sample force vs. stroke graph generated directly from the UTM during flexural testing is presented in Fig.3. From the figure it has been observed that, the displacement increases with the increase of applied load up to around 500 N, then, it tends to decrease, i.e., breaking takes place. The maximum displacement observed is 19 mm. The flexural strength comparison of the different combinations of the banana fiber epoxy composites are presented in Fig. 4. The result indicated that the 60% banana fiber and 40% epoxy resin polymer composites are performing better than the other composite combinations tested which can withstand the flexural load of 76.53kN.

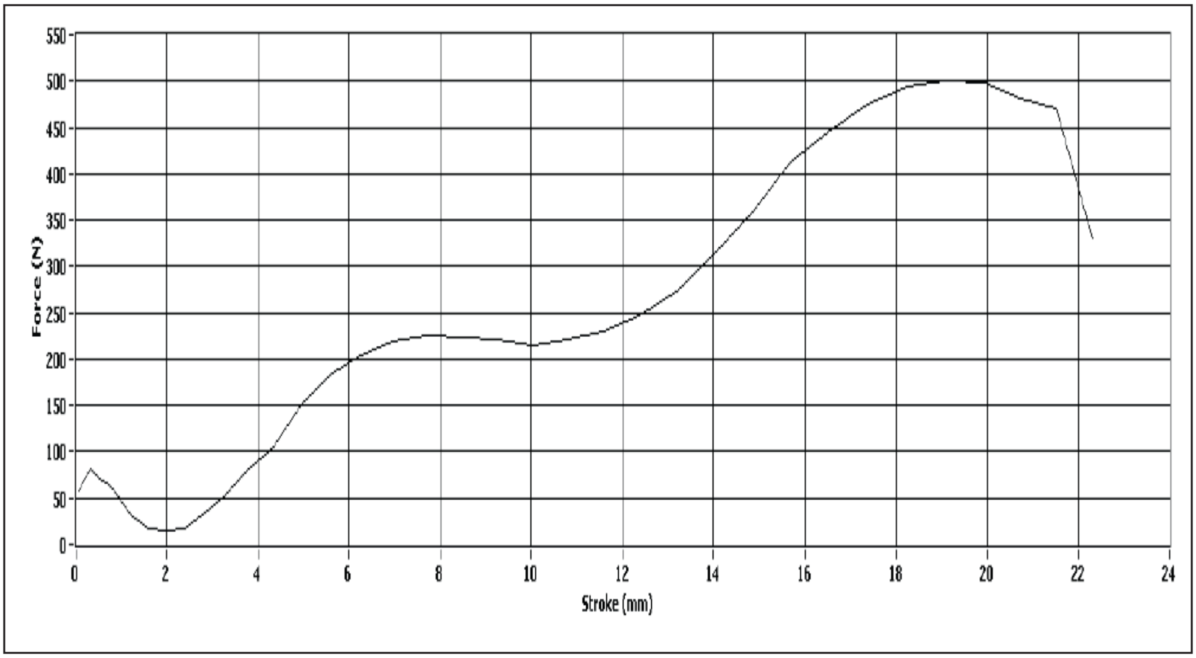


Fig.3 Sample force vs. stroke graph generated directly from the universal testing machine during flexural loading

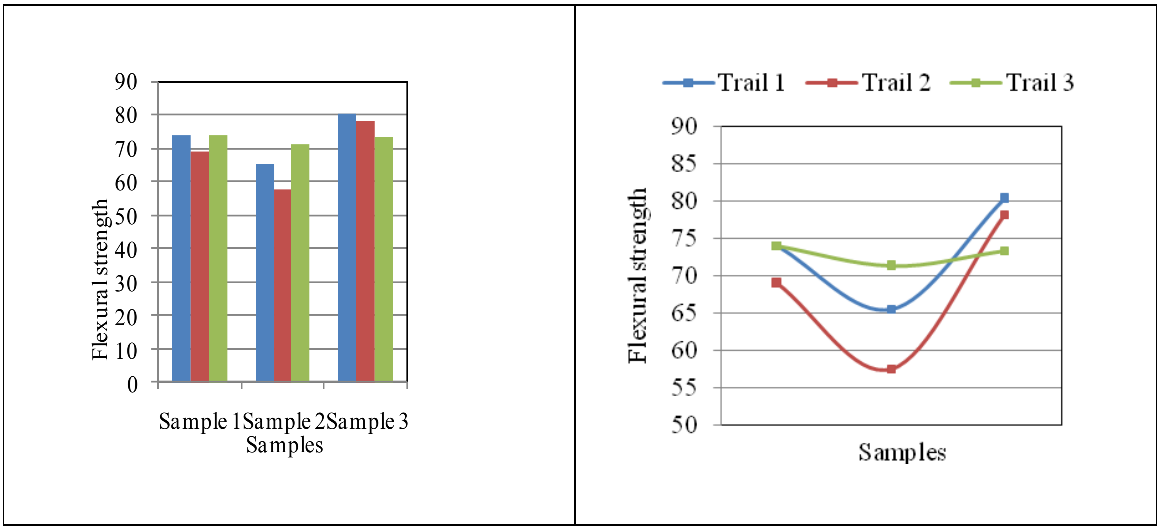


Fig. 4 Flexural strength comparison of the banana fiber composite samples

4.3. Impact strength analysis

For analyzing the sudden load carrying capacity of the banana fiber reinforced composite samples an impact test is carried out. The energy loss is found out on the results obtained from the charpy impact testing machine. The impact strength comparison of the different combination of banana fiber reinforced polymer composites is presented in Fig. 5. From the figure it can be observed that, the 60% banana fiber and 40% epoxy resin polymer composites are performing better than the other composite combinations tested which can hold the impact load of 11.22Joules followed by 50% banana fiber and 50% epoxy resin polymer composites can withstand the impact load 9.48Joules.

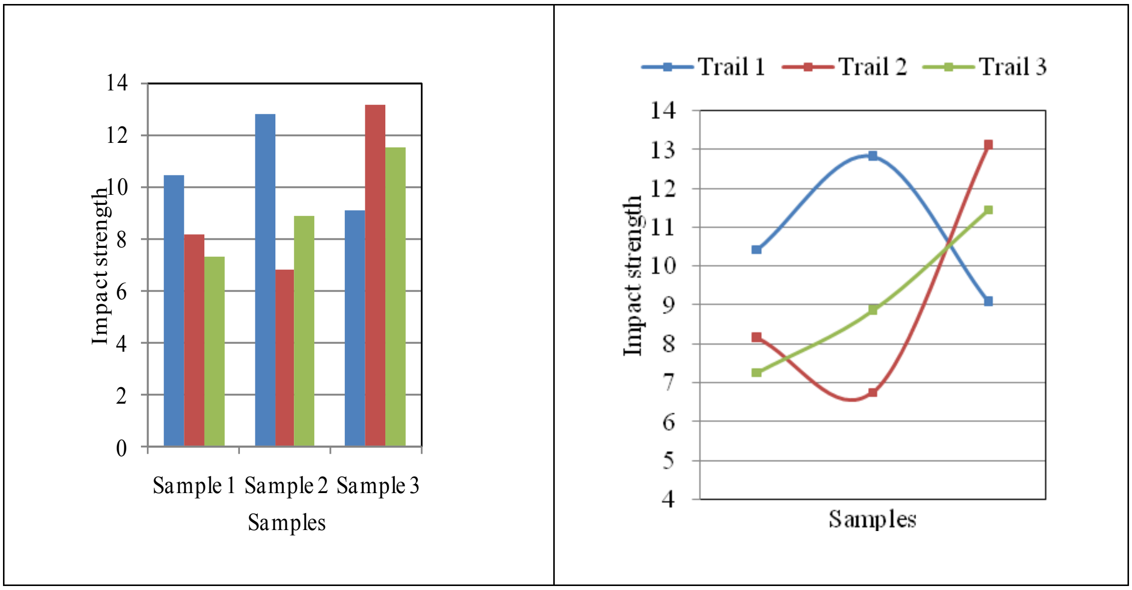


Fig. 5 Impact strength comparison of the banana fiber composite samples

4.4. Scanning Electron Microscopy (SEM) analysis

The structure of the fractured surfaces due to the mechanical loading is observed through SEM analysis. The SEM micrographs are used to observe the internal cracks, fractured surfaces and internal structure of the tested samples of the composite materials. The SEM micrograph of the sample subjected to tensile loading is presented in Fig.6. The reinforcement of the banana fibers and fiber fracture due to tensile loading are clearly visible from the micrograph.

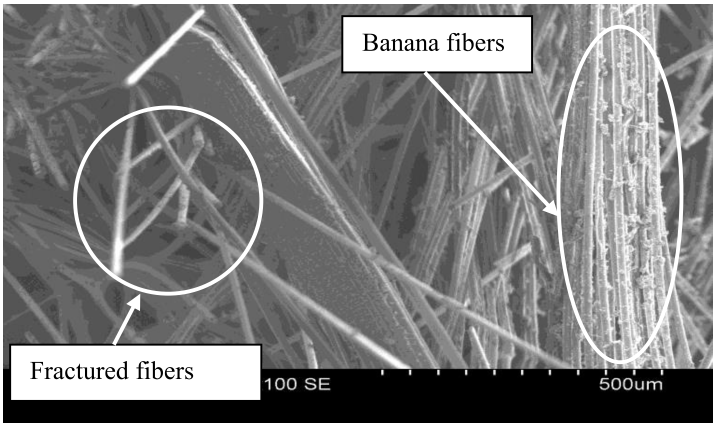


Fig.6 SEM micrograph of banana fiber composite subjected to tensile loading

The SEM image of the composite sample underwent to flexural loading is given in Fig. 7. The figure clearly showed that the broken banana fibers due to the application of load acting to the perpendicular direction of the banana fiber reinforcement. The figure further revealed that the arrangement of the banana fiber and fiber dispersion in to the matrix. The SEM micrograph of the sample subjected to impact loading is presented in Fig. 8. The breakage of the banana fiber layer is clearly visible in the image.

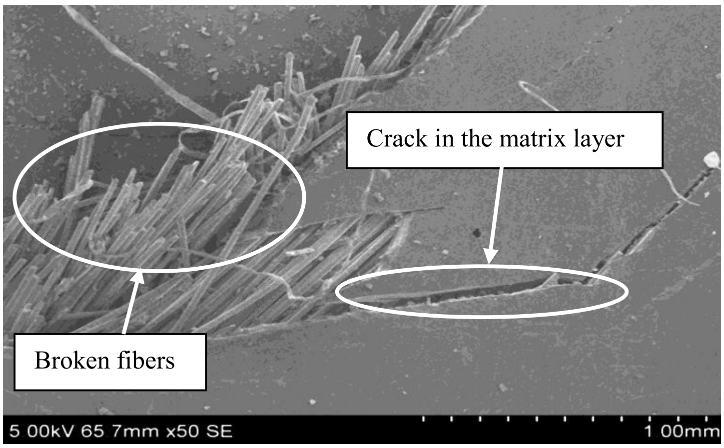
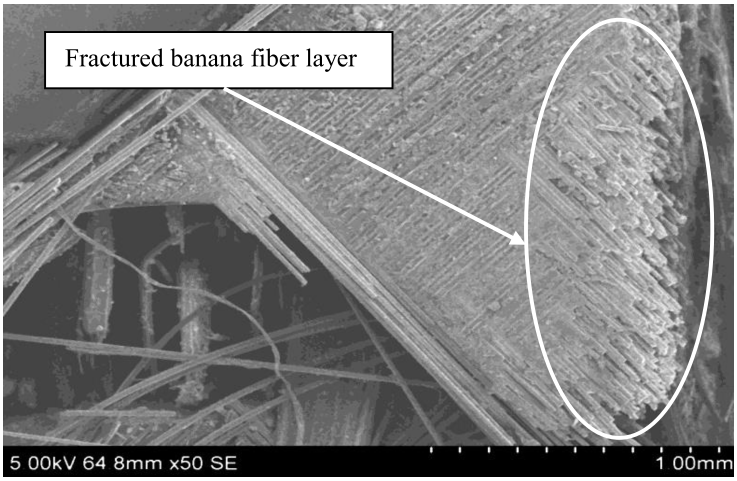


Fig.7 SEM micrograph of banana fiber composite subjected to flexural loading



impact test

Fig.8 SEM micrograph of banana fiber composite subjected to impact loading

5. Conclusions

In the experimental study, the banana fibers are used as a reinforcing material with epoxy matrix, the composites have been fabricated and physical characteristics of these materials are examined. From the experiment, the following conclusions have been drawn.

- The maximum tensile strength is 112.58MPa which is hold by the 50% banana fiber and 50% epoxy resin composites.
- The maximum flexural strength is 76.53MPa and this is also hold by the same combination of the composite samples.
- The maximum impact strength hold by the 60% glass fiber and 40% epoxy resin composites is 11.22 Joules followed by 50% banana fiber and 50% epoxy resin composites can withstand the impact load of 9.48Joules.
- From the SEM analysis, the nature of fiber fracture due to mechanical loading, crack formation in the matrix layer and the matrix failure are clearly observed.
- From the experimental study it can be suggested that, the 50% banana fiber and 50% epoxy resin composite materials can withstand the higher loads when compared to the other combinations and used as an alternate materials for conventional fiber reinforced polymer composites.

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