

Improvement of Jute Fiber Through Ultraviolet-Cured Films of Urethane Acrylate

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SYNOPSIS

Formulations were developed with urethane acrylate in combination with different monomers. The role of plasticizers used as coadditives in the formulations was investigated. Physical and mechanical properties of the UV-cured films were studied. Hessian cloths made with jute fibers were coated with these formulated solutions and cured under UV radiation. Though plasticizers decrease the tensile properties of the UV-cured films, but they substantially enhance both tensile strength by 80% and elongation of the coated hessian cloths by more than 300%. Uptake of water and moisture at different relative humidity conditions decreases significantly by the hessian cloths when coated with these formulations. © 1994 John Wiley & Sons, Inc.

INTRODUCTION

Jute is one of the most common and well-known natural fibers, mainly produced in Bangladesh, India, China, etc. Jute has widely been regarded as a versatile, useful, and valuable industrial material. It is really difficult to suggest another natural fiber possessing such diverse properties and basic utilities as those of jute. In the traditional use in carpets, ropes, sacks, hessian cloths, etc., jute fibers have been partially replaced by synthetic fibers, which have some advantages over jute. Thus, it is important to discover new fields of applications for jute fiber. Jute has a relatively hard cellulose fiber and a high tensile modulus and low elongation at break.¹ Hessian cloths made of jute are used mainly for packing materials. Reinforcement of plastic with such fibers has gained interest because jute is cheap and abundantly available. Many workers^{2,3} improved the jute fiber (hessian cloth) by reinforcement with thermoplastics; but there is yet very little information about this method. Jute fiber contains 60–64% cellulose, 14–16% pentosan, 12–14% lignin, and other components like fats, protein, ash, and mois-

ture.⁴ The present study reports on the investigation of physicomechanical properties of UV-cured films reinforced with hessian cloths in the presence of urethane acrylate mixed with additives and coadditives.

EXPERIMENTAL

Oligomer urethane acrylate (LR 8739) obtained from IAEA and monomers *N*-vinyl pyrrolidone (NVP) and 2-ethylhexyl acrylate (EHA) procured from E. Merck were used as received; the photoinitiator Irgacur 184 (Ciba-Geigy) and some plasticizers (PT1 and PT2) were also used.

Six types of formulations were prepared with oligomers, monomers, and photoinitiator (Table I). Glass plates and hessian cloths were coated with these formulated solutions with the help of a bar coater no. 0.018 (Abbey Chemicals). The coated substrates were then irradiated by a UV lamp using a Minicure (Me 200 UV lamp IST Technik, Germany). The UV lamp (254–313 nm) had a 2 kW power capacity and the speed of the conveyor was 4 m/min. The substrates were irradiated at different UV radiation intensities, represented by the number of passes. Films and coated hessian cloths cured with UV radiation were used for characterization of various physical and mechanical properties.

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Table I Different Formulations

A	B	C	D	E	F
O = 60%	O = 50%	O = 50%	O = 50%	O = 50%	O = 50%
NVP = 38%	NVP = 48%	EHA = 48%	NVP = 24%	NVP = 24%	NVP = 24%
P = 2%	P = 2%	P = 2%	EHA = 24%	EHA = 12%	EHA = 12%
			P = 2%	PTI = 12%	P = 2%
				P = 2%	PT2 = 12%
V = 117.52	V = 69.16	V = 58.22	V = 59.80	V = 81.19	V = 78.02

V = viscosity (mp); O = oligomer LR 8739; NVP = *N*-vinyl pyrrolidone; EHA = 2-ethylhexyl acrylate; PT1 and PT2 = plasticizers; P = photoinitiator Irgacure 184.

Pendulum hardness of the cured films was measured directly by a digital Pendulum Hardness Tester (Model 5854, Byke Laboraton). Tensile strength and elongation at break of the film and treated and untreated hessian cloths were measured by a tensile strength machine (Instron Model 1011, U.K.). Gel content was measured by extraction of both cured films and coated hessian cloths with hot benzene in a Soxhlet for 48 h. This was done by

wrapping a known weight of the cured material in a finely meshed stainless-steel net that was put into the Soxhlet for extraction. The difference of weights of the material before and after the extraction determines the gel content.

The samples of coated hessian cloth were used for the sorption study after drying them at 105°C for 6 h. The moisture sorption experiment was done in a closed air-tight container with a supersaturated

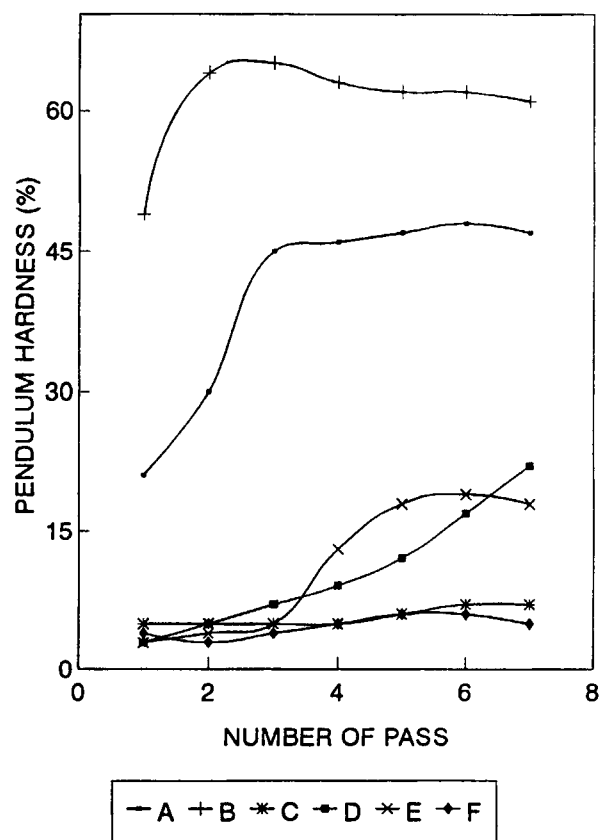


Figure 1 Pendulum hardness of the cured films of different formulations against radiation intensity.

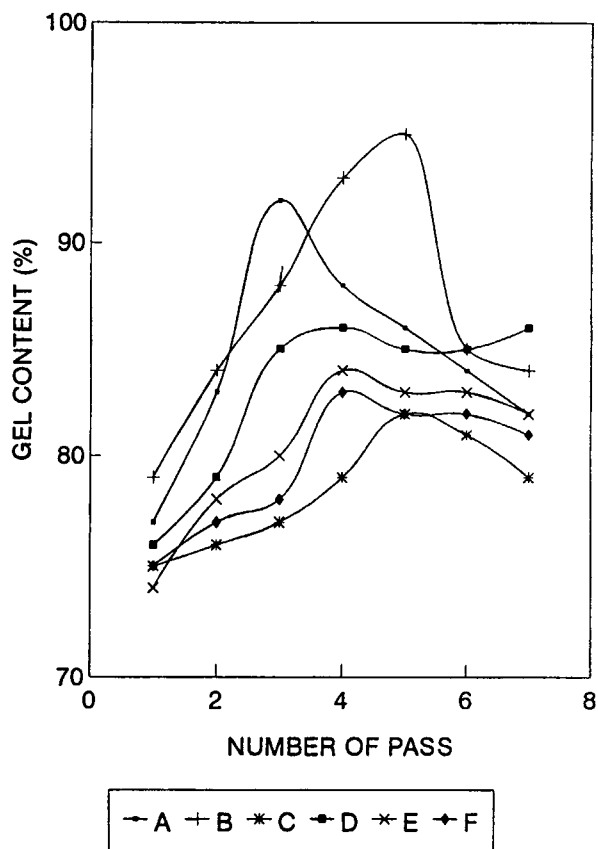


Figure 2 Gel content of the cured films of different formulations against UV radiation intensity.

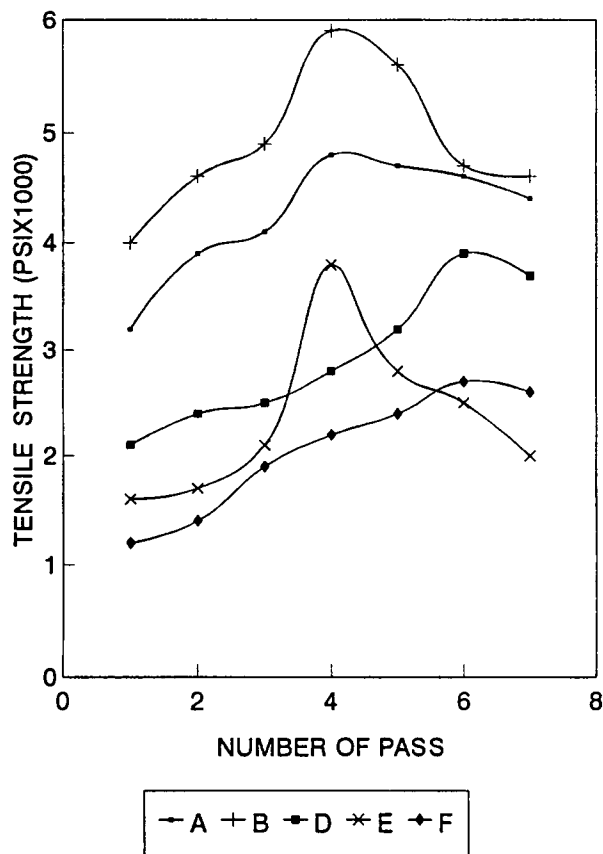


Figure 3 Tensile strength of the cured films of different formulations against UV radiation intensity.

salt solution. The samples were placed over the salt solution. The salts used were $\text{NaOH} \cdot \text{H}_2\text{O}$, $\text{LiCl}_2 \cdot \text{H}_2\text{O}$, $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, $(\text{NH}_4)_2\text{SO}_4$, $\text{BaCl}_2 \cdot \text{H}_2\text{O}$, NaI , and $\text{CuSO}_4 \cdot 2\text{H}_2\text{O}$. The water activities of the salt solutions were taken from the literature.⁵ The samples were exposed to various relative humidities until each reached the equilibrium moisture content.

The water absorption uptake by treated and untreated hessian samples was carried out; samples were tied to rods and lowered into a static water bath so that they were completely immersed. Weights of the samples were recorded with time. Samples were wiped with tissue paper to remove surface water before weighing each time. Finally, the weight gain by water absorption was determined.

RESULTS AND DISCUSSION

Six formulations were prepared with urethane acrylate in combination with monomers and plasticizers (Table I) in order to coat the hessian cloths

(jute fibers) and to cure them under the UV radiation. The UV-cured films prepared with these formulations were first characterized to determine the suitability of these formulated solutions to improve the properties of jute fibers through grafting the hessian cloths. Figure 1 represents the pendulum hardness of the UV-cured films of these formulations as a function of dose intensity (the number of passes). Solutions A and B contain oligomer and NVP at different proportions in the presence of 2% photoinitiator (Table I). The decrease of oligomer with increase of NVP by 10% causes substantial changes of the viscosity and pendulum hardness. The monomer NVP has a carbamide group (N attached to $=\text{C}=\text{O}$) that favors cross-linking for achieving better tensile and physical properties.⁶ Thus, solution B, which contains 10% more NVP with 10% less oligomer than does solution A, exhibits the highest hardness. In addition, solution B can be easily diffused into the reacting zone at the equilibrium condition, because its viscosity is lower than that of A. When the amount of NVP of solution B is shared with EHA (D), the pendulum hardness is

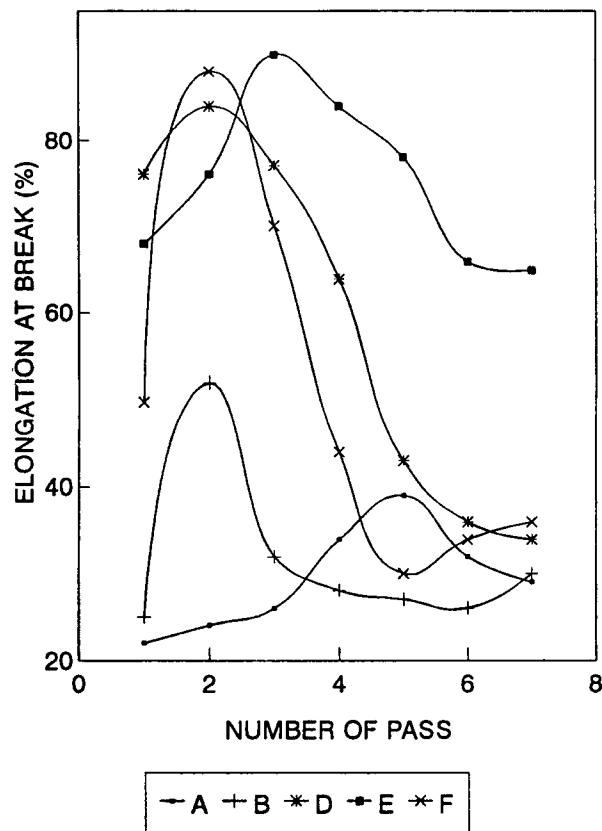


Figure 4 Elongation at break of the cured films of different formulations against UV radiation intensity.

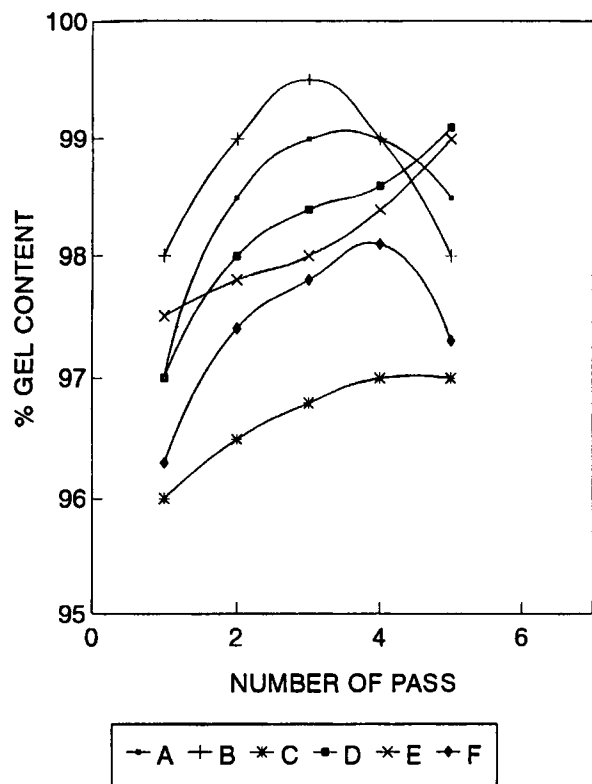


Figure 5 Gel content of the cured hessian cloth against UV radiation intensity.

reduced drastically, particularly at low UV dose, but it increases slowly to some extent with the number of passes. This low hardness is due to low glass transition temperature ($T_g = -50^\circ\text{C}$)⁷ of the homopolymer of EHA. The gradual increase of the pendulum hardness with UV dose is caused by the reactivity of NVP present in solution D. This can be demonstrated by the fact that solution C contains only the EHA monomer (24%) in place of NVP (B) along with the oligomer and the pendulum hardness of the solution C is quite low. Since EHA induces low hardness to the films due to low cross-linking density, the proportion of EHA was reduced to 12% and a plasticizer (PT1 or PT2) was incorporated into the system (solution E or F). It was expected that NVP would dominate because of its higher proportion (24%) over EHA (12%). However, the plasticizer plays the role of reducing the cross-linking activity. Solution F contains a long-chain plasticizer that has a further dominating role for low cross-linking over the PT1-containing plasticizer.

When gel content is determined for these films, it is observed that the gel increases with UV dose at the initial stages for all these films, and after attaining the maxima up to certain doses, the gel de-

creases, indicating that higher UV doses have degraded the films (Fig. 2). The order of the gel content can be represented as $B > A > D > E > F > C$. The UV radiation between three and five passes appear to be optimum depending on the types of the formulations. The tensile strengths determined for these films are shown in Figure 3 against the number of passes under UV radiation. The tensile strengths initially increase with UV dose, attain the maxima at three passes for B, A, and E and at six passes for D and F solutions, and then decrease with the dose. The highest gel content and tensile strength for solution B are due to the presence of NVP, which is a unique monomer for inducing these properties. The most interesting phenomenon is observed when elongation properties of these films are measured. The highest elongation at break (E_b) is exhibited by the formulation (E) that contains PT1, which has the plasticizer effect (Fig. 4). This is followed by solution F containing PT2. The quite high E_b value observed by formulation D is caused by the presence of EHA. The lowest E_b of formulation A is caused by the high percentage of the oligomer

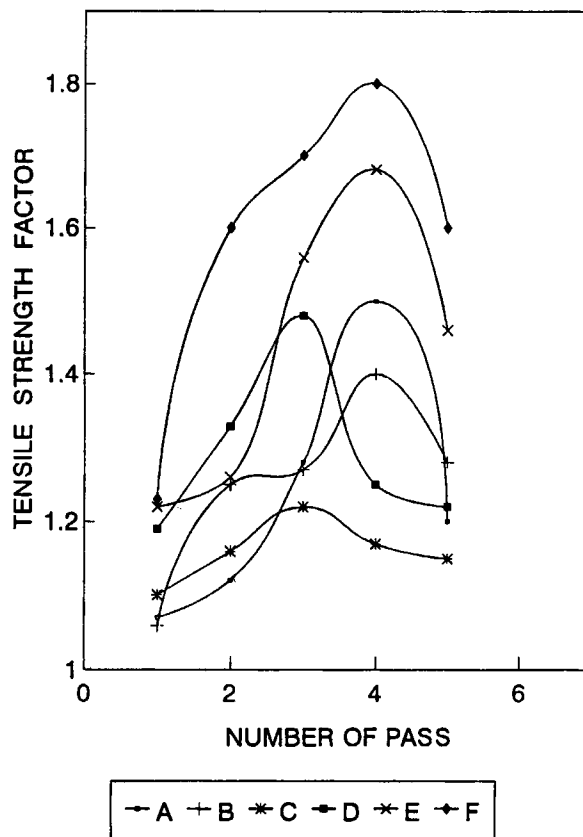


Figure 6 Tensile strength factor of the cured hessian cloth against UV radiation intensity.

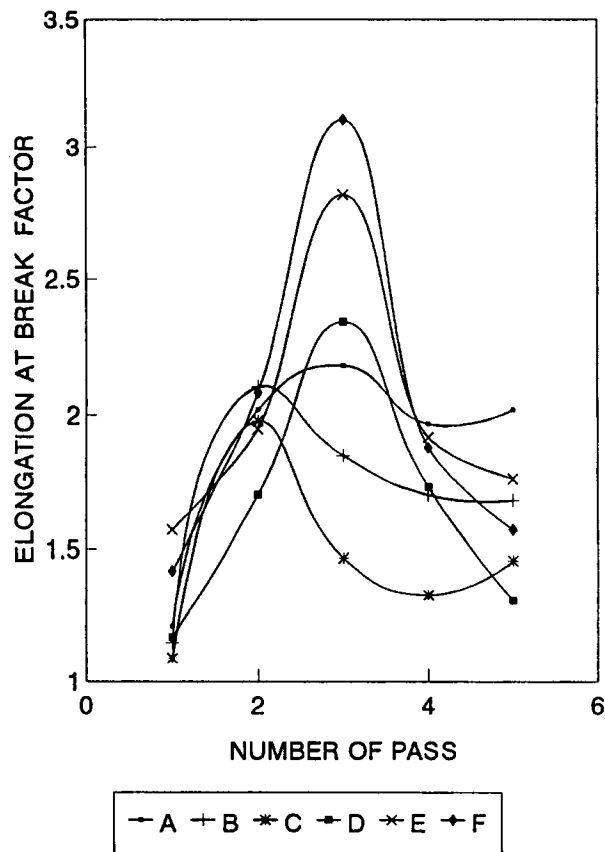


Figure 7 Elongation at break factor of the cured hessian cloth against UV radiation intensity.

present in formulation A. The E_b value of B is higher than that of A and this is due to different proportions of oligomer and NVP in the formulations.

On having characterized the properties of the films of these five formulations, sheets of hessian cloths made of jute fiber were coated with these solutions and were irradiated under the UV lamp as before. The gel contents have significantly increased in the presence of jute. The trend of the highest gel obtained in the presence of jute (Fig. 5) is similar to that obtained in the absence of jute (Fig. 2). The order is $B > A > D > E > F > C$. The maximum gel is obtained mostly up to three passes with some exceptions. The higher gel content in the presence of jute fiber is caused by the fact that there has occurred a cross-linking network between jute fiber and the polymer units formed with oligomer and monomer moieties. This phenomenon of grafting between jute fiber and the polymer unit foretells that the coated hessian cloth will have higher tensile property. It has actually been observed in Figure 6 where the tensile strength factor (T_f) is plotted vs. the number of passes that the tensile strength (TS)

of the hessian cloth has increased up to 80% in the presence of PT2 (F). The tensile strength factor T_f can be represented as $T_f = \text{TS of coated hessian cloth} / \text{TS of untreated hessian cloth}$. The PT2 compound is more dominating than is the PT1 material to improve the tensile strength of the jute material (Fig. 6). This is very important in the sense that the plasticizer compounds do not increase the gel (Fig. 2) and the tensile strength (Fig. 3) very much in the absence of jute fiber but they do so when present with jute (Fig. 6). The jute fiber is almost a rigid fiber. Its elongation (E_b) is very low, but the E_b is observed (Fig. 7) to be increased by more than 300% in the presence of plasticizers with the formulation of urethane acrylate, EHA, and NVP. This is very important. The elongation factor E_f is plotted in Figure 7 against the number of passes, where E_f is calculated as $E_f = E_b \text{ of coated hessian cloth} / E_b \text{ of untreated hessian cloth}$.

Both untreated and coated hessian cloths were kept immersed in water for 10 days continuously. The water uptake was about 70% by the untreated hessian samples, whereas the coated samples ab-

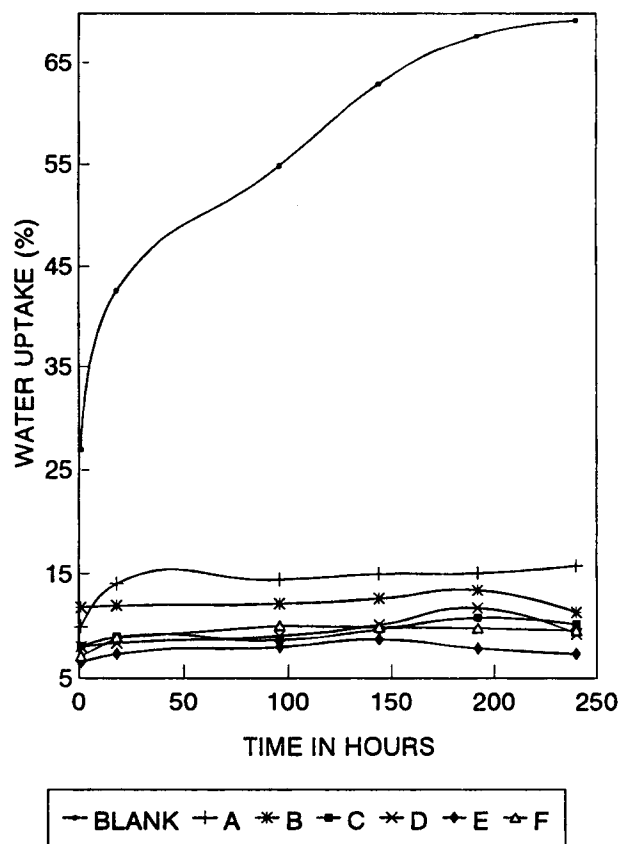


Figure 8 Water uptake by the treated and untreated hessian cloth with respect to soaking time.

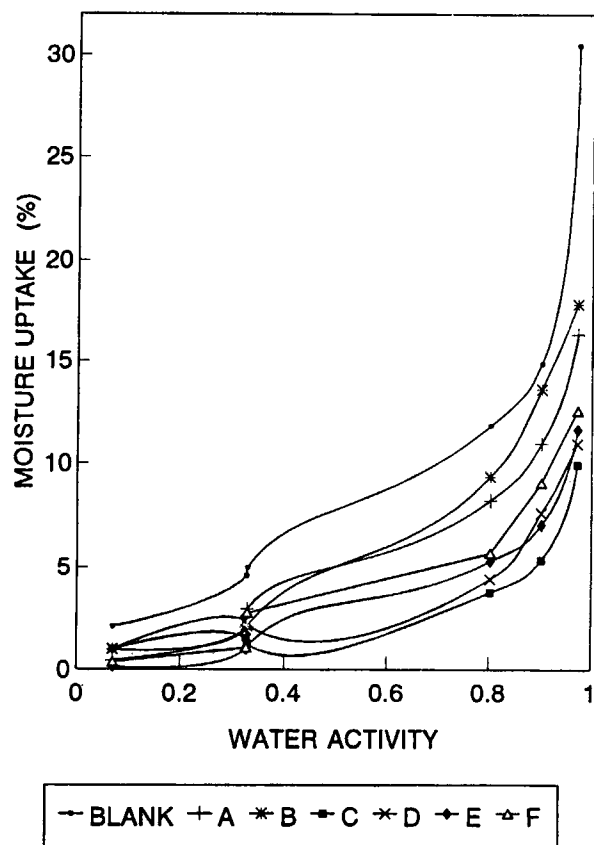


Figure 9 Moisture uptake by the treated and untreated hessian cloth with respect to water activity.

sorbed very little water over this period (10 days). This is less than 10%, as shown in Figure 8, where water uptake of both coated and untreated hessian cloths is plotted against the period of soaking in water under normal conditions of the atmosphere and humidity. However, when the samples (both coated and untreated) were subjected to moisture absorptions at different humidities controlled by various salts solutions, it was observed that the moisture uptake by the normal hessian cloth was the highest. This is found in Figure 9, where moisture uptake by the samples is plotted against the

water activity. The low water absorption capability of the hessian cloth coated with formulations E and F, under different humidity conditions, is a step forward for diversified applications of jute products. The coated hessian cloths can now be used for carrying salts, sugar, fertilizer, cement, etc., which need protection against damage by rain and water. Moreover, the coated hessian cloths can be stretched to accommodate materials inside the bags made with these cloths and can, thus, protect materials holding inside against any damage. The enhancement of tensile strength (Fig. 6) by 80%, the elongation (Fig. 7) by more than 300% of the hessian cloths (jute fiber), and the reduction of water absorption by 60% (Fig. 8) in the presence of plasticizers mixed with urethane acrylate and other monomers under the UV radiation is a very significant achievement for exploring the diverse applications of jute, the golden fiber of Bangladesh. It appears that the jute that almost lost its unique name, "the golden fiber," will regain it in the near future.

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