

Effect of Guar-Gum Treatment on Mechanical Properties of Vinylester Resin Matrix Composites Reinforced with Jute Yarns

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ABSTRACT: The focus of this work was to use an inexpensive and easily available water-soluble natural resin like guar gum as a surface treating agent for jute yarns and to study their effect on the mechanical properties of the treated jute yarn reinforced vinylester resin matrix composites. Jute yarns were treated with 0.1, 0.2, and 0.3% guar gum solution at room temperature for 30 min. The composites were fabricated with the untreated and treated yarns and the vinylester resin having 36 wt % fiber loading. Maximum improvement was observed in the 0.2% guar-gum treated, jute yarn reinforced composites. The flexural modulus and flexural strength improved by 23.85 and 7.7%, respectively, for

the 0.2% treated composites. The fracture behavior of the composites differed considerably, depending on the concentration of guar gum that was used. The experimental results gave a positive indication that simple ecofriendly chemicals like guar gum can be used effectively as surface treating agents of jute yarns for enhancement of the mechanical properties of the jute composites and can be a success from the technocommercial point of view. © 2005 Wiley Periodicals, Inc. *J Appl Polym Sci* 98: 557–563, 2005

Key words: composites; natural resin; interface; flexural properties; fracture surfaces

INTRODUCTION

Because natural fibers are light weight, inexpensive, and easily renewable, they have the potential of being used as reinforcements in the polymer matrix. A large abundance of natural fibers, like jute, coir, sisal, pineapple leaf fiber, flax, hemp, kenaf, banana, and so forth, has enhanced the interest of researchers to explore new avenues of value-added applications. These composites can be used effectively in many areas, such as a substitute for wood, for making household articles and decorative items, and in various other technical fields like automobile parts, building materials, and so forth. The presence of a large number of —OH groups in the structure of these fibers make them susceptible toward moisture absorption from the surroundings. Being hydrophilic, they also show poor wetting behavior with the hydrophobic resin matrix. Hence, for increased adhesion between the fiber and resin, and for enhanced mechanical properties of the composites, chemical modifications of the fibers are suggested. Several researchers have focused their

attention on different types of surface treatments of natural fibers with suitable reagents.^{1–14}

Although many findings have been reported for the surface treatment of natural fibers to increase their suitability as reinforcements in polymer matrix composites, not much success has been observed from the commercial point of view.

Our aim was therefore to use an inexpensive, easily available, and water-soluble natural resin, which will be compatible with the jute fiber surface and will increase the reactivity of the fibers with the resin. Hence, guar gum, which contains many —OH groups in its structure, was selected for the purpose and the performance of the guar-gum treated, jute reinforced vinylester resin matrix composites was studied.

An attempt was made to investigate the effect of guar gum as a surface treating agent on the behavior of guar-gum treated, jute reinforced vinylester resin composites. The composites reinforced with untreated and guar-gum treated jute yarns were examined for their mechanical properties, and their fracture behaviors were correlated with their microstructures.

EXPERIMENTAL

Materials

Jute yarns (8 lb of white jute, *Corchorus capsularis*) were wrapped in black paper, kept in sealed polyethylene

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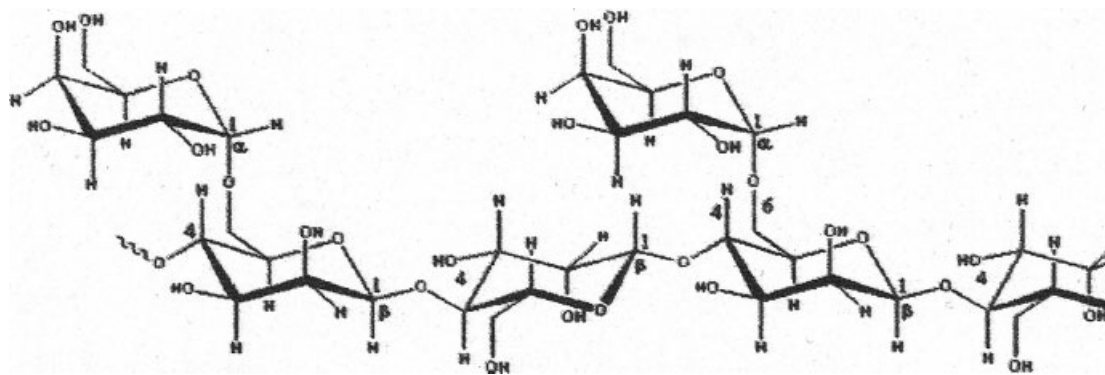


Figure 1 The chemical structure of guar gum.

bags, and stored under 65% relative humidity at 25°C. The vinyl ester resin that was used was FB-701 grade (Ruia Chemicals). Methyl ethyl ketone peroxide, Co naphthenate, and *N,N*-dimethylaniline were used as catalyst, accelerator, and promoter, respectively.

Guar gum is a natural accumulated hydrocolloid stored in the endosperm of the seeds of the guar plant. From the chemical point of view, guar is a galactomannan with a characteristically configured macromolecular structure. The macromolecular structure of guar lies between a spherocolloid (like amylopectin) and a linear hydrocolloid (like cellulose). The backbone of the carbohydrate is made of a chain of (1 to <4) glycosidic linked mannose units, on which every second unit is branched with a (1 to <6) linked galactose. The chemical structure is shown in Figure 1. Like most polysaccharides, guar has two or three free hydroxyl groups on the mannose unit of the main chain or the galactose side chains. These are available for bonding and can be utilized in bonding with the numerous hydroxyl groups present in the jute fiber structure.

Guar-gum treatment

Guar-gum solutions were prepared by adding the dry guar-gum powder slowly into the water with constant mechanical stirring to avoid lump formation. Three solutions with concentrations of 0.1, 0.2, and 0.3 wt % were prepared in three separate beakers. Jute yarns were wrapped in a GoodBrand WrapReel machine and were soaked in 0.1, 0.2, and 0.3% guar-gum solutions in three separate beakers at 30°C while maintain-

ing a liquor ratio of 15 : 1. The yarns were immersed in the guar-gum solution for 30 min. They were allowed to dry at room temperature for 48 h, followed by oven drying at 100°C for 6 h.

Sample preparation

Jute/vinylester composites containing untreated and guar-gum treated jute yarns were fabricated in the form of 6-mm diameter cylindrical rods. Hollow cylindrical glass tubes (6-mm internal diameter) were used as the molds. The resin was mixed with accelerator, promoter, and catalyst (2% each). The jute yarns were dried in an oven at 100°C for 4 h prior to use and soaked in the mixed resin, and the wetted yarns were pulled through the glass tube by hand.

The samples within the glass tubes were cured at room temperature for 24 h followed by postcuring in an oven at 80°C for 4 h. The glass tubes were then cleanly broken to release the composite rods. Composites reinforced with 36 wt % jute were prepared for the investigation. Vinylester resin rods were cast using the glass tubes as the molds by the same method used for preparing the composites.

Test methods

The composites reinforced with the treated and untreated jute yarns were tested for their flexural strength under three-point bending in an Instron 4303 machine in accordance with ASTM D 790M-81. Test specimens were 120 mm long cylindrical rods having

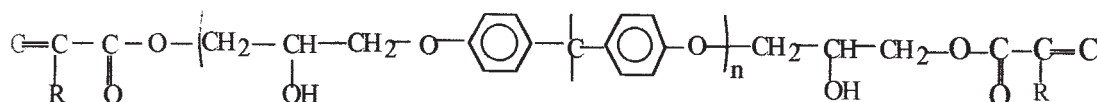


Figure 2 The chemical structure of the vinyl ester resin.

a diameter of 6 mm. A span of 100 mm was employed with a crosshead speed of 2 mm/min.

The flexural strength and flexural modulus were determined using the following equations:

$$\text{flexural strength} = 8FL\pi d^3$$

$$\text{flexural modulus} = 4mL^3/3\pi d^4$$

where F is the load, L is the span, d is the diameter of the specimen, and m is the slope of the initial straight line portion of the load-displacement curve.

The IR spectra of untreated and guar-gum treated jute yarns were recorded with KBr pellets in a Nicolet Magna-IR 750 spectrometer.

The surface characteristics of the untreated and treated jute yarns and the fractured surfaces of the composites were investigated under SEM in a Jeol JSM-5200, using a voltage of 20 kV.

RESULTS AND DISCUSSION

Guar gum, which has numerous —OH groups in its structure (Fig. 1), can take part in hydrogen bonding with the fibers, as well as with the vinylester resin, which also bears —OH groups in the repeating units of its backbone chain (Fig. 2). However, the very high viscosity of the guar-gum solution might cause problems in resin penetration into the fibers.

Guar-gum treated jute yarns

The untreated and the guar-gum treated jute yarns were subjected to FTIR tests to confirm the coating of the guar gum on the fiber surface. The FTIR studies are shown in Figure 3. In the jute fiber, the peak in the area of 3100–3800 cm^{-1} arises because of O—H stretching vibrations. The peak at 2923 cm^{-1} is attributable to the stretching vibration of C—H bonds in the cellulosic structure. The other peaks are due to various characteristics of the specific groups, as mentioned in our earlier work.⁷

The peak area at 3100–3800 cm^{-1} increased by 14, 21, and 37.5% in the 0.1, 0.2, and 0.3% guar-gum treated jute yarns, respectively. The peak area at 2923 cm^{-1} also increased by 20, 27, and 52% in the 0.1, 0.2, and 0.3% guar-gum treated jute yarns, respectively. These enhanced peak areas confirmed the fact that more guar gum was coated on the fiber surface with the increase in the concentration of the guar-gum solution. This is also reflected in the SEM micrographs of the untreated and treated jute yarns shown in Figure 4(a–d).

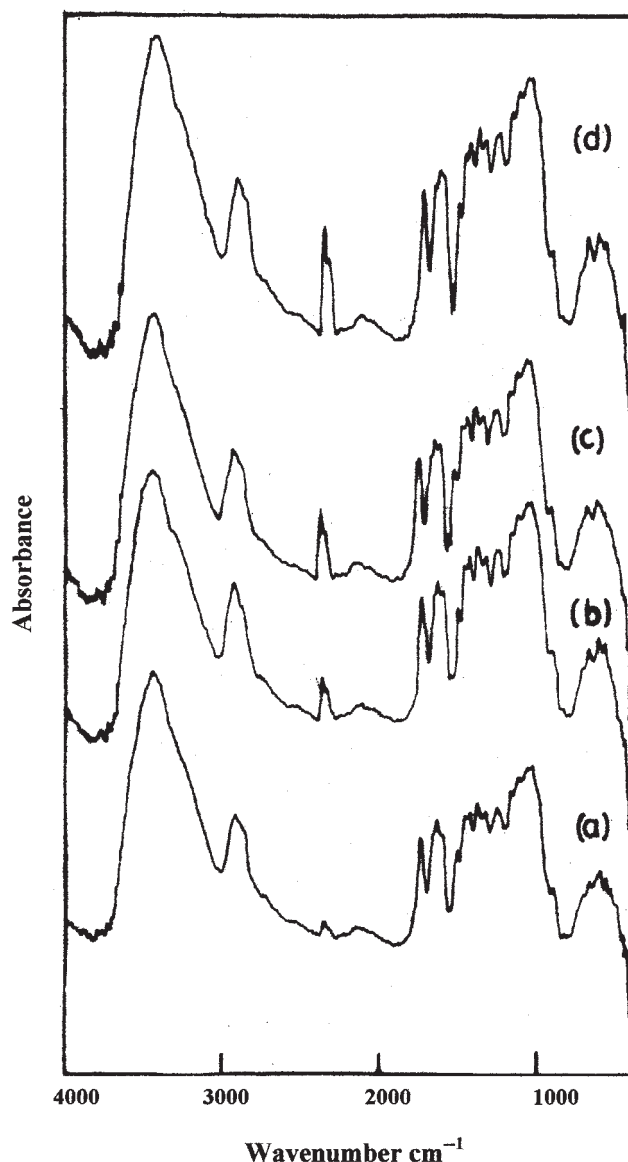


Figure 3 The FTIR curves of untreated (spectrum a) and 0.1 (spectrum b), 0.2 (spectrum c), and 0.3% (spectrum d) guar-gum treated jute yarn.

Untreated and guar-gum treated, jute yarn reinforced composites

In our experiments, we used three concentrations (0.1, 0.2, and 0.3%) of guar-gum solution in water for fiber treatment. The flexural properties of 36 wt % jute yarn reinforced vinylester resin composites before and after guar-gum treatment are given in Table I. For each data point, a minimum of five samples were tested and the value given is the mean of those results. The load-displacement curves of the neat vinylester resin and the composites reinforced with the untreated as well as the guar-gum treated jute yarns are shown in Figure 5. The curves display a few distinct features. After the initial rise, nonlinearity occurred up to the fracture

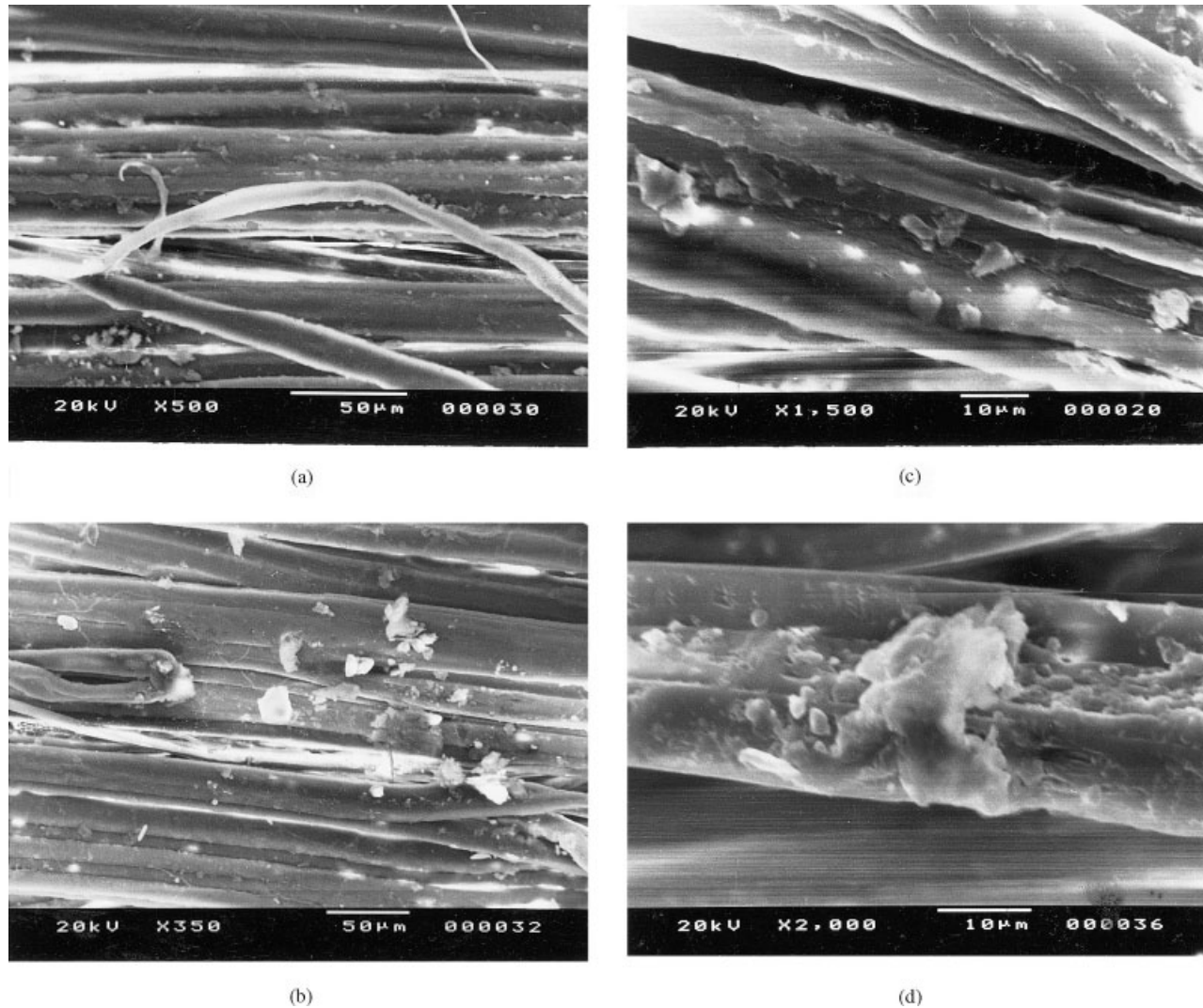


Figure 4 SEM micrographs of (a) untreated and (b) 0.1, (c) 0.2, and (d) 0.3% guar-gum treated jute yarns.

load, indicating the flexible nature of the composites. The composites with the 0.2% guar-gum treated fibers exhibited the highest peak load, indicating higher mechanical properties of the composites.

The modulus of the 0.1, 0.2, and 0.3% guar-gum treated jute composites improved by 7.43, 23.85, and 6.46%, respectively (Fig. 6). The flexural strength

also showed a similar trend, although the improvement was not that significant. The flexural strength of 0.2% guar-gum treated composites had a maximum improvement of 7.7%, whereas the 0.1 and 0.3% guar-gum treated composites had only 3.44 and 2.16% improvement, respectively (Fig. 6). The breaking energy and the breaking strain values did

TABLE I
Flexural Properties of 36 wt % Jute Reinforced Vinylester Composites Reinforced with Untreated and Guar Gum Treated Jute Yarns

Type of sample	Modulus (GPa)	Breaking strength (MPa)	Breaking energy (J)	Toughness (MPa)	Breaking strain (mm/mm)
Untreated	7.614	148.0	0.6253	0.0125	0.0275
0.1%	8.180	153.1	0.5166	0.0109	0.0245
0.2%	9.430	159.5	0.5743	0.0123	0.0266
0.3%	8.106	151.2	0.5581	0.0116	0.0258

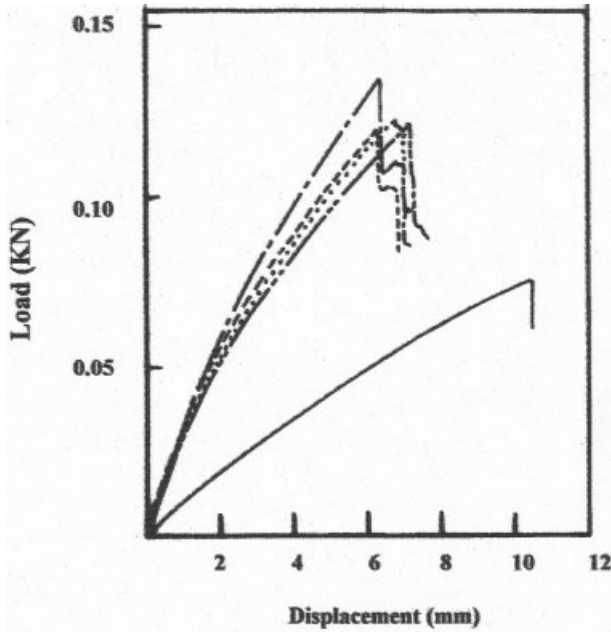


Figure 5 The load-displacement curves of the 36 wt % composites reinforced with (—) vinyl ester, (— — —) untreated, and (---) 0.1, (— · —) 0.2, and (·· ·) 0.3% guar-gum treated jute yarns.

not show any significant change in the treated composites.

In the untreated composites, debonding and fiber pull-out were predominant, as shown in Figure 7. In the 0.1% guar-gum treated composites, fiber pull-out was much less compared to the untreated composites, with shorter pull-out lengths (Fig. 8). The slippage of

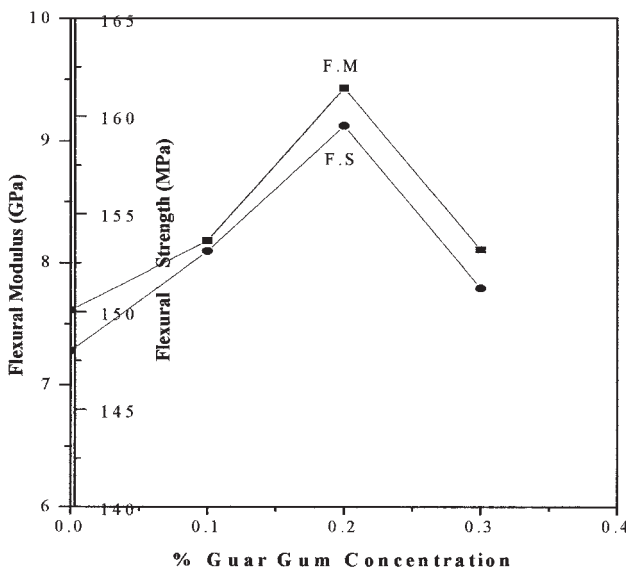


Figure 6 The variation of the flexural strength and flexural modulus of untreated and 0.1, 0.2, and 0.3% guar-gum treated composites with 36 wt % fiber loading.

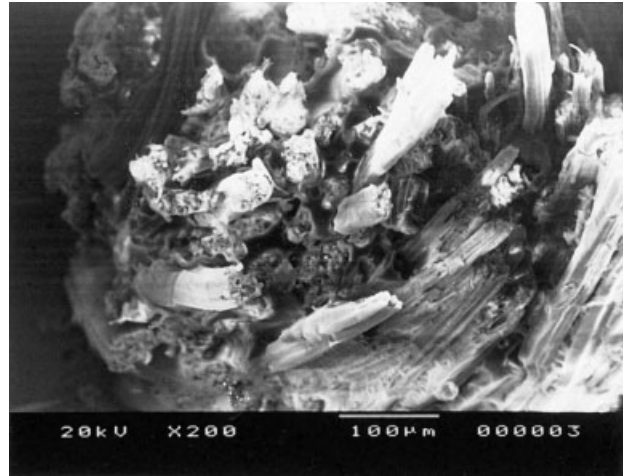


Figure 7 The debonding and fiber pull-out in untreated composites.

the fiber bundles with respect to the matrix along with some fiber breakage was evident (Fig. 9) and pull-out of some of the individual cells from the jute fiber bundles was also observed (Fig. 10). In the 0.2% guar-gum treated composites, the fracture occurred nearly at the crack plane, with a transverse failure of the composite. Interfacial debonding and fiber pull-out almost disappeared and very intimate bonding between the fiber bundles and the resin was evident (Fig. 11). A uniform thin coating of guar-gum solution (up to 0.2%) on the jute yarns enhanced the bonding between the fiber and the resin, which was reflected in their improved flexural properties, as seen from Figure 11. However, with a slight increase in the concentration of the guar-gum solution (0.3%), there was a decreasing trend in the flexural properties. In the 0.3% guar-gum treated composites, the thickly coated jute

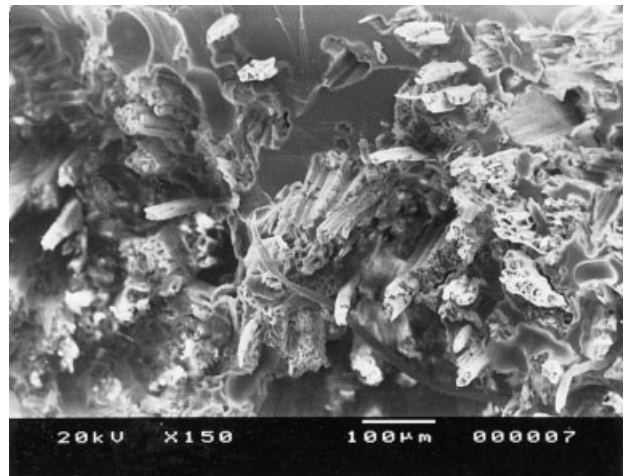


Figure 8 The fractured surface of the 0.1% treated composites with shorter pull-out lengths.

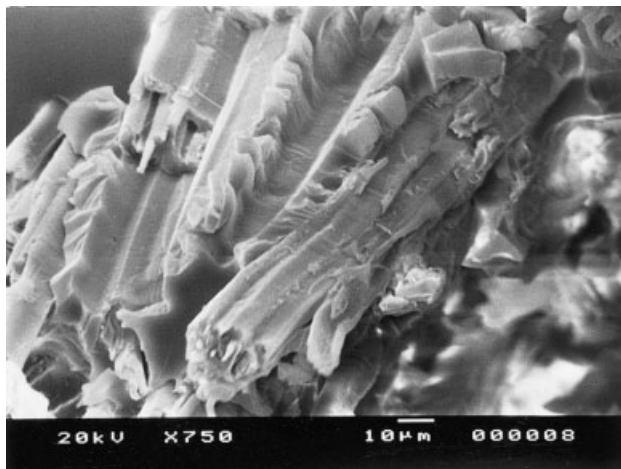


Figure 9 The slippage of the fiber bundles along with some fiber breakage in the 0.1% treated composites.

fiber bundles were bonded to the resin only at some parts, whereas the other parts were mostly devoid of any resin, as shown in Figure 12, indicating insufficient penetration of the resin into the fibers because of the high viscosity of the coating solution. A catastrophic fracture of the fiber bundles was also seen with much less pull-out of the individual cells (Fig. 13).

CONCLUSION

The use of guar gum as a surface treating agent for jute yarns had an increasing effect on the performance of the treated jute/resin composites. However, the improvement was evident only at an optimum concentration of 0.2%. With a further increase in guar-gum concentration (0.3%), the high viscosity of the solution



Figure 11 The intimate bonding between the fiber bundle and the resin in 0.2% treated composites.

might have caused a thicker coating on the jute fiber surface, which resulted in an insufficient penetration of the resin into the fibers, lowering the mechanical properties of the composites.

Because guar gum is an inexpensive, water-soluble, and highly ecofriendly natural resin, its use in either its raw form or some suitably modified form (which will be further investigated in future work) can be very effective for the jute composite industry. It is known that silane coating of glass fibers is extensively used in the glass fiber composite industry for improved bonding between the glass fibers and the resin. However, for natural fibers like jute, such a universal coating material is not yet available, which could be used effectively and extensively for jute fibers to make them more suitable as reinforcements in polymer composites. The use of inexpen-

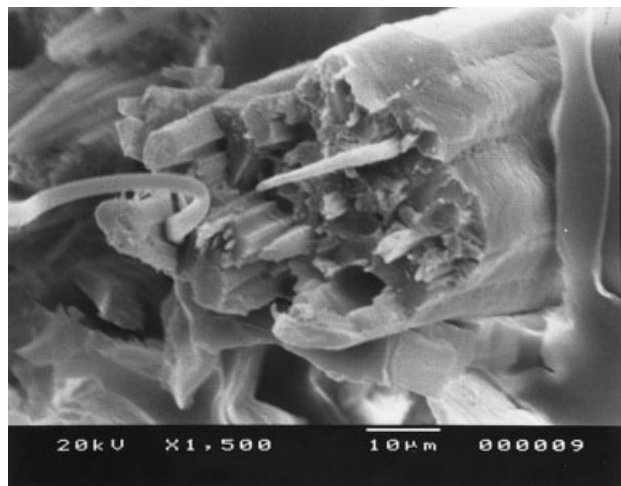


Figure 10 The pull-out of some individual cells from the fiber bundles in 0.1% treated composites.

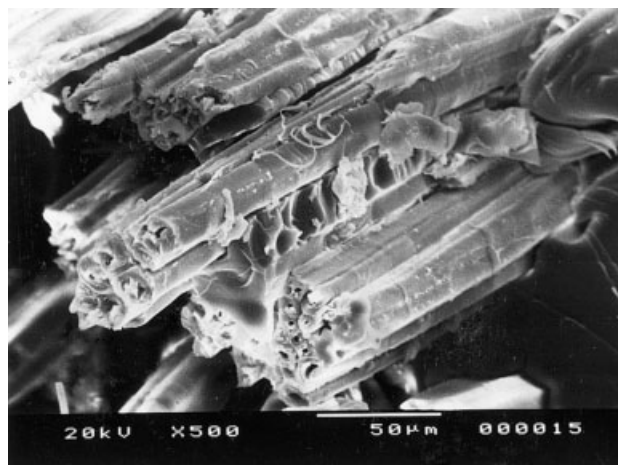


Figure 12 The insufficient resin penetration into the fiber bundles in 0.3% treated composites.

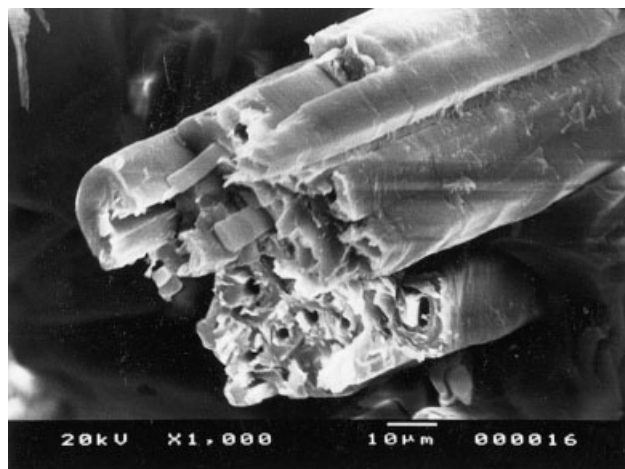


Figure 13 A catastrophic fracture of the fiber bundles in 0.3% treated composites.

sive natural materials like guar gum, as a surface treating agent of natural fibers like jute, can be a technocommercially viable one.

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