In Situ Jute Yarn Composite with HEMA Via UV Radiation

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ABSTRACT: Jute yarns soaked for 30 min in 2-hydroxyethylmethacrylate (HEMA) + MeOH solutions at different proportions [1-20% HEMA in MeOH (v/v)] were irradiated *in situ* with a UV lamp for different periods. The treated jute yarns that were washed in acetone after the irradiation to remove the unused excess monomer HEMA gained about 10% polymer loading with enhanced tensile strength (80%) and elongation (95%). The tenacity was not further increased by incorporation of a minute amount (1%) of novel additives into the HEMA + MeOH solutions, but elongation was enhanced up to 140% when the additive urethane acrylate (1%) was mixed with the solution. © 1999 John Wiley & Sons, Inc. J Appl Polym Sci 71: 841–846, 1999

Key words: jute yarn; natural fiber; yarn composite; UV radiation; degradable composite; jute composite

INTRODUCTION

Natural polymers (jute, flax, wood, etc.) are biodegradable and easily decomposable in the environment and are thus environmentally friendly compared to the synthetic polymers (polystyrene, polypropylene, polyvinyl chloride, etc.) that are not biodegradable and cause pollution of the environment. But synthetic polymers have higher tensile strength, sustainability, and durability compared to the natural polymers. Thus, natural polymers are treated with different materials in different modes to increase their strength, durability, and sustainability while possessing their inherent degradable character to maintain an environment free of pollution.

With this aim in mind, many researchers developed different products with the natural polymers. This article deals with only one natural polymer: jute. Some developed jute reinforced

EXPERIMENTAL

Materials

Jute yarns were collected from the local market in Bangladesh. The monomer HEMA and methanol were procured from BASF (Germany). The addi-

thermoplastic¹ while others prepared jute plastic composites using different impregnating solutions under γ radiation^{2,3} or UV radiation.^{4–7} Recently a degradable jute plastic composite⁸ was prepared with specially formulated solutions using UV radiation. Most of the impregnating solutions used in the above systems were multicomponent, but the present investigation deals in a single impregnating monomer, 2-hydroxyethylmethacrylate (HEMA), solution in methanol. The polymer loading was kept at a minimum level to maintain the inherent degradable nature of the jute, as well as to reduce the amount of impregnating monomer, thereby minimizing the production cost while substantially enhancing the tensile properties.

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tives such as ethylhexyl acrylate (EHA), N-vinyl pyrrolidone (NVP), acrylamide (AM), urea (U), and urethane acrylate (Eb-264, UA) were procured from Aldrich (Germany).

Methods

Jute yarns were dried at 105°C for 20 h to remove moisture and stored in a desiccator. The dried yarns (15 cm long and weighing about 2 g) were immersed for 30 min in HEMA + MeOH solutions mixed at different proportions (1-20%) of HEMA with MeOH in test tubes that were placed in a rotatory rack that moved around a global UV lamp (100 W). During the radiation the test tubes spinned around their own axes while rotating around the lamp that was hung in the middle. This arrangement ensured equal radiation to all the test tubes containing different samples. The irradiation period varied from 5 to 120 min. After the desired irradiation the jute yarns were withdrawn from the test tubes and washed in acetone by simply dipping the samples in acetone for 5 min; then the samples were dried at 105°C for 20 h. The polymer loading of HEMA with the jute yarns was determined on the basis of weight gained by the jute sample after the entire treatment process.

Tensile properties (strength TS and elongation at break E_b) of the jute yarn samples were directly measured with an Instron machine (model 1011) at a crosshead speed of 0.003 m/min and a gauge length of 1.2 cm.

The water uptake of treated and untreated samples was determined by immersing the substrates in water contained in a static water bath at 25°C. The samples were kept immersed in water with suitable means. The uptake of water was periodically monitored to find the profile of water uptake. Before taking the weight, the wet sample was dabbed between two filter papers (Whatmann no. 4) for 30 s. The increase in weight of the wet sample determined the water uptake.

RESULTS AND DISCUSSION

Polymer Loading

Polymer loadings (PL) were determined of the jute yarns that were soaked in HEMA + MeOH solutions containing different HEMA concentrations (1-20%) and irradiated under a UV lamp at



Figure 1 Polymer loading of HEMA with jute yarns at different HEMA concentrations against different UV radiation periods.

different lengths of irradiation time. The results are shown in Figure 1 where PL is plotted against the time of UV irradiation as a function of HEMA concentration. The PL values increase quite sharply at the initial irradiation time. The maximum polymerization occurs within 0.5 h of the irradiation, after which the polymer loading decreases sharply up to 60 min of irradiation and then the decrease is slow; in fact, there is a steady PL values afterward. The decrease in PL values after the attainment of the maximum PL values could be caused by the radiation degradation at higher UV doses. However, the highest PL value is achieved with 3% HEMA solution, after which the PL maximum values decrease with increase in HEMA concentration. The PL maximum value is obtained with 30 min irradiation. The decrease in PL values at higher HEMA concentration could be associated with the fact that the homopolymerization reaction between HEMA + HEMA radicals is dominant than the HEMA + jute cellulose reaction.



Figure 2 Enhancement of jute yarns (tenacity factor) with HEMA at different HEMA concentrations against different UV radiation periods.

Tensile Properties

The change in tensile properties of the jute yarns as a result of the above treatment with HEMA is expressed by the tenacity and elongation factors T_f and E_f . The TS factor or T_f is the ratio of the TS or tenacity of the treated jute sample (TS_t) to that of the untreated sample (TS₀). This means T_f = TS_t/TS_0 . Similarly, $E_f = Eb_t/Eb_0$, where Eb_t is the elongation at break of the treated jute sample and Eb_0 is that of the untreated virgin sample. The T_f values of different samples are plotted in Figure 2 against irradiation time as a function of HEMA concentration. The tenacity increases with irradiation time up to 15 min and then decreases as the irradiation increases beyond 15 min. Some of the samples, particularly the sample that contains 20% HEMA, attains tenacity that is even lower than that of the virgin jute sample when the sample is irradiated beyond 40 min. The highest TS value is produced by the sample treated with 3% HEMA, followed by 2% HEMA. The highest PL is achieved with 30-min irradiation (Fig. 1), whereas the highest TS is obtained with 15-min irradiation; the corresponding PL is about 5% at which the highest TS is attained. The jute samples possessing the maximum PL values are quite brittle and the samples break very easily. This may be one of the reasons that the highest TS values are not obtained with the samples containing the highest PL values.

The enhancement in elongation of the treated jute yarns is depicted in Figure 3 where the E_f is plotted against irradiation time as a function of HEMA concentration. The maximum E_b values are obtained mostly at 15-min irradiation, and then the elongation decreases. However, there is an E_b maximum at 20-min irradiation for 3% HEMA. There is sharp rise in elongation at the initial irradiation period with each sample. The highest E_b is attained by the sample treated with 5% HEMA and the lowest is by the 1% HEMA sample.

The highest values of tensile properties $(T_f \text{ and } E_f)$ and PL obtained with samples treated with



Figure 3 Enhancement of jute yarns (elongation factor) with HEMA at different HEMA concentrations against different UV radiation periods.



Figure 4 Different properties of jute yarns treated under UV radiation at different HEMA concentrations.

solutions of different HEMA concentrations are shown in bars in Figure 4 against the concentration of HEMA. It is observed that 5% HEMA solution induced the highest elongation to the jute yarn while 3% HEMA produced the highest tenacity with the sample. This is followed by the 2% HEMA sample. The bars give a comparison for different properties induced on the samples treated with different solutions under UV radiation.

Effect of Additives

A 3% HEMA solution induces better properties to the treated jute samples as observed above. A minute amount (1%) of an additive selected from EHA, NVP, AM, U, and UA was incorporated into the 3% HEMA solution containing 97% MeOH. The values of PL, T_f , and E_f are shown in the bars in Figure 5 against different additives used; the Y_1 axis represents polymer loading while Y_2 axis indicates tensile properties $(T_f \text{ and } E_f)$. Observe that the incorporation of these additives into the HEMA : MeOH [3 : 97 (v/v)] solution has substantially reduced the tensile properties $(T_f \text{ and } E_f, Y_1)$ axis) and PL $(Y_2 \text{ axis})$ more for all the additives except U and UA than the corresponding properties of the jute samples treated with HEMA + MeOH only (without any additive). However, the E_f values were enhanced to about 135% by UA and to 118% by U. This enhancement could be caused by the augmentation process rendered by the carboamide group (=N-CO-) present with

U and UA. These additives (EHA, NVP, AM, and U) enhanced the tensile properties of other systems of wood composites^{9,10} and jute composites¹¹ but in this particular case of UV radiation *in situ* with HEMA these additives were not found to induce any enhanced property to the treated jute yarns.

Effect of Coadditives

EHA is a monomer of low glass transition temperature $(T_g, -50^{\circ}C)$, and it induces enhanced elongation to the substrates. Methacrylated monomer is also known to produce a polymer film or coating that has a brittle character. Thus, most of the jute samples treated with HEMA in this particular investigation were brittle and the extent of brittleness varied, depending on the concentration of HEMA, as well as on the UV dose intensity. A low $T_{\boldsymbol{g}}$ monomer is expected to produce soft polymer film and loading unlike methacrylated monomer. Considering this viewpoint, EHA was incorporated as a coadditive into the HEMA + MeOH solutions that also contained different carboamide monomers such as NVP, AM, U, and UA. The results of PL, tensile properties $(T_f \text{ and } E_f)$ are shown by the bars in Figure 6 against each formulation (H = 3% HEMA, N = 1% NVP, U = 1% urea, UA = 1% urethane acrylate, and E = 1% EHA). By comparing the results of Figures 5 and 6, it is observed that the PL values were enhanced by the presence of EHA with NVP, AM, and U; but the PL value was



Figure 5 Different properties of jute yarns treated under UV radiation in the presence of different additives (1%) with 3% HEMA.

decreased with EHA + UA. Similarly, TS values were also enhanced by the presence of EHA with NVP, AM, and U but NOT with UA. Elongation was mostly decreased with NVP and AM; in these cases the E_b values were slightly increased by the presence of EHA.

Figure 5 shows that 1% UA enhanced the E_b value quite substantially. Thus, it is necessary to optimize its concentration in the solutions. The results of PL, E_f , and T_f values of the treated jute yarns against different UA concentrations clearly demonstrate that E_b increases with the increase of UA concentration up to 1% and decreases beyond 2% UA; but the values of TS and PL decrease with an increase in UA concentration in the solutions and steady PL and TS values are observed with a 1% UA concentration.

Water Uptake

Water uptake of the treated and untreated samples was monitored at 25° C. The results are shown in Figure 7 in which water uptake is plotted against water soaking time. Almost all the samples attained the maximum water uptake within the initial 5 min; there was a plateau after 20 min of soaking time in the treated samples while the untreated samples still continued to soak very slowly in the water. The untreated sample gained water uptake up to about 61% whereas the treated sample could soak up water by about 51–55%, depending on the time of radiation imparted to the sample.



Figure 6 Different properties of jute yarns treated under UV radiation in the presence of coadditives (1%) with 3% HEMA.



Figure 7 Water uptake of treated and untreated jute yarns.

CONCLUSION

Jute yarns treated with HEMA + MeOH solution under a low capacity lamp (100 W) attained an enhanced tenacity of 80% and a stretching ability of 95% when polymer loading of HEMA was 10% with the jute cellulose. This is significant information for diverse applications of jute and its products. Jute is biodegradable and is expected to behave so at such a low level of polymer loading (10%) with HEMA. This treatment may improve the shredding and resilience properties of the jute yarns. These properties are yet to be determined with the treated jute yarns.

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