

Mechanical properties of banana empty fruit bunch fibre reinforced polyester composites

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A light weight composite material has been prepared using banana empty fruit bunch fibre (banana-EFB) as reinforcement in polyester resin matrix, and its mechanical properties studied. The composites are formulated up to a maximum fibre volume fraction of about 0.37, resulting in a mean tensile strength of 43 MPa and tensile modulus of 1.06 GPa which are 36% and 68% higher than those of the plain polyester respectively. The flexural strength of banana-EFB composites is decreased, whereas flexural modulus has shown a mixed trend compared to that of plain polyester. The specific flexural modulus of the composite is 1.42 times to that of polyester resin and the work of fracture in impact is found to be 141.7 J/m.

Keywords: Banana empty fruit bunch fibre, Mechanical properties, Natural fibres, Polyester, Reinforced composite

1 Introduction

In many parts of the world, apart from agricultural uses, different parts of the plants and fruits of many crops have been found to be viable sources of raw materials for industrial purposes. The use of natural fibres in polymer matrices is highly beneficial because the strength and toughness of the resulting composites are greater than those of the un-reinforced plastics. Moreover, cellulose-based natural fibres are light in weight, cheap, abundant, renewable and bio-degradable compared to synthetic fibres such as nylon, glass and carbon which are expensive and non-renewable.

Recently, cellulosic products and wastes such as wood flour, wood chips and pulp have been used as fillers in polymers, primarily for cost effectiveness and high volume applications¹⁻³. Several researchers have studied the use of lignocellulosic natural fibres like sisal⁴, coir⁵, jute⁶, bamboo⁷⁻¹³ and grass fibres like elephant grass¹⁴ as reinforcing agents in thermosetting and thermoplastic polymers. Over the past decade, cellulose fillers of a fibrous nature have been of great importance, because the composites made from these fibres exhibit improved mechanical properties

compared to those containing non-fibrous fillers. Annual crop fibres such as sugarcane bagasse¹⁵, wheat straw^{16,17} and rice straw^{18,19} have also been used as fibrous reinforcement in composites. The performance of these fibres depends on their cellulose content. Recent investigations have shown that the valuable products such as thermoplastic composites, sheet molding compounds, and pulp and paper could be produced from the bio-fibres of oil palm tree, namely empty fruit bunch (EFB)²⁰⁻²².

The objective of the present study is to explore the possible use of banana fibrous wastes as reinforcement in a polymer matrix for making composites. Banana empty fruit bunch was chosen in terms of its abundant availability and it is estimated that 15.07 million tones of banana is produced every year in India²³. Furthermore, banana grows to its mature size in only 10 months, whereas wood takes a minimum of 10 years¹³. Thus, considerable research and development efforts need to be undertaken in finding useful utilization of the banana empty fruit bunch. This will also surely help in solving the environmental problems related to the disposal of banana fibrous wastes. Unsaturated polyester resin has been chosen as the matrix material because it is relatively cheap, having lower shrinkage and can be moulded at room temperature. Hence, various volume fractions of banana empty fruit bunch fibre were combined with an unsaturated polyester resin to

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produce fibre reinforced polyester composites and their tensile, flexural and impact strengths were reported.

2 Materials and Methods

Banana empty fruit bunch (banana-EFB) fibres were obtained from M/s Kodali Arjuna Rao & Co., India. The fibres (Fig. 1) were extracted using decorticating machine (Fig. 2). The fibres have a diameter of 0.015 – 0.12 mm, tensile strength of 62.40 MPa, modulus of 2.0 GPa and elongation at break of 3.10%.

The unsaturated polyester resin of the grade ECMALON 4411 was purchased from Ecmass Resins (Pvt) Ltd., Hyderabad, India. The resin has 1258 kg/m³ density, 500 cps viscosity at 25°C, and 35% monomer content.



Fig. 1—Banana empty fruit bunch fibres



Fig. 2—Decorticating machine used for extraction of fibre

2.1 Volume Fraction and Density of Fibre

The density and volume fraction of fibres in a cured polyester resin matrix is calculated by a method which enables the rule of mixtures analysis of measured composite properties.

The picnometric procedure was adopted for measuring the density ρ_C of the composite of mass M_C at a given mass fraction of resin M_R . Volume fraction (V_R) of resin was calculated using the following relationship:

$$V_R = \frac{M_R \rho_C}{M_C \rho_R} \quad \dots(1)$$

where ρ_R is the resin density. Then, the volume fraction (V_F) and density (ρ_F) of fibre were calculated using the following equations:

$$V_F = 1 - V_R \quad \dots(2)$$

$$\rho_F = \frac{M_F \rho_C}{M_C V_F} \quad \dots(3)$$

The density of fibre was also measured taking a known weight of fibre separately using picnometric method. Both the methods produced similar results and an average value of 581 kg/m³ was obtained as fibre density.

2.2 Fabrication and Testing of Composites

2.2.1 Fabrication

Banana empty fruit bunch fibres of required length (160 mm for tensile, 100 mm for flexural and 63.5 mm for impact specimens) were accurately weighed and moulded with a mixture of unsaturated polyester resin, and catalyst + accelerator 1.5% by volume of resin each. Hand lay up method was adopted to fill up the prepared mould with an appropriate amount of polyester resin mixture and EFB fibres, starting and ending with layers of resin. The fibres were aligned parallel in mould so that they were oriented at 0° along the axial direction of the specimen. A compression pressure of 0.05 MPa was applied on the mould and left for 24 h to cure. The composites were also post-cured for 2 h at 80°C after removing from the mould. The maximum volume fraction of fibre was limited to 0.37 in the present study as composites with higher volume fractions could not be removed from the mould without sample delamination.

2.2.2 Tensile and Flexural Testing

Tensile test specimens were made in accordance with ASTM D 638M to measure the tensile properties. The samples were 160 mm long, 12.5 mm wide and 3 mm thick; five identical specimens were tested for each composition. Overlapping aluminium tabs were glued to the ends of the specimen with epoxy resin, filling the space at the tab overlap to prevent compression of the sample at the grip. The samples were tested at a cross-head speed of 0.5 mm/min and the strain was measured using an extensometer.

Three-point bend tests were performed in accordance with ASTM D 790M test method I (procedure A) to measure flexural properties. The samples were 100 mm long, 25 mm wide and 3 mm thick. In three-point bending test, the outer rollers were 64 mm apart and the samples were tested at a strain rate of 0.5 mm/min. A three-point bend test was chosen because it requires less material for each test and eliminates the need to accurately determine center point deflections with test equipment. The flexural modulus and the maximum composite stress were calculated using the relationships given in an earlier paper¹⁸.

2.2.3 Impact Testing

Izod impact test specimens were prepared in accordance with ASTM D 256M to measure the impact strength. The specimens were 63.5 mm long, 12.7 mm deep and 10 mm wide. A sharp file with included angle of 45° was drawn across the centre of the saw cut at 90° to the sample axis to obtain a consistent starter crack. The samples were fractured in a plastic impact testing machine and the impact toughness was calculated from the energy absorbed and the sample width.

3 Results and Discussion

3.1 Tensile Tests

The mean tensile strength versus volume fraction of fibre for the composites is shown in Fig. 3. It is observed that the mean tensile strength of banana-EFB/polyester composites decreases up to a volume fraction of 0.11, and then starts increasing with the increase in volume fraction of fibre in the composite. This indicates that at lower fibre volume fractions the banana-EFB fibre acts more as impurities than as reinforcement. As the volume fraction of the fibre is increased beyond 0.11, an increase in tensile strength is observed up to a volume fraction of 0.37 which is

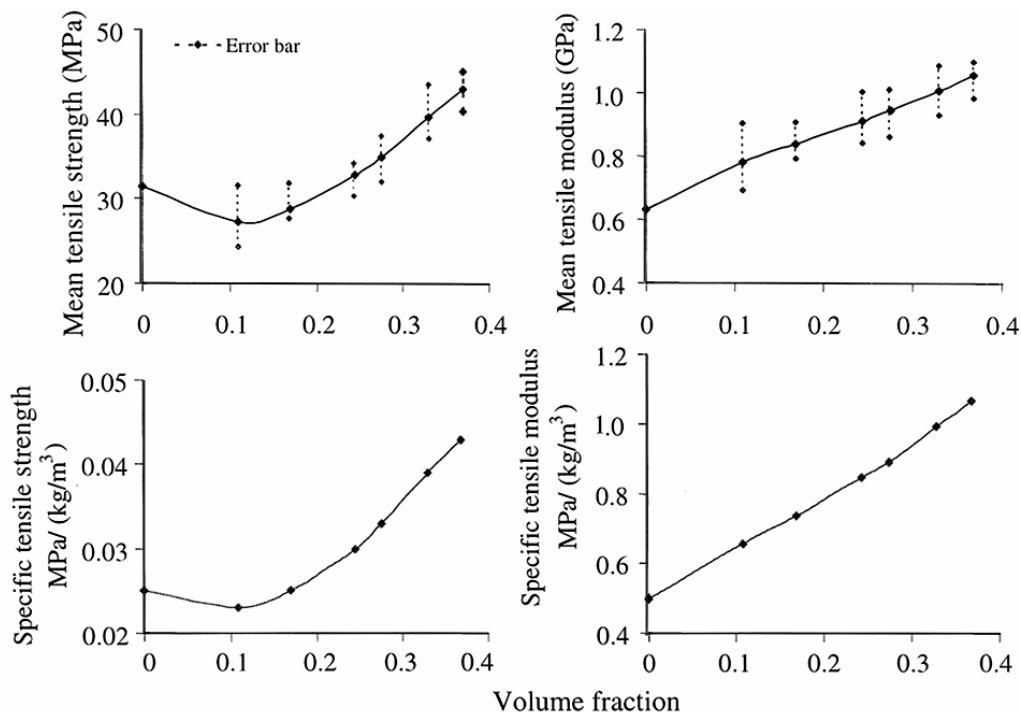


Fig. 3—Effect of volume fraction of banana – EFB fibre on mean tensile strength, mean tensile modulus, specific tensile strength and specific tensile modulus

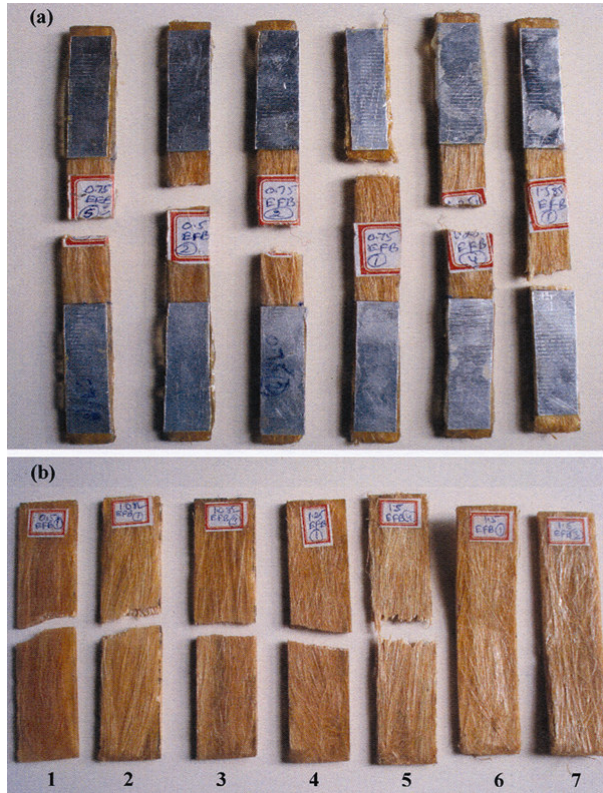


Fig. 4—Photographs showing failed sample specimens of banana-EPB/polyester composites under (a) tensile loading and (b) flexural loading

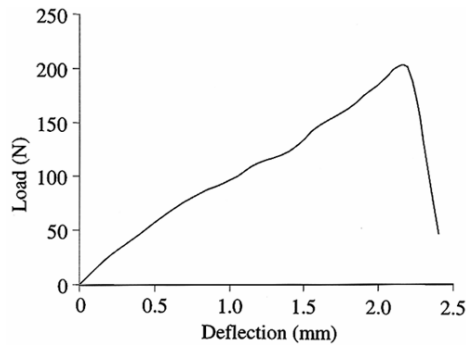


Fig. 5—Load against deflection curve for banana-EPB fibre composites at 0.20 volume fraction of fibre

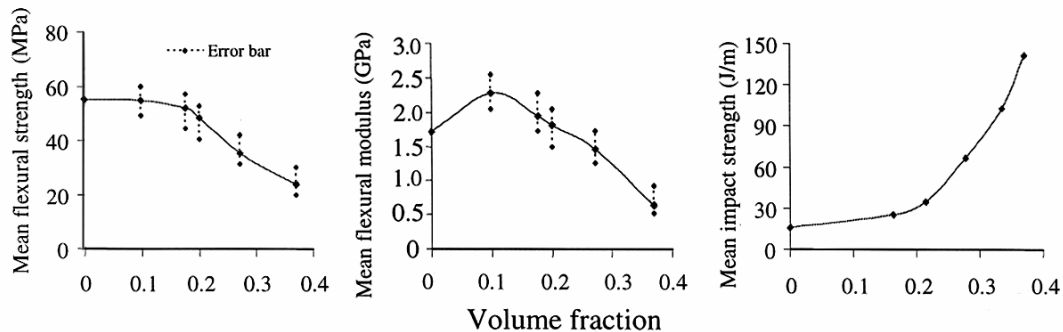


Fig. 6—Effect of volume fraction of the banana-EPB fibre on mean flexural strength, mean flexural modulus and mean impact strength

36% more than that of pure polyester resin used in the present work. This is due to the increased area of bonding in the interfacial region between the matrix and the fibres.

Figure 3 also illustrates the results of tensile modulus as a function of EPB fibre loading. The tensile modulus increases continuously as the volume fraction of fibre increases unlike tensile strength, and is 1.06 GPa at 0.37 volume fraction of fibre in the composite, which is 68% more than that of pure polyester resin. From Fig. 4, it is evident that the tensile failure of specimens is without any pull out of fibre. The specific tensile strength and modulus results follow the same trend as shown for the tensile strength and modulus respectively (Fig. 3). The tensile strength and modulus of banana-EPB fibre reinforced composites have not increased appreciably due to the lower strength of banana-EPB fibres.

3.2 Flexural Tests

In flexural testing, the flexural modulus is calculated from the initial close to linear portion of the load-deflection curve (Fig. 5) and the maximum composite stress at the point of maximum load. The flexural strength of banana-EPB fibre composites is presented in Fig. 6. It can be seen that the flexural strength of banana-EPB/polyester composites decreases as the volume fraction of fibre increases in the composite. This is due to the lack of capability of banana-EPB fibres to support the bending stress transmitted from the polyester matrix.

Figure 6 depicts the relationship between the flexural modulus and the volume fraction of the fibre in the composite. It is observed that the modulus of the composite increases up to a volume fraction of approximately 0.10, and then decreases suddenly as the banana-EPB fibre content increases further in the composite. The decrease in flexural modulus at higher volume fractions of fibre may be due to the poor

fibre-matrix interaction or compatibility and also dispersion problem. The specific flexural strength increases by a minor magnitude up to a volume fraction of 0.10, which is due to lower density of the composite. The specific flexural modulus results (Table 1) have followed the same trend as discussed in case of flexural modulus with respect to volume fraction of fibre. At a volume fraction of 0.10, the specific flexural modulus is 1.42 times to that of plain polyester. The flexural failure surfaces of the specimens are shown in Fig. 4.

As the volume fraction increases, the nature of failure changes from maximum shear stress failure [Fig. 4 (specimens 1 & 2)] to maximum normal stress failure [Fig. 4 (specimens 3 & 4)] and then to maximum normal stress combined with fibre pullout failure [Fig. 4 (specimen 5)]. As the volume fraction increases to 0.37, the specimen acts as a bunch of unbonded fibres in bending without taking much load, which happens in the case of free fibres [Fig. 4 (specimens 6 & 7)].

The poor performance in ultimate properties has also been attributed to the nature of banana-ECF fibres, which are irregular in shape and have strong tendency to exist in the form of fibre bundles. This was also observed by earlier researchers in oil palm ECF fibre-polyethylene composites²¹. The stiffness and strength enhancement in ECF fibre composites are, in general, much lower than that of other fibre reinforced systems.

Table 1—Specific flexural properties of banana-ECF fibre composites as a function of fibre content

Volume fraction of fibre	Specific flexural strength MPa/(kg/m ³)	Specific flexural modulus MPa/(kg/m ³)
0.0000	0.0437	1.3585
0.0984	0.0461	1.9230
0.2015	0.0351	1.3569
0.3700	0.0237	0.6268



Fig. 7—Photograph showing fractured sample specimens of banana-ECF composites in impact testing

3.3 Impact Tests

The results of pendulum impact tests are shown in Fig. 6. As the volume fraction of banana-ECF fibre increases in the composite, the value of impact strength increases and at $V_F = 0.37$, the composite has a impact strength of 141.7 J/m, which is 9 times to that of pure polyester resin. The impact strength of jute-polyester composites at a volume fraction of 0.30 is nearly 4 times to that of polyester resin⁶. The impact strength of banana-ECF/polyester composites at the same volume fraction of fibre is 5 times to that of polyester resin and definitely much higher to that of jute-polyester composites and also 70% of the toughness of softwoods¹⁶. The photograph of the fractured sample specimens of banana-ECF/polyester composite in impact testing is shown in Fig. 7.

4 Conclusions

4.1 The incorporation of the banana-ECF fibre into the polyester matrix shows the moderate improvement in the tensile properties of composites.

4.2 The flexural strength is decreased and the modulus is increased by 33% at a volume fraction of approximately 0.10. The values decrease further with the increase in volume fraction of fibre.

4.3 Since the banana-ECF/polyester composite has shown considerable work of fracture (impact strength), the composite may be considered for tough engineering materials.

4.4 Due to the low density of banana-ECF fibre (581 kg/m³) as compared to those of sisal, jute, coir and bamboo (>1000 kg/m³), the composite can be regarded as a useful lightweight engineering material.

Industrial Importance: At present banana-ECF fibre is a waste product of banana cultivation. Hence, without any additional cost input, the banana-ECF fibre/polyester composites can be used for industrial applications like partition panels, packaging and automotive industry in addition to solving environmental problems related to the disposal of banana-ECF.

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