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Physical, Mechanical and Thermal Properties of Jute and Bamboo Fiber Reinforced Unidirectional Epoxy Composites

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Abstract

A detailed investigation of physical, mechanical and thermal properties of jute and bamboo fiber reinforced epoxy resin unidirectional void free composites was carried out. The composites were prepared by using vacuum technique. Scanning electron microscopic analysis, tensile and flexural testing and thermogravimetric analysis were performed in order to evaluate surface morphology, mechanical properties and thermal behavior of the unidirectional composites respectively. The relationship between theoretical and experimental values was figured out using rules of mixture. The analytical results showed good agreement with the experimental results. Comparing jute and bamboo fiber reinforced unidirectional composites, it is observed that bamboo fiber reinforced epoxy composites showed good results in terms of tensile strength, while jute fiber reinforced epoxy composites had higher Young's modulus values. Bamboo fiber reinforced epoxy composites showed good flexure strength in the longitudinal distribution. On the other hand, jute fiber reinforced epoxy composited had better flexural strength with transverse fiber distribution in the composites. Fiber distribution was not uniform for both bamboo and jute fiber reinforced unidirectional epoxy composites. Scanning electron microscopic analysis showed that morphological changes took place depending on the fiber orientation in epoxy composites. It is also observed from thermogravimetric analysis that jute fiber reinforced epoxy composites had better thermal behavior compared to bamboo fiber reinforced epoxy composites.

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1. Introduction

Natural fiber reinforced composites (NFRC) are finding much interest as a substitute for glass or carbon reinforced polymer composites recently. Some advantages associated with using natural fibres as reinforcement in polymers are their non-abrasive nature and low energy consumption. Natural fibres sequester CO_2 from the atmosphere, hence provide an advantageous contribution to the global carbon budget. The easy disposal of natural fiber composites is also important, since they can be easily combusted or composted at the end of their product life cycle. Next to the cost benefits compared to synthetic fibers, natural fibers comparably offer high security if used for automotive applications as an example [1]. Additionally, natural fibres have low density and high specific properties. The specific mechanical properties of natural fibres are comparable to those of traditional reinforcements [2-4]. Thus, the intrinsic properties of natural fibres can satisfy the requests of the global market [5] especially for those industries concerned in weight reduction [6]. That is why they can be potential substitute for non-renewable synthetic fibres [7]. However, high moisture absorption, poor wettability and insufficient adhesion between untreated fiber and polymer matrix lead to debonding at fibre-matrix interface [8]. Again, biodegradable fibres need to be reinforced to improve their properties [9-11]. In present study, epoxy, the most common thermoset resin material was used as a polymer for jute and bamboo fibers. The objectives of this study are to determine the physical, mechanical and thermal properties of unidirectional jute and bamboo fiber reinforced epoxy composites.

2. Experimental

Jute fibers (*corchorus olitorius*) (diameter between 39 to 66 µm) were extracted by mechanical process and supplied by Bangladesh Jute Research Institute (BJRI), Bangladesh. Bamboo fibers (diameter between 178 to 181 µm) were extracted by steam explosion method and supplied by the Hanoi University of Technology, Vietnum. Epoxy resin (Prime^{TM} 20LV) was provided by Gurit (Kassel) GmbH, Germany. The tensile strength (cured), modulus and densities of the epoxy resin used were 68.6 MPa, 2.97 GPa and 1.15 g/cm^3 respectively. For preparing the composites, a defined stacking sequence (eight layers of aligned jute and six layers of aligned bamboo) of bamboo and coir fiber across the aluminium plate was arranged. Upper side of the aligned fibers were covered by pupe paper. A thick flexi glass sheet was used on the upper side to prevent rough surface of the composite. Finally the aligned fibers were surrounded by polypropylene sheet using tacky tape to make sure that there is no air flow. After that one side of the mould system was added with air vacuum machine and another side was doped in resin bath (mixed with hardener) with using Teflon tube. Void was removed from resin mixture using vacuum desiccator. Liquid resin was pumped into the system through the tube which infiltrated the fibres and consequently filled the mould cavity. The resin supply was suspended when the mould was filled up with resin. Both resin and air vacuum tube was sealed and then processed in a Pinette press (hot press) in order to get desired thickness. Heat was applied (at 65^0 C for 1 hour) for curing the resin. When the resin became completely cured, the composite was removed. Tensile tests of unidirectional composites were subsequently carried out following ASTM D638 using an Instron 3369 machine. The cross-head speed was set at 10 mm/mim. An extensometer was placed at the middle portion of the specimen. Load cell of the machine was 30 kN. Flexural tests of the composites were carried out using ASTM D790-03 standard method. Both transverse and longitudinal fiber oriented composites were tested. All the specimens were dried in a vacuum woven at 60^{0}C during 24 hours and then they were left in the tensile testing room 72 hours before testing to assure good conditioning. The temperature and relative humidity was approximately 30^{0}C and 50% respectively. The crosshead speed was set at 0.85 mm/min and 1 kN loadcell was used during the test. The surface morphology and interfacial bonding between the UD jute and coir fiber with epoxy resin in manufactured composites were examined using a scanning electron microscope (JSM-6701F, JEOL Company Limited, Japan). Thermogravimetric analysis (TGA) was conducted using SDT Q600 T.A Instrument machine under nitrogen atmosphere for untreated jute and bamboo fibers.

3. Results and Discussion

3.1. Tensile properties

Table 1 shows tensile properties of jute and bamboo fiber reinforced epoxy unidirectional composites. In comparison of jute and bamboo fiber UD composites, bamboo fiber reinforced composites had higher tensile strength and strain to failure. However jute fiber composites had higher Young's modulus as compare to bamboo fiber composites. The rule of mixture was used to calculate the theoretical strength and modulus of jute and bamboo fiber epoxy resin composites. The theoretical tensile strength of the jute and bamboo fiber reinforced epoxy composites was found to be 225 and 451 MPa respectively. The experimental values of tensile strength of those composites were 216 and 392 MPa respectively. Thus the experimental results were a bit smaller compared to the theoretical values. Nevertheless, it is important to note that the fibres were not perfectly aligned as shown in Figure 1. Also in the case of jute fiber composites, some of the fibres were crushed during composite fabrication, which is also observed from the SEM morphology.

Table 1. Tensile properties of UD jute and bamboo fiber reinforced epoxy composites.

Name of the fiber	Tensile strength (MPa) ± STD	Young's modulus (GPa) ± STD	Stain to failure (%) ± STD
Jute (52 wt%)	216 ± 1.02	31 ± 1.34	0.78 ± 0.05
Bamboo (57 wt%)	392 ± 8.51	29 ± 1.25	1.38 ± 0.02

The measured Young's modulus of jute and bamboo fiber reinforced composites were 31 and 29 GPa respectively (Table 1), whereas calculated theoretical values were 29 and 36 GPa for jute and bamboo fiber composites. Theoretical results obtained in previous research were in the range of 13-54 GPa for jute fiber composites [12] and 11-30 GPa for bamboo fiber composites [13, 14]. This discrepancy is most likely due to the difficulty of measuring the displacement during the single fiber tensile test by an external tool and possible slippage in the clamps during the tensile test of single fiber leading to an underestimation of fiber modulus. Comparing the tensile strength of jute and bamboo fiber reinforced composites with other natural fiber reinforced composites [15], it is clearly seen that bamboo fiber composites had much higher values. When the density is taken into account, several natural fibres show performance comparable with synthetic fibres like glass fibres. Since this is the case for bamboo and jute fibers, they look set to compete in terms of specific properties with glass fibres in various applications. SEM images are a practical way of confirming the adhesion between fiber and matrix. Images of fracture surfaces reveal whether the fiber bundles are actually impregnated by the matrix or not. The good interface quality is demonstrated in Figure 2 where the fiber surface with trace of the matrix is observed. These micrographs also show that the fibres were pulled out from the matrix rather than broken for bamboo fiber composites and vice versa for the jute fiber composites. Fibers were debonded before pull out. This reveals that there may be formation of mechanical interlocking or chemical bonding between fiber and matrix. Obviously the shrinkage of the matrix will always impose a compressive load that insists the mechanical interlocking between the fibres and matrix.

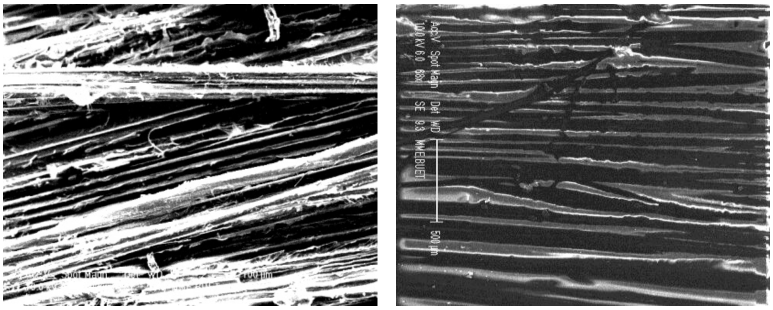


Fig. 1. SEM micrographs of UD fiber reinforced epoxy composites using (a) bamboo and (b) jute.

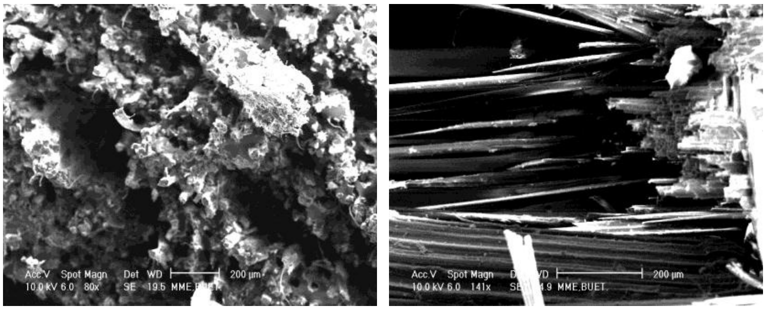


Fig. 2. SEM images of the tensile fracture surface of UD fiber reinforced epoxy composites using (a) jute and (b) bamboo.

3.2. Flexural properties

3.2.1. Flexural properties at longitudinal fiber distribution

Table 2 shows the results of flexural test for unidirectional jute and bamboo fiber reinforced epoxy composites. As shown in Table 2, flexural modulus was almost same for both jute and bamboo fiber reinforced epoxy composites. The flexural strength was higher for bamboo fiber composite as compared to jute fiber reinforced composite. This may be due to difference between the extraction processes of two fibers. As described in section 2, bamboo fibers were extracted by steam explosion method, whereas jute fibers were extracted through mechanical process. Apparently the mechanical extraction process gives fibers with rough surface and little amount of lignin.

Table 2. Flexural properties of unidirectional jute and bamboo fiber composites with longitudinal fiber distribution.

Fiber	Flexural strength (MPa) ± STD	Flexural modulus (GPa) ± STD
Jute (52 wt%)	158 ± 18.90	18 ± 1.92
Bamboo (57 wt%)	226 ± 25.13	19 ± 1.32

The experimental flexural strength was lower compared to theoretical ones in concern of both jute and bamboo fiber composites. However in the case of flexural modulus for both fiber composites, the experimental values were very close to theoretical values. The crack profile SEM images of the flexure specimen of UD jute and bamboo longitudinal fiber reinforced epoxy composites from are shown in Figure 3. It is clearly observed from the micrographs that the fibers were broken in the middle bottom portion of the specimen. Closer looks towards the fracture surface shows that the fracture slide parallel to the load direction for jute fiber composites (Figure 3 (a)), while the slide was perpendicular to the load direction for bamboo fiber reinforced composites (Figure 3 (b)).

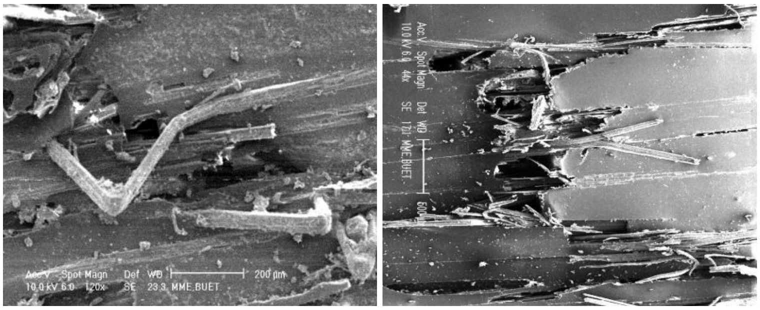


Fig. 3. SEM micrographs of flexural fracture surface of longitudinal fiber reinforced epoxy composites using (a) jute and (b) bamboo.

3.2.2. Flexural properties at transverse fiber distribution

Table 3 shows the flexural properties of unidirectional jute and bamboo fiber reinforced epoxy composites for transverse distribution of fibers. Jute fiber composite was two times higher than that of bamboo fiber composite in terms of transversal flexural strength. Jute fiber composite still had higher modulus value as compared to bamboo fiber composite as jute fiber has more compact structure and broader surface area as compared to bamboo fiber. Compared to natural fiber reinforced thermoplastics, jute and bamboo fiber composites with a thermoset epoxy showed better performance in terms of flexural stiffness. Thermoset resins have low viscosity and require lower processing temperature compared to thermoplastic resins, which clearly benefit the creation of a good fiber/matrix interface. The inclusion in fibers reduced the strength of the epoxy resin. This indicates that the interface was the weakest link in the composite system. Figure 4 shows the SEM micrographs of flexural fracture surface of UD jute and bamboo fiber reinforced epoxy composites in transverse direction. It is observed that fiber could not take any stress as they were aligned to the parallel direction of flexural load.

Table 3. Flexural properties of unidirectional jute and bamboo fiber reinforced epoxy composites for transverse distribution of fibers.

Fiber	Flexural strength (MPa) ± STD	Flexural modulus (GPa) ± STD
Jute (52 wt%)	25.7 ± 2.17	2.73 ± 0.28
Bamboo (57 wt%)	11.89 ± 3.87	2.01 ± 0.11

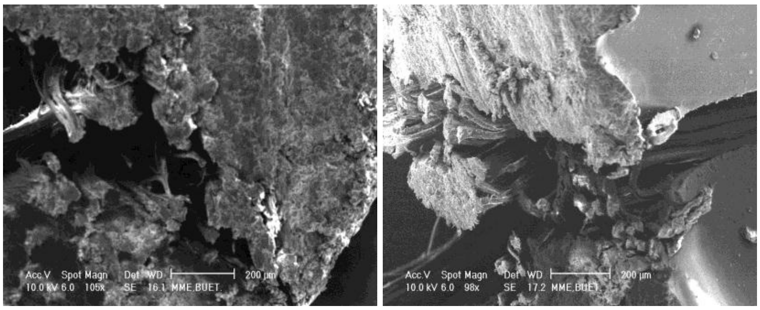
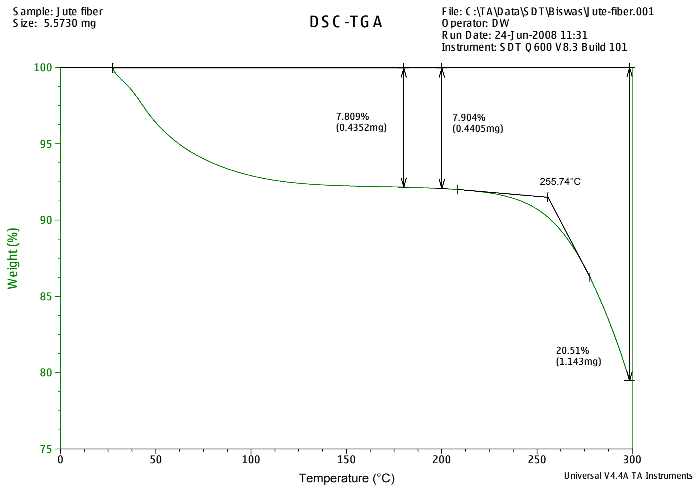


Fig. 4. SEM micrographs of flexural fracture surface of transverse fiber reinforced epoxy composites with using (a) jute and (b) bamboo.

3.3. Thermogravimetric analysis results

TGA curves for jute and bamboo fiber reinforced epoxy composites are shown in Figures 5 (a) and 5 (b) respectively. There was a peak at approximately 100^0C indicating the removal of moisture for both fiber. Both fibers showed thermal decomposition in the temperature range of 240–260^0C. However, the exact thermal decomposition temperature for jute and bamboo fiber epoxy composites was 255^0 and 246^0 respectively. Thus the jute fiber epoxy composite had higher thermal stability as compared to bamboo fiber epoxy composite. During processing of epoxy composites, both jute and bamboo fibers were exposed to high temperature often combined with trapped air, which might cause thermal degradation. If serious degradation of natural fiber occurs at the melt processing temperature, the mechanical reinforcement effect of the fiber is decreased. Thus, TGA analysis was used to determine the high temperature degradation behaviour of the composites under air and nitrogen atmospheres.



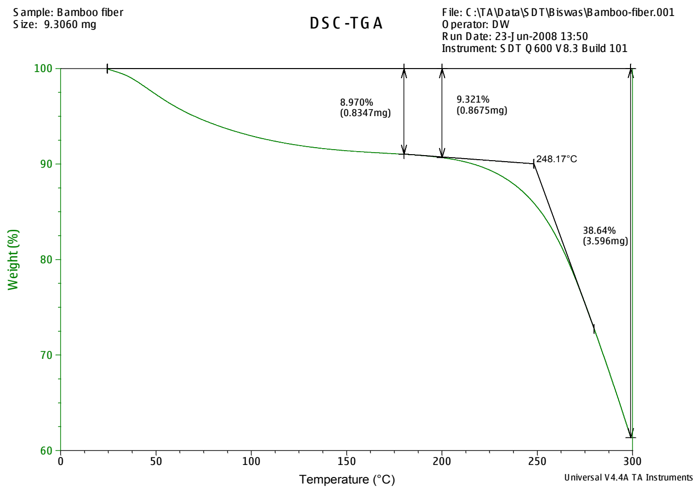


Fig. 5. TGA curves of UD fiber reinforced epoxy composites using (a) jute and (b) bamboo.

4. Conclusions

Void free unidirectional composites were made by using vacuum technique. The analytical results showed good agreement with the experimental results. Bamboo fiber reinforced epoxy had higher tensile strength; while jute fiber reinforced epoxy composites had higher Young's modulus. Bamboo and jute fiber reinforced epoxy composites had better flexure strength with longitudinal and transverse fiber distribution respectively Fibre distribution was not uniformly for both bamboo and jute fiber reinforced UD composites. In case of jute fiber composites, some fiber was broken during processing. It is also revealed that jute fiber reinforced epoxy composites showed better thermal behavior compared to bamboo fiber reinforced epoxy composites.

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