Effect of environment on the mechanical properties of fly ash-jute-polymer composite

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The present investigation is aimed at processing a composite using fly ash, jute with epoxy (binder) and to study its weathering behaviour on mechanical properties such as flexural strength. The fracture surfaces of the specimen are examined under scanning electron microscope. From the study, it appears that fiber pullout is the predominant mode of failure. The cracking of the fiber structure is avoided due to adherence of fly ash particles which indicates the increase in strength of interfacial bonding. It can be concluded that this composite can be successfully used as a structural material in household and automobile application and as a low cost building material.

Keyword: Fly ash, Epoxy, Reinforcement, Environment, Flexural strength

Fiber reinforced composites are popularly being used in many industrial applications because of their higher specific strength and stiffness. Therefore, such composites are frequently used in engineering parts in automobile, aerospace, marine and energetic applications. With low cost and high specific mechanical properties, natural fibers represent a good, renewable and biodegradable alternative to most common synthetic reinforcement (i.e. glass fiber). Synthetic fibers such as carbon or glass fibers have constant diameters, smooth surfaces and considerable rigidity. On the other hand, natural fiber can be flexible, have variable diameters along the length of each fiber and have rough surfaces. They are sensitive to temperature and moisture and usually have irregular cross-section. The main bottlenecks in the broad use of natural fiber in various polymer composites are poor compatibility between the fibers and the matrix, and the inherent high moisture absorption; which brings about dimensional changes in the lignocelluloses based fibers. In order to improve the mechanical properties, adhesion between fiber and matrix has to be improved. One of the techniques is to modify the surface of the fiber by chemical treatment. Several researchers have contributed to the development of jute fibers surface modifications by different techniques. Ray et al. characterized the physical and mechanical properties of the composites reinforced with alkali treated jute fibers. Similarly, jute fibers were treated with 2% NaOH solution for 1 h by Samal et al. and 13% improvement on tenacity of the fibers was observed. Rout et al. reported 26% improvement in tensile strength, 15% in flexural strength and 20% in charpy impact strength after the coir fibers were treated with 2% NaOH solution for 1 h. It can be concluded from these discussions that to improve physical and mechanical properties of a composite, the reinforcing fibers has to be compatible and good bonding characteristics with the matrix.

Keeping in view the above facts, in the present investigation instead of treating the jute fiber for better adhesion with the matrix we have introduced fly ash as an interface material. The composite is subjected to different environmental treatments. The degradation/improvements in the mechanical properties are reported here. Micro structural examinations are also made to ascertain the fracture behaviour of the composite.

Experimental Procedure

Materials

Woven jute mats were used in the present investigation. These jute mats were cut from the jute bags used for packaging potato and onion in all parts of India. The cut jute mats were cleaned with pressurized water and oven dried at 100°C to remove any starch present. The average diameter of the fibers in the mats are about 1.5 mm with inter fiber spacing of about 2 mm.
Fly ash used was collected from the second captive power plant of Rourkela Steel Plant, Orissa, India. The chemical composition of fly ash used for the present case is given in Table 1 and belongs to class ‘F’ as per ASTM standard. Araldite (LY556) an unmodified epoxy resin based on bisphenol A and hardener (Ciba-Geigy, India) HY951, aliphatic primary amine were used with woven jute mats and fly ash to fabricate the laminated composites.

**Composite fabrication**

Jute fiber-fly ash/epoxy composite laminates were fabricated by wet layout method; the jute mats of required dimension (25 × 30 cm) were laid over a mold and then catalyzed epoxy resin mixed with 30% fly ash was poured over the reinforcement. The wet composite was rolled to distribute the resin and to remove the air pockets. The sequence was repeated for single, three and four layered composites (Fig. 1). The layered structures were allowed to harden on cure. It was cured at room temperature for 72 h. After curing the laminates were cut in to the required size (10×12×100 mm) for treatment and 3 point bend test by diamond cutter.

**Measurements**

The prepared samples (single, three and four layer) were treated in various environment conditions such atmospheric, subzero, sodium chloride (NaCl) and steam. The dimensions and weight of each specimen were noted prior to and after treatment, which were incorporated into the dimensional change/stability of the composite with the treatment.

Composites after treatment were tested for their flexural strength under three point bend test in Instron 1195 tensile testing machine in accordance with ASTM D 2344-84 standard. Test specimen were 120 mm length, 10 mm breadth and 7.5 mm thickness were used. A span of 60 mm was employed maintaining a cross head speed of 10 mm/min for all the mechanical flexural tests. Inter laminar shear strength (ILSS) was measured as follows:

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Requirement as per IS:3812-1981</th>
<th>Test values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{SiO}_2+\text{Al}_2\text{O}_3+\text{Fe}_2\text{O}_3$ % by mass</td>
<td>70.00(minimum)</td>
<td>92.07</td>
</tr>
<tr>
<td>$\text{SiO}_2$ by mass</td>
<td>35.00(minimum)</td>
<td>57.80</td>
</tr>
<tr>
<td>$\text{Al}_2\text{O}_3$ by mass</td>
<td>-</td>
<td>25.84</td>
</tr>
<tr>
<td>$\text{Fe}_2\text{O}_3$ by mass</td>
<td>-</td>
<td>8.43</td>
</tr>
<tr>
<td>Total Sulphur(SO$_3$)% by mass</td>
<td>2.75(maximum)</td>
<td>0.46</td>
</tr>
<tr>
<td>Available Alkalis(Na$_2$O)% by mass</td>
<td>1.50(maximum)</td>
<td>0.80</td>
</tr>
<tr>
<td>CaO</td>
<td>1.60</td>
<td></td>
</tr>
<tr>
<td>Loss of ignition % by mass</td>
<td>12.0(maximum)</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Fig. 1—Schematic view of the composites

Fig. 2—Change in volume in single layer composite for different time of exposure under steam treatment
ILSS = 0.75 \( P/\sqrt{bt} \) where \( P \) is the breaking load, \( b \) is the width and \( t \) the thickness of the sample.

**Results and Discussion**

Figures 2-4 show the change in volume of different series of samples for different time exposures, subjected to steam treatment (i.e. at 90% RH and 100°C) for single, three and four layered composites respectively. It is clear from these plots that the rate of increase in volume is more with composite having more volume fraction of jute. This may be due to the swelling of the jute fiber subjected to treatment.

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**Fig. 3**— Change in volume in the three-layered composite for different time of exposure under steam treatment.

**Fig. 4**— Change in volume in the four-layered composite for different time of exposure under steam treatment.

**Fig. 5**— Time dependent weight change (due to moisture absorption) for different layer composite exposed to steam (RH-90%; Temp-100°C)

**Fig. 6**— Variation of shear stress of the composites for natural (condition) treatment
Fig. 7— Variation of shear stress of the composites for steam treatment

Fig. 8— Variation of shear stress of the composites for saltwater treatment

Fig. 9— Variation of shear stress of the composites for subzero treatment

Fig. 10— The scanning electron fractograph of the samples treated in subzero condition
Figure 5 shows the percentage change in weight for 0-6 h of exposure to steam for three types of samples. All these figures show similar trend but with a variation of magnitude (of weight). Beyond certain times of treatment, about 4 h linearity in the curves are observed, which is indicative of saturation of moisture absorption. Same type of results have been reported by Thomas et al.\textsuperscript{12} and Stark\textsuperscript{13} while working with pineapple leaf-fiber reinforced with LDPE and wood flour-polypropylene composites. Figures 6-9 show the variation of shear stress for three types of composites in natural steam, salt water and subzero environment. In all the cases similar trend is observed, i.e., decrease in stress value with increase in time of treatment and this decrease in stress value is more for composite, containing more layers of natural fiber, i.e., jute mats.

In Fig. 9 for subzero treatment the rate of change fall outs for particular pattern up to 21 days of treatment, i.e., gradual decrease beyond which a sharp values are observed. This may be due to the rigidity of the epoxy matrix or/and debonding of the fibers for the long time to exposure in subzero conditions.

**Micro structural observation**

Figures 10a and 10b show the typical structure of the samples treated in subzero condition. In Fig. 10a two different mode of fracture are observed. In some regions, fiber pull out is prominent and brittleness of the matrix is observed which implies brittle fracture of the matrix. Figure 10b shows the magnified view of the above samples. It is observed that some small particles adhere to the fiber surface, but no cracking of the fiber structure or fibril strands are observed. This may be due to the adherence of the fly ash particles to the fiber surface which plays a vital role in interfacial bonding.

Figure 11 shows a typical sample treated in sodium chloride (NaCl) for 28 days. The breaking of the fibril strand is seen at some places. This implies the weakening of the fibers during the treatment. Debonding of the fibers from the matrix is also viewed from the photograph.

Figure 12 shows the fracture surface of the sample after steam treatment. Adherence of fly ash particles on the fibre surface is less as compared to other treatments. Striations on the polymer matrix are seen. The debonding of the fiber from the matrix; the breaking of fibrils and fiber strand is well visualized.

**Conclusions**

The following conclusions are drawn from the study:

(i) The moisture absorption of NaCl affects the change in volume, weight and density of the composite.

(ii) The volume and weight change of the composite attains stability after certain period of exposure.

(iii) The shear stresses of composite are very sensitive to the treatments. The shear stresses decreases with increase in treatment time.

(iv) It is found that increase in moisture percent decrease the shear stress but the three layered composite shows optimum value of stress (40 MPa). This indicates that about 50-60% volume fraction of the second phase. Jute (with 15% fly ash) composite gives the optimum result.
References