Jute Sliver–LDPE Composites: Effect of Aqueous Consolidation on Mechanical and Dynamic Properties

A. K. RANA,[1] A. MANDAL,[1] A. N. BANERJEE[2]

[1] Indian Jute Industries' Research Association, 17 Taratola Road, Calcutta-700 088, India

[2] Department of Polymer Science & Technology, University of Calcutta, 92 A.P.C. Road, Calcutta, 700 009, India

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ABSTRACT: The aqueous consolidation of jute slivers and its comparison with the control in the LDPE matrix were studied in this article. The increase in strength of the consolidated jute sliver–LDPE composite was noticed. Jute slivers were immersed in water, squeezed, air dried, and finally consolidated at 160°C for 5 min. These treated jute slivers with or without CSM (chopped strand mat) and LDPE films were compression molded to different boards and compared among themselves. The studies undertaken for characterization and analysis of the system were (a) flexural behavior, (b) tensile behavior, (c) impact behavior, (d) DMA study, and (e) SEM study. Among mechanical properties maximum gain was found in the impact strength. In the SEM study splitting of fibers were observed after consolidation. © 2000 John Wiley & Sons, Inc. J Appl Polym Sci 76: 684–689, 2000

Key words: jute; natural fiber; composite; thermoplastic composite; consolidation

INTRODUCTION

Steam explosion, steam stabilization, and steam consolidation are some of the treatments being considered at present for the modification and diversification of natural fibers. These are for different end uses, like cottonization of lignocellulosic fiber, to prolong the life of biodegradable fibers and modification of natural fiber-based composites.[1–3] The process of steam explosion is to crack the pectins and hemicelluloses to degum the fiber bundles but to preserve the cellulosic material.[4] The major problem of a steam explosion treatment is separating the fibers from admixtures of the plant without reducing the quality.[5] A steam stabilization technique was also reported by Rowell et al.[6] for application in the field of composites. Inoue et al.[7] explained the phenomena as the plasticization of the cell wall matrix by steaming during compression so that the fiber takes on a new shape. The effect of steam consolidation using thermosetting resin was also studied by Bowen et al.[8] for increasing the jute content of the composites and thus increased the mechanical properties, and because less resin was used, decreased the cost also.

In our study, we have used a thermoplastic matrix and tried to find out the reason behind the increase in mechanical properties.

EXPERIMENTAL

Fibers and the Other Reagents Used

The reagents used in this article were jute slivers (made of grade W-2, Chorchorus Capsularies); a glass mat (300 GSM CSM, FGP Ltd, Calcutta); LDPE film (Indothene LDPE, 100 GSM), and ordinary tap water.

Correspondence to: A. N. Banerjee.

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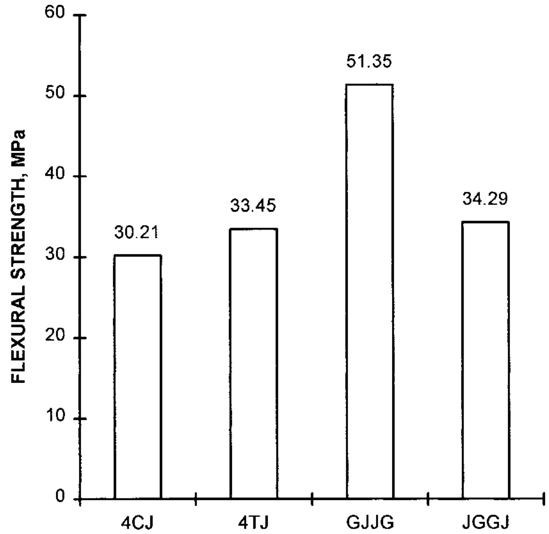

Figure 1 Flexural strength of different jute–LDPE boards.

Methods

Jute slivers were immersed in water for 1 h, and then passed between the two rollers to a water content of 1 : 1 based on oven dry weight. The wet sliver was then dried in open air for 1 h. Air-dried wet slivers were then pressed in a hydraulic press at 160°C for 5 min by placing one per daylight. After consolidation of the slivers different types of pack making were done by using a control sliver, treated sliver, CSM, and LDPE film. The total number of reinforcing fiber layers was four, and LDPE films were placed at the top, bottom, and between the layers. In every case 50% LDPE film and 50% fiber was used. All these boards were analyzed by Instron, DMA, and SEM.

RESULTS AND DISCUSSION

Flexural Behavior

Flexural strengths and modulus of different jute boards are shown in Figures 1 and 2. It was found that after consolidation of the jute sliver the increase in strength was about 11% in comparison with the control. An interesting feature of the present study is that the change in flexural behavior is largely dependent on its replacement by the treated sliver and its position. In 4TJ, replacement of two middle layers of treated jute slivers by glass showed practically no increase in strength. However, a remarkable change took place when two outer layers of treated jute slivers were replaced by two glass layers. In the three-point bending test, when the load is applied on the specimen through the crosshead, the load is transferred to the outermost layer (tension side) from the compression side; as a result, the maximum fiber stress at failure occurs on the tension side. As the elongation at break of jute is less than the glass, early failure of jute fiber took place, due to expansion during the three-point bending test, when the jute layer was on the outer surface. This resulted in loss of strength when jute slivers were on the outer surface. This is in agreement with the work done by Saha et al.[10] using glass and polyethylene fiber.

The least and highest flexural moduli were shown by 4CJ and GJJG, as expected. The difference between JGGJ and 4TJ was found to be marginal. However, about a 10% increase in modulus in JGGJ than 4TJ might be due to the hybridization effect. The hybrid effect may be due to the residual thermal strain, as explained by earlier worker.[9,10] These studies identified a phenomenon called “synergistic strengthening” or the “hybrid effect.” In general, hybrid effects are defined as a positive or negative deviation from the rule of mixtures. The percent coefficient of variation (CV%) for flexural properties were between 5 to 10.

Tensile Behavior

It was observed that the tensile strength and modulus of 4TJ was increased by 36 and 40%,

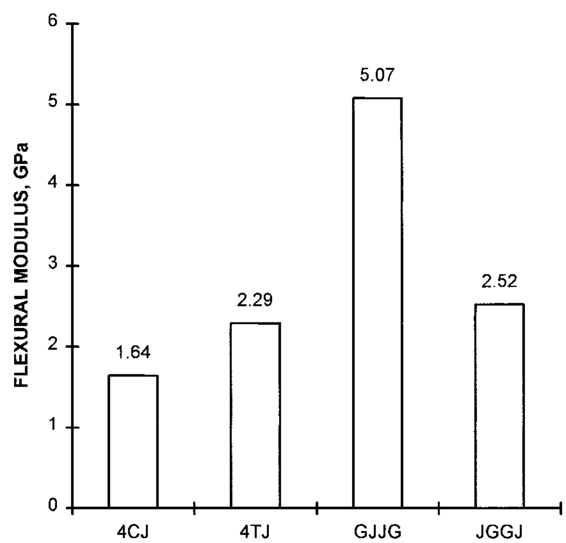

Figure 2 Flexural modulus of different jute–LDPE boards.

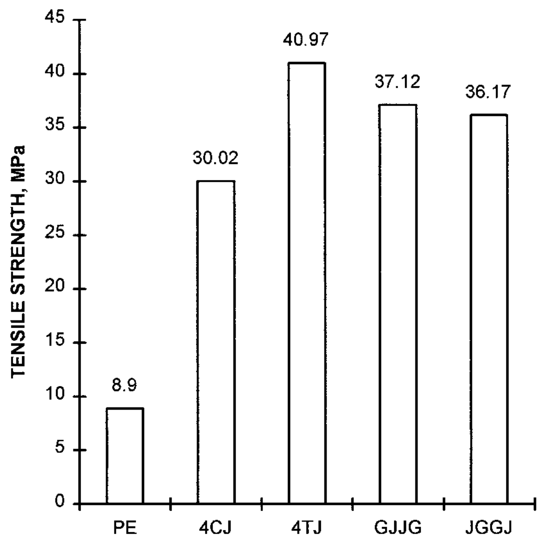

Figure 3 Tensile strength of different jute–LDPE boards.

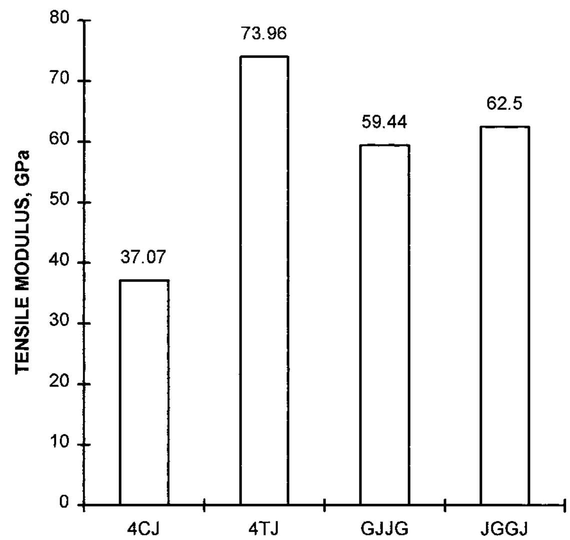

Figure 4 Tensile modulus of different jute–LDPE boards.

respectively, compared to the control. After 50% replacement of the treated jute sliver by the glass fiber in the form of CSM, there was a marginal reduction in strength instead of an increase as expected. The glass fiber in CSM is in the staple form. The continuity among the fiber, held by the PE film (in the matrix), was broken by the application of stress. So in the tensile strength test, glass fiber could not continue to sustain the tension stress. However, it did help in increasing modulus with reference to a control board. In the tensile strength and modulus values, the presence of glass in the middle or center had no effect. This behavior is shown in Figures 3 and 4. The CV% lie between four to nine for tensile properties.

Impact Behavior

Figure 5 shows the unnotched impact strength of different jute–LDPE boards. The impact strength of the treated jute board was found to be about 75% higher than the untreated jute board. This indicates that better energy-absorbing capacity of the treated jute board. This might be due to the better fiber–matrix adhesion. An interesting feature of the present study is that when 50% of the treated sliver was replaced by the glass in the two middle layers, the impact values remained very close to each other. However, when glass layers were kept only on the two surfaces, the impact value was highest. The reason could be attributed to the fact that the glass is more ductile than the jute. When glass was on the outer surface, it was absorbing more energy by self-elongation. This is in agreement with the work done by Saha et al.[11] using polyethylene–glass fiber–PMMA hybrid composites. The % CV values for impact properties were 5 to 12.

Dynamic Mechanical Study

In Figure 6 the variation of storage flexural modulus with temperature for different jute–glass–polyethylene composites was shown. The DMA

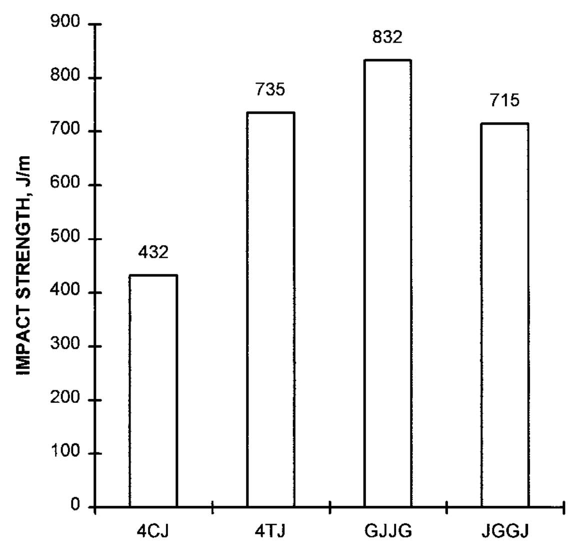

Figure 5 Unnotched impact strength of different jute–LDPE boards.

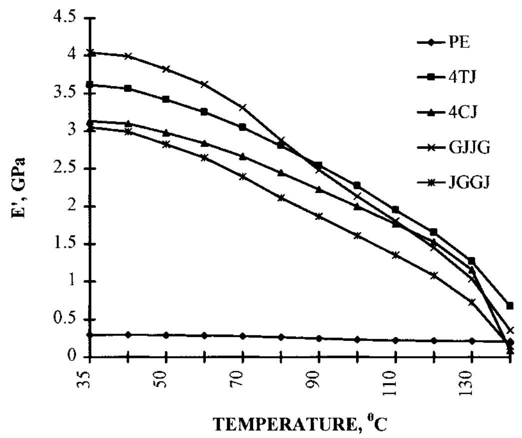

Figure 6 Variation of the storage flexural modulus with temperature for different jute–glass–polyethylene composites.

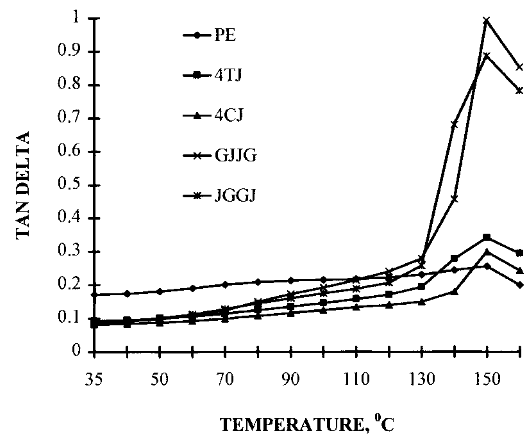

Figure 8 Variation of tan δ with temperature for different jute–glass–polyethylene composites.

analysis was done by the resonance mode. The highest E' value was shown by the sample having glass on the outer surface. This was reversed when glass was in the middle. The treated sliver showed a higher value than the control one. In every case there was reduction in value with an increase in temperature. In the tan δ plot there was large difference between the peak height of jute and the jute–glass board. The thermal conductivity value of glass (0.002 cal/cm/°C/s) is about 3.5 times more than the jute (thermal conductivity, 0006 cal/cm/°C/s).[12] So when glass layer was on the outer surface, the penetration of heat in the core was faster. This softened the thermoplastic matrix, increased the mobility, and in turn, increased the tan δ value. When glass was in the middle, the tan δ value is a little bit low, and least when there was no glass. This is shown in Figure 8. This is in agreement with the earlier experiments on the effect of moisture in the polyamide, the effect of vinyl acetate in EVA, and the postcuring of phenolic.[13] In every case there was increase in magnitude of tan δ values arising out of the flexibility. In the plot of E'' values, for the jute board the peak was broader than the glass–jute board, i.e., transition was sharper for the latter. This is evident from the Figure 7.

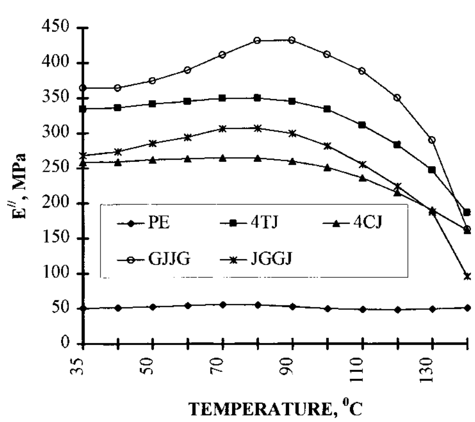

Figure 7 Variation of the loss flexural modulus with temperature for different jute–glass–polyethylene composites.

SEM Study

An attempt has been made to investigate the reason for increase in strength of the consolidated jute sliver in the LDPE matrix. Other instrumental analysis like FTIR and DSC did not confer any clue. However, from the scanning electron micrograph we found that splitting of the fibers took place during the consolidation of sliver. These resulted in an increase in surface area, and there-

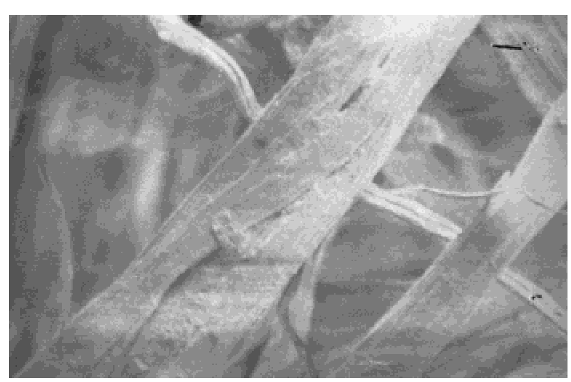

Figure 9 SEM micrograph of untreated jute fiber.

Figure 10 SEM micrograph of treated (consolidated) jute fiber.

fore, better bonding. SEM micrographs are shown in Figures 9 and 10.

Jute fiber in the presence of water swelled, and when it was compressed under heat and pressure, the water came out in the form of steam with the splitting of fibers resulting in a fineness of fibers. Similar observations were made while working with kenaf fibers for applications in the field of textiles.[14]

Interface studies were carried out to investigate the fiber surface morphology and fiber–polymer interface by an SEM. Figures 11 to 13 show the micrographs of impact-fractured specimens of 4CJ, 4TJ, and GJJG boards. In 4TJ, the pullout fiber surface layer was found to be teared off after impact failure. This proved a better adhesion between the matrix and the treated fiber. In GJJG, on the glass surface several beads of discrete matrix was evident, leaving the remaining area clean.

CONCLUSION

Flexural Behavior

There was marginal increase in flexural strength after consolidation of the sliver. However, the

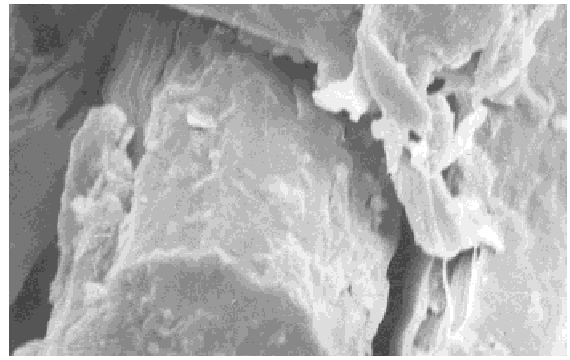

Figure 12 SEM micrograph of impact-fractured fiber pullout of 4TJ.

presence of glass on the outer surface has a better effect on strength than in the middle. Similar observations were also made for flexural modulus.

Tensile Behavior

The increase in tensile properties were observed after treatment. The presence of glass did not contribute to strength properties over treated jute. However, it increased the modulus of the board.

Impact Behavior

Among mechanical properties maximum gain was in impact strength. Other observations were very similar to flexural properties.

DMA Study

The remarkable observation in the DMA study was the large difference of tan δ values of jute and jute–glass hybrid board.

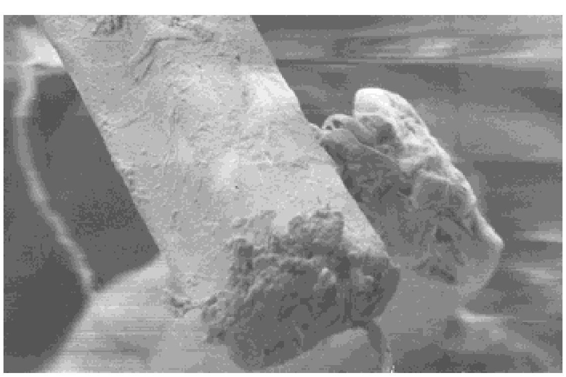

Figure 11 SEM micrograph of impact-fractured fiber pullout of 4CJ.

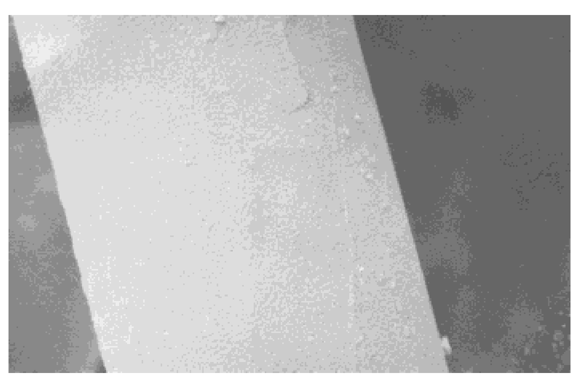

Figure 13 SEM micrograph of impact-fractured fiber pullout of GJJG.

SEM Study

The splitting of fibers was observed after consolidation. Better adhesion between treated jute and LDPE was also observed in the fiber–polymer interface.

In conclusion, the aqueous consolidation of jute sliver is found to improve the mechanical properties of the jute sliver–LDPE composites, and this is further pronounced by hybridization with glass.

NOMENCLATURE

4CJ four layers of control jute sliver
4TJ four layers of treated jute sliver
JGGJ treated jute sliver one layer each at top and bottom and CSM in the middle two layers
GJJG one layer CSM each at top and bottom and two layers treated jute sliver in the middle

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