Study on the Mechanical and Dielectric Properties of Photocured Jute Fabrics with 2-Hydroxyethyl Methacrylate

Mubarak A. Khan,[1] L. R. Das,[2] A. H. Khan,[2] F. Ahmed,[2] S. M. Badier Rahman[3]

[1]*Radiation and Polymer Chemistry Laboratory, Institute of Nuclear Science and Technology, Bangladesh Atomic Energy Commission, P.O. Box 3787, Dhaka-1000, Bangladesh*
[2]*Department of Physics, Jahangirnagar, University, Savar, Dhaka, Bangladesh*
[3]*Department of Biochemistry & Molecular Biology, Jahangirnagar University, Savar, Dhaka, Bangladesh*

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ABSTRACT: Jute fabric (Hessian cloth) was treated with 2-hydroxyethyl methacrylate (HEMA) under ultraviolet radiation in order to improve the mechanical and electrical properties. Concentration of the monomer 2-hydroxyethyl methacrylate (HEMA), radiation dose, and soaking time were optimized with respect to mechanical properties such as tensile strength and elongation at break of the treated and untreated Hessian cloth. The 10% HEMA, 15 min soaking time, and 15th pass of radiation rendered the best tensile properties. The variations of dielectric properties with temperature were measured at 10 kHz frequency. It was observed that dielectric constant and loss tangent (tan Ω) increased with increasing temperature up to the transition temperature and then decreased, and at the end become almost constant. The surfaces of treated and untreated jute were characterized by scanning electron microscope. © 2003 Wiley Periodicals, Inc. J Appl Polym Sci 89: 655–661, 2003

Key words: photocuring; jute fabrics; ultraviolet radiation; dielectric constant; loss tangent

INTRODUCTION

Jute is a complex polymeric substance, and is composed chiefly of cellulose, hemicellulose, and lignin. It is a natural biodegradable fiber. So, it keeps the environment free from pollution. Usually dielectric properties under the action of dc voltage offers very high resistance to the passage of electric current. The dielectric properties of jute are increased by photocuring of vinyl monomers. It can be used in preventing the leakage of electric charges in electrical engineering devices. Because of universal concern about environment pollution from synthetic fiber, scientists are becoming interested in natural fibers. Nowadays jute is loosing its demand in the local and foreign market. So, to save the economy of Bangladesh, we have to increase the use of jute in various fields. The survival of the use of jute, in competition with the synthetic fibers of the world, depends on the demand of jute as preferred material. So it must be constantly developed and improved in its physical and chemical properties to retain its demand status. Therefore, improving the quality of jute and jute products in terms of chemical, electrical, and physicomechanical properties has been receiving considerable attention in recent years. Improvement of jute fiber through ultraviolet (UV)-cured film of urethane acrylate was studied by Ali et al.[1] They investigated physical and mechanical properties of the UV-cured film; the role of plasticizers and water uptake were also studied. Though plasticizers decrease some textile properties of the UV-cured films, they substantially enhance the tensile strength of jute by 300%. Kahn et al.[2] prepared a number of formulations in the presence of plasticizers and monomers of different characteristics using urethane acrylate prepolymer with an aliphatic chain. Hessian cloth was treated with these formulations and the tensile properties of these jute plastic composites were found to increase. The degradation character of the composite was also studied. Modification of jute by grafting was reported by Varma et al.[3] Moisture absorption of jute fibers could be reduced significantly by treatment with graft copolymerization using methyl methacrylate (MMA). The tensile strength and elongation at break of jute fiber decreased on grafting whereas the initial modulus increased with increasing percentage of grafting. Patnaik et al.[4] reported the grafting copolymerization of acrylonitrile onto jute fiber using the lippuric acid redox initiator system. They also studied the effect of time, temperature, and monomer concentration on graft yield. Graft copolymerization of MMA onto jute fiber was reported by Haque et al.[5] using a ceric ion initiator. They studied the effects of temperature, time of reaction, monomer concentration, etc. They also found the percentages of grafting and grafting efficiency. The objective of this work is to improve

Correspondence to: Mubarak A. Khan (makhan@bangla.net).

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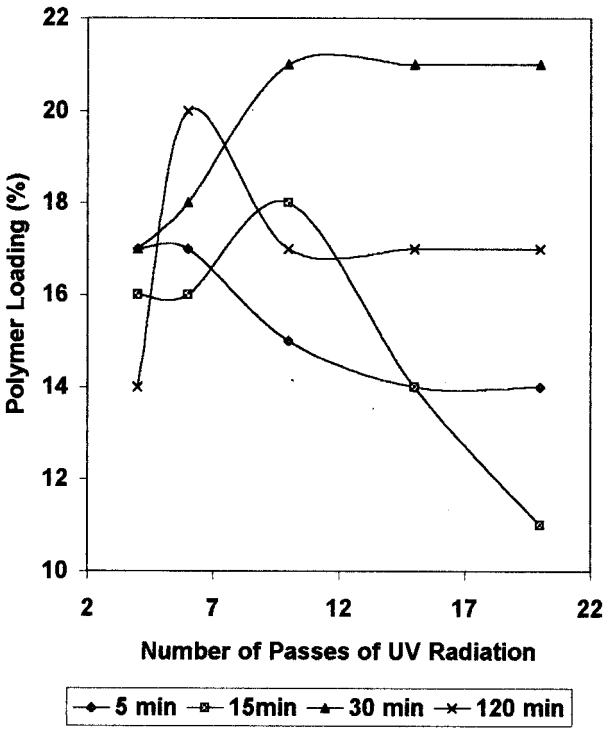


Figure 1 PL vs number of passes of UV radiation with respect to soaking time.

the mechanical and dielectric properties of jute fabrics by means of grafting of the monomer 2-hydroxyethyl methacrylate (HEMA) under UV radiation.

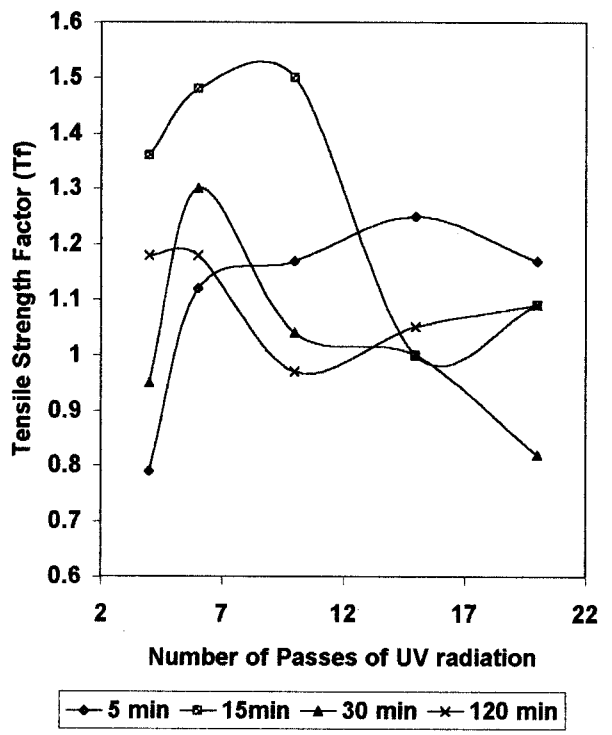


Figure 2 Tensile strength of Hessian cloth (Tf) vs number of passes of UV radiation with respect to soaking time.

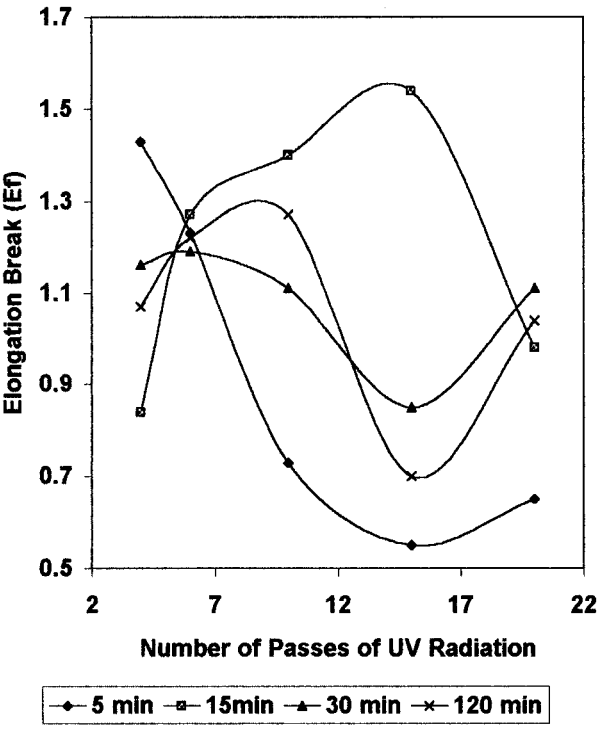


Figure 3 Elongation at break of Hessian cloth (Ef) vs number of passes of UV radiation with respect to soaking time.

EXPERIMENTAL

Materials

Hessian cloths (jute fabrics) were collected from Bangladesh Jute Research Institute (BJRI), Dhaka. The specimen cloth was cut into small pieces (5 × 3 in.) Then these pieces were dried at 105°C for 1 h to remove moisture. The samples thus made were ready for grafting. HEMA was procured Merck (Germany); the photoinitiator, Irgacure-907 [2-methyl-1-(4-methyl thiophenyl-2-morpholino-propanones], was received from Ciba–Geigy (Switzerland), and the solvent methanol was obtained from BDH (UK).

Methods

Preparation of solutions

Several percentages of monomer solutions were prepared in methanol. For this, 3, 5, 10, and 30% of monomer were taken in 95, 93, 88, and 68% of methanol, respectively, in different beakers in each of which 2% of photoinitiator (Irgacure-907) was added. Thus, the required formulation was made for each treatment. The jute samples were soaked in each of the above solutions for 5, 15, 30, and 120 min to optimize the soaking time. The soaked samples were irradiated under UV radiation, using IST-UV minicure (U-200-M-I-Tr, Germany), which gives 2 kW light intensity at 245–313 nm wavelength. The irradiated jute samples

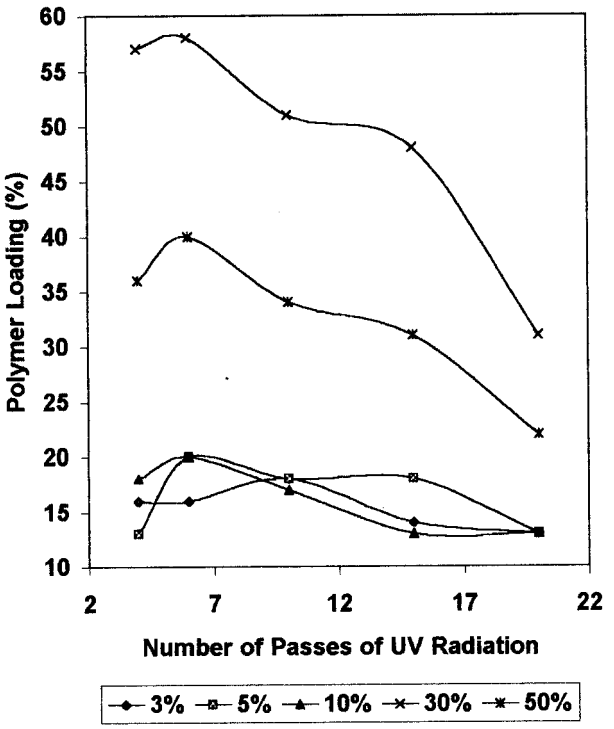


Figure 4 Polymer loading against number of passes of UV radiation with respect to monomer (HEMA) concentration.

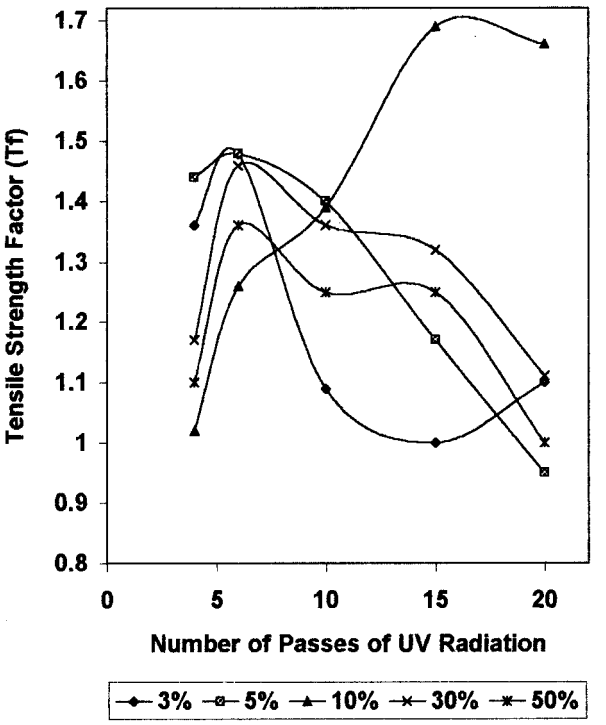


Figure 5 Tensile strength of Hessian cloth (Tf) against number of passes of UV radiation with respect to monomer (HEMA) concentration.

were washed with acetone for 6 h to remove the unreacted and homopolymer. Polymer loading (PL) values of the treated samples were determined from the weight increased after the UV radiation per unit initial weight before radiation. This means that PL (%) $= [(W_t - W_0)/W_0] \times 100$, where, W_t is the weight of the treated dry sample and W_0 the weight of the sample before treatment.

Tensile properties such as tensile strength (TS) and elongation at break (EB) of both treated and untreated Hessian cloths were directly measured by a tensile strength machine (Instron, model 1011, UK). From this TS factor (Tf) and Eb factor (Ef) were calculated, respectively, TS = TSt/TSo (TSt and TSo are the tensile strengths of the treated and untreated samples, respectively) and Ef = Ebt/Ebo (Ebt and Ebo are the elongation at break of treated and untreated samples, respectively).

Measurement of dielectric properties

The treated and untreated Hessian cloths were cut into very small pieces and then powdered for making tablets. For making tablets, an hydraulic press and dies were used. The dielectric constant ($\mathcal{D}$) was calculated from the measured capacitance of samples using the relation $\mathcal{D} = C/C_0$, where C is the capacitance of the samples and C_0 is the capacitance of the samples in vacuum. C_0 is calculated from the knowledge of the dimensions of the sample using the following relation

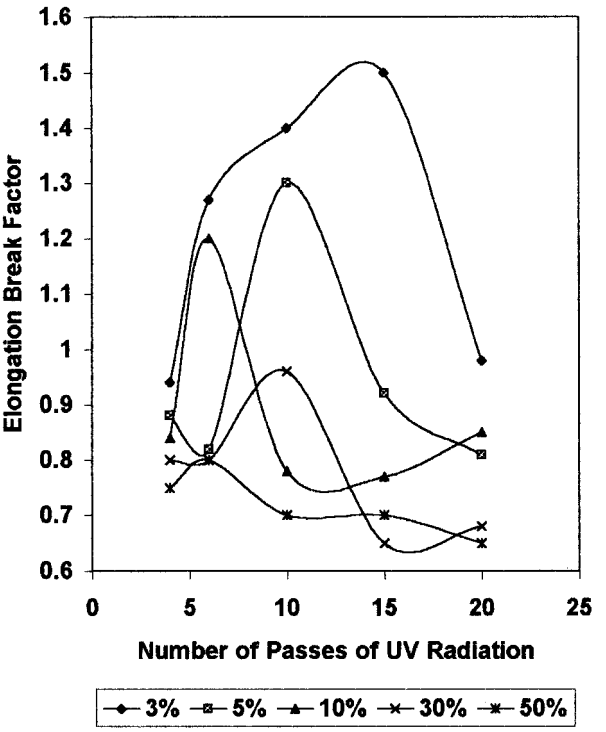


Figure 6 Elongation at break of Hessian cloth (Tf) against number of passes of UV radiation with respect to monomer (HEMA) concentration.

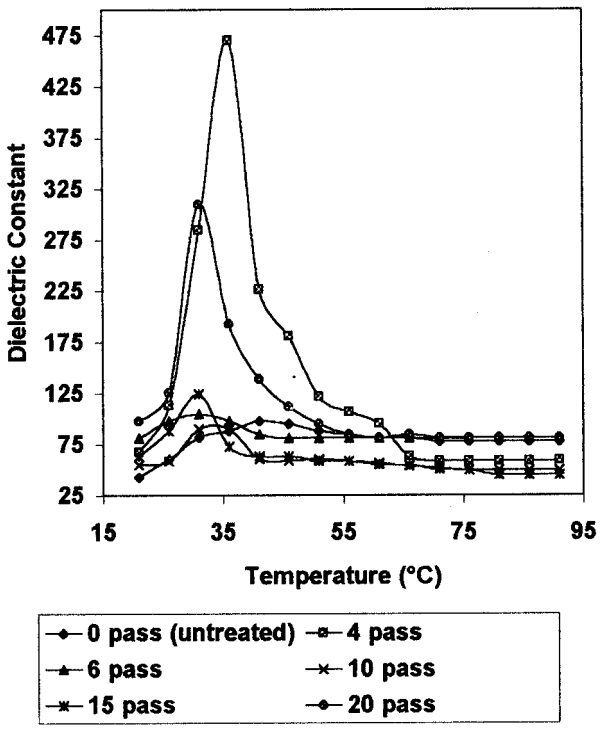


Figure 7 Variation of dielectric constant of virgin and 10% HEMA- treated jute with radiation intensities against temperature.

$C_0 = 0.8854 \times A/t$, where A is the area in cm^2 and t is the thickness in cm of the sample.

Environmental scanning electron microscopy

The treated and untreated jute (Hessian cloth) surface were examined by an environmental scanning electron microscope (ESEM) (model 2020, Electro Scan of Boston, MA). The ESEM was equipped with a LaB6 filament and was operated at an accelerating voltage of 20 kV with water vapor pressure ranging from 2–3 Tore. The working distance ranged from 8 to 10 mm.

RESULT AND DISCUSSION

Hessian cloths were cured with HEMA by using UV radiation. Then the effect of soaking time, concentration of monomer radiation dose on the extend of PL, and tensile properties were investigated. The dielectric properties like (1) dielectric constant and (2) loss tangent (tanΩ) of both treated and untreated fabrics were also investigated with variation of temperature. These are discussed below.

Optimization of soaking time

In order to optimize the soaking time Hessian cloth samples were soaked in 30% HEMA solution for different soaking time (5, 15, 30, and 120 min) and irradiated under a UV lamp. The PL (%) values of the treated Hessian cloths were plotted against the number of passes as a function of soaking time (Fig. 1). The PL values sharply increases with increasing radiation doses. But for 5 and 15 min soaking time after attaining a maximum value, the PL decreases. However, the highest value of PL is achieved for 30 min soaking time, after which PL values decrease with an increase in soaking time. The radiation-induced graft-copolymerization reaction on vinyl monomer onto cellulose backbone is affected by the diffusion of monomer in to the fiber.[6] The swelling of trunk polymer (cellulose) and the Trommsdroff effect of solvent on grafting also affected on grafting of monomer on to cellulose.[7] Soaking increases the cross-section area of the fiber as the same time the fiber surface becomes lustrous. As a result, the monomer can easily diffuse in the fiber and react with cellulose in a lower soaking time. In higher soaking time, the fiber became twisted, and shrinkage and changes its outer fibrillar layer.[8]

Tensile strength of the grafted Hessian cloth is determined and compared with those of the untreated Hessian cloth. The result is expressed as the tensile strength factor (Tf). The result is shown in the (Fig. 2), where tensile strength factor (Tf) is plotted against number of passes for different soaking times. The tenacity factor increases with the increase of soaking time up to 15 min and then decreases as the number of

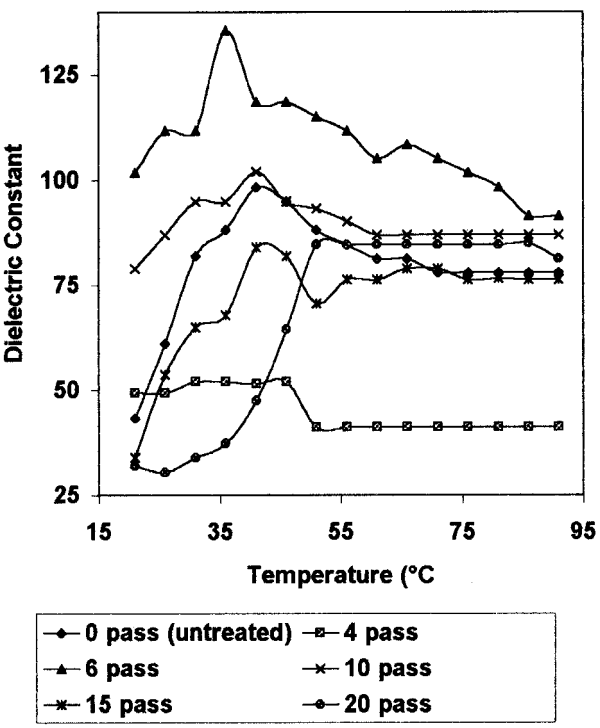


Figure 8 Variation of dielectric constant of virgin and 30% HEMA- treated jute with radiation intensities against temperature.

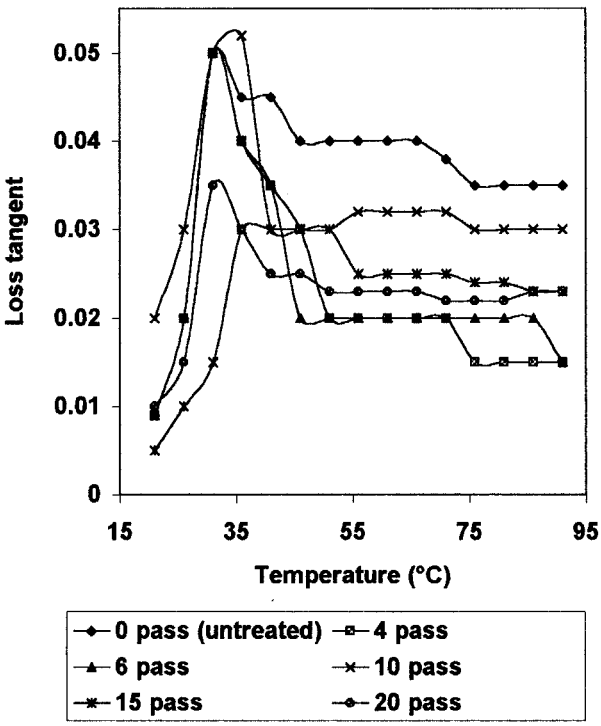


Figure 9 Variation of loss tangent of virgin and 10% HEMA-treated jute with radiation intensities against temperature.

time increases so the highest tensile strength is obtained at 15 min soaking time and its value is about 50% of the untreated sample.

The elongation of both treated and untreated Hessian cloths were expressed as the elongation factor, which was expressed before as Ef = Ebt/Ebo. The results are shown in Figure 3, where Ef is plotted against number of passes at different soaking times. Like Tf, Ef increases with an increase in soaking time. The maximum Ef occurs at 15 min, and after this Ef decreases. The maximum value of Ef is 53.8% of the untreated sample. The lowest value of Ef is found at the 5 min soaking time.

Optimization of monomer concentration

PL values (%of HEMA onto Hessian cloths are plotted in Figure 4 against number of passes with respect to monomer (HEMA) concentrations. It is observed that maximum PL is obtained for 30% HEMA solution at radiation pass 4, and after this radiation pass the value of PL decreases. The decrease in PL values after the attainment of maximum value may be due to radiation degradation. The vinyl monomer promotes rapid free radical propagation reaction with the help of photoinitiator leading to network (crosslinking) polymer structures through grafting via their double bonds.[9,10] When concentration of vinyl monomer is increased, the amount of residual unsaturation also increases as a consequence of the faster rate of formation of the three-dimensional network causing restricted mobility in the early stage. The crosslinking rate especially during the early stages of radiation is proportional to HEMA concentration. HEMA increases the radical–radical reaction termination, and hence decreases the extent of secession reaction and oxidation.[11] The decrease of grafting values at higher HEMA concentration could be associated with the fact that homopolymerization reaction between HEMA–HEMA radicals is more dominant than the HEMA–jute fiber reaction.[12]

Tensile strength factors are plotted against number of passes as a function of different HEMA concentration in Figure 5. The tensile strength factor increases with increasing monomer concentration, attains a maximum mostly at the 10% monomer concentration, and then decreases. The decreases of Tf values at higher HEMA concentration could be associated with the fact that the homopolymerization reaction between HEMA +HEMA radicals is more dominant than the HEMA+jute fabric reaction,[12] and the decrease of oxidation as well as increase the radical–radical termination reaction.[11]

The elongation factor (Ef) is plotted against number of passes for different concentrations of monomer. The results are shown in Figure 6. It is obsessed that maximum elongation factor (Ef) is obtained for the 15th pass and 3% HEMA concentration. Then, the mono-

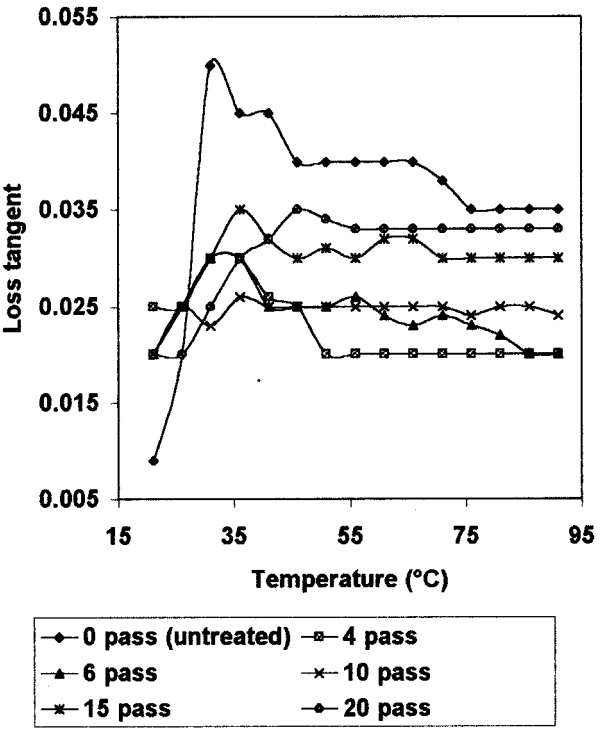
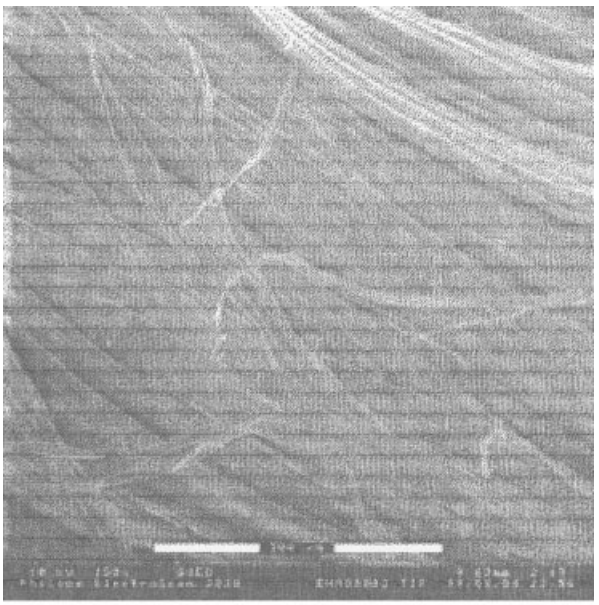
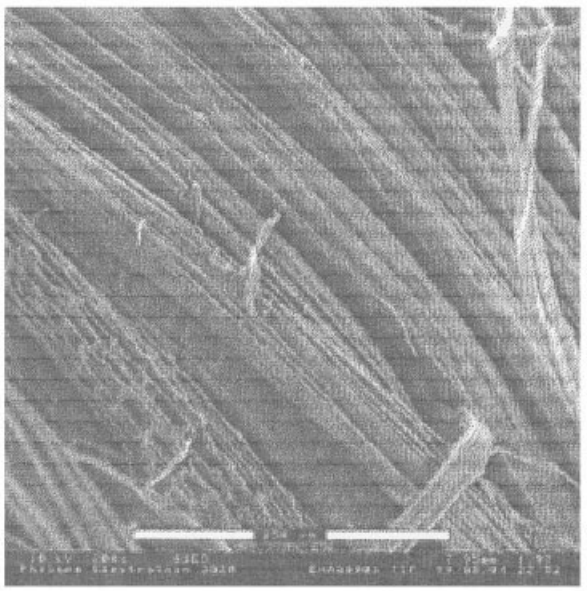


Figure 10 Variation of loss tangent of virgin and 30% HEMA-treated jute with radiation intensities against temperature.



(a)



(b)

Figure 11 SEM picture of virgin (a) and treated Jute (b).

mer concentration was increased up to 30%. It is found that E_f decreases with increasing concentration up to a certain point. Figure 5 reveals that 3% HEMA-treated Hessian cloth shows the lowest Tf at the 15th pass but 10% HEMA- treated Hessian cloth shows the maximum Tf. This could be due to the fact that the 3% HEMA-treated sample is flexible enough to enhance Ef but not Tf.

Dielectric properties

The dielectric constant and loss tangent of both untreated and 10 and 30% HEMA treated jute fabrics have been studied with variation of radiation intensities (number of passes) at a fixed frequency of 10 kHz. The results are presented in Figures 7 and 8 for 10 and 30% HEMA-treated samples respectively. It is observed from Figure 7 that for untreated sample and without radiation (pass 0) the dielectric constant increases with increasing temperature up to 41°C and drops irregularly with some fluctuations. At 71°C the dielectric constant reaches a constant value. The dielectric constant vs temperature curves for 10% HEMA-treated jute samples with varying radiation passes are presented in Figure 7. It is evident from the figures that all the measurements show a sharp initial increase of dielectric constant up to the transition temperatures, and above the transition temperature the dielectric constant decreases rapidly to almost room temperature values; with a further increase of temperature it reduces to a constant value. With the increase of radiation passes, the transition temperature decreases (Fig. 7). For the 4th pass, the transition temperature is 36°C, but for the 6th, 10th, 15th, and 20th pass the transition temperatures are 30. 5, 31, 31, and 31°C, respectively.

Again, the dielectric constants of 30% HEMA-treated jute are presented in Figure 8 against temperature with respect to radiation intensity. It is observed that the dielectric constant increases with increasing temperature up to the transition temperature then decreases. This phase transition is likely to be a ferroelectric to paraelectric transition.[13] Like the dielectric constant, the loss tangent (Ω) increases with increasing temperature up to the transition temperature, then decreases and finally becomes constant.

Variations of loss tangent with temperature of 10 and 30% HEMA-treated jute with respect to radiation pass are plotted in Figures 9 and 10, respectively. The dielectric constant and loss tangent depend on the transition temperature. The transition temperature of the untreated, 10% and 30% HEMA-treated jute lie with in 31–41°C but 30% HEMA-treated jute for the 20th pass (Fig. 10) shows the transition temperature at 51°C, and from this temperature the dielectric constant become constant. This may be due to the structural change of the sample. The main constituent of jute is cellulose, which is a hydrogen-bonded material.[14] As temperature increases, the bond breaks and form dipoles.[15] These dipoles tend to align with the electric field and thus increase the dialectic constant. At the transition temperature the formation of dipoles and alignment toward the field is maximum, giving rise to maximum dielectric values. Above the transition the dipoles tend to be random. As the randomness increases with increasing temperature, dielectric constant decreases and eventually becomes constant.

Characterization of jute fiber surface topography

To analyze the surface topography and morphology of jute, fabrics of both HEMA-treated and untreated were analyzed by ESEM. The ESEM pictures of both treated and untreated surfaces are shown Figure 11. The surface of untreated fiber [Fig.1l(a)] is smooth and shows their multicellular nature. The fibrillar structure as well as porosity of the individual fiber is revealed on the fiber surface. Figure 11(b), where the fibers are HEMA treated, rough surface topography and fragment on the surface are observed. The significant change of morphology and topography of the fiber surface results in various etchings out of structure by HEMA.

CONCLUSIONS

Jute fabrics were cured with HEMA of different concentrations under UV radiation. Every concentration of HEMA produced the enhanced mechanical properties. Among all the concentrations, 10% HEMA reveals the best performance. The dielectric constant and loss tangent of virgin, 10% HEMA-, and 30% HEMA-treated jute increase with increasing temperature up to the transition temperature, and then decrease and finally the dielectric became almost constant. The 30% HEMA-treated jute at the 20th of UV radiation showed constant dielectric constant from the transition temperature. The present data are encouraging and informative, and might help in diversified jute and jute products.

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