Mechanical Studies of Methyl Methacrylate Treated Jute and Flax Fibers under UV Radiation

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ABSTRACT: Jute and flax fibers were improved under UV radiation using methyl methacrylate (MMA) mixed with methanol (MeOH). There was a 30% enhancement of tenacity for these fibers against 3–8% grafting of MMA with the fibers. Incorporation of 1% of one of the additives 2-ethyl hexyl acrylate (EHA), urea (U), or *N*-vinylpyrrolidone to MMA + MeOH solution increased the grafting very slightly and enhanced the tenacity of jute by 110% and flax by 50%. Enhancement of elongation of the treated fibers was up to 30%. © 1998 John Wiley & Sons, Inc. J Appl Polym Sci 70: 843–848, 1998

Key words: mechanical studies; methyl methacrylate; jute and flax fibers; UV radiation

INTRODUCTION

Jute and flax are both natural fibers and are important industrial materials for making bags, sacks, carpets, and so forth. These products are not very durable and are rather easily destroyed and decomposed. Various treatments have been used to improve the properties of the natural fibers.[1,2] Low grade jute and its cuttings have been improved by microbial activity.[3] Easy moisture absorption by the natural polymer materials is one of the reasons for their short life. Combining synthetic polymers with the natural polymers under chemical or radiation treatment brings about a composite that has less affinity toward water and is thus hydrophobic in nature. Such modification provides relatively strong, durable, and sustainable materials. Many workers have prepared such composites by treating jute with monomers[4,5] under γ radiation or with urethane oligomer[6,7] under UV radiation. In all these studies, there was a large uptake of the impregnating solutions. The initial increase of tenacity was followed by decreased tenacity against higher polymer loadings. This was particularly true with the γ radiation system.[8] This trend was improved under UV irradiation. The tenacity was enhanced by 200% with increased elongation up to 60% when jute was treated with an urethane acrylate under UV radiation in the presence of certain additives.[9] In these cases, there was a large uptake of the impregnating materials.

EXPERIMENTAL

Materials

Jute (*tossa*) was collected from local market in Bangladesh and flax fibers were obtained from the Technical University of Berlin (Germany). Methyl methacrylate (MMA), *N*-vinylpyrrolidone

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(NVP), 2-ethyl hexyl acrylate (EHA), urea, and methanol (general grade) were used as obtained from Merck Co.

Methods

MMA was mixed with methanol at different proportions as shown in Table I. To these solutions, 1% of an additive of NVP, urea, or EHA and 2% of photoinitiator (Irgacur 184) were added. The Irgacur 184 is a white crystalline powder of 1-hydroxycyclohexylphenyl ketone; its melting point (mp) is 44–48°C, and its molecular weight (mw) is 204.3. The fiber samples (20 cm) were soaked for 10 min in these solutions and then irradiated with a Minicure-200 UV lamp (1ST-Technik, Germany). The lamp (254–313 nm) has 2-kW light intensity. The conveyor speed was 4 m/min and the Minicure-200 has an efficiency within ±1%. The samples were irradiated several times under the UV lamp to ensure the full curing of MMA onto the fibers. Polymer loading (PL) of the treated samples was determined by drying the samples for 20 h at 105°C in an oven to a constant weight. Polymer loading is calculated from the knowledge of weight increased after the UV radiation followed by drying at 105°C. This means

$$\% \text{ PL} = 100\ (W_t - W_o)/W_o$$

where W_t is the weight of the treated dry sample and W_o is the weight of the virgin sample before any treatment. The results are given in Table II.

Grafting was determined after extracting a known weight of the treated sample in hot benzene for 48 h in a Soxhlet unit. The loss of weight after the extraction yields the grafting. This means

$$\% \text{ grafting} = 100\ (W_e - W_o)/W_o$$

where W_e is the weight of the sample after the extraction. The results are given in Table II.

The treated samples were then used to determine the tensile properties (strength, TS, and elongation at break, E_b) with the help of an Instron machine (model 1011). The gauge length was 1.0 cm, and the crosshead speed was 2.5 mm/min.

Table I Composition of Formulations

A	F	MMA	MeOH	IRG-184
Blank	A1	10	88	2
	A2	30	68	2
	A3	50	48	2
	A4	70	28	2
	A5	90	8	2
EHA	A6	10	87	2
	A7	30	67	2
	A8	50	47	2
	A9	70	27	2
	A10	90	7	2
NVP	A11	10	87	2
	A12	30	67	2
	A13	50	47	2
	A14	70	27	2
	A15	90	7	2
Urea	A16	10	87	2
	A17	30	67	2
	A18	50	47	2
	A19	70	27	2
	A20	90	7	2

A, additive, 1% (w/w); F, formulations (% w/w).

RESULTS AND DISCUSSION

PL and Grafting

Polymer loading of MMA with jute was 6–8% while that with flax was only 2–3%. The maximum polymer loading was obtained at an initial monomer level of 70% MMA for both jute and flax. The extent of polymer loading and grafting slightly increased when additives were incorporated into the solutions. The maximum values of PL and grafting were mostly obtained at 50% MMA. The highest PL value was obtained with EHA addition for jute (16%) and flax (6%), followed by NVP and urea addition. EHA can easily diffuse into the fiber cellulose molecule compared to NVP and urea molecules that have some of the molecular parts under the plane of the molecule, and this arrangement causes a slightly inconvenient diffusion during the polymerization process. Low values of polymer loading yielded low grafting of MMA onto the fibers. Flax fibers yielded lower values of PL and grafting compared to jute fibers. This is possibly because of the different cellulose arrangements in the jute and flax fibers and needs further investigation. However, the flax has higher cellulose content (75%) and tenacity (449 MPa) than jute fiber (63% and 293 MPa, respectively).[10]

Table II Polymer Loading and Grafting of Jute and Flax Fibers

		Polymer Loading (%)		Grafting (%)	
A	F	Jute	Flax	Jute	Flax
Blank	A1	7.1	2.0	7.0	1.8
	A2	6.3	2.1	5.9	2.0
	A3	7.7	3.1	7.0	3.0
	A4	8.3	3.2	7.7	3.1
	A5	6.3	2.0	5.9	1.9
EHA	A6	8.3	2.1	7.7	2.0
	A7	8.3	2.1	7.7	2.0
	A8	15.8	5.9	13.7	5.5
	A9	11.3	3.2	10.0	3.1
	A10	4.6	2.0	3.5	1.9
NVP	A11	10.0	2.9	9.1	2.7
	A12	10.0	3.1	9.1	3.0
	A13	12.5	2.2	11.0	2.0
	A14	10.0	2.2	9.1	2.0
	A15	7.8	2.3	7.0	2.0
Urea	A16	6.7	2.2	6.0	2.1
	A17	5.3	2.3	8.0	2.2
	A18	9.1	3.5	5.0	3.4
	A19	4.7	2.2	4.5	2.1
	A20	4.6	2.1	4.1	2.0

Tensile Properties

Jute and flax fibers were treated with MMA + MeOH solutions prepared at different proportions. The tensile properties were measured of the treated fibers that were cured under UV radiation with different passes. Enhancement of these properties was monitored and expressed by tenacity factor, T_f, and elongation factor, E_f. The tenacity factor is the ratio of the tenacity of the treated sample (TS_t) to that of the untreated sample (TS_o). This means $T_f = TS_t/TS_o$. Similarly, the elongation factor was obtained. Here

$$E_f = E_{b_t}/E_{b_o}$$

where E_{b_t} is the elongation at break of the treated fiber and E_{b_o} is the elongation at break of the untreated sample. The results of the tenacity factors of the jute samples are plotted against the concentration of MMA in Figure 1 as a function of the number of passes of the samples through the UV radiation. It was observed that the tenacity of treated jute increased with UV radiation (represented by the number of passes), as well as with increase of MMA concentration. The maximum tenacity was attained at 50% MMA, and then the tenacity decreased as MMA concentration increased up to 90%. This indicated that the 50% MMA + MeOH solution gave the most favorable condition for easy diffusion of the impregnating solution into the cellulose backbone during the equilibrium condition required for the polymerization process under the UV radiation system. A similar observation was also made with wood plastic composites: the highest polymer loading and tensile strength were attained with a impregnating solution that contained 50% monomer.[11] The highest TS (tenacity) was obtained with three passes after which the strength decreased. This could have been caused by the damage done to the samples by the higher radiation dose. The decrease in tenacity with the increase in MMA after the 50% MMA concentration could have arisen for various reasons, such as the fibers became brittle at higher MMA concentration and the rates of radical–radical combination and recombination reactions between them (radical) were also differ-

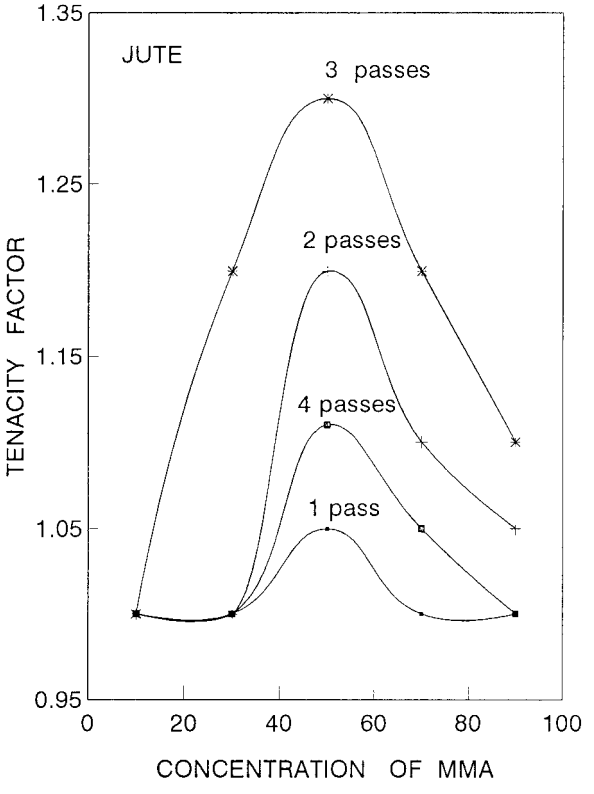

Figure 1 Tenacity factor of treated jute against MMA concentration as a function of UV dose represented by the number of passes.

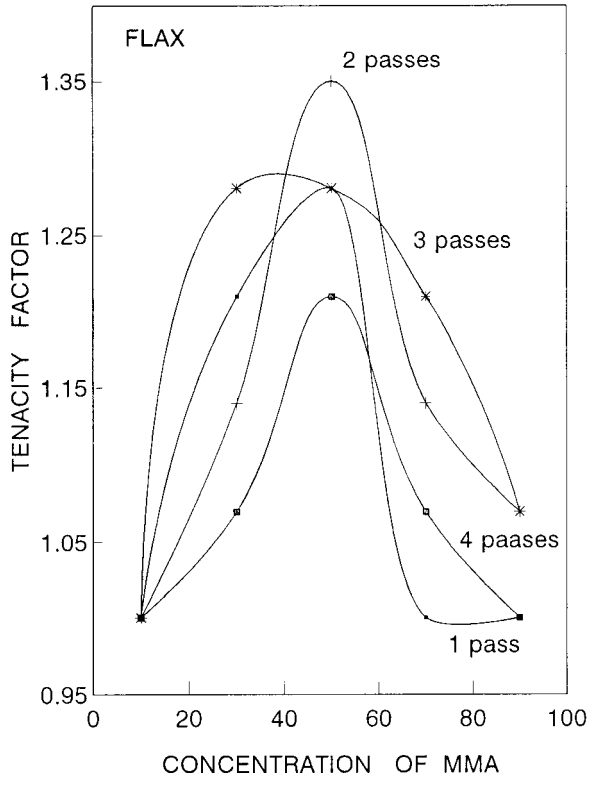

Figure 2 Tenacity factor of treated flax against MMA concentration as a function of UV dose represented by the number of passes.

ent from that of the optimum conditions that occur at 50% MMA concentration. A 30% enhancement of the tenacity of jute was obtained when the jute was treated with 50% MMA solution with three passes under the 2-kW capacity UV lamp.

There was an approximate 35% enhancement in the tenacity of the flax fiber that was treated with 50% MMA with two passes under the UV lamp. The results are shown in Figure 2; tenacity factor is plotted against MMA concentration as a function of the number of passes under the UV lamp. After attaining the maximum tenacity enhancement at 50% MMA concentration, the tenacity decreased with the flax fiber.

Effect of Additives

Having established the optimum MMA concentration (50%) and UV radiation dose represented by the number of passes (three passes for jute and two passes for flax) for attaining the highest tenacity (Figs. 1, 2), small amounts (1%) of different additives (EHA, NVP, or urea) were incorporated into the formulations in order to study the effect of these additives on the enhancement of tensile properties. The effect on the tenacity (T_f) and on the elongation factors (E_f) of jute and flax are both given in Table III. The enhancement of tenacity for jute was about 100% and for flax was about 50%, depending on the additives used. The elongation was increased between 20% (jute) and 40% (flax). This is more clearly demonstrated by plotting tenacity (T_f) and elongation (E_f) factors in Figure 3 (jute) and Figure 4 (flax) against additives. The tenacity of jute fibers was increased to 30% when these fibers were treated with MMA + MeOH solution (without any additive) under UV radiation. The tenacity enhancement for flax was about 35% (Fig. 4). The elongation at break was enhanced to 20% for both fibers in the absence of any additive under the above conditions.

It is interesting to note that treated flax has greater tenacity than treated jute, although the grafting of jute is almost double the grafting of flax with MMA (Table II). Jute and flax fibers both had a 25% gain in stretching ability (elongation) because of MMA grafting with these fibers. The enhancement of tenacity of the treated jute was further increased to 100, 50, and 110% by incorporating EHA, NVP, and urea, respectively, into the MMA + MeOH solutions. The tenacity enhancement in the flax fibers was up to 50% from 35% in the presence of the additives. Although there was some increment of elongation for flax materials from 23 to 45% by the addition of EHA, there was little change in the increment of elongation for jute fibers by the incorporation of any additive into the MMA + MeOH solution.

Incorporation of the additives (EHA, NVP, or urea) enhanced the tenacity more for jute than for flax (Figs. 3, 4). The highest tenacity increment was obtained in the presence of urea, a carboamide molecule. The lone pair of electrons around the nitrogen atom plays an important role in augmenting the reaction with the MMA molecule through the free radical mechanism process. Although NVP also has a carboamide molecule, it causes some steric restriction for diffusion into the MMA and cellulose molecules compared to urea molecules because a part of the NVP molecule remains below the plane of the molecule. On the other hand, EHA has a simple long plane molecule that easily diffuses into the reaction zone during the polymerization process under UV

Table III Tenacity and Elongation Factors of Jute and Flax Fibers

		Tenacity Factor								Elongation Factor							
		Jute				Flax				Jute				Flax			
A	F	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Blank	A1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.80	1.20	1.00	0.80
	A2	1.00	1.00	1.20	1.00	1.21	1.14	1.28	1.07	1.00	1.20	1.00	0.90	0.80	1.00	1.00	0.75
	A3	1.05	1.20	1.30	1.11	1.28	1.35	1.28	1.21	1.00	1.20	1.20	0.90	1.20	1.20	1.00	1.20
	A4	1.00	1.10	1.20	1.05	1.00	1.14	1.21	1.07	0.90	1.20	1.00	0.90	1.00	1.00	1.10	0.75
	A5	1.00	1.05	1.10	1.00	1.00	1.07	1.07	1.00	0.90	1.20	0.90	0.90	0.80	1.00	0.80	0.75
EHA	A6	1.34	1.50	1.50	1.37	1.00	1.50	1.50	1.50	1.00	1.20	1.20	1.00	1.20	1.40	1.20	1.00
	A7	1.50	1.67	1.67	1.67	1.50	1.50	1.50	1.50	1.00	1.20	1.20	1.00	1.00	1.40	1.20	1.20
	A8	1.67	1.80	2.00	1.50	1.50	1.50	1.50	1.50	0.90	1.20	1.20	0.90	1.00	1.40	1.20	1.00
	A9	1.50	1.50	2.00	1.50	1.50	1.50	1.50	1.50	0.75	1.20	1.20	0.90	1.00	1.20	1.20	1.00
	A10	1.34	1.50	1.67	1.50	1.00	1.28	1.28	1.00	0.90	1.20	1.00	0.90	0.75	1.00	1.20	0.75
NVP	A11	1.00	1.25	1.15	1.00	1.00	1.28	1.28	1.00	0.75	0.90	0.90	0.75	0.75	0.80	1.00	0.80
	A12	1.00	1.25	1.16	1.00	1.28	1.50	1.28	1.28	0.75	0.90	0.75	0.60	0.80	1.00	1.20	1.00
	A13	1.16	1.33	1.50	1.16	1.28	1.50	1.28	1.00	0.75	1.20	0.90	0.75	1.00	1.28	1.28	1.28
	A14	1.16	1.16	1.33	1.16	1.00	1.28	1.28	1.00	0.75	0.90	0.90	0.60	1.00	1.00	1.20	1.00
	A15	1.15	1.16	1.15	1.00	1.00	1.28	1.28	1.00	0.75	0.90	1.20	0.75	0.80	1.00	1.20	1.00
Urea	A16	1.37	1.37	1.37	1.16	1.40	1.50	1.50	1.28	1.00	1.20	1.00	0.75	1.00	1.20	1.28	1.00
	A17	1.37	1.50	2.10	1.50	1.50	1.50	1.50	1.50	0.90	1.20	1.20	0.75	1.20	1.28	1.28	1.20
	A18	1.80	2.10	2.10	2.00	1.50	1.50	1.50	1.50	1.20	1.20	1.20	1.00	1.20	1.20	1.28	1.20
	A19	2.00	2.00	2.07	2.00	1.40	1.50	1.50	1.37	0.90	1.20	1.20	1.00	1.00	1.00	1.20	1.00
	A20	1.37	1.50	1.37	1.37	1.28	1.50	1.50	1.28	0.65	1.00	1.00	0.75	1.00	1.20	1.00	1.00

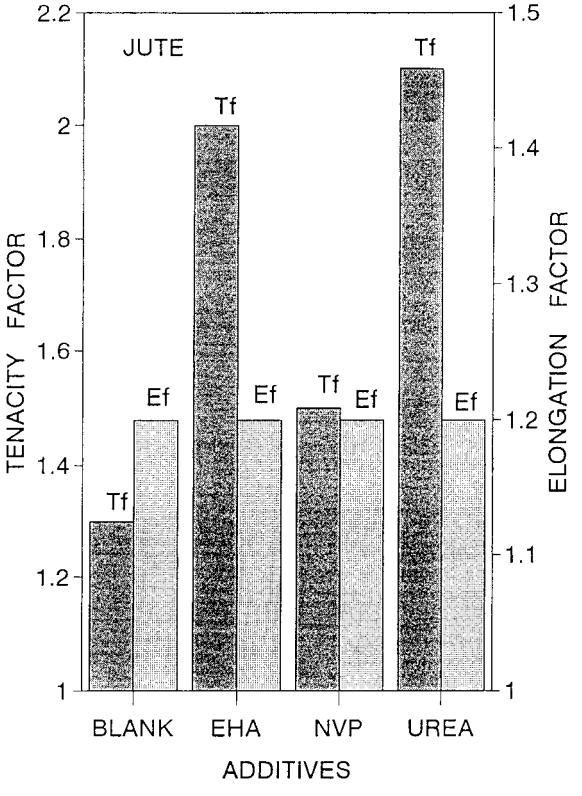

Figure 3 The highest values of tenacity factor ($Y1$ axis) and elongation factor ($Y2$ axis) of treated jute versus additives.

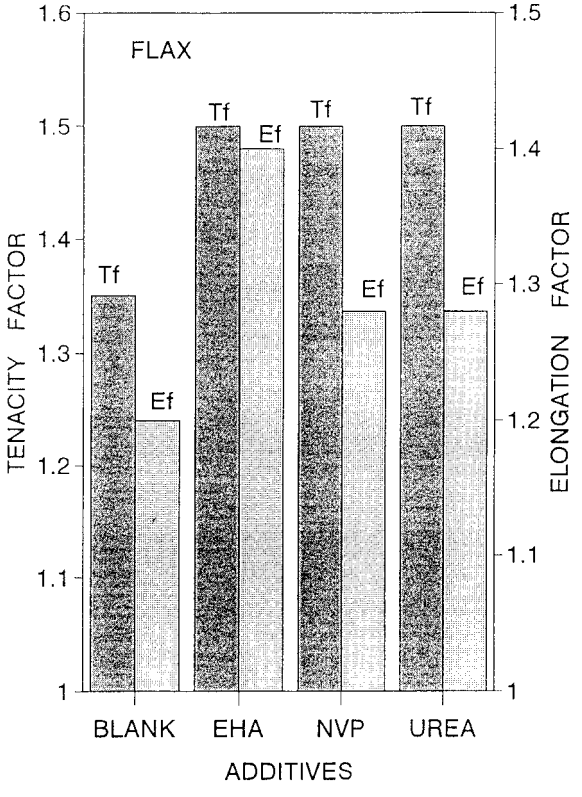

Figure 4 The highest values of tenacity factor ($Y1$ axis) and elongation factor ($Y2$ axis) of treated flax versus additives.

radiation at the time of equilibrium. Somehow all the additives (EHA, NVP, urea) are able to contribute a similar effect and activity with the flax cellulose molecules (unlike the jute cellulose) to yield the same tenacity increment. This needs further investigation, particularly on the structural arrangement of the flax molecule compared to that of the jute molecule.

CONCLUSION

The mechanical strength (tenacity) of jute and flax fibers was enhanced by 110 and 50%, respectively, when these fibers were treated with MMA in methanol solutions under UV radiation, which is a significant achievement. The extent of grafting MMA onto these fibers varied between 3 and 14%. The treated fibers also gained stretching ability up to 45% for flax and 25% for jute. A study of the mechanisms of these property enhancements is one of the important major projects that need sophisticated and precise experimental approaches for future research.

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