Tensile Properties of Polystyrene-Coated Tamarind Fruit Fiber

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Abstract—The effects of chemical treatments on the mechanical, morphological and water absorption properties of polystyrene coated tamarind fibers were studied. In order to enhance the interfacial interactions between the polystyrene (PS) and the Tamarind fiber, two different types of chemical treatments, alkali (NaOH) and silane (3-aminopropyl-triethoxysilane) were used. Tensile strength and Young’s modulus increased with employment of the chemical treatments accompanied by a decrease in water absorption with treatment due to the better adhesion between the fiber and polymer. SEM investigation showed that the surface modification of fiber has better fiber-polymer interaction. Thus, chemical treatments on the fiber improve fiber/polymer adhesion especially for silane on alkali treated fiber treatment.

Keywords—Tamarind fruit fiber, polymer coating, tensile properties, morphology.

I. INTRODUCTION

In recent years, significant effort has been done to investigate the use of natural fibers as reinforcement in polymer composites [1]. Natural fibers materials have found many applications as fillers in polymer composites for economic and environmental reasons. Among these reasons, the availability of low cost raw materials, their biodegradability and recyclability must be cited [1]. The incorporation of natural fibers in polymer formulations allows the bio-components content to be increased and improvement of mechanical and thermal insulating properties. Natural fiber composites are gaining increasing significance as renewable and environmentally acceptable raw material for civil engineering, building and automotive applications [2-4]. However, these fibers are covered with surface impurities, thus hindering the hydroxyl groups from reacting with polymer matrices. This can lead to the formation of ineffective interfaces between the fibers and matrices, with consequent problems such as debonding and voids in resulting composites [5]. Different approaches have been applied to change the fiber/matrix adhesive properties in natural fiber-reinforced composites: chemical or physical modifications of the matrix, fiber or both the components [6-9]. Chemical treatments provide an important and effective means to remove non-cellulosic components in cellulose fibers and add functional groups to enable better bonding in polymer composites. Many chemicals have been screened in laboratory experiments to enhance the potential fiber/matrix interface, such as sodium hydroxide, peroxide, organic and inorganic acids, silane, anhydrides and acrylic monomers [6].

Research on a cost-effective modification of natural fibers is necessary since the main attraction in today’s market of biocomposites is the competitive cost of natural fibers. Many researchers have reported improvements in mechanical properties of natural fibers by alkali and silane treatments and by polymer coating [10, 11]. This method is inexpensive and effective in modifying the fiber surface for enhanced interfacial adhesion between the natural fiber and the polymeric matrix.

Polystyrene is one of the most widely used plastics, the scale of its production being several billion kilograms per year. Polystyrene can be naturally transparent, but can be colored with colorants. Polystyrenes are used in furniture, packaging, appliances, automobiles, construction, radios, televisions, toys, house ware items and disposable cutlery. The tamarind (Tamarindus indica L.) is a long-lived tree belonging to the Fabaceae family. It is widely distributed throughout the tropical areas [12]. The tamarind tree produces edible, pod-like fruit that is extensively used in various cuisines around the world [12]. The authors selected tamarind fruit fibers for the study because large quantities of this fiber are produced as waste in many food-processing industries. The authors have already reported preliminary studies on properties of tamarind fruit fibers and mentioned their suitability as reinforcement [13]. In the present work, tamarind fruit fibers were coated with polystyrene and their tensile, morphological and water absorption properties were determined. The effect of alkali and silane treatment on the tensile properties of the fibers was also investigated. SEM has been used to examine the fiber surface modification and fiber/polymer interactions.

II. MATERIALS AND METHODS

A. Materials

Extracted tamarind fruit fibers, polystyrene (Rare & Research Chemicals), sodium hydroxide (SD Fine Chem.),
acetic acid, 3-aminopropyltriethoxy silane and toluene (Merck) were used.

**B. Extraction of Fibers**

The shells of fully ripened tamarind fruits were broken and the fibers were separated. The extracted fibers were thoroughly washed with water with occasional shaking to remove any leftover pulp sticking to them. The cleaned fibers were dried at room temperature for a week and finally kept in a hot air oven at 100 °C until dry.

**C. Alkali treatment**

Pre-dried fibers were soaked in 5 % (w/v) sodium hydroxide solution at ambient temperature, maintaining a liquor ratio of 20:1 (by weight). The fibers were immersed in the solution for 30 min. After treatment, fibers were plentifully washed with water to remove any traces of alkali on the fiber surface, subsequently neutralized with dilute acetic acid solution and finally washed thoroughly with distilled water. Then the treated fibers were dried at room temperature for one week and finally kept in a hot air oven at 100 °C until dry.

**D. Silane treatment**

A solution of 1% silane [3-aminopropyltriethoxy] was prepared in acetone. Acetone was used in preference to water to promote hydrolysis to take place with the moisture on the surface of the fibers rather than within the carrier. Also that acetone promotes swelling of the fiber and so increases the fiber surface area exposed to treatment. The pH of the solution was adjusted to 4 with acetic acid and stirred continuously for 5 min. Fibers were then immersed in the solution for 1 h. After treatment, fibers were removed from the solution and dried in oven at 60 °C for 12 h. similar silane treatment procedures also employed for fibers that were previously alkali treated.

**E. Polystyrene Coating**

A solution of 10% w/v polystyrene was prepared using toluene as solvent, and then the untreated, alkali treated and alkali with silane treated fibers were coated with the polymer solution. The coated fibers were vertically hang on a wooden frame, allowed to dry at room temperature for 24 h, and dried in a hot air oven at 60 °C for 2 h.

**F. Tensile Properties**

The tensile properties (Young’s modulus, maximum stress, and elongation at break) of the fibers were determined using an Instron 3369 Universal Testing Machine. All the fibers tested were conditioned for 24 h in a standard testing atmosphere of 21°C and 65% relative humidity. Tensile testing of the fibers was carried out at a crosshead speed of 5mm/min, maintaining a gauge length of 50mm using a 10 kN-load cell. A total of 10 fibers were tested for each condition and the average values along with standard deviation reported.

**G. Scanning Electron Microscopy Analysis (SEM)**

In this study, uncoated and polystyrene-coated tamarind fiber surface morphology was studied using a JEOL JSM 820 scanning electron microscope operating at a voltage of 8 kV. Samples were mounted with carbon tape on glass stubs and then sputter coated with gold to make them conductive prior to SEM observation.

**H. Water absorption**

To study the water absorption of the uncoated and coated tamarind fibers, tests were carried out as per the ASTM D 543-87 standard. The pre-weighed specimens were dipped in the distilled water for 24 h, removed, dried by pressing them between filter paper and reweighed. The % water absorption was determined using the following equation.

\[
\text{Water absorption (\%)} = \left(\frac{\text{FW} - \text{IW}}{\text{IW}}\right) \times 100
\]

**III. RESULTS AND DISCUSSION**

The prime work relating to the extraction of the Tamarind fibers from fruit, study of the chemical composition, thermal properties and the influence of the alkali treatment on the properties of the fibers were reported in the literature [13]. In this study, the SEM analysis of alkali treated fibers showed the roughness of the fibers after alkali treatment, suggested the removal of impurities; facilitate good interaction between fibers and matrices. In addition, alkali treatment reduces fiber diameter and thereby increases the aspect ratio, improving mechanical characteristics of the resulting composites.

Tensile (Young’s modulus, strength and elongation at break) of the tamarind fruit fibers under different conditions are presented in Table 1 and as bar diagrams in Figure 1. Untreated fibers showed 2165 MPa of modulus and 60.5 MPa of strength with 5.8% of elongation at break, while treated (5% NaOH concentration, 30 min h soaking time) fiber showed 3073 MPa of modulus and 65.2 MPa of strength with 7.6% of elongation at break. Tensile properties of the alkali treated fibers were much higher than those of the untreated fibers (Table 1). Increase in tensile properties of treated fibers is thought to occur due to the improvement of cellulose chain packing order. Moreover, alkali treatment of natural fibers causes a reduction in the spiral angle of cellulose micro fibrils, which in turn allowed for the rearrangement of the cellulose chains and consequently improves tensile properties [10]. The tensile properties of alkali treated and alkali combined with silane treated fibers were much closer to one another (Table 1). This behavior is due to the similar chemical composition of these two types of fibers. Silane is used as coupling agent to allow natural fiber to adhere to a polymer matrix, thus stabilizing the composite material. The increase in tensile modulus, strength and elongation at break of chemically modified fibers, respectively (presented in parentheses), over the untreated fibers were as follows: alkali treated (41.9, 7.7 and 31%), and alkali and silane treated (43.9, 9.2 and 37.9%).
### Table I

**Tensile Properties of Uncoated and Polystyrene-Coated Tamarind Fibers**

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Modulus (MPa) [SD]</th>
<th>Strength (MPa) [SD]</th>
<th>Elongation at break (%) [SD]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uncoated fiber</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untreated</td>
<td>2165 [113]</td>
<td>60.5 [5.2]</td>
<td>5.8 [1.4]</td>
</tr>
<tr>
<td>Alkali treated</td>
<td>3073 [105]</td>
<td>65.2 [6.8]</td>
<td>7.6 [1.1]</td>
</tr>
<tr>
<td>Alkali and silane treated</td>
<td>3117 [109]</td>
<td>66.1 [4.2]</td>
<td>8.0 [1.1]</td>
</tr>
<tr>
<td><strong>PS coated fiber</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untreated</td>
<td>2372 [87]</td>
<td>62.8 [2.1]</td>
<td>6.3 [1.5]</td>
</tr>
<tr>
<td>Alkali treated</td>
<td>3248 [58]</td>
<td>68.8 [1.3]</td>
<td>7.8 [1.3]</td>
</tr>
<tr>
<td>Alkali and silane treated</td>
<td>3674 [45]</td>
<td>74.9 [1.4]</td>
<td>8.5 [1.1]</td>
</tr>
</tbody>
</table>

SD: Standard deviation; PS: Polystyrene.

Uncoated with polystyrene coated fibers showed 2372 MPa of modulus and 62.8 MPa of strength with 6.3% of elongation at break; alkali treated with polystyrene coated fiber showed 3248 MPa of modulus and 68.8 MPa of strength with 7.8% of elongation at break, while alkali and silane treated with polystyrene coated fibers showed 3674 MPa and 74.9 MPa of strength with 8.5% of elongation at break (Table 1). From Figure 1 and Table 1, it is also evident that the tensile properties of the polystyrene-coated tamarind fibers under all conditions were higher than those of the uncoated fibers. Further, the tensile properties of alkali and silane treated fibers with polystyrene coating were higher than those of untreated fibers with polystyrene coating. Silane can be hydrolyzed into silanol when it reacts with moisture in the fiber. This silanol groups reacts with the hydroxyl groups on the surface of fiber, forming a stable covalent bond on the cell wall. For now, the remaining silanol groups are adequate of hydrogen bonding or condensing with adjacent silanol groups (Si–O–Si) [11]. Therefore, the hydrocarbon chain of polymerized silane can adhere to the matrix mainly because of the van der Waals type of attractive forces. As a result, silane-coupling agent forms a bridge at the interface and improves the adhesion between fiber and polymer. The increase in tensile modulus, strength and elongation at break of polystyrene coated fibers, respectively (presented in parentheses), over the untreated fibers were as follows: untreated with coated (9.5, 3.8 and 8.6%), alkali treated with coated (50, 13.7 and 34.4%) and alkali and silane treated with polymer coated (69.7, 23.8 and 46.5%). This is understandable as modification of natural fibers results in surface roughening, facilitating better wetting between the fibers and polymer.

![Fig. 2 Scanning electron micrographs of (a) untreated, (b) alkali treated and (c) alkali with silane treated Tamarind fiber](image)

![Fig. 3 Scanning electron micrographs of (a) untreated, (b) alkali treated and (c) alkali with silane treated polystyrene-coated Tamarind fiber.](image)

Scanning electron micrographs of the uncoated and polystyrene-coated fibers are shown in Figures 2 and 3 respectively. Untreated fiber (Figure 2(a)) shows a very thick and compact surface, where cellulose fibers are packed tightly by hemicellulose, lignin and surface impurities; however, alkali treated fiber (Figure 2(b)) has become a rough surface. Alkali treatment helps to remove the hemicellulose and surface impurities from the fiber surface, thus improves the fiber–matrix adhesion by rearranging the units in the cellulose macromolecule and led to better fiber–matrix interface, fiber wetting characteristics and bonding. The amount of cellulose exposed on the fiber surface resulting in better mechanical interlocking. However, the surface of the alkali and silane-treated fiber (Figure 2(c)) was found to be still rougher with scratches, due to the swelling of the fiber by the action of the solvent (acetone) used in silane coupling agent treatment. Micrographs of the polystyrene-coated tamarind fibers under all conditions are presented in Figure 3(a-c); from this figure, it is evident that the surface of the fibers was covered by polystyrene matrix.
Figure 4 shows the percentage of water absorption of uncoated and PS coated tamarind fiber. Over all the alkali and silane treated with polystyrene coated fibers are shows good resistance for water. This is due to the fact that fiber coated with polymer is a close packed manner in which the water-impermeable polystyrene act as barrier, preventing the contact between water and fiber and lowering water absorption. On other hand, it is due to the good interfacial bonding between fiber and the polymer.

IV. CONCLUSION

In this work, the tensile properties of the polystyrene-coated natural tamarind fruit fibers were studied. It may be pointed out that silane treatment on alkalized coconut fiber results in an increase in tensile properties. Moreover, from tensile results, alkali and silane treated with polystyrene coated tamarind fiber leads to the increase, which can be related to the effect of improved interfacial adhesion between tamarind fiber and polystyrene. The water absorption studies showed that alkali and silane treatment decreases the water absorption of the polystyrene coated fiber, which supports a better fiber/polymer interaction. Based on improved tensile properties, renewability and environment friendly nature, Tamarind fibers can be favorably considered as reinforcement in biocomposites.

ACKNOWLEDGMENT

The authors acknowledge the Faculty of Engineering and Built Environment and the Research Committee of University of Johannesburg, South Africa, for the award of Postdoctoral Research Fellowships and research support.

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