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Physical and Morphological Properties of Thermoset Composites Reinforced with Jute Preforms

Neha Sah[1], Alka Goel[2], Arun Kumar Chaudhary[3]
[1]Ph. D Student, [2]Professor, [3]Assistant Professor
[1, 2,3]G.B.Pant University of Agriculture & Technology. Pantnagar, Uttarakhand

Abstract: *Jute, an eco-friendly and affordable fiber grown profusely in India, possess unique combination of properties suited for the manufacture of non-textile products. However, its contribution for technical applications is limited at present. In this research, an effort has been made to investigate the physical and morphological properties of jute fiber when incorporated in epoxy matrix with a view to widen the share of jute fibers for engineered applications. Composite specimens containing nonwoven jute mat and alkali treated short jute fibers with different weight percentages (1, 2 wt%) were made using epoxy resin. The water absorption, thickness swelling (TS) and morphology [scanning electron microscopy (SEM)] tests of the bio composites were performed. As the fiber fraction ratio was increased the values for water absorption (WA) and thickness swell (TS) were found to be increased. The samples reinforced with 2 wt. percent fiber fractions showed maximum WA and TS in both water environments.*

Keywords: composites, nonwovens, jute fiber, physical properties, morphological properties.

INTRODUCTION

Fiber-reinforced polymer composite materials are fast gaining ground as preferred materials in wide gamut of industries ranging from everyday consumer products to the sophisticated niche applications. They are mostly and widely made from man-made fibres i.e. glass fibre, carbon fibre etc. embedded in polymer matrix system. The reason for excessive utilization of these fibers lies in their excellent mechanical performance and ease of processing. However, their life cycle performance is very dubious. They are extracted from finite petroleum resources, consume huge energy during manufacturing, price high and at disposal stage disturb the environmental hygiene. But in the current scenario due to strong regulations and criteria for cleaner and safer environment, there is a trend of valuing materials which are concerned with aspects of being renewable, biodegradable and recyclable.

The natural fibers in this context are just perfect. Besides ecological consideration, the unique combination of properties offered by natural fibers at relatively low cost are the major driving force to prefer natural fibers over their synthetic counterparts for composite applications. They are low-density material yielding comparatively lightweight composites with high specific properties and therefore offer a high potential for an outstanding reinforcement in lightweight structures [1].

India is bestowed with profuse availability of variety of natural fibers. Among them jute fibers deserve special mention. According to Commission for Agricultural Costs and Prices (2013), globally, India is the largest producer of raw jute (jute, kenaf and allied fibres) with a 55.7 percent share in global production in triennium 2011-12 followed. Jute industry provides direct employment to 2.0 lakh workers in organized mills and in diversified units including tertiary sector and allied activities. It supports the livelihood of around 4.0 million farm families [2]. Despite such remarkable contribution, the full potential of jute fiber is still untapped. The jute product profile is very much restricted to packaging materials for bagging of foodgrains. Some other minor applications involved jute ropes, mats etc. Owing to the properties of this golden fiber, there is needed to create diversified range of jute products to scale up its share for technical applications also.

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Jute fibre has some unique physical properties like high tenacity, bulkiness, sound & heat insulation property, low thermal conductivity, antistatic property etc. suited for the manufacture of non-textile products such as fiber reinforced polymer composites. Fibres can provide reinforcement in polymer matrix in different forms and structures. One of the most economical techniques of using the fibre inside a polymer matrix is using of "Textile Preforms". Textile preforms are structures made from fibre strands using different traditional textile technique and machinery. This is the most effective way of handling fibres without any distortions before impregnation in resin [3]. In this study, composites made by using non-woven mat and carded jute sliver with different weight percentages as reinforcements have been used to characterize their water absorption and thickness swell behaviour in two water environments namely rain and tap water. High moisture uptake is a major demerit of lignocellulosic fibers that may weaken the interfacial bonding between polymer matrix and fibers. To overcome this problem the raw jute fibers were given alkali treatment before being fabricated to composite.

Materials and Methods

Materials

Raw jute fibres were procured from Basu Jutex Pvt. Ltd., Kolkata (India) at an expense of Rs.70/kg. Thermoset epoxy resin Araldite CY-230 and hardener HY-951, purchased from M/s CIBATUL Limited, Mumbai (India) were used as the matrix system to produce natural fiber reinforced composites.

Methods

Processing and treatment of fibres

Raw jute fiber bales were opened, washed and treated with 1% NaOH solution for one hour at room temperature to improve mechanical properties. The fibres were then washed several times to remove any alkali traces and dried at room temperature for 24 hours. The length of dried fibers were then cut to smaller length (3 inch) and later passed through carding machine to parallelize the entangled mass of fibers. Nonwoven mat was prepared by thermal bonding technique using low melt fiber as bonding medium. The properties of jute fibers (raw and alkali treated) have been shown in Table 1.

Fig. 1 (a) Carded jute fibers

Fig. 1 (b) Nonwoven jute mat

Composite fabrication

The jute fibre reinforced polymer matrix composites were fabricated by using hand lay-up technique. Thermoset epoxy resin Araldite CY-230 and hardener HY-951 were used as the matrix system. Jute fibers (carded form) and jute thermo-bonded nonwoven mat were used as reinforcement media with epoxy resin as the matrix material. Total three types of composite samples were made with selected reinforcement type. The code designation of the composites developed for this study is given in Table 2.

The mold of (160x160x10) mm^3 was made for casting the composites. An accurate amount of epoxy resin was pre-heated to the temperature of 90 $\pm$ 10^0C and then allowed to cool down to the temperature of 40^0C. At this temperature the hardener (10% by weight of resin) was added and stirred thoroughly to minimize air entrapment. The mixture was then immediately used for casting. At first mold release gel was uniformly spread over the mold base than half of matrix was poured on the mold base, the layer of fibers was placed over it and gently pressed using paint roller and coated with rest of the resin mixture. Utmost care was taken to avoid formation of air bubbles. The samples were allowed to cure for about 48 hours at room temperature. Similar procedure was adapted for the preparation of the jute nonwoven mat reinforced polymer composite.

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Fig. 2 Composite samples

Water absorption test

Specimens were immersed into two different aqueous environments, which were rain water (RW) and tap water (TW). These two mediums were selected as they relate closely to the real life situations where these samples can find applications. The pH and conductivity of rain and tap water were found to be 7.7, 0.077 ms/cm and 8.07, 0.314 ms/cm respectively. For the water absorption measurements, the specimens were withdrawn from the water after a predetermined time interval, wiped dry to remove surface moisture and then weighted. The water absorption (WA) of each specimen was calculated from Equation (1) as per ASTM D570 standard.

$$WA = \frac{(W_2 - W_1)}{W_1} \times 100 \qquad (1)$$

Where W_1 and W_2 are the initial and wet specimen weight (g) after N hours of soaking time respectively.

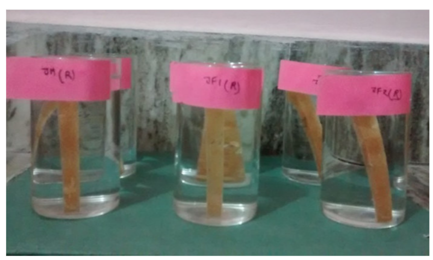

Fig. 3 Water absorption and thickness swelling test

Thickness swelling test

This test was used to measure the dimensional change in composite specimens by immerging them in two different aqueous environments namely rain water and tap water. Before immerging the test specimens into water, the thickness of each sample was measured and after pre-determined time interval of 6 hours the samples were taken out, blotted to remove surface water and thickness value was taken. The test was continued till constant readings were obtained. Thickness swelling (TS %) was calculated as per the Equation (2).

$$TS = \frac{(T_2 - T_1)}{T_1} \times 100 \qquad (2)$$

Where T_2 (mm) is the thickness after soaking and T_1 (mm) is the thickness before soaking.

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SEM

Dispersion state of jute fibers in epoxy resin which plays an important role on the WA and TS of the bio composite was observed with SEM analysis. The analysis was done at the Institute Instrumentation Centre, IIT, Roorkee. Square samples were cut from the tensile fractured surface and gold coated before the photomicrographs were taken to avoid any consequence associated with sample charging. The samples were then placed inside a chamber in which an electron beam fell on the material with 10 kV accelerated voltage.

Fig. 4 SEM set up

Results and discussion

The results obtained have been reported and discussed as below:

Water absorption test

The percentage of weight gain in various composites with time duration in rain and tap water is shown in Fig. 5 and Fig. 6 respectively. All the three different kinds of composites showed gradual increase in water absorption with time in both water environments. The maximum water absorption [1.39% (RW), 1.44% (TW)] was obtained at 2 wt% fibre loading and the minimum values were recorded for nonwoven mat reinforced composites [1.12% (RW), 1.17% (TW)] irrespective of water type. There was a sudden increase in water absorption at the initial stage for the samples reinforced with different percentages of carded slivers with slightly higher absorption rates in tap water compared to rain water. The water absorption behaviour of the composites reinforced with nonwoven jute mat showed no water uptake for initial 18 hours in tap water and slight absorption (0.28%) in rain water. In nearly all cases the water absorption process was quick at the beginning and levelled off for some length of time where it approached to equilibrium. Water uptake reached the saturation limit in about 42 root hours in all the samples.

It was found that as the fiber loading ratio was increased water uptake was also increased. This behaviour was possibly due the introduction of voids or microgaps introduced between the polymer chains with increased fiber fractions. Being hydrophilic in nature, the jute fibers absorb moisture which causes swelling of the fibers resulting in microgaps in the matrix fiber interface. However, due to alkali treatment the absorption was not way high as usually exhibited by untreated natural fiber composites and reached saturation soon. The mat reinforced composites took up less water with time as compared to fiber reinforced samples. The reason behind this may lie in the intact structure of the thermal bonded nonwoven mat that resulted in good adhesion with epoxy resin, leading to less water absorption.

Three main reasons because of which water can reside in natural fiber reinforced composite are the voids present in the composites, interfacial adhesion between the fibre and matrix and type of fibres reinforced [4]. A similar study was conducted to study the effects of number of layers of woven jute fabric on moisture absorption, thickness swelling, volume swelling, and density as a function of immersion time and it was observed that the moisture diffusion rate into composites increases with an increase in the jute-fiber-to-epoxy ratio. The type of epoxy used as the matrix appeared to have an influence on the moisture absorption percentages of the composites. The study showed that both water absorption and swellings were higher in the bio-epoxy parts compared to the epoxy parts. The swelling of composites was correlated with an increase in diameters of jute fiber in water [5].

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Thickness swelling test

The thickness swelling results are shown in Fig. 7 and Fig. 8 respectively. It can be seen that the thickness swelling for composites followed a similar trend to the water absorption behaviour, increasing with immersion time until a saturation condition was obtained. It is clear from the figures that the dimensional change is negligible in initial 12 hours for all the samples irrespective of water environments. The highest rate of thickness swelling was observed in samples with 2 wt. percent fiber loading which circuitously confirmed the presence of higher number of voids in the system. In contrast, thickness swelling of nonwoven mat reinforced samples was lowest (value 0%), in other words, there was no thickness swelling in these samples in both the water environments. It may be due to the compact packing of fibers in the mat structure resulting from the particular bonding technique that limit the water absorption by the samples. All the samples attained the saturation limit for thickness swell nearly in about 36 root hours.

A study conducted to compare the thickness swelling of woven jute fiber based hybrid composites with chopped hybrid composites concluded that woven jute fiber based hybrid composite showed more thickness swelling which indirectly indicates higher void content in the system, allowing water to easily diffuse into the composites through void spaces [6]. In another report the water absorption (WA) and thickness swell (TS) behaviour of biocomposites containing different weight percentages of almond shell particle and coconut fiber was observed. The influence of the addition of coconut fiber was more for both WA and TS as compared to almond shell particles possibly due to the presence of a higher percentage of α-cellulose in coconut fiber. The thickness swell for all types of biocompostíes were negligible for the initial soaking period of 4 hours which later found to be increased with soaking time [7]. All these studies provide some rational grounds necessary to define the current behaviour of thermoset composites reinforced with jute preforms when subjected to water absorption and thickness swelling tests.

SEM

The micrographs obtained from scanning electron microscopy are shown in Fig. 9 (a-c).

It can be seen from Fig. 9a that there were evidence of matrix cracking and fiber debonding at some places. However no sign of cavities or voids were seen which indicate better mixing of fiber in the matrix.

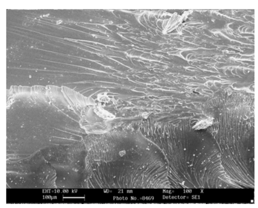

Fig. 9a SEM micrograph for 1 wt % of jute fibers in epoxy resin

According to the SEM fractograph (Fig. 9b), debonding between both the phases along with matrix cracking predominate in fracture surface.

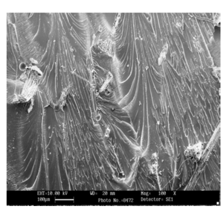

Fig. 9b SEM micrograph for 2 wt % of jute fibers in epoxy resin

Presence of voids can also be seen which shows that increasing the fiber percentage in the matrix reduced uniformity between fibers and matrix. This led to the poor mechanical properties and more water absorption and thickness swelling. It has been stated that small amount of moisture if present can reduce the bond strength between the phases resulting in differential strain which is created by the expansion force exerted by the liquid while stretching polymeric chains and induce additional residual stresses [8].

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SEM micrograph of jute mat reinforced composite specimen (Fig. 9c) showed fibre fracture along with few incidence of fiber pull-out. The existence of cracks around the broken fiber sites indicating the adherence of epoxy to fiber. This could be attributed to good bonding between fabric and matrix

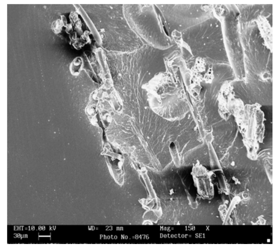

Fig. 9c SEM micrograph for jute mat rooted in epoxy resin

Conclusion

The effect of fiber geometry was clearly observed on the water absorption and thickness swell behaviours of the samples. As the fiber fraction ratio was increased the values for water absorption (WA) and thickness swell (TS) were found to be increased. The samples reinforced with 2 wt. percent fiber fractions showed maximum WA and TS in both water environments. However, the rate of water absorption was slightly high with tap water as compared to rain water for all the samples. Jute mat reinforced composites absorbed less water with time as compared to fiber reinforced samples and were found to have no dimensional change in both the water environments. The alkali treatment given to the fibers played a key role in limiting the undue absorption as well as swelling of the composites.

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