Effect of Graft Copolymerization of Mixtures of Acrylamide and Methyl Methacrylate on Mechanical Properties of Jute Fibers of Different Compositions

PREMAMOY GHOSH, DEBAPRASAD DEV, ASISH KUMAR SAMANTA

Department of Polymer Science and Technology, Calcutta University, College of Science and Technology, 92, Acharya Prafulla Chandra Road, Calcutta 700 009, India

ABSTRACT: The role of persulfate-induced graft copolymerization of mixtures of acrylamide and methyl methacrylate at 50°C in modifying mechanical properties of jute fibers of different compositions was studied in a limited aqueous system following a pretreatment technique. Results obtained indicate that such a process admits a good scope for modification of mechanical properties of jute fiber depending on degree of grafting achieved and compositional variations of (1) the feed monomer mixture and (2) the multiconstituent jute itself, consequent to selective removal of lignin and hemicellulose to different extents from the fiber. Low to moderate removal of hemicellulose is more effective than a similar degree of removal of lignin from jute in rendering the fiber more amenable to vinyl grafting using the mixed monomer system without being adversely affected with respect to tensile properties. © 1998 John Wiley & Sons, Inc. J Appl Polym Sci 68: 1139–1147, 1998

Key words: graft copolymerization of jute; mechanical properties of vinyl-grafted jute; vinyl grafting on delignified and hemicellulose-depleted jute

INTRODUCTION

Jute, a lignocellulosic bast fiber, is grown extensively in India and some neighboring countries. It is biodegradable as well as renewable by agro efforts. However, jute faces stagnation in production and application due to stiff competition from some synthetic substitutes. Efforts are being vigorously pursued to develop newer and improved products from jute with wider application prospects through its chemical modification, including graft copolymerization of selected vinyl and related monomers.[1-8] The multicellular and multiconstituent nature of jute,[9,10] however, poses some problems in modifying it by graft copolymeriza-

tion[11-12] using peroxy compounds such as $K_2S_2O_8$, H_2O_2, and other oxidizing agents as initiators under thermal or photochemical conditions. In most cases with jute fiber, very low degrees of grafting were reported compared with those reported for graft copolymerization of cellulose; presence of lignin in jute is reported to cause a prominent retarding or inhibitory effect. It is also known that jute loses a part of its lignin or hemicellulose constituents during chemical treatments such as bleaching and chemical texturization.[13-14]

Even though vinyl grafting on jute has been the subject of many investigations, studies of the effect of such grafting on the mechanical properties of jute from which hemicellulose or lignin is selectively and progressively removed has not attracted much attention as yet. In this article we report effects of graft copolymerization of a mixture of acrylamide (AAm) and methyl methacrylate

Table I Lowering of Lignin Content and Associated Changes in Jute on Treatment with 0.7% NaClO$_2$

Time of Treatment (min)	Weight Loss (%)	Changes in Composition of Jute		
		α-Cellulose Content (%)	Lignin Content (%)	Hemicellulose Content (%)
—	—	61.72	13.52	22.81
10	4.51	61.52	10.16	21.91
30	9.42	61.22	6.20	21.22
60	12.91	60.61	3.90	20.61
120	17.32	60.12	1.40	20.22

Fiber : liquor ratio = 1 : 50 (w/w); temperature: 100°C; time: 10–120 min; concentration of NaClO$_2$ = 0.7% in water.

(MMA) on jute and chemically modified jute where the chemical modification was accomplished by selective and progressive removal of lignin or hemicellulose constituents from the fiber.

EXPERIMENTAL

Materials

Analytical grade AAm and stabilized MMA monomer were obtained from E. Merck, India Chemicals (Calcutta, India). MMA was purified by the usual procedures involving dilute alkali wash, drying, and vacuum distillation. Potassium persulfate (K$_2$S$_2$O$_8$), and copper sulfate (CuSO$_4$, 5H$_2$O) used as initiator components for polymerization were also obtained from E. Merck India; sodium chlorite (NaClO$_2$) and sodium hydroxide used for the removal of lignin and hemicellulose, respectively, from jute were obtained from BDH-Glaxo, India.

Scouring and Defatting of Jute

Raw jute fiber (*Corchorus capsularis*) obtained locally was scoured by treating with a 2% solution of a nonionic detergent at 70°C for 30 min using a fiber–liquor ratio of 1 : 50 (w/w) followed by washing with water and drying. The scoured fiber was then defatted by refluxing with 2 : 1 (v/v) benzene–alcohol mixture for 24 h; it was dried in air and finally under vacuum at 40°C. For experimental purposes, reference to use of jute means use of scoured and defatted jute.

Progressive Removal of Lignin and Hemicellulose from Jute

Progressive removal of lignin from scoured and defatted jute was accomplished[13] by treatment of the fiber with 0.7% NaClO$_2$ solution in distilled water at boiling temperature for specified time periods at pH 4.0 using a fiber–liquor ratio of 1 : 50 (w/w). It was followed by washing with water and treatment with 2% sodium metabisulfite solution at 50°C for 30 min. The fiber was then washed with distilled water and dried. This procedure resulted in lowering of lignin content of scoured jute from 13.52% to 10.16, 6.2, 3.9, and 1.4% for treatment with 0.7% NaClO$_2$ for 10, 30, 60, and 120 min, respectively (Table I).

Jute having progresively lower hemicellulose content was prepared[11] by reacting scoured jute for 30 min at 25°C with solutions of selected concentrations (1% to 18%) of NaOH using a fiber–liquor ratio of 1 : 50 (w/w) in each case. It was followed by washing with distilled water, neutralizing with 1% acetic acid solution, further washing with distilled water to acid-free condition, and finally drying in vacuum at 40°C. Hemicellulose content of scoured jute dropped from 22.81% to 20.31, 15.71, 12.41, and 11.23% for treatment with 1, 5, 10, and 18% NaOH solutions, respectively (Table II).

Estimation of α-cellulose, hemicellulose, and lignin contents of jute substrates was carried out following standard procedures.[14–16]

Graft Copolymerization

Known weight (1 g) of dry jute fiber, scoured, defatted, and chemically modified by different ex-

Table II Lowering of Hemicellulose Content and Associated Changes in Jute on Treatment with NaOH

| | | Changes in Composition of Jute | | |
NaOH (%)	Weight Loss (%)	α-Cellulose Content (%)	Lignin Content (%)	Hemicellulose Content (%)
—	—	61.72	13.52	22.81
1	4.10	61.04	12.62	20.31
5	9.10	61.00	12.11	15.71
10	13.6	60.42	11.62	12.41
18	15.3	60.20	11.34	11.23

Fiber : liquor ratio = 1 : 50 (w/w); temperature: 25 $\pm$ 1°C; time: 30 min; concentration of NaOH: 1% to 18% in water.

tents of selective removal of lignin and hemicellulose, was soaked in an aqueous solution containing $K_2S_2O_8$ (0.08 mol L^{-1}) and $CuSO_4$ (0.008 mol L^{-1}) for 20 min using a fiber–liquor ratio of 1 : 10 (w/w). The jute substrate was thereafter squeezed hard between parallel, horizontally placed, perforated, stainless-steel plates under a dead load of 2 kg for 5 min to remove excess solution as much as possible. The overall uptake of $K_2S_2O_8$ and copper sulfate was calculated from the increase in weight after squeezing, assuming no preferential absorption. Independent titrimetric (iodometric) analysis[17] of $K_2S_2O_8$ pickup or $CuSO_4$ pickup, using 2% solution in each case, was also done on separately soaked jute samples. In either case the agreement between the iodometric result and the calculated value (from weight gain) was within 5%. The squeezed sample was then taken in a stoppered 100-mL conical flask, flushed with a stream of purified N_2 for 5 min, tightly stoppered, and exposed to light from a pair of 40-watt fluorescent tube lamps for 30 min to obtain pretreated jute substrate. To the so-called "pretreated" (photoexposed in presence of $K_2S_2O_8$ and Cu^{2+}) fiber samples, requisite volumes of MMA and aqueous solution of AAm of known concentration (10%) were quickly and successively added under N_2 cover. For use of a low water content, relevant polymerizations are said to have been done in a limited aqueous system.

The conical flask was then placed in a thermostatted bath maintained at 50°C and graft copolymerization was allowed to proceed in the limited aqueous system over a specified time period. The gross polymer product was washed with a water–alcohol (1 : 1) mixture[18] and dried in vacuum at 40°C to a constant weight. The ungrafted free polymer (MMA–AAm copolymer) was isolated from the gross product by successive extraction for 24 h each, using water, acetone, and dimethylformamide (DMF) under reflux in a Sohxlet apparatus.[18] The residue was then dried in air and finally in vacuum at 45°C. The dried residue expectedly contains the graft copolymer of jute (or modified jute) and, in an extreme case, also some ungrafted fiber, if part of the jute substrate escaped grafting.

Measurement of Tensile Properties

Jute fiber samples (scoured or subjected to different extents of removal of lignin and hemicellulose and subsequent vinyl grafting on them using selected mixtures of MMA and AAm monomers) were conditioned at 27 $\pm$ 2°C and 65% relative humidity for 72 h before evaluation of their tensile properties using a Zwick 1445 CRT Universal Tensile Testing Machine. A test length of 30 mm for the fibers and a crosshead speed of 10 mm min^{-1} were employed and an average of 50 tests was taken for each sample.[1,19] The initial modulus (at 0.5% extension) was also recorded in each case and the average linear density (tex) of the conditioned fibers was determined from weights of 50 pieces of fiber, each of 5-cm length.

RESULTS AND DISCUSSION

Preliminary attempts to graft-copolymerize a mixture of MMA and AAm monomers on scoured and defatted jute soaked with $K_2S_2O_8$ solution

Table III   Graft Copolymerization of a Mixture of AAm and MMA on Jute Fiber, Showing Effect of Pretreatment (Initial Photoexposure) of Jute Fiber on Degree of Grafting

$CuSO_4$, $5H_2O$ (g)	Time of Photoexposure of $K_2S_2O_8$/$CuSO_4$-Soaked Jute Before Monomer Addition (min)	Grafting (%)
—	0	4.6–5.1
—	30	9.3–10.2
0.004 ± 0.0002	0	11.2–13.3
0.004 ± 0.0002	30	20.0–31.5

Scoured jute: 1.0 g; AAm: 0.4 g; MMA: 1.0 g; temperature: 50°C; time of polymerization: 3 h; $K_2S_2O_8$: 0.04 ± 0.002 g; water: 4 mL.

without initial photoexposure produced a relatively low degree of grafting ($\leq$5%). However, initial photoexposure of the substrate fiber soaked in the initiator ($K_2S_2O_8$) solution (pretreatment technique) led to somewhat-improved grafting effects (up to 10% grafting) using the said monomer mixture (Table III). The relevant observations are much in tune with reports on graft copolymerization of cellulosic and lignocellulosic fibers made earlier from our laboratory.[1–3,6,18,20–23] The overall poor or low degree of grafting on jute without pretreatment or initial photoexposure was somewhat overcome[2] (grafting up to 11–13%) by use of low concentrations of $CuSO_4$ along with $K_2S_2O_8$ initiator in the graft copolymerization; however, grafting as high as 20–30% was readily obtained if initial photoexposure was allowed using $K_2S_2O_8$ and $CuSO_4$ combination as the initiator (Table

III). Cu^{2+} apparently reacts or complexes with the phenolic moieties of lignin in jute, thereby preventing their oxidation to the quinonoid form, thus minimizing or eliminating the chance of inhibition or retardation of free radical graft copolymerization by the influence of $K_2S_2O_8$ or similar other oxidants used as the initiator.[2,23] Initial photoexposure of the initiator-soaked jute fiber significantly favored grafting, limiting the scope for formation of ungrafted (or free) copolymers of the monomer mixture, thus effecting improved grafting efficiency.[18,20,21]

Effect of Variation of AAm Monomer Content for a Fixed MMA Content

Table IV reveals how the percent of grafting varies with use of different amounts of AAm for a fixed amount of MMA and how some physical and mechanical properties of the fiber change with subsequent changes in the degree of grafting. For a fixed MMA content, progressive increase in AAm content apparently leads to an initial slow falling trend in grafting and hence in the tex value for the fibers. However, for use of AAm in an amount of more than 30% of MMA, the composition of the grafted copolymer being formed and the chemical and physical nature of the overall system containing the fiber–monomer–copolymer–solvent (water) mixture change such that a developing trend of gel effect or autoacceleration effect[18,22]—causing a rising trend in the tex value—ensues and it reverses the trend of change in the degree of grafting (and degree of conversion,[18] not shown), i.e., an upward turn is seen to follow in the values of the said pa-

Table IV   Graft Copolymerization of Mixtures of AAm and MMA on Jute Fiber: Effect of Variation of AAm Content in Monomer Mixture

AAm (g)	MMA (g)	Grafting (%)	Tex (g/Km)	Tenacity (N/Tex)	Modulus (N/Tex)	Elongation at Break (%)
0.0	0.0	—	2.45	0.340	19.26	1.74
0.0	1.0	32.0	3.20	0.300	20.95	1.44
0.1	1.0	32.1	3.20	0.476	24.37	1.75
0.25	1.0	29.0	3.10	0.386	22.34	1.45
0.30	1.0	27.5	3.08	0.355	21.90	1.38
0.40	1.0	31.0	3.18	0.356	22.38	1.39
0.50	1.0	34.0	3.28	—	—	—

Scoured jute: 1.0 g; water: 5 mL; $K_2S_2O_8$ (polymerization initiator): 0.04 g; $CuSO_4$, $5H_2O$: 0.004 g; time of polymerization: 3 h; temperature of polymerization: 50°C.
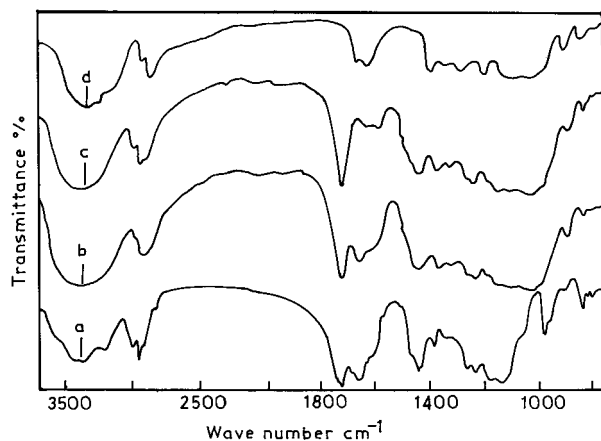
Figure 1 Infrared spectra of (a) a copolymer of MMA and AAm; (b) jute grafted with a copolymer of MMA and AAm; (c) jute grafted with PMMA; (d) jute grafted with PAAm.

rameters, as in Table IV. The initial falling trend in degree of grafting with increase in AAm content against a fixed MMA content may be understood on the basis of a role of the hydrophilic AAm monomer and polymer/copolymer derived from it acting as a physical barrier[18] for approach of the hydrophobic monomer MMA toward the jute macroradicals generated in the aqueous medium. Graft copolymerization using a high AAm : MMA ratio was not technically sound as in that case the products obtained under comparable conditions were found to be in a swollen gel form from which isolation of the graft copolymer was uncertain and difficult and the fiber lost its usefulness as a textile item.

The reported[24,25] reactivity ratios for copolymerization of the two monomers AAm (M_1) and MMA (M_2) in aqueous system at 70°C ($r_1 = 2.29$ and $r_2 = 2.345$) indicate the likelihood of random copolymerization with a more prominent tendency for homopropagation than cross propagation. The grafted-on copolymer chains would have higher incidences of long or short sequences of blocks of each of the two monomeric units, rather than their alternating sequences, with obvious dependence of the block length of a given monomeric unit on the feed monomer ratio and on relative ease of approach of the two monomers to the radical sites on the swollen chain molecules of jute and the grafted-on propagating chains. The degrees of swelling of the initial preformed polymer (jute) and of the overall system containing jute and unbound or jute-

bound copolymers of MMA and AAm are likely to increase with time and hence with percent of conversion, though to different extents depending on the amount of water and monomer ratio taken for a given amount of the fiber. Kinetic literature[26] indicates that k_p^2/k_t for AAm homopropagation, is higher (60 times) than that for MMA homopropagation, k_p and k_t being rate constants of propagation and termination reactions, respectively. The different kinetic effects and the physical barrier due to differences in the hydrophilic nature of the two monomers or of the two monomeric units incorporated in the bound or unbound copolymer structures give rise to a net result showing an initial dropping trend and a final improving trend in the degree of grafting with progressive increase in the proportion of the hydrophilic monomer AAm. For $S_2O_8^=$-induced photopolymerization of mixtures of the two monomers (MMA 1.0 g, AAm 0.3–0.5 g) to low conversions (<10%) in the absence of jute, the polymer products showed complete insolubility in water or acetone indicating no measurable formation of homopolymers [polyacrylamide (PAAm) or poly(methylmethacrylate) (PMMA)]; the copolymers, however, showed good solubility in DMF.

Grafting of PMMA only (i.e., grafting without the use of AAm in the monomer system) under conditions given in Table IV, causes the tenacity of the jute fiber and elongation at break (EB) to drop measurably, though with slight enhancement in the modulus value. Grafting of PMMA, a stiff polymer, to the extent of nearly 30–32% makes jute fiber gain in stiffness. However, for use of a mixture of MMA and AAm where AAm content was only 10% of MMA content, and for nearly the same level of grafting achieved ($\sim$ 32%), the enhancement in the tex value of the jute fiber was much the same, as expected; but significant enhancements in both tenacity and modulus values of the fiber were observed with little lowering or change in the EB percentage value. Use of AAm, a hydrophilic monomer (yielding a hydrophilic polymer) in a small proportion along with a hydrophobic monomer (MMA) apparently allows improved penetration of the monomer molecules deeper into the intercellular spaces of the multicellular jute fiber having inherently a good degree of hydrophilicity, thereby allowing the fiber cells to become cemented together by the copolymers formed more effectively; incorporation of the hydrophilic AAm moieties in the grafted copolymer in a small proportion infuses

Table V Graft Copolymerization of AAm and MMA Mixture on Jute Fibers: Effect of Selective Removal of Lignin on Degree of Grafting and Some Physical Properties of the Fiber

| Fiber Identity | | Some Textile-Related Properties | | | | | | | |
| (a) Ungrafted Jute | (b) Grafted Jute | Tex (g/Km) | | Tenacity (N/Tex) | | Modulus (N/Tex) | | Elongation at Break (%) | |
Lignin Content (%)	Grafting (%)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
				Initial Jute, No Delignification					
13.52	15.0	2.45	2.81	0.34	0.36	19.26	20.34	1.74	1.69
				Jute Delignified to Different Extents					
10.16	11.15	2.34	2.17	0.38	0.40	20.94	23.55	1.80	1.89
6.20	12.62	2.22	2.76	0.16	0.32	16.39	23.91	1.31	1.38
3.90	27.34	2.13	3.03	0.16	0.22	16.12	18.67	1.29	1.24
1.40	27.36	—	—	—	—	—	—	—	—

MMA: 0.80 g, AAm: 0.20 g; water: 4 mL; $K_2S_2O_8$ (polymerization initiator): 0.04 g; $CuSO_4$, $5H_2O$: 0.004 g; time of polymerization: 3 h; temperature of polymerization: 50°C. Properties under (a) relate to ungrafted fiber; those under (b) relate to grafted fibers.

internal plasticization and is amply reflected in the retention of the EB of the fiber practically unchanged despite substantial gafting (>30%).

Use of a progressively higher proportion of AAm in the MMA–AAm monomer mixture under otherwise comparable conditions of grafting imparts changes in the tensile properties of the fiber for a close or comparable degree of grafting, as shown in Table IV. With use of higher proportions of AAm (from 10% to 25% of MMA), a prominent lowering in the tenacity, modulus, and EB values follows, though with further increase in the proportion of the hydrophilic monomer (AAm), the said parameters of the correspondingly grafted jute fiber further change marginally or tend to level off, as in Table IV.

Infrared Spectra

Infrared spectra of (a) a copolymer of MMA and AAm, (b) jute grafted with a copolymer of MMA and AAm, (c) jute grafted with PMMA, and (d) jute grafted with PAAm are shown in Figure 1. A broad, strong absorption band appearing in the $3100-3600$ cm^{-1} region in each of these spectra corresponds to O—H stretching[27] of the cellulosic, hemicellulosic, and lignin constituents of jute and of moisture, and is also due to weak N—H stretching for the samples containing amide groups [Fig. 1(a,b,d)]. The weak N—H stretching peak at 3200 cm^{-1} for the copolymer from MMA and AAm taken in 1 : 1 molar ratio, [Fig. 1(a)] becomes much weaker and masked in the spectrum for the corresponding grafted jute sample (31.0% grafting), much as a consequence of dilution effect [Fig. 1(b)]. The absorption peaks at $2900-3050$ cm^{-1} correspond to C—H stretching in the respective resin/grafted jute samples. Presence of ester groups in the copolymer or in copolymer-grafted jute due to the incorporation of MMA moieties in the polymer structure is indicated by the sharp absorption peak at $1720-1740$ cm^{-1} (C=O stretching). The presence of amide groups in the said copolymer structures is evidenced[18,22,27] by an absorption band in the 1660 cm^{-1} region in Figure 1(a,b,d); here, two close absorption peaks, one for C=O stretching and the other for N—H deformation, in slightly upfield and downfield regions, respectively, become coupled almost to merge into a single band, particularly for the jute sample grafted with PAAm [Fig. 1(d)] and copolymer of MMA and AAm [Fig. 1(b)]. The prominent absorption band in the 1450 cm^{-1} region common to the spectra of the four samples corresponds to C—H deformations.[27]

Table VI   Graft Copolymerization of AAm and MMA Mixture on Jute Fibers: Effect of Selective Removal of Hemicellulose on Degree of Grafting and Some Physical Properties of the Fiber

Fiber Identity		Some Textile-Related Properties							
(a) Ungrafted Jute	(b) Grafted Jute	Tex (g/Km)		Tenacity (N/Tex)		Modulus (N/Tex)		Elongation at Break (%)	
Hemicellulose Content (%)	Grafting (%)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Initial Jute, No Removal of Hemicellulose									
22.81	15.0	2.45	2.81	0.34	0.36	19.26	20.34	1.74	1.69
Defatted Jute with Varied Degrees of Hemicellulose Removal									
20.31	31.42	2.35	3.18	0.36	0.32	20.11	21.25	1.70	1.68
15.70	38.36	2.23	3.30	0.41	0.22	21.52	19.81	1.84	1.51
12.41	42.64	2.12	3.32	0.47	0.33	22.83	22.70	2.56	1.52
11.23	42.18	—	—	—	—	—	—	—	—

MMA: 0.80 g, AAm: 0.20 g; jute fibre: 1.0 g; $K_2S_2O_8$ (polymerization initiator) = 0.04 g; water = 4 mL; time of polymerization: 3 h; temperature of polymerization: 50°C; $CuSO_4$, $5H_2O$ = 0.004 g. Properties under (a) relate to ungrafted fibers; those under (b) relate to grafted fibers.

Effect of Progressive Removal of Lignin from Jute

Table V reveals how the degree of grafting of copolymers of MMA–AAm varies for progressive removal of lignin from jute and also how different degrees of delignification effected changes in tensile properties of jute fiber itself and of the grafted-on jute fiber. Treatment of jute fiber with $NaClO_2$ for increasing time periods from 10 to 120 min resulted in progressive mass loss from the fiber and a lowering of its lignin content from 13.52% to 1.4%, as shown in Table I. Corresponding changes in α-cellulose and hemicellulose contents are also shown in Table I.

Low to moderate degrees of delignification (lowering of lignin content from 13.52% to a little over 6%) expectedly cause the tex value of the fabrics decrease and grafting on them under the conditions given in Table V results in a slightly lower degree of grafting than that for the fiber with no delignification. Extensive delignification of jute fiber (lignin content dropping to 3.9–1.4%) renders it more amenable to grafting in view of the fact that a much greater reactive and accessible surface area on the fiber is now made available for grafting to take place consequent to relatively heavy mass loss from the base fiber due to the chemical action (Table

I); as high as 27% grafting is now readily achieved, as opposed to 11–15% achieved otherwise (Table V). The tex value of the grafted fiber thus increases substantially. Loss in jute fiber tex value on delignification is partly or more than compensated for by vinyl grafting on the delignified fiber. For very slight or limited delignification (lowering of lignin content from nearly 13.5% to about 10%), the tenacity values of the ungrafted and grafted fibers, as shown in Table V, are seen to increase measurably; the trends of change in modulus and EB are also much the same.

For delignification leading to moderate lowering of lignin content in jute (i.e., to about 6%), the fiber becomes substantially weak, showing relatively low tenacity, modulus, and EB at the same time. All these property parameters can, however, be substantially and satisfactorily improved by grafting of a copolymer of MMA and AAm under conditions as in Table V, much as a consequence of the cementing effect of the grafted copolymer formed. Further lowering of lignin content to < 4% weakens the fiber severely but makes it more responsive to grafting at the same time. The net result is a higher degree of grafting which, however, fails to repair

the initial damage in fiber strength. Both the corresponding ungrafted and grafted delignified jute samples now show poor tenacity and modulus, appear somewhat brittle, and become particularly unsuitable for use as durable textile fibers.

Effect of Progressive Removal of Hemicellulose from Jute

Relevant data are shown in Table VI. Hemicellulose removal to a higher extent from jute was effected by treatment of the fiber using a higher concentration of alkali, as described earlier. The compositional changes and overall mass loss are shown in Table II. The trends of change in tex values on hemicellulose removal and subsequent grafting of a copolymer of MMA and AAm follow a pattern similar to that for lignin removal as shown in Table V and are much in tune with expectations.[2] For nearly comparable mass loss on delignification and hemicellulose removal separately, the latter apparently generates higher active fresh surface area from inside the fiber to cause a much improved degree of grafting on the fiber in the subsequent step of graft copolymerization under comparable conditions (Tables V and VI).

Initial low degree of removal of hemicellulose (from nearly 22.8% for no alkali treatment to about 20.3% for treatment with 1% NaOH for 30 min at 25°C, as in Table II) renders the fiber much more amenable to vinyl grafting, causing a greater than 2-fold increase in degree of grafting under comparable conditions (Table VI). The tenacity and modulus of jute fiber continue to change as a result of initial mass loss and subsequent mass gain due to alkali treatment and subsequent vinyl grafting, respectively; consequently, the tex values of the resulting fibers also change correspondingly, as shown in Table VI. Observed data clearly indicate that lowering of hemicellulose content in jute from initial 22.8% to about 12% by alkali treatment does not weaken the fiber or adversely affect its tensile property profile.

Thus, for improved vinyl grafting on jute accomplished to incorporate an improved range of properties in the fiber and to make the fiber suitable for nontraditional and diverse applications,[3] low to moderate removal of hemicellulose is more prospective than a low to moderate degree of delignification; moderate delignification renders jute critically weak (Table V); but moderate removal of hemicellulose makes the fiber appear even stronger and more resilient (showing much higher EB). The correspondingly grafted fibers of up to 40% grafting of a copolymer of MMA and AAm, as in Table VI, also show a better balance of strength, modulus, and EB. Such grafted fibers/fabrics have also been reported to have substantially improved dyeability using basic and reactive dyes, and high rot resistance, retaining up to 70% of the tensile strength against zero retention of strength for raw, delignified, and hemicellulose-depleted jute fiber samples when subjected to a standard test condition for microbiological attack or degradation.[1] The prospects of development of applications of fabrics from such grafted jute fibers in furnishing, upholstery, and apparel sectors, in geotextiles, and as filter cloths are rated high.

REFERENCES

1. P. Ghosh and P. K. Ganguly, *J. Appl. Polym. Sci.,* **52,** 77 (1994).
2. P. Ghosh, P. K. Ganguly, and S. K. Bhaduri, *Eur. Polym. J.,* **30,** 743 (1994).
3. P. Ghosh and P. K. Ganguly, *Plast. Rubber Composites Processing Appl.,* **20,** 171 (1993).
4. P. Ghosh, S. Biswas, and C. Datta, *J. Material Sci.,* **24,** 205 (1989).
5. J. Das, A. K. Mohanty, and B. C. Singh, *Text. Res. J.,* **59,** 525 (1989).
6. P. Ghosh, A. R. Bandyopadhyay, and S. Das, *J. Macromol. Sci., Chem.,* **A19,** 1165 (1983).
7. S. K. Majumdar and W. H. Rapson, *Text. Res. J.,* **34,** 1007 (1964).
8. A. K. Mohanty and B. C. Singh, *J. Appl. Polym. Sci.,* **34,** 1325 (1987).
9. B. C. Kundu, K. C. Basak, and P. B. Sarkar, in *Jute in India,* Indian Central Jute Committee, Calcutta, India, 1959, p. 40.
10. S. G. Barker, *J. Text. Inst.,* **30,** 273 (1939).
11. P. Ghosh and C. Dutta, *J. Mater. Sci.,* **24,** 205 (1989).
12. A. K. Mohanty, *J. Macromol. Sci.-Rev. Macromol. Chem. Phys.,* **C27,** 593 (1987).
13. A. Mukherjee, P. K. Ganguly, and D. Sur, *J. Text. Inst.,* **84,** 348 (1993).
14. *TAPPI Standard and Suggested Methods.* T.22205-74, Technical Association of the Pulp and Paper Industries, Atlanta, 1974.
15. A. B. Sengupta and H. J. Callow, *J. Text. Inst.,* **40,** 650 (1949).
16. C. Doree, *The Methods of Cellulose Chemistry,* Chapman and Hall, London, 1947, pp. 20–26.

17. A. I. Vogel, *Textbook of Quantitative Inorganic Analysis,* Longman, London, 1978, p. 357, 389.
18. P. Ghosh and D. Dev, *Eur. Polym. J.,* **32,** 165 (1996).
19. S. Samajpati, A. Majumdar, and P. C. Dasgupta, *Text. Res. J.,* **49,** 8 (1979).
20. P. Ghosh and C. Datta, *J. Mater. Sci.,* **25,** 445 (1990).
21. P. Ghosh and S. K. Paul, *J. Macromol. Sci., Chem.,* **A20,** 169 (1983).
22. P. Ghosh, D. Dev, and A. K. Samanta, *J. Appl. Polym. Sci.,* **58,** 1727 (1995).
23. N. S. Hon, *J. Polym. Sci., Polym. Chem. Ed.,* **13,** 2641 (1975).
24. G. Saini, A. Leoni, and S. Franco, *Macromol. Chem.,* **144,** 235 (1971).
25. R. Z. Greenley, *J. Macromol. Sci., Chem.,* **14,** 427 (1980).
26. J. Ulbricht, *Polymer Handbook,* J. Brandrup and E. H. Immergnt, Eds., Interscience, New York, 1968.
27. W. Kemp, *Organic Spectroscopy,* English Language Book Society edition, Macmillan, London, 1986, p. 25.