

Effect of Benzohydroxamato-Ethylenediamine-Titanium Complex on Modification of Jute and Cotton Yarns by UV-Radiation-Induced Urethane Acrylate

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ABSTRACT: Several formulations were developed consisting of an aliphatic-based urethane triacrylate oligomer (Ebcryl 264) combined with *N*-vinyl pyrrolidone (NVP), a carboamide monomer, and tripropylene glycol diacrylate (TPGDA) at different proportions. A plasticizing agent, diallyl phthalate (DP), and methyl ethyl ketone (MEK), an antibubbling solvent, were incorporated into the solutions. Thin polymer films prepared with these solutions under UV radiation were characterized. Jute and cotton yarns were treated with these solutions and cured with UV radiation. As a result, the rheological properties of jute and cotton were improved. The effect of ethylenediamine–titanium (EDA–titanium) complex and its ligands was studied. A very minute amount (0.1%) of the complex enhanced rheological properties of jute and cotton very significantly. © 1997 John Wiley & Sons, Inc. *J Appl Polym Sci* **65**: 1571–1580, 1997

Key words: jute; cotton; natural fibers; UV radiation; titanium complex; organo-metallic complex

INTRODUCTION

Both natural fibers and synthetic films are polymer. The natural polymer is biodegradable, readily and abundantly available, and ecofriendly. The synthetic polymer, in contrast, is nondegradable, durable, and sustainable in the environment, causing pollution after its end uses. Environmentally conscious citizens are therefore reverting to the use of natural polymers wherever possible in place of man-made synthetic polymers to minimize pollution of the environment. The main advantage of the synthetic polymer over the natural polymer is that the synthetic polymer can be made as desired according to the requirement of its applications by simply incorporating the ap-

propriate ingredients into the formulations, whereas natural polymers (jute, wood, flax, cotton, etc.) possess certain characteristic properties that are essentially unalterable. However, genetic treatment may slightly modify these properties somewhat but not to the extent required for the desired applications. It is therefore necessary to improve the characteristic properties of these natural polymers chemically so that the improved natural polymers will behave like synthetic polymers with respect to durability, sustainability, and mechanical strength but will at the same time be degradable and ecofriendly. In an attempt to induce such properties in natural polymers, various physical and chemical treatments have been adopted since ancient times. As a result, different products are already available; such as natural polymer reinforced thermoplastics,¹ jute plastic composites,² wood plastic composites,³ cellulose reinforced thermosetting products,⁴ and so forth.

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Specific additives and coadditives are incorporated in the formulations to induce the desired properties such as fire resistance enhanced tensile⁵ and bending strengths.⁶ These additives and coadditives are both organic and inorganic. Thus, substances such as lithium nitrate, copper sulfate, urea, and potassium persulfate, have been used to alter properties the substrates. This article discusses the preparation of thin polymer films under UV radiation of formulated solutions of urethane oligomer combined with a carboamide vinyl monomer and a difunctional acrylated monomer. These solutions are applied to jute and cotton to enhance their rheological properties. In addition, our study investigates the effect of organo-metallic titanium complex on these properties.

EXPERIMENTAL

Materials

The oligomer Ebcryl 264 is an aliphatic-chain triacrylated urethane compound obtainable from Merck Co. *N*-Vinyl pyrrolidone (NVP) and tripropylene glycol diacrylate (TPGDA) were also used as obtained from Merck Co. Diallyl phthalate (DP) and methyl ethyl ketone (MEK) from Aldrich Chemicals Co. were used as plasticizing and antibubbling agents, respectively. A photoinitiator (Irgacur 184) was used to initiate radical formation reactions. Titanium oxide (TiO₂), benzo-hydroxamic acid (BHA), and ethylenediamine (EDA) were obtained from BDH Ltd. The ethyl-

enediamine-titanium complex called bis(benzohydroxamato)ethylenediamine titanium(II) was prepared in the laboratory using the conventional method⁷ for preparing organo-metallic complexes. Jute yarn and cotton thread were collected from the local market.

Methods

Polymer Films

Thirteen formulations were prepared with the oligomer Ebcryl 264 in the presence of reactive diluents (NVP and TPGDA), DP, MEK, Irgacur 184, and other additives (BHA, EDA, TiO₂, and EDA-Ti complex) in such a way that the proportions of Ebcryl 264, NVP, TPGDA, DP, and Irgacur 184 remained fixed, whereas the proportion of MEK was varied to accommodate the proportions of BHA, TiO₂, EDA, or the complex. The compositions of these formulations are shown in Table I. Thin polymer films were prepared by coating these formulations on glass plates (10 × 8 × 0.2 cm) with the help of a No. 018 bar coater from Abbey Chemical Co. (Australia). The resulting film had a thickness of 36 ± 3 μm. The plates were irradiated under UV light (254–313 nm, 2 kW) using a minicure 200-UV radiation unit from 1ST Technik (Germany). The speed of the conveyor was 4 m/min. The plates were passed through the UV radiation several times to ensure full curing of the film. Film hardness was determined after 24 h of radiation with a Model 5854 Pendulum Hardness Tester from BYK Labotron

Table I Composition of Different Formulations (% w/w)

F	O	NVP	TPGDA	DP	PI	MEK	Additives
H1	45	20	18	9	3	5	0.00
H2	45	20	18	9	3	4.95	0.05
H3	45	20	18	9	3	4.90	0.10
H4	45	20	18	9	3	4.85	0.15
H5	45	20	18	9	3	4.95	0.05
H6	45	20	18	9	3	4.90	0.10
H7	45	20	18	9	3	4.85	0.15
H8	45	20	18	9	3	4.95	0.05
H9	45	20	18	9	3	4.90	0.10
H10	45	20	18	9	3	4.85	0.15
H11	45	20	18	9	3	4.95	0.05
H12	45	20	18	9	3	4.90	0.10
H13	45	20	18	9	3	4.85	0.15

F = formulations; O = oligomer (Ebcryl 264); PI = photoinitiator.

(Germany). The gel content of the film was determined by wrapping up a known weight of the cured film in a stainless steel net that was put in a Soxhlet and extracted for 48 h in the Soxhlet. The differences in the weights of the film before and after the extraction yielded the gel content. Tensile strength (TS) and elongation at break (Eb) of the cured films were directly measured with an INSTRON Model 1011 tensile property measurement machine (UK) at a crosshead speed of 0.003 m/min. The efficiency of the INSTRON Model 1011 is within $\pm 1\%$; gauge length was 1.2 cm.

Application on Jute and Cotton

Jute yarn or cotton thread was pulled through these solutions and passed under the UV lamp at a speed of 4 m/min. It was necessary to pass the treated substrates (jute and cotton) through the UV radiation several times to ensure curing.

Tensile properties of the treated substrates were measured as above using the INSTRON machine. The change in tenacity was expressed as a factor T_f , which is a ratio of tenacity (TS_t) of treated substrate to that (TS_o) of the untreated sample (i.e., $T_f = TS_t/TS_o$; similarly, elongation at break factor E_f is expressed as $E_f = Eb_t/Eb_o$).

Water absorption ability of both treated and untreated substrates was determined simply by dipping the substrates with the help of a suitable weight in a static water bath at 25°C. The amount of water taken up (absorbed) by the samples was periodically monitored by taking the wet sample

out of the bath and dabbing it with tissue paper for 10 s. The amount of water uptake was calculated as % water uptake = $100 (W_t - W_o)/W_o$, where W_t is the weight of the wet sample at any time and W_o is the weight of the sample before immersion. The samples were kept soaked in water for about 6 h.

RESULTS AND DISCUSSION

The formulations developed with Ebcryl 264, NVP, and TPGDA in the presence of ethylenediamine–titanium complex and its ligands were used to prepare thin polymer films as well as to improve jute and cotton yarns under UV radiation. Various properties of the films and the treated substrates were studied and are described in this section.

Polymer Films

Film Hardness

Thin polymer films prepared on glass plates were used after 24 h of the UV curing to determine film hardness by the pendulum method. The resultant pendulum hardness (PH) of the various films cured under different UV doses represented by the number of passes under the UV lamp is given in Table II. It is observed that the hardness increases as the UV dose is intensified, reaches a maximum value, and then decreases. The increase in hardness with respect to UV dose indi-

Table II Pendulum Hardness Percentages of the UV-Cured Films

F	Number of Passes						(% Additives)
	2	4	6	8	10	12	
H1	31	47	51	41	41	37	0.00
H2	26	32	41	40	31	34	0.05
H3	29	31	45	39	37	36	0.10
H4	31	34	43	41	36	30	0.15
H5	32	42	42	39	30	32	0.05
H6	26	38	44	40	38	30	0.10
H7	28	35	38	38	30	29	0.15
H8	22	36	41	37	37	31	0.05
H9	35	38	45	42	40	35	0.10
H10	27	34	43	40	36	31	0.15
H11	26	35	48	41	41	38	0.05
H12	43	45	59	46	46	34	0.10
H13	33	35	48	47	46	46	0.15

cates that the curing of the polymer continues at the film surface up to a certain maximum level, and then the degradation of the film starts as the radiation is increased, which is represented by the decrease in *PH* value. The maximum hardness values are obtained at the sixth pass for all films. This means that films of these formulations should not be cured beyond the sixth pass under the UV lamp used in this investigation. This finding can be well represented by plotting the *PH* values of the films that contain 0.1% additives against the number of passes (Fig. 1). The highest *PH* value is achieved by the film that contains the EDA–titanium complex. The presence of other ligands (BHA, EDA, and TiO₂) in the formulations substantially reduces the *PH* values of these films. It appears that all these ligands have not contributed towards enhancing crosslinking density at the film surface during the polymerization process among the oligomer and the reactive diluents (NVP and TPGDA) at the time of equilibrium conditions. On the other hand, the EDA–titanium complex has entered into the crosslinking process

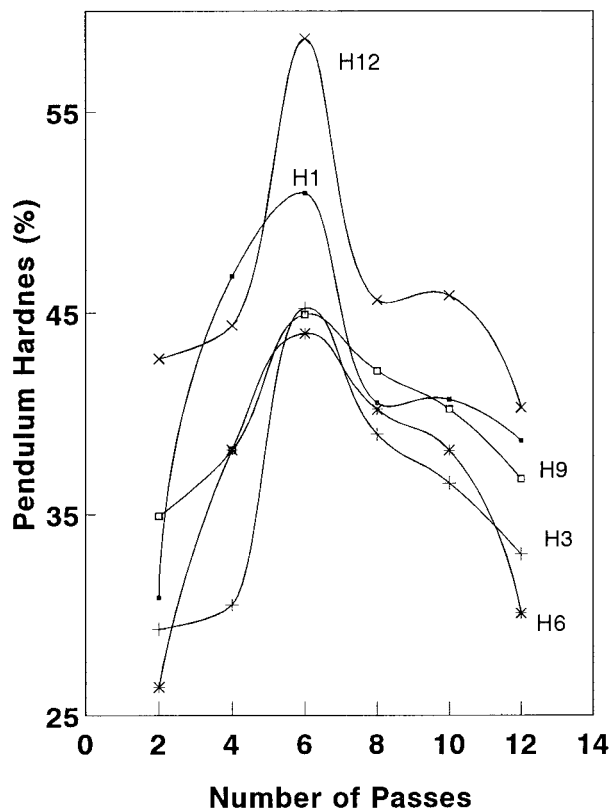


Figure 1 Pendulum hardness of UV-cured films versus number of passes.

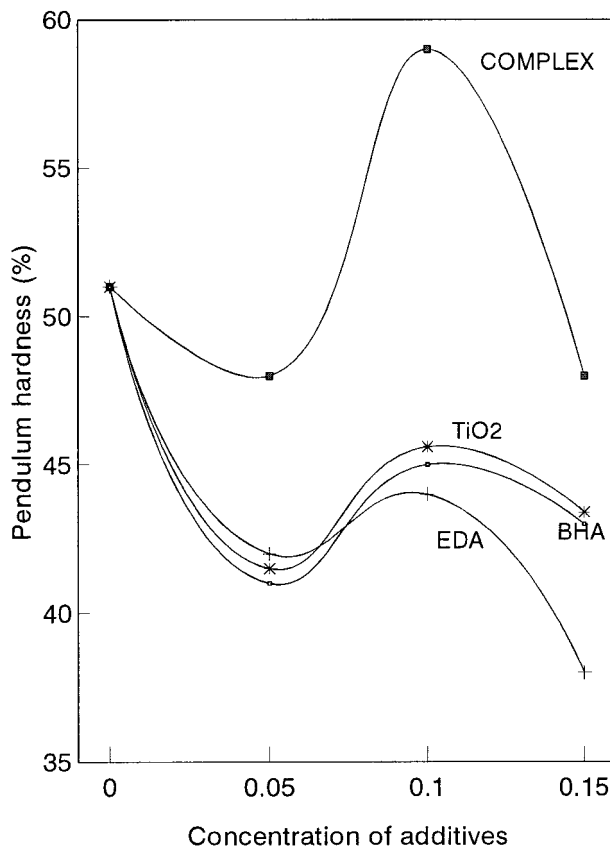


Figure 2 Pendulum hardness of UV-cured films containing ligands and complex at different concentrations.

as reflected by the enhanced *PH* value of the film containing the complex. The complex may have enhanced the film hardness simply by entering into the polymer matrix as a compact filler or as a crosslinking entity that interacts among the polymer moieties through lone pairs of electrons present in the complex. This hypothesis needs further investigation through other suitable techniques.

Incorporation of a very minute amount of ligand and complex into the formulations has substantially altered the film hardness. Different proportions (0.05–0.15% w/w) of ligands and complex are made variable with MEK only; MEK is used as an antibubbling agent in the solutions and does not enter into any reactions involving the polymerization process. The *PH* values obtained at the sixth pass of the films containing different proportions (0.05–0.15%) of ligands and complex are plotted in Figure 2 against the concentrations of additives. It is observed that the

Table III Gel Content Percentages of the UV-Cured Films

F	Number of Passes						(%) Additives
	2	4	6	8	10	12	
H1	95	96	99	96	95	94	0.00
H2	92	94	94	93	93	90	0.05
H3	91	97	97	96	94	92	0.10
H4	92	95	95	94	94	93	0.15
H5	94	95	95	94	90	90	0.05
H6	94	97	96	94	93	93	0.10
H7	94	96	95	95	94	93	0.15
H8	90	93	92	92	91	90	0.05
H9	91	94	94	94	93	94	0.10
H10	91	93	93	92	92	91	0.15
H11	94	95	95	94	94	93	0.05
H12	93	98	96	96	93	93	0.10
H13	90	96	95	94	93	94	0.15

PH value (52%) of the polymer film (H1) is higher than the *PH* values of the films (H2–H13) that contain ligands and complex at different concentrations. However, the films that contain 0.1% complex have the highest *PH* value (58%) among all the films. It is really interesting and important that the presence of a very minute amount (0.1%) of the complex in the formulation has enhanced the *PH* value quite significantly. It may be possible that the EDA–Ti complex possesses a convenient environment at 0.1% concentration with respect to easy diffusion of the complex into the polymer matrix. At concentrations higher than

0.1%, the complex may have encountered other entities that are unknown at this stage.

Gel Content

Gel content is the amount of polymer actually formed through the crosslinking process between the oligomer and reactive diluent monomers. The gel content represents the polymer crosslinking in the entire film. The ingredients present in the H1 formulation are urethane triacrylate oligomer, NVP, and TPGDA. These are quite reactive materials under UV radiation as reflected by the high

Table IV Tensile Strength of the UV-Cured Films (kg/cm²)

F	Number of Passes						(%) Additives
	2	4	6	8	10	12	
H1	317	360	444	352	352	360	0.00
H2	340	444	423	295	324	213	0.05
H3	374	571	465	465	345	317	0.10
H4	324	493	374	352	310	282	0.15
H5	275	472	374	326	254	254	0.05
H6	317	550	448	388	381	297	0.10
H7	296	383	326	299	299	299	0.15
H8	211	564	374	423	303	282	0.05
H9	529	627	500	373	373	352	0.10
H10	430	606	536	493	430	430	0.15
H11	402	662	648	529	423	388	0.05
H12	698	1100	641	600	536	493	0.10
H13	451	698	543	536	409	409	0.15

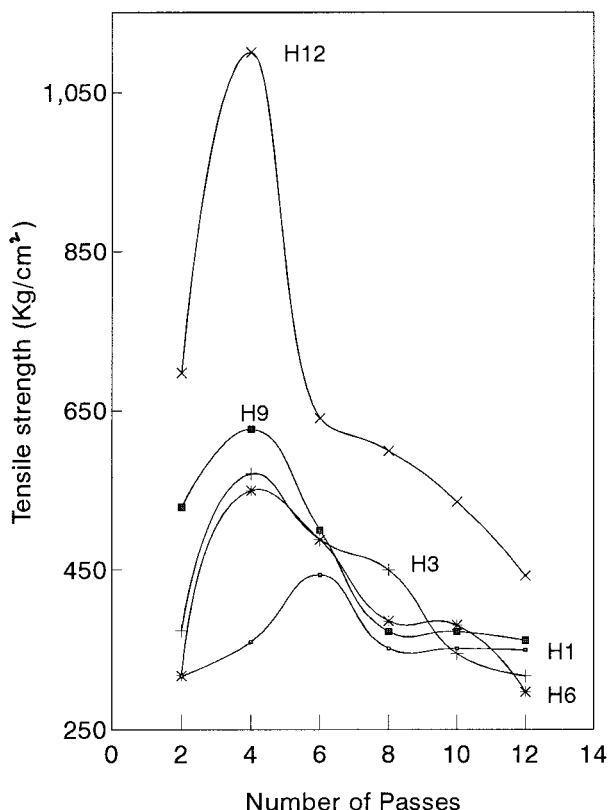


Figure 3 Tensile strength of UV-cured films containing 0.1% additives versus number of passes.

gel content (94–99%) present in the H1 film (Table III). Although the highest gel content (97%) is obtained at the sixth pass, the gel formation is quite high (95%) even at the second pass. Incorporation

of additives into these formulations (H2–H13) has slightly reduced the gel content, which remains between 91 and 98%. However, the complex has resulted in slightly higher gel values compared with the other additives (BHA, EDA, and TiO_2). It appears that the highest gel content is achieved at an additive concentration of 0.1% in each case, which is consistent with the *PH* values obtained for these films (Table II) and the finding that the highest *PH* values result at 0.1% concentration. Although the maximum gel content is obtained at the sixth pass with the H1 film, the maximum gel values for other films (H2–H13) are obtained mostly at the fourth pass irrespective of the concentration of the additives. It is observed in Table II that the highest *PH* is obtained with the H13 film that contains the complex, but it is also observed in Table III that the highest gel content is obtained with the H1 film that does not contain any additive. Thus, both pendulum hardness and gel content are related to the crosslinking density. The *PH* represents the crosslinking density at the surface of the film, whereas the gel content reflects the crosslinking density in the entire film.

Tensile Properties

Tensile strength (*TS*) of different films (H1–H13) are given in Table IV versus number of passes. The *TS* values increase with UV dose and attain maxima. The maximum *TS* value of the H1 film is obtained at the sixth pass, whereas for other films (H2–H13), the maximum *TS* values are ob-

Table V Elongation at Break Percentages of the UV-Cured Films

F	Number of Passes						(% Additives)
	2	4	6	8	10	12	
H1	10	10	13	10	10	11	0.00
H2	12	13	13	11	12	11	0.05
H3	11	14	13	12	10	11	0.10
H4	8	12	9	10	8	8	0.15
H5	6	13	12	10	11	10	0.05
H6	7	14	13	12	13	8	0.10
H7	7	12	12	11	11	7	0.15
H8	12	14	13	11	10	10	0.05
H9	14	15	13	12	12	11	0.10
H10	13	14	12	12	12	10	0.15
H11	12	16	15	14	10	10	0.05
H12	15	22	15	13	14	13	0.10
H13	12	16	14	12	13	13	0.15

Table VI Tensile Properties of the UV-Cured Jute Yarn

Tenacity Factor													
No. of Passes	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13
2	1.09	1.04	1.07	1.41	1.26	1.61	1.13	1.02	1.04	1.00	1.97	2.49	2.00
4	1.08	1.62	1.84	1.50	1.53	1.72	1.61	2.35	2.44	2.28	2.52	3.23	2.62
6	1.25	1.62	1.71	1.10	1.33	1.57	1.48	1.81	1.88	2.15	2.49	3.10	2.58
8	1.25	1.41	1.47	1.10	1.39	1.46	1.18	2.20	1.79	1.63	2.41	2.86	2.20
10	1.13	1.25	1.46	1.06	1.26	1.46	1.00	2.27	1.14	1.63	2.28	2.88	1.62
12	1.08	1.28	1.25	1.04	1.26	1.38	1.00	1.14	1.14	1.34	2.27	2.56	1.97

Elongation Factor													
No. of Passes	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13
2	0.86	1.00	0.87	1.11	0.95	1.33	0.89	1.00	0.85	1.10	1.35	1.58	1.33
4	1.03	1.28	1.56	1.46	1.40	1.47	1.44	1.41	1.47	1.39	1.68	2.00	1.76
6	1.35	1.23	1.20	1.35	1.38	1.35	1.26	1.41	1.44	1.38	1.68	1.84	1.65
8	1.22	1.16	1.12	1.22	1.31	1.24	1.34	1.32	1.33	1.26	1.45	1.79	1.47
10	1.17	1.09	1.08	1.16	1.24	1.18	1.26	1.21	1.31	1.22	1.42	1.79	1.25
12	1.15	1.21	1.00	1.02	1.18	1.18	1.12	1.10	1.32	1.22	1.42	1.59	1.25

served at the fourth pass. After the maxima, the *TS* values decrease, which may be caused by radiation damage to the cured films. It is observed that the highest *TS* values are obtained by the films that contain 0.1% additive concentration (BHA, EDA, TiO₂, and complex). Incorporation of these additives has enhanced the tensile strengths of all the films, and this is unlike pendulum hardness (Table II, Fig. 1). Enhancement of film strength by the incorporation of these additives is an indication that they have been involved in the polymerization process, which has possibly taken place through interaction with lone pairs of electrons associated with nitrogen or oxygen atoms, or both, present in these additives. This is similar to the case of monomer additives that contain carboamide.³ The *TS* increments are 6.3–8.1 kg/cm² for BHA, 6.7–7.8 kg/cm² for EDA, 7.9–8.8 kg/cm² for TiO₂, and 9.4–15.6 kg/cm² for the complex. Addition of 0.1% complex to the H1 formulation has enhanced the film strength (*TS*) by about 2.5 times, which is undoubtedly a significant achievement. It is observed from pendulum hardness (Table II) and gel contents (Table III) that the highest *PH* and gel values are obtained with films that contain 0.1% additives. Similarly, the highest *TS* values are also obtained with films that contain 0.1% additives. Their difference are pictorially represented in Figure 3 in

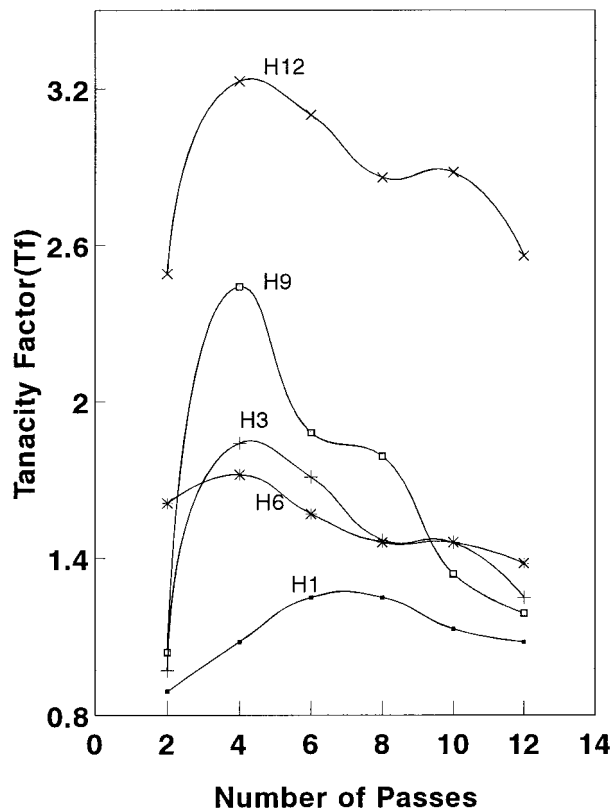


Figure 4 Tanacity factor of jute yarns treated with 0.1% additives versus number of passes.

which TS values of the films containing 0.1% are plotted against the number of passes. It can be observed clearly in Figure 3 that there is sharp decay of film strength after the TS_{max} is attained at the fourth pass for films containing additives. It is also clear that the films should not be cured (radiated) beyond the fourth pass in order to retain its full strength; otherwise, the film would be degraded.

Generally, the monomer that enhances the tensile strength of the polymer film reduces elongation capability and vice versa. For example, ethyl hexyl acrylate (EHA) enhances elongation with reduced tensile strength; similarly, trimethylol propane triacrylate (TMPTA) yields higher film strength with decreased elongation.⁸ In the case of the EDA-Ti complex, however, tensile strength is increased by 2.5 times and elongation by about 2 times (Tables IV and V). As is the case with tensile strength values, the maximum E_b value of H1 film is obtained at the sixth pass, whereas the E_b values of films H2-H13 are greatest at the fourth pass. The highest E_b value is noted

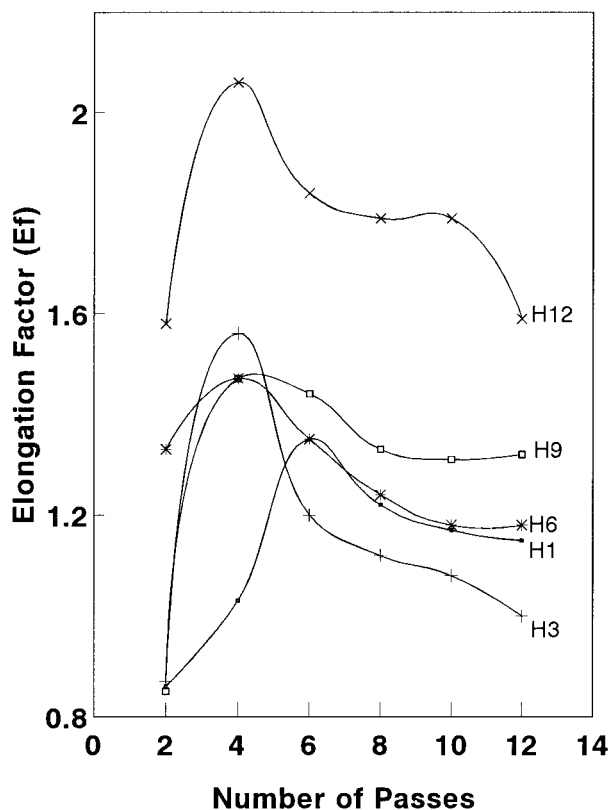


Figure 5 Elongation factor of jute yarns treated with 0.1% additives versus number of passes.

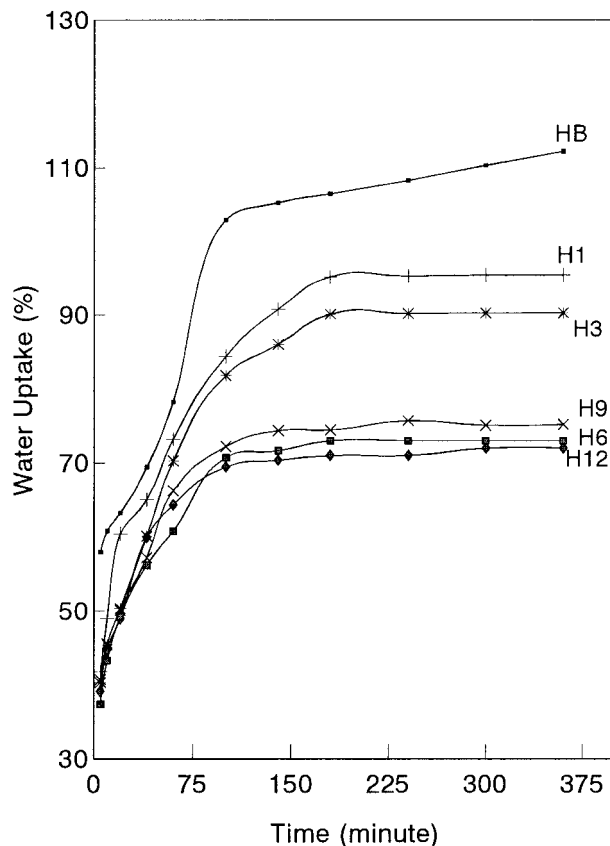


Figure 6 Water uptake of jute yarns treated with 0.1% additives versus soaking time.

with the H12 film that contains 0.1%, EDA-Ti complex. It is also observed that the elongation values are higher in the presence of additives. The E_b values are 9–13% for the H1 film, 8–14% for films H2–H7, 10–15% for films H8–H10, and 10–22% for the H11–H13 films.

Application to Jute Yarn

Jute yarns soaked in the formulated solutions were cured under UV radiation. Changes in tensile properties expressed as factors such as tenacity factor T_f and elongation at break factor E_f are given in Table VI. It is observed that the tenacity of the jute yarn has increased 25% as a result of having been treated with formulation H1. The maximum tenacity is achieved at the sixth pass. However, the radiation dose requirement is reduced when the additives (BHA, EDA, TiO_2 , and complex) are incorporated into the H1 solution. In this case, the maximum T_f values are gained at the fourth pass, as expressed pictorially in Figure 4 in which the tenacity factor is plotted

Table VII Tensile Properties of the UV-Cured Cotton Composite

Tenacity Factor													
No. of Passes	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13
2	1.00	1.08	1.02	1.09	1.02	1.05	1.07	1.08	1.00	1.02	1.09	1.55	1.09
4	1.20	1.40	1.50	1.30	1.38	1.45	1.38	1.28	1.42	1.23	1.03	1.78	1.11
6	1.25	1.30	1.38	1.23	1.33	1.38	1.33	1.15	1.14	1.20	1.12	1.45	1.21
8	1.22	1.26	1.32	1.23	1.16	1.21	1.16	2.12	1.23	1.16	1.05	1.40	1.17
10	1.11	1.13	1.21	1.07	1.01	1.25	1.16	2.12	1.30	1.13	1.30	1.40	1.17
12	1.11	1.13	1.08	1.06	1.01	1.18	1.06	1.08	1.30	1.06	1.09	1.29	1.06

Elongation Factor													
No. of Passes	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13
2	1.02	1.30	1.42	1.36	1.34	1.29	1.43	1.16	1.43	1.34	1.18	1.96	1.31
4	1.45	1.74	1.94	1.78	1.61	1.91	1.76	1.76	1.89	1.81	1.56	2.29	1.74
6	1.60	1.74	1.86	1.69	1.50	1.71	1.34	1.58	1.84	1.68	1.26	1.68	1.43
8	1.60	1.61	1.76	1.49	1.53	1.68	1.34	1.48	1.74	1.55	1.47	1.62	1.53
10	1.42	1.58	1.67	1.49	1.45	1.68	1.19	1.29	1.55	1.45	1.56	1.62	1.53
12	1.42	1.34	1.59	1.40	1.28	1.47	1.18	1.29	1.71	1.45	1.48	1.43	1.34

against the number of passes. The results obtained for polymer films are paralleled by those obtained for the treated jute yarns. This means that the highest T_f values are realized with 0.1% additives. The enhancement of tenacity as a result of the addition of BHA is up to 84%, 72% for EDA, 144% for TiO_2 , and 223% for the EDA–Ti complex. All of these T_f values were obtained with 0.1% additives at the fourth pass (Table VI). The addition of only 0.1% of the complex to the H1 formulation has significantly enhanced the tenacity (strength) of the jute yarn (223%). The TiO_2 addition has also resulted in a substantial jute strength increase (144%). These findings will help expand the applications of jute products in diverse areas.

Similarly, the elongation factor (E_f) values given in Table VI also indicate that treatment of jute yarns with the H1 formulation has enhanced elongation of the treated jute yarns by 35%, whereas this enhancement has been made more pronounced when ligands (BHA, EDA, and TiO_2) and the EDA–Ti complex were added to the H1 formulation. This can also be seen in Figure 5 in which elongation factor E_f is plotted against number of passes. These E_f values are for those jute yarns that were treated with 0.1% additives. In each case, BHA has enhanced the elongation of jute yarn by 56%, EDA and TiO_2 by 47%, and

complex by 100%. These results are significant and imply that treated jute yarn can be made more stretchable and elastic. These properties of jute will make the substrates suitable for diverse applications.

Water Uptake

Both treated and untreated jute yarn samples were immersed in water at 25°C for about 6 h. The amount of water taken up by different samples was periodically monitored. The results are shown in Figure 6, in which water uptake is plotted against soaking time. The untreated jute sample (HB) has exhibited the highest uptake of water. The lowest water uptake is noted for the jute sample H12 containing the Ti–EDA complex. Almost all the samples manifested high initial water uptake up to about 1 h, after which the uptake became slower. The results of soaking the H6, H9, and H12 samples in water were almost the same after 1–2 h of immersion. However, samples H1 and H3 took longer to reach the equilibrium of water uptake. Lower uptake of water by samples H12, H6, and H9 indicate that the additives may have entered into the process of the polymer chain of both the natural (jute cellulose) and synthetic polymers (oligomer + NVP + TPGDA).

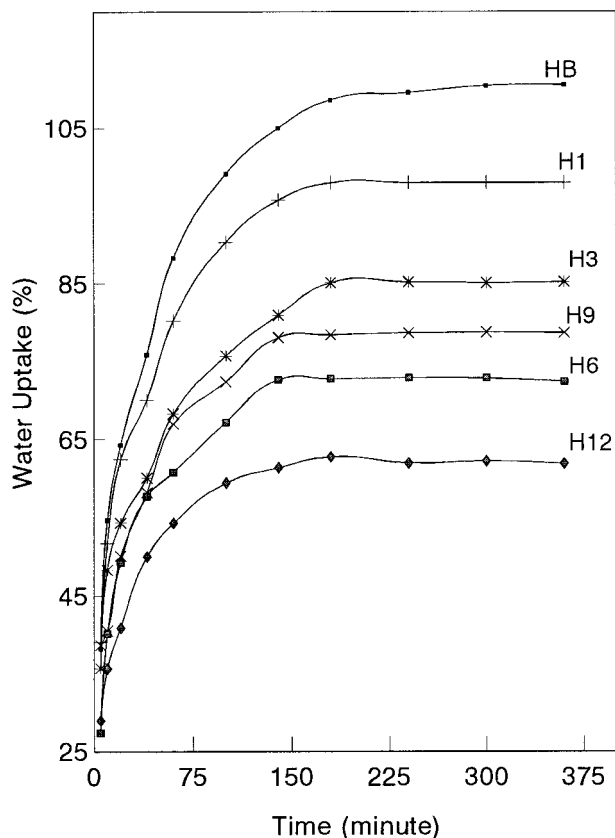


Figure 7 Water uptake of cotton yarns treated with 0.1% additives versus soaking time.

Application to Cotton

Cotton thread was treated with formulated solutions (H1–H13) and irradiated under UV light at different doses represented by passes. Changes in tenacity and elongation as a result of the composite formation were measured and expressed as factors such as the tenacity factor T_f ($T_f = \text{tenacity of treated sample} / \text{tenacity of untreated sample}$) and elongation factor E_f ($E_f = Eb \text{ treated} / Eb \text{ untreated}$). The results are given in Table VII. Both the tenacity and elongation of cotton treated with formulation H1 increase with UV radiation and reach maxima at the sixth pass, after which they decline, indicating damage of the composite at higher doses. The increments in tenacity and elongation are 25 and 60%, respectively. These increments are further enhanced when additives are incorporated into the H1 formulation. BHA increases tenacity by 30 to 50% and elongation by 74 to 94%, depending on the amount of BHA used.

Similarly, EDA, TiO_2 , and the complex have enhanced tenacities by 38–45%, 23–42%, and 3–78%, respectively; and elongation by 61–91%, 76–89%, and 56–129%, respectively. The highest increment is realized by the presence of the complex among the additives. This is undoubtedly a good achievement.

Water Uptake

Cotton thread samples, both treated and untreated (HB), were soaked in water for about 6 h at 25°C. The results are plotted in Figure 7 as water uptake versus time of immersion. As expected, the untreated cotton thread has gained more water than the treated samples. The initial water uptake was rapid, but it gradually slowed. Eventually, an equilibrium condition was reached by each sample. The time for reaching equilibrium was different for various samples for obvious reasons. The lowest water uptake was achieved by the H12 sample treated with the complex.

The maximum water uptake by the cotton sample treated with the complex was about 60% (Fig. 7), whereas the maximum uptake for the jute sample treated with the same complex was about 70% (Fig. 6). These results mean that the cotton cellulose has a more favourable condition for making the compact composite than does the jute cellulose. The trend of water uptake by different cotton samples is similar to that of the jute samples. The water uptake is the lowest by sample H12, followed by H6, H9, H3, and H1. This indicates that the incorporation of additives in the formulations has reduced the uptake of water.

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