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Impact and flexural properties of hybrid jute/HTPET fibre reinforced epoxy composites

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In this study, hybridizing jute with high tenacity polyethylene terephthalate (HTPET) fibres has been proposed. Different hybrid jute/HTPET fibre reinforced epoxy composite samples have been fabricated with different weight ratios of HTPET, and subjected to charpy impact and three-point bending test. The results show that increasing the content of HTPET fibres in the composites will considerably improve their energy absorption capabilities and structural integrity after impact and bending test. However, hybrid composites with HTPET show lower flexural stress and bending modulus than pure jute composites.

Keywords: Composite, Flexural properties, High tenacity polyethylene terephthalate, Impact properties, Jute, Jute/HTPET hybrid

1 Introduction

Over the past few decades, there is a rapid increase in the demand of the fibre reinforced polymers (FRPs) because of the unique combination of high performance, great versatility and processing advantages at favorable costs by permutation and combination of different fibres and polymers. Lately, many researchers have focused on natural fibre composites, since they are easily available, relatively of low cost, environment friendly, user friendly, non-abrasive to the equipment, recyclable and bio-degradable. Moreover, they possess good elastic properties, low density and comparable specific tensile properties[1-5].

Among natural fibre reinforcements, jute fibres have gained much attention during recent years. Generally, jute is a relatively inexpensive vegetable bast fibre, with some intrinsic advantages, such as high strength, low extensibility, high modulus and silky luster. It also shows more densified and compact structure than other natural fibres[6,7]. Applications of jute fibre reinforced composites are found in such products as housing construction materials, furniture, and automotive parts[8,9]. However, there are some disadvantages in using jute fibres as reinforcement in composite materials, such as their brittle tensile behavior[6-10], high moisture absorption tendency, poor wettability, low thermal stability during processing, poor adhesion and lower strength than common synthetic reinforcements[11,12].

Jute has a linear stress-strain curve until breakage, hence, its composites show a brittle response to loading. Many composite materials such as glass and carbon fibre composites are also classified as brittle materials. In brittle materials, there is a sudden catastrophic failure with no pre-warning when it is subjected to a large component of the load. Therefore, they may not be suitable for many structural components in which high energy absorption and excellent post failure integrity are required. Hybridizing jute with other fibres can be regarded as a technic to address this problem.

Some researchers have studied mechanical properties of hybrid composites reinforced with jute and some other natural fibres[13-16], however significant improvement in energy absorption capabilities of the composites has not been reported so far. Hybridizing jute with glass fibres enhances the overall mechanical performance of the composites[6]. Nevertheless, since glass is also a brittle fibre, the problem of brittleness of the composites has not been solved with this kind of hybrids.

In spite of extensive literature search, no related studies were observed in the field of hybridization of jute with high performance viscoelastic fibres, which exhibit high values of toughness and work at rupture. Ordinary viscoelastic fibres, like common polyester fibres used in the textile industry show moderate tensile strength at relatively high elongations. Their

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breaking strain values are usually much higher than those for many common polymeric matrix materials; as a result, they don't show considerable contribution to the overall tensile properties of the composites.

However, high tenacity polyethylene terephthalate (HTPET) fibres which are also called high tenacity polyester fibres, exhibit much higher tensile strength at considerably lower strains, due to their longer molecular chains with higher longitudinal orientation. Therefore, it seems that hybridizing them with a brittle fibre, like jute, may have a positive effect on improving the post failure structural integrity of its composites. The aim of this work is to study the impact and flexural properties of hybrid jute/HTPET fibre reinforced epoxy composites.

2 Materials and Methods

2.1 Materials

In the present study, HTPET fibres with molecular weight of 34407 g/mol and carboxyl end groups of 16.4 mmol/kg were used to hybridize with jute fibres. The epoxy resin E-8128 and epoxy hardener H-3895 were used in the current work as the matrix material. Some properties of the fibre and matrix materials are given in Table 1. Average tensile stress-strain curves of the materials are shown in Fig. 1.

Jute and HTPET in the form of yarns with nearly similar linear densities (327 and 336 tex respectively) were utilized to produce various types of hybrid fabrics using a sample weaving machine.

Table 1 — Jute and HT Polyester fibres properties

Property	Jute fibre	HT Polyester fibre	Epoxy matrix
Density, g/cm^3	1.32	1.38	1.25
Tensile strength, MPa	198.06	230.13	23.44
Strain at break, %	2.14	6.97	4.87
Tensile modulus, GPa	24.3	3.56	0.65

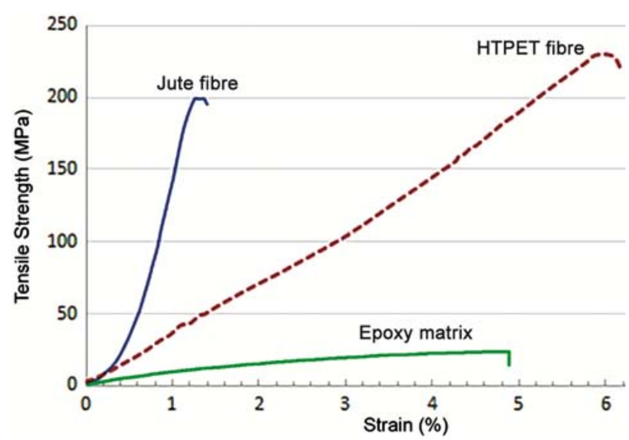

Fig. 1 — Stress-strain curve of jute (a), and HTPET (b) fibres

2.2 Fabrication of Composite Samples

The composite samples were fabricated using hand layup method. First, the fabrics were dried in sunlight to remove the moisture. A smooth glass sheet was used as the mold. The mold surface was cleaned and a polyethylene film was placed on it as a releasing film. Four layers of hybrid reinforcement fabric were used for each sample. Resin and hardener mixture (10:4) was applied to each layer using a brush. The layers were then rolled to remove the entrapped air and to uniformly spread the mixture. After placing four layers of woven fabrics, one over the other with the orientation of [0/0/0/0], another releasing film and then the upper glass sheet were placed on the layers. A total pressure of about 500 Pa was applied on the laminate and the entire setup was left for 24 h in the room temperature to be cured.

Four types of samples were produced by varying the reinforcement fabrics. Since in flexural and charpy impact loading, the longitudinal reinforcements in the composites has a much more important role in carrying the load than the transverse ones, hybridizing was performed only in longitudinal direction, i.e. the fabrics were woven with a combination of jute and HTPET yarns in warp direction and pure jute yarns in weft direction. Figure 2 shows various structures of the woven fabrics produced in this work, in which brown color represents jute yarns and white color is for HTPET yarns.

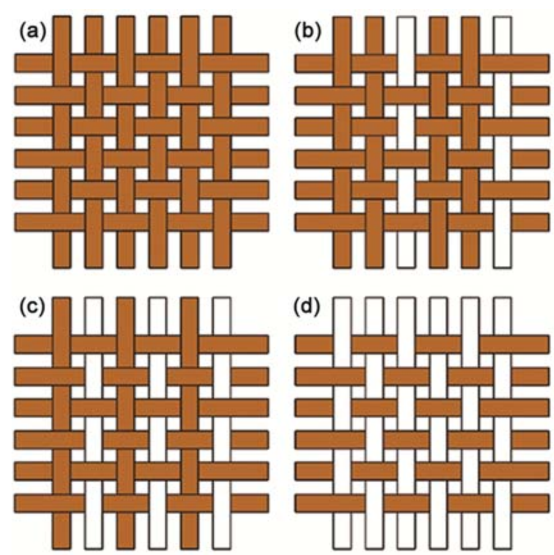

Fig. 2 — Structures of woven fabrics produced [Pure jute (a), Jute to HTPET ratio of 2:1 in warp (b), Jute to HTPET ratio of 1:1 in warp (c), and Pure HTPET in warp (d)]

Using the mentioned fabrics, four different composite samples with 0, 0.34, 0.5 and 1 weight ratios (WR) of HTPET in the fabric's longitudinal direction (FLD) were fabricated. After the samples were consolidated, the volume of a representative element from each sample was measured. The volume of every yarn piece in the fabric layers inside the representative element was also calculated according to following equation:

$$v_y = \frac{l_y \cdot T_y}{\rho_y} \times 10^{-5} \quad \ldots (1)$$

where l_y is the length of the yarn piece after removing the crimp (cm); T_y, count of the yarn (tex); and ρ_y, the density (g/cm^3).

Hence, total volume of the fibrous reinforcement in the element can be calculated by summing up the volumes of all constituent yarn pieces. Total FVF (fibre volume fraction) was then calculated by dividing total volume of the fibrous reinforcement by the volume of the composite representative element. The characteristics of the composite samples are given in Table 2, in which HTPET FVF refers to the volume ratio of HTPET fibres to the sample's volume.

2.3 Charpy Impact Test

The charpy impact test was performed according to ASTM D6110 to determine the energy absorbed by the hybrid composite specimens under impact loading. Five specimens were cut and prepared from each sample, however the width of the specimens were chosen in such a way that an exact number of yarn repeats exists in the transverse direction. The test was done using Santam SIT-200B charpy impact tester at room temperature, and the maximum energy absorbed by each specimen in the impact test was noted.

2.4 Flexural Test

Flexural properties of composite samples were measured according to ASTM D790. Five specimens were cut and prepared from each sample for three-point bending test. The tests were carried out using Shirley Testometric – Micro 350 universal testing machine with a 250 kgf load cell at 3 mm/min rate of loading at room temperature. The variation of load with respect to deflection was obtained graphically and flexural strength and bending modulus of the samples were calculated.

Table 2 — Characteristics of composite samples

Sample code	Thickness mm	Weight ratio of HTPET in FLD	Total FVF	HTPET FVF
A	4.04	0	0.3	0
B	3.95	0.34	0.299	0.024
C	4.02	0.55	0.298	0.077
D	3.92	1	0.295	0.1239

3 Results and Discussion

3.1 Charpy Impact Properties

The energy absorbed by the specimens in charpy impact test was observed and averaged over for each sample. As discussed before, the widths of the samples were not exactly the same, since they were chosen in such a way that an exact number of yarn repeats exists in the transverse direction of each sample. Therefore, the absorbed energy value for each sample was normalized by dividing it by the sample's width. The absorbed energy per unit width of samples A, B, C and D are 0.5, 1.35, 1.81 and 4.66 J/cm respectively (Fig. 3). The error bars in the figure indicate standard errors for each sample.

As can be seen, the more the content of HTPET fibres in the composites, the higher is the impact energy they absorb. It is observed that the 0.025 volume fraction of HTPET fibre in the composite (sample B) leads to 170% increase in energy absorption capability as compared to the pure jute reinforced sample (A). The sample D with 100% HTPET fibres in longitudinal direction (LD) absorbs the highest amount of impact energy.

Figure 4 shows images of representative specimens of each sample after the impact test. It is seen that sample A is completely separated into two pieces. However, the samples with any content of HTPET fibres retained their structural integrity. It is observed that a considerable portion of HTPET fibres remains unbroken, which causes the samples not to fail in a catastrophic manner.

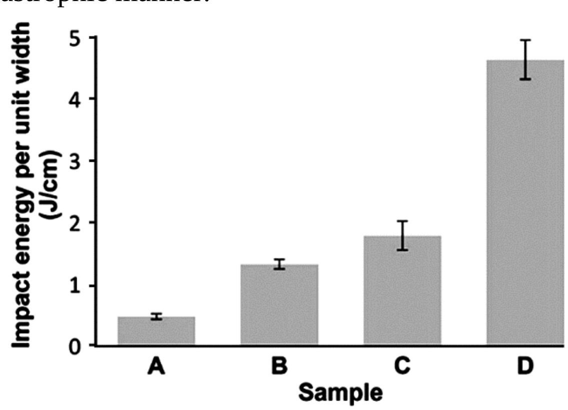

Fig. 3 — Comparison of impact resistance of the composite samples

3.2 Flexural Properties

Maximum flexural strength in the outer surface at midpoint and flexural elastic modulus of the samples are calculated using the following equations:

$$\sigma_f = \frac{3PL}{2bd^2} \quad \ldots (2)$$

$$E_B = \frac{mL^3}{4bd^3} \quad \ldots (3)$$

where P is the maximum flexural force; L, the length of the support span; b, the specimen's width; d, the specimen's thickness, and m, the slope of the tangent to the initial straight-line portion of the load-deflection curve.

The average values of flexural stress and elastic modulus of the samples are compared and the results are shown in Fig. 5. As it can be seen, sample A possesses the highest value of flexural strength and modulus. By increasing the content of HTPET fibres in the composites, both values decrease.

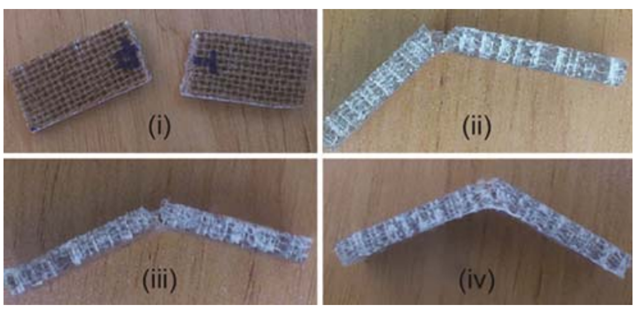

Fig. 4 — Images of representative specimens after impact test [Sample A(i), Sample B(ii), Sample C(iii) and Sample D(iv)]

Flexural force – deflection curves of the samples are depicted in Fig. 6. It can be seen that the pure jute reinforced sample (A) shows a nearly linear force –

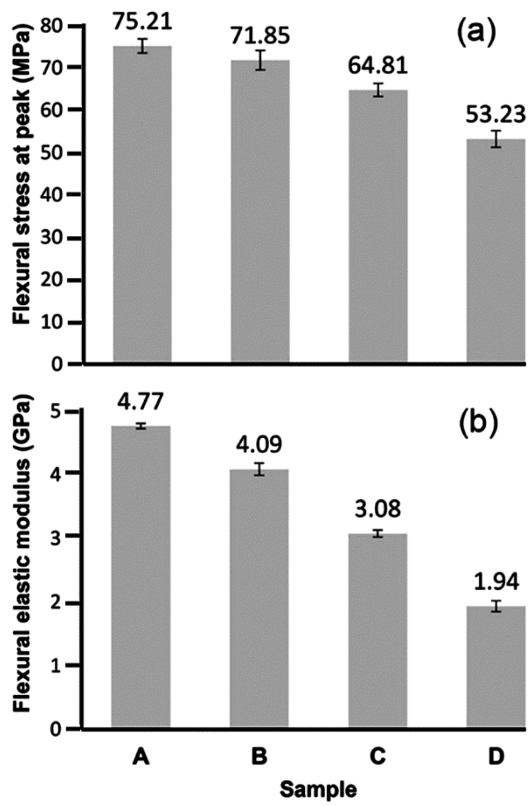

Fig. 5 — Comparison of flexural strength at peak (a), and flexural elastic modulus (b) of the composite samples

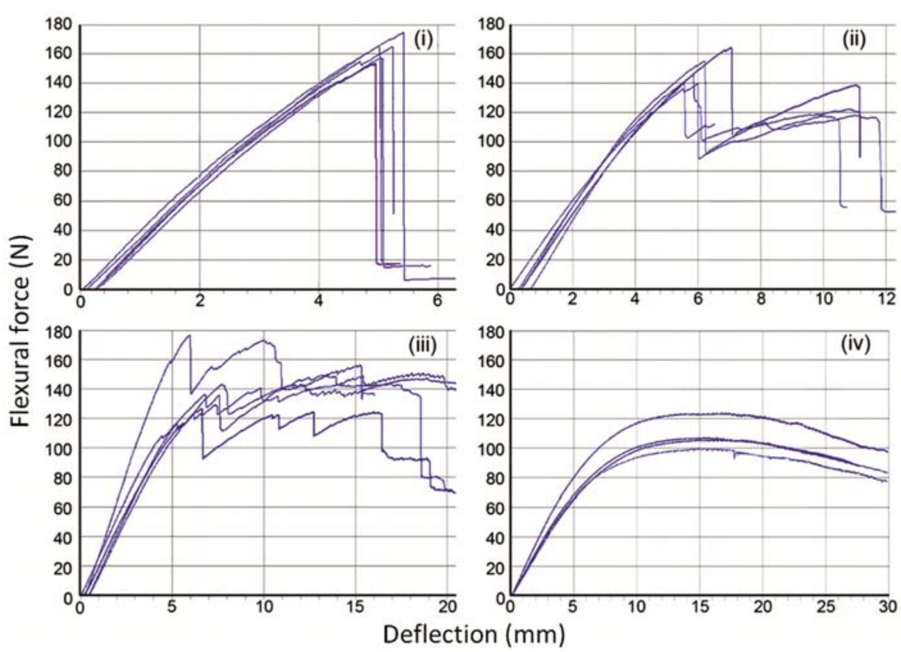

Fig. 6 — Flexural force (N)-deflection (mm) curves for the composite samples [Sample A(i), Sample B(ii), Sample C(iii) and Sample D(iv)]

deflection behavior, until a sudden failure at low deflections. However, the curves for hybrid samples B and C comprise two distinct phases. In the first phase, both jute and HTPET fibres resist against the applied force. The behavior in this phase is nearly linear but with significantly lower slope or modulus than that of Sample A (Fig. 6).

In fact adding HTPET fibres to the composites decreases their flexural elastic modulus of the composites, since the elastic modulus of HTPET is considerably lower than that of jute (Table 1). The second phase of the graphs begins after a sudden and considerable drop in load value. Following Eq. (4) gives the strain in the outer surface of a sample with thickness of d and support span of L at the deflection of D:

$$\varepsilon_f = \frac{6Dd}{L^2} \quad \ldots (4)$$

It can be calculated that the first drop in the load value occurs at about 1.7-1.9% strain which corresponds to the breakage of jute fibres in the outer surface of the sample. In the second phase, the curves continue with much lower slopes than the first phase which shows that HTPET fibres are the dominant reinforcements in the composites in this phase.

The samples then experience multiple drops in the load due to a combination of fibre breakage and matrix cracking phenomena up to the end of the test. However, in the curve of sample D no sudden drop in the load is observed, meaning that no HTPET fibres break during the test. As can be seen in Fig. 1, epoxy matrix fails at a lower elongation than HTPET fibres do. Therefore, in the bending test of sample D, the curve continues ascending until the matrix in the outer surface of the sample starts to crack. HTPET fibres are then gradually released from the surrounding matrix and easily bent without being broken.

In fact, unlike sample A, samples B-D do not show brittle behavior during bending and retain their structural integrity after the test due to the presence of HTPET fibre in the composites.

Considering the results of bending test, it can be concluded that increasing the content of HTPET fibres in the composites leads to the decrease in their flexural strength and elastic modulus. Although ultimate tensile strength of HTPET is higher than that of jute (Table 1), it is reached at a higher strain than the breaking strain of epoxy. Thus HTPET contributes to the mechanical properties of the composite with a lower strength than its ultimate strength which is even less than the ultimate strength of jute (Fig. 1). However, it can be seen that adding HTPET to the composite, not only results in considerable increase in energy absorption capabilities (Fig. 6), but also causes the composites to show excellent post-failure integrity and not to experience catastrophic failure in bending.

4 Conclusion

In this work some hybrid jute/HTPET fibre reinforced epoxy composites have been fabricated with different weight ratios of HTPET and subjected to charpy impact and three-point bending tests.

4.1 It is found that hybrid composites absorb considerably higher energy during the test as compared to pure jute composites. The higher the content of HTPET fibres, the higher is the energy absorption capability of the composites. Moreover, composites with HTPET fibres do not experience catastrophic failure and retain their structural integrity after impact and bending tests.

4.2 However, the higher the content of HTPET fibres, the lower is the flexural strength and flexural modulus of the composites. Therefore, selection of HTPET content in the hybrid must be done carefully with regard to the properties expected from the composite.

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