Mechanical, Thermal and Degradation Characteristics of Jute Fabric-reinforced Polypropylene Composites: Effect of Potassium dichromate as Oxidizing Agent

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Abstract: In this study, potassium dichromate ($K_2Cr_2O_7$) was used to investigate the oxidizing effect on the properties of the compression molded jute fabrics-reinforced polypropylene (PP) composites. Jute fabrics were treated with $K_2Cr_2O_7$ in oxalic acid and sulphuric acid media. Solutions of oxalic acid and sulphuric acid were prepared in water as 1.0-10.0 % w/v and 0.1-2.0 % v/v respectively, where percentage of $K_2Cr_2O_7$ was maintained at 0.02 % w/v. Among the treatments, 5.0 % oxalic acid treated jute-PP composite showed better mechanical performance over the other combinations and also than that of the untreated sample. The treatment of jute fabrics improved the thermal stability of the composites by shifting the thermal degradation temperatures of the composites to higher temperature regions compared to PP or jute fabrics. Treated jute composites were found less degradable in soil, water and simulated weathering conditions as well as less water sensible compared to the untreated composite sample.

Keywords: Composites, Oxidizing agent, Mechanical properties, Thermal properties, Simulated weathering

Introduction

Composite materials are being used in different areas such as auto mobile industries, building materials, house hold appliances, marine vessels, space crafts and so on. Synthetic fibers based composites due to their outstanding mechanical performances and durability control the markets of the composite materials. But, because of the negative environmental impact during processing or dumping of the synthetic fibers composites, their ultimate uses are now critically considered. So, the use of natural fibers-reinforced composites is coming forward as an alternative for synthetic fibers composites. Depending on the nature of the polymer matrices in natural fibers based composites the negative environment effect can be completely or partly reduced. Natural fibers possess some important advantages such as environment friendliness, availability and renewability. The additional advantages include chemical and sound resistance, low cost, light weight, high specific strength and stiffness [1-7].

Jute is a bast fiber which is a lignocellulosic biopolymer and is abundantly available in Bangladesh. It is, therefore, of particular interest to use jute fiber as reinforcement in polymer matrix. Low microfibril angle and high cellulose content make the jute fiber as a promising reinforcement in polymer matrix [8-10]. In spite of these advantages, jute fiber-like other natural fibers-experiences some major drawbacks such as high moisture sensitivity, inherent polarity, poor dimensional stability, low thermal resistance, anisotropic fiber characteristics. These limitations result in poor fiber-matrix adhesion. So, a strong adhesion between fiber and matrix is needed for an effective transfer of stress and load distribution through out the interface. This situation promotes to develop strategies for surface modification of natural fibers or polymer matrices. The composite scientists worldwide keep their all out effort on developing strong interfacial adhesion between fiber and matrix to get expected properties from the composite materials. The chemical surface modification of jute fiber with potassium permanganate (acid and alkali media) as an oxidizing agent was extensively studied by Jahangir *et al.* [11]. The concentrations and types of the oxidizing media had significant effect on the mechanical and thermal properties of jute fiber-PP composites. For each type of oxidizing media, an optimum concentration was determined above which the mechanical properties of the composites were found to decrease. The optimum concentrations of sulphuric acid, oxalic acid and alkaline solution were 0.5, 5 and 5 % respectively. The study revealed that potassium permanganate in oxalic acid medium earned the maximum values of the mechanical and thermal properties over the other media. Sultana *et al.* [12,13] studied on the oxidized jute fibers, and the mechanical properties of raw jute and oxidized jute based composites were measured. Jute fiber was oxidized with sodium periodate and post-treated with urea and urotropine in order to increase the compatibility of the jute fiber with the polypropylene matrix. Post-treated jute fiber reinforced specimens yielded better mechanical properties compared to the oxidized and raw ones. Tripathy *et al.* [14] worked on the interfacial properties of four different forms of jute fibers (sliver, bleached, mercerized and untreated) and polyolefinic matrices (LDPE and PP). The jute fibers were bleached with an oxidizing agent (0.7 % $NaClO_2$ in aqueous solution) and then treated with 2.0 % aqueous NaOH solution. The fiber-matrix adhesion

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was estimated by means of the critical fiber length and the stress transfer ability parameter. The parameters were obtained by single fiber composite tests. Thermal-mechanical characterization of the fibers was also carried out to evaluate the resistance to processing conditions. It was found that the adhesion was better in jute-PP composites than in LDPE-jute composites. In both cases the results showed that the sliver jute and the untreated jute had better adhesion to both matrices than had the bleached and the mercerized fibers. Zaman *et al.* [15] treated jute fabrics (hessian cloth) with $KMnO_4$ solution in acetone of different concentrations and at different soaking times. The optimized $KMnO_4$ treated jute fabrics were again treated with 2-hydroxyethyl methacrylate (HEMA) solution along with the additive urea. The investigation showed a promising improvement in the mechanical properties of the composites. Potassium permanganate-initiated graft copolymerization of methyl methacrylate onto defatted jute fibers brought no remarkable improvement in the tensile properties of the fibers [16]. However, $KMnO_4$ treated jute fabrics reinforced urethane based thermoset composites were found to improve the fiber-matrix adhesion to a greater extent [17].

As the structural unit of cellulose contains three hydroxyl groups- one primary and two secondary- it undergoes chemical reactions typical of hydroxyl groups. These hydroxyl groups can be oxidized with the suitable oxidizing agents. The bonds between C2-C3 and even chains of the cellulose structure may be ruptured with the severity of the oxidizing conditions. The rate of formation of oxidized cellulose is influenced by the temperature, concentration of oxidant, and the nature of the oxidizing agent itself. Oxidation promotes roughness of the fiber surface and causes brittleness in fibers depending on the nature and strength of the oxidizing agent. The primary oxidized products of cellulose (aldehyde, ketone and carboxyl group at C-6 position of cellulose unit) can be further oxidized to dialdehyde by the scission of bond between C2 and C3 which can again transform into carboxyl groups depending on the strength of the oxidants and reaction time. Thus various oxidized products can be formed during oxidation of cellulose with oxidizing agents [18,19].

The present research work deals with the treatment of jute fabrics with potassium dichromate in acid (oxalic acid and sulphuric acid) medium. Polypropylene is used as a matrix material. The objective of this study is to investigate the effect of potassium dichromate as an oxidizing agent on the mechanical and thermal properties of jute fabrics-PP composites. The research work also involves exploring the degradation characteristics and water uptake tendency of the composites.

Experimental

Materials

Jute fabrics (Hessian cloth) were supplied by SADAT Textile Industries Ltd., Dhaka, Bangladesh. Average area weight of each sheet of jute fabric is 223.72 g/m^2. Potassium dichromate, oxalic acid, sulphuric acid and polypropylene (PP) pellets (trade name: Cosmoplene) were procured from Merck, Germany and the Polyolefin Company (Singapore) Pte. Ltd. respectively. The materials were used as received.

Surface Modification of Jute Fabrics

The different concentrated solutions of oxalic acid (1.0-10.0 %w/v) and sulphuric acid (0.1-2.0 %v/v) were prepared in distil water. In these solutions concentration of $K_2Cr_2O_7$ was maintained 0.02 %w/v. Jute fabrics were soaked separately with these solutions for 2 mins at room temperature. The soaked jute fabrics were washed with running tap water for about 30 mins to remove the unbound oxidizing agent. After soaking, jute fabrics were dried in an oven at 105 °C for 6 hrs and then kept in a desiccator.

Fabrication of Composites

PP sheets of desired size (15×13 cm^2) were prepared by compressing PP granules in the heat press (Carver, Inc., USA, model 3856) at 190 °C for 5 mins under 5 tons pressure. PP sheets of different thicknesses were used for fabrication of the composites of different weight fraction of jute fabrics. Average area weight of each PP sheet for control composite is 237.66 g/m^2. Jute fabrics were cut into small pieces of 15×13 cm^2 size. For composite fabrication, sandwich was made by placing alternately four layers of pre-weighed jute fabrics inside five layers of PP sheets. The sandwich was then placed between two steel plates with a composite fabrication mold which maintains the thickness of composite about 2 mm. The sandwich with this arrangement was compressed in the heat press at the same conditions which were applied for PP sheets preparation. After being heat pressed, PP sheets and composites were cooled to another press (Carver: model 4128) which is operated at cooling mode.

Mechanical Testing

Tensile test of composite samples was carried out by a universal testing machine using a gauge length of 20 mm and cross-head speed of 2 mm/min. Three point bending strength of the composite samples was measured in the same machine with a span length of 58 mm and a cross-head speed of 2 mm/min. Both the tests were carried out according to DIN 53455 and DIN 53452 standard methods, respectively. Impact strength (Charpy) of the composites and PP was carried out in an impact tester (MT-3016, Pendulum type, Germany) following ASTM D 6110-97. All the results were taken as the average value of five samples.

Thermal Analysis

Thermogravimetric and differential thermal analyzer (TG/DTA 6300, USA) have been used to simultaneously perform

thermo-gravimetric and differential thermal analytic mea-surements. Temperature was maintained at the range of 30 to 600 $^{\circ}$C with a heating rate of 20 $^{\circ}$C/min in a nitrogen (purged at 100 ml/min) environment.

Water Uptake

Specimens ($60 \times 15 \times 2$ mm^3) of the composite samples (control and treated) were immersed in the static water of a glass beaker at room temperature for different time periods (up to 30 days). Before immersion, weight of the samples was taken. At certain time intervals, samples were taken out from the beaker and wiped smoothly with tissue paper and then weighed immediately. Percent water uptake was then calculated.

Water Degradation Test

Composite samples were completely immersed into the static water of a glass beaker at room temperature for a period of 30 days. At certain time interval, samples were taken out of water and dried in an oven at 105 $^{\circ}$C until the samples reached a constant weight and kept at room temperature for at least 24 hrs. Mechanical properties of the composites were then measured.

Soil Degradation Test

The composite samples were buried in mud at about 6 inches depth for different periods of time. After a certain period, samples were taken out carefully and washed with tap water to remove the soil particles from the surface of the specimens. Samples were dried in an oven at 105 $^{\circ}$C until the samples reached a constant weight and then kept at room temperature for at least 24 hrs. Mechanical properties of the samples were then measured.

Simulated Weathering Test

Specimens of the composite ($60 \times 15 \times 2$ mm^3) were exposed for aging in simulated weather to an Accelerated weathering tester (model Q.U.V, the Q-Panel Company, USA). The test was carried out with alternating cycles of sunshine over 4 hrs (65 ± 2 $^{\circ}$C), and dews and condensation for 2 hrs (45 ± 2 $^{\circ}$C). This treatment was carried out for a maximum period of 600 hrs.

Results and Discussion

### Mechanical Properties of the $K_2Cr_2O_7$ Treated Jute-PP Composites

The fiber volume fraction has a significant effect on the mechanical properties of the composites. The jute content in the composites was optimized at 45 % by the weight of jute fiber [20]. The highest values of tensile strength (TS), bending strength (BS), tensile modulus (TM), bending modulus (BM) and impact strength (IS) of the composite were recorded as 52 MPa, 63 MPa, 1.03 GPa, 3.27 GPa and 19.1 kJ/m^2 at

45 % by the weight of jute fiber. $K_2Cr_2O_7$ treated jute fabrics-PP composites were prepared by maintaining 45 %w/w jute fiber. The mechanical properties of the treated jute composites were evaluated and compared with that of the control composite (45 %w/w untreated jute fabrics). Composites prepared with $K_2Cr_2O_7$ treated jute fabrics in oxalic acid (OA) and sulphuric acid (SA) media are denoted here as $C_{K(OA)}$ and $C_{K(SA)}$ and jute fabrics as $J_{K(OA)}$, and $J_{K(SA)}$.

The effect of $K_2Cr_2O_7$ in OA medium on TS, BS, TM and BM of the composites is presented in Figure 1. It is observed that the values of TS, BS, TM and BM of the composites increase up to 5.0 % OA treatment after that there is observed a decrease in strength and modulus. It is found that TS of the treated composite (5.0 % $C_{K(OA)}$) increases from 52 to 71.8 MPa, which is 38.07 % higher than that of the control composite, and BS increases from 63.0 to 82.0 MPa which shows 30.16 % improvement. On the other hand, TM and
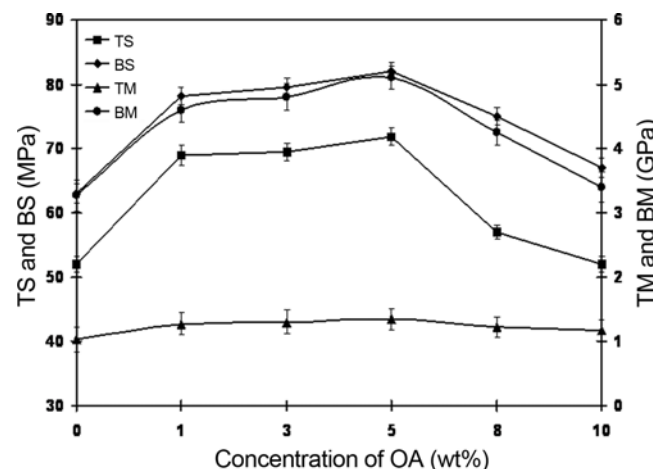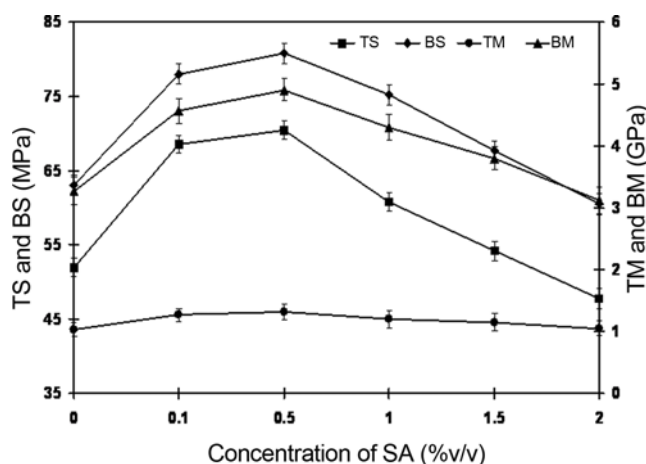

Figure 1. Effect of potassium dichromate (in OA) on tensile and bending strength and modulus of the composite.
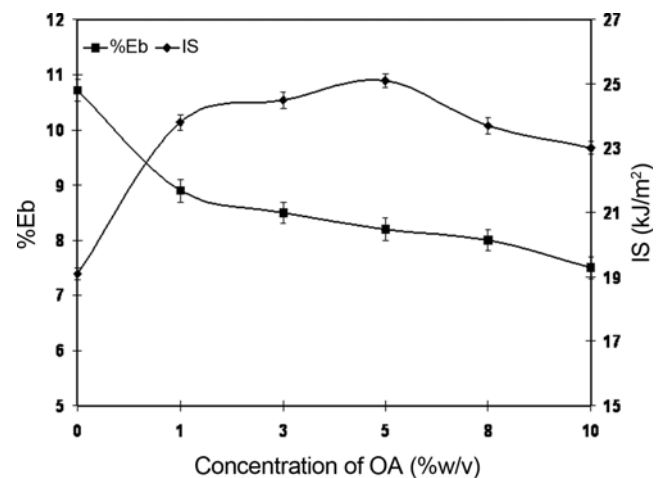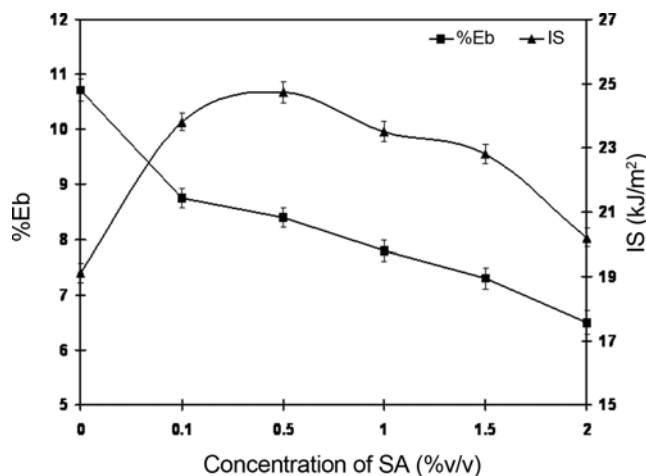

Figure 2. Effect of potassium dichromate (in OA) on elongation at break and impact strength of the composite.

BM increase to 31.07 % (from 1.03 to 1.35 GPa) and 55.96 % (from 3.27 to 5.1 GPa) respectively than that of the control composite. The effect of $K_2Cr_2O_7$ (in OA) on impact strength and elongation at break of the composites is shown in Figure 2. The value of IS shifted to 25.1 kJ/m^2 (5.0 % $C_{K(OA)}$) from 19.1 kJ/m^2 (for control sample) which shows 31.41 % improvement. Elongation at break of the treated samples is found to decrease with increasing concentrations of OA solution.

In SA medium, the effect of $K_2Cr_2O_7$ on TS, BS, TM and BM of the composites is presented in Figure 3. It is observed that all the mechanical parameters achieve the highest values for 0.5 % $C_{K(SA)}$. The observed improvement of TS, BS, TM and BM of the 0.5 % $C_{K(SA)}$ than that of the control composite is found to be 35.58 % (from 52.0 to 70.5 MPa), 28.25 % (from 63 to 80.8 MPa), 28.15 % (from 1.03 to 1.32 GPa) and 49.84 % (from 3.27 to 4.9 GPa) respectively. Figure 4 shows the effect of $K_2Cr_2O_7$ (in SA) on impact strength (IS) and

Figure 3. Effect of potassium dichromate (in SA) on tensile and bending strength and modulus of the composite.

Figure 4. Effect of potassium dichromate (in SA) on elongation at break and impact strength of the composite.

elongation at break of the composites. The value of IS increases from 19.1 kJ/m^2 to 24.75 kJ/m^2 (for 0.5 % $C_{K(SA)}$) which indicates 29.58 % improvement. Elongation at break of the treated samples gradually decreases with the increase of SA concentrations in $K_2Cr_2O_7$ solution.

Comparison on the Mechanical Properties of the Control and $K_2Cr_2O_7$ Treated Jute Composites

Table 1 shows a comparative study on the mechanical properties of the control composite and of the $K_2Cr_2O_7$ treated jute composites in different media. It is easily apprehensible that composite prepared with $K_2Cr_2O_7$ treated jute fabric in 5.0 % oxalic acid had the highest values of all the mechanical parameters compared to the control composite and also to the composite prepared with $K_2Cr_2O_7$ treated jute fabrics in sulphuric acid media.

The changes in mechanical properties of the treated jute composites may be explained on the basis of the oxidizing effect of $K_2Cr_2O_7$ in acid media onto jute fabrics. During oxidation many changes happen into the cellulosic materials. The chemical and physical properties of the oxidized celluloses depend upon the nature of the oxidizing agents, oxidizing medium and the conditions applied. The rate of formation of oxidized cellulose is influenced by the concentration of oxidant, and the nature of the oxidizing agent itself. The rate of oxidation of the cellulose may be greatly accelerated by the simultaneous oxidation of a third substance in the system. For example, when cellulose is treated with potassium dichromate and oxalic acid, both the oxalic acid and the cellulose are oxidized and the oxidation of the latter takes place much more rapidly than when cellulose is treated with potassium dichromate and sulphuric acid. Oxycelluloses of the extreme reducing type can be conveniently prepared in oxalic acid medium. During oxidation cellulosic materials may undergo the attack on the surface of the crystallites which causes roughness of the fibers. On the severity of the action the penetration into the amorphous and crystalline areas may also occur that degrades the fiberous materials [18,19,21]. So, it can be assumed that at lower concentrations of oxidizing treatments, the oxidized jute fabrics experience surface roughness and a reduction in compactness of the fiber bundles, which enhance the effective surface area available for contact with the matrix. The additional sites of mechanical interlocking promote more interpenetration

Table 1. Comparison on the mechanical properties of control composite and composites prepared with $K_2Cr_2O_7$ treated jute fabrics in oxalic acid and sulphuric acid media

Sample	TS (MPa)	BS (MPa)	TM (GPa)	BM (GPa)	IS (kJ/m^2)
Control composite	52.00	63.00	1.03	3.27	19.10
OA (5.0 %)	71.80	82.00	1.35	5.10	25.10
SA (0.5 %)	70.50	80.80	1.32	4.90	24.75

between the fibers and the PP matrix. As a result, mechanical properties of the composites increase upon treatment of jute fabrics with $K_2Cr_2O_7$ at lower concentrations of oxidizing media. At higher concentrations, the oxidizing agents may penetrate and attack into the amorphous regions and some of the crystalline regions that may degrade the fiberous materials. This morphological change might have caused agglomeration of fibers in the matrix or inhomogeneous stress transfer when load is applied. This may result in poor mechanical properties in the composites [11].

Thermal Properties of PP, Untreated and $K_2Cr_2O_7$ Treated Jute Fabrics and Composites

Polypropylene

The different thermograms of PP are shown in Figure 5. The DTG thermogram comprises with a broad single peak which starts around 371.6 °C with a maximum degradation at 413.8 °C at the rate of 1.634 mg/min. This peak corresponds to the cleavage of C-C backbone along with H- abstraction at the site of rupture [22,23]. PP is strongly hydrophobic (moisture content is 0 %) in nature and totally decomposed at 426.8 °C without formation of any char residue (TG thermogram). The DTA thermogram of PP indicates the melting temperature of PP at 163.9 °C.

Jute Fabrics

The treated jute fabrics (for each solvent) which produce the best mechanical properties in the composites are considered for thermal experiment, e.g., for oxalic acid medium 5 % OA in $K_2Cr_2O_7$ (5 % $J_{K(OA)}$) and for sulphuric acid 0.5 % SA in $K_2Cr_2O_7$ (0.5 % $J_{K(SA)}$) Thermograms of $K_2Cr_2O_7$ treated jute fabrics along with untreated jute sample are presented in Figure 6. The major changes occurred in jute fabrics during thermal treatment under thermo gravimetric and differential thermal investigations are illustrated below.

Removal of Moisture

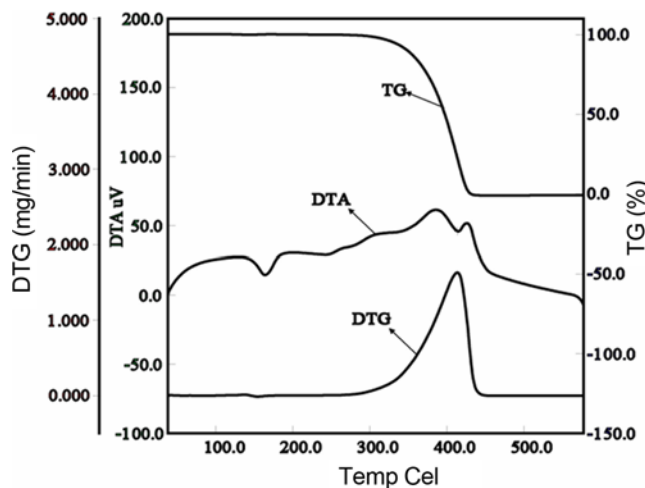It is observed from TG thermograms that the loss of
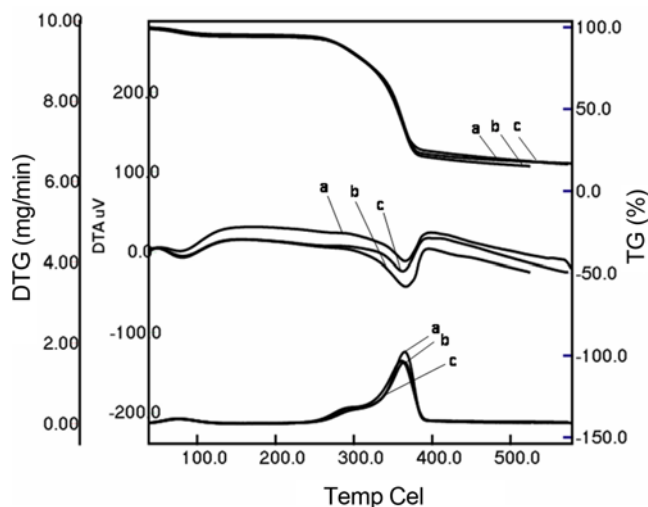

Figure 5. Thermograms of PP.

Figure 6. Thermograms of (a) untreated jute fabric, (b) 5.0 % $J_{K(OA)}$, and (c) 0.5 % $J_{K(SA)}$ (top: TG, middle: DTA, bottom: DTG).

moisture from the jute fabrics is occurred below 100 °C. The loss of moisture from untreated jute fabric, 5.0 % $J_{K(OA)}$ and 0.5 % $J_{K(SA)}$ was found to be 4.5, 4.9 and 3.8 % respectively. Jute fiber is hydrophilic in nature, so it absorbs moisture from the atmosphere which is released during thermal treatment.

Decomposition of Hemicelluloses

The decomposition of hemicelluloses from untreated jute fabric, 5.0 % $J_{K(OA)}$ and 0.5 % $J_{K(SA)}$ starts at 296, 302.8 and 290.8 °C with the rate of 0.390, 0.28 and 0.90 mg/min respectively (DTG thermogram). The similar observation was also recorded for untreated jute fibers in the previous literature [11,22].

Decomposition of α-Cellulose

The decomposition of α-cellulose from untreated jute fabric, 5.0 % $J_{K(OA)}$ and 0.5 % $J_{K(SA)}$ may occur at 365.0 °C (rate 1.781 mg/min), 365.2 (1.24 mg/min) and 362.6 °C (1.68 mg/min) respectively (DTG thermogram). Celluloses decompose at higher temperature regions compared to hemicelluloses which can be apprehended by the above observations [11].

Formation of Char Residues

TG thermograms show that untreated jute fabric, 5.0 % $J_{K(OA)}$, and 0.5 % $J_{K(SA)}$ produce 20.7, 16.0 and 18.3 % char residues at 377.8, 379.2 and 377.1 °C respectively. The formation of char residues may involve the scission of glycosidic linkage, rupture of C-O and C-C bonds, condensation and aromatization of carbon atoms from each pyranose ring to form discrete graphite layers [22,24-26].

Composites

The Thermograms of control composite, 5.0 % $C_{K(OA)}$ and 0.5 % $C_{K(SA)}$ are displayed in Figure 7. In composite, two stage degradations occur: first stage is responsible for jute fiber and second stage is for PP.
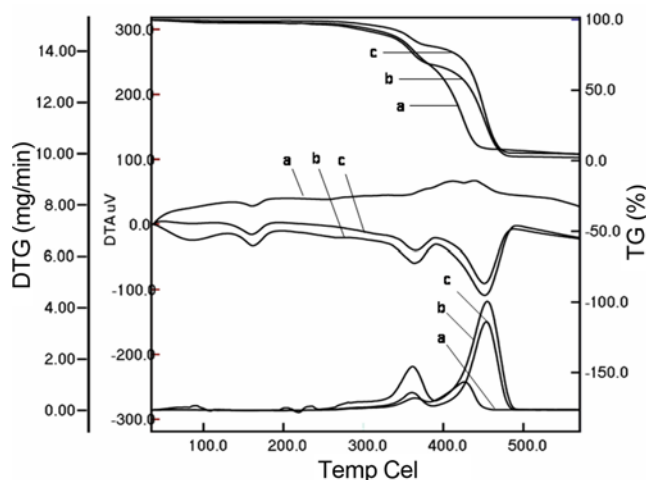
Figure 7. Thermograms of (a) control composite, (b) 5.0 % $C_{K(OA)}$, and (c) 0.5 % $C_{K(SA)}$ (top: TG, middle: DTA, bottom: DTG).

Loss of Adsorbed Water

It is observed from TG thermograms that the loss of adsorbed water from control composite, 5.0 % $C_{K(OA)}$ and 0.5 % $C_{K(SA)}$ are 1.9, 1.9 and 1.8 % respectively. It is thought that during processing or testing, water could have been absorbed from the atmosphere [27].

Maximum Degradation Temperature (MDT)

The DTG thermograms show that the MDT of control composite for first and second stage is 365.1 °C and 426.7 °C respectively. It is observed that the MDT of neat PP (413.8 °C) is shifted to higher temperature region by 12.9 °C in the control composite (426.7 °C). It indicates that the composite is more thermally stable compared to neat PP. On the other hand, the MDT of 5.0 % $C_{K(OA)}$ and 0.5 % $C_{K(SA)}$ for first and second stage is observed at 365.0 and 465.4 °C, and 363.6 °C and 456.6 °C respectively. So, the MDT of neat PP is shifted to higher temperature regions by 51.6 and 42.8 °C for 5.0 % $C_{K(OA)}$ and 0.5 % $C_{K(SA)}$ respectively.

Formation of Char Residues

It is observed from TG thermogram that the residues obtained for control composite, 5.0 % $C_{K(OA)}$ and 0.5 % $C_{K(SA)}$ are 9.4, 5.1 and 2.5 % at 438.6, 476.6 and 468.0 °C respectively.

Comparison on Thermal Properties of PP, Untreated and $K_2Cr_2O_7$ Treated Jute Fabrics and Composites

A comparative thermal study of PP, untreated and treated jute fabrics and composites is shown in Table 2 and 3. Comparing the onset, 50 % and maximum degradation temperatures (Table 2), the order of thermal stability of PP, untreated and $K_2Cr_2O_7$ treated jute fabrics can be stated as: 0.5 % $J_{K(SA)}$ < untreated jute fabric < 5.0 % $J_{K(OA)}$ < PP. The similar observation of higher thermal stability of PP compared to jute fiber in nitrogen atmosphere was also recorded in previous literature [11,22]. For PP and composites (Table 3), the thermal stability of PP, control and $K_2Cr_2O_7$ treated jute

Table 2. Comparative thermal stability of PP, untreated jute fabrics and $K_2Cr_2O_7$ treated jute fabrics in oxalic acid and sulphuric acid media

Sample	Degradation temperature (°C)		
	Onset	50 %	Maximum
PP	371.6	398.0	413.8
Untreated jute	327.7	352.1	365.0
5.0 % $J_{K(OA)}$	330.4	353.4	365.4
0.5 % $J_{K(SA)}$	325.5	352.2	362.2

Table 3. Comparative thermal stability of PP, control composite and $K_2Cr_2O_7$ treated jute composites in oxalic acid and sulphuric acid media

Sample	MDT (°C)	Increased from neat PP (°C)
PP	413.8	-
Control composite	426.7	12.9
5.0 % $C_{K(OA)}$	465.4	51.6
0.5 % $C_{K(SA)}$	456.6	42.8
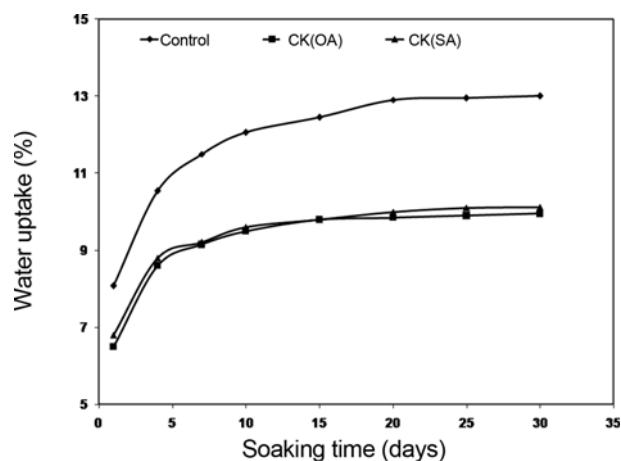
Figure 8. Percent water uptake of the control composite, 5.0 % $C_{K(OA)}$ and 0.5 % $C_{K(SA)}$ versus soaking time (days).

composites can be summarized in the order of: PP < control composite < 0.5 % $C_{K(SA)}$ < 5.0 % $C_{K(OA)}$. Better fiber-matrix adhesion may be responsible for the improved thermal stability of the treated jute-PP composite [11,22].

Water Uptake

The results of percent water uptake of the control and $K_2Cr_2O_7$ treated jute fabrics-PP composites with different soaking times (days) are shown in Figure 8. It is observed that water absorption of the control composite is higher than that of the $K_2Cr_2O_7$ treated jute composites. The percent water gain of the control composite is found to be 8.0-13 % during the experimental periods, which drops down to 6.5-9.95 and 6.8-10.12 % for 5.0 % $C_{K(OA)}$ and 0.5 % $C_{K(SA)}$ respectively. During the initial period of water soaking (first

Table 4. The percent loss of mechanical properties of control and K$_2$Cr$_2$O$_7$ treated jute-PP composites due to water aging

Time (days)	Control				5.0 % C$_{K(OA)}$				0.5 % C$_{K(SA)}$			
	TS	BS	TM	BM	TS	BS	TM	BM	TS	BS	TM	BM
5	4.8	4.0	3.6	3.0	2.5	2.0	1.9	1.8	2.6	2.2	1.95	1.8
10	6.5	6.3	4.9	4.3	4.2	3.8	3.7	3.2	4.2	3.96	3.8	3.5
15	8.8	7.8	6.3	5.7	6.3	6.1	4.8	4.5	6.0	5.9	5.2	4.8
20	11.5	10.2	8.2	7.4	8.5	8.0	6.5	6.15	8.8	8.2	6.8	6.0
25	14.4	12.3	10.0	9.6	10.0	9.4	8.5	7.8	10.6	10.3	8.7	8.0
30	16.5	15.0	12.4	11.6	11.5	10.8	10.3	9.2	12.1	11.8	10.4	9.9

24 hr), water absorption for both the untreated and treated composites is very rapid. After 20 days of water soaking, the percent water gain of the control composite remains almost static which is observed after 10 days for the treated samples. For better fiber-matrix adhesion, the treated composites may take up lesser amount of water from the water bath as compared to the control composite.

Degradation Studies

Degradation in Water

Both control and K$_2$Cr$_2$O$_7$ treated jute fabrics-PP composite samples were immersed in the water of a glass beaker at room temperature for a maximum period of 30 days. The percent loss of tensile and bending properties of the treated and control composite samples was periodically measured with respect to their degradation time and the results are shown in Table 4. It is observed that the percent loss of mechanical properties of the composite samples increases with the increase of degradation time. However, the loss is higher for the control sample than that of the treated samples. The loss of TS, BS TM and BM of the control sample within the maximum period of observation is about 16.5 15.0, 12.4 and 11.6 % respectively. The loss of TS and BS of C$_{K(OA)}$ is 11.5 and 10.8 %, of C$_{K(SA)}$ is 12.1 and 11.8 %, respectively. The loss of TM and BM of C$_{K(OA)}$ is 10.3 and 9.2 %, of C$_{K(SA)}$ is 10.4 and 9.9 % respectively. Due to better interfacial adhesion, treated jute composites may retain much of its properties under water aging condition. During water aging, water diffuses through the cutting edges of the samples and micro-organisms may attack into the jute

fibers. This affected the mechanical properties of the composites [28,29].

Degradation in Soil

Both control and K$_2$Cr$_2$O$_7$ treated jute fabrics-PP composite samples were buried in soil (at least 25 % moisture) for up to 30 days in order to study the effect of such an environmental condition on the degradability of the samples. The percent loss of tensile and bending properties of the treated and control composite samples was periodically measured with respect to their degradation time and the results are shown in Table 5. As expected, it is found that the percent loss of tensile and bending properties for both control and treated composite samples increases gradually with increasing soil burial time. After 30 days of soil degradation, the loss of TS, BS, TM and BM for control composite is about 25.6, 23.4, 18.4 and 17.5 % respectively. The loss of TS and BS observed for C$_{K(OA)}$ is 16.4 and 15.8 %, for C$_{K(SA)}$ is 16.8 and 15.7 %, respectively. The loss of TM and BM for C$_{K(OA)}$ is 12.6 and 12.2 %, for C$_{K(SA)}$ is 14.7 and 14.0 %, respectively. It is quite clear that treated composites retain much of its mechanical properties than that of the untreated composite sample during soil degradation. Jute is a natural biodegradable fiber and has a strong tendency to degrade when it is buried in soil [30].

Simulated Weathering Effect

The samples of the control and K$_2$Cr$_2$O$_7$ treated jute composites were set in the simulated weathering tester and the mechanical properties of the composite samples were measured with stipulated time intervals. The percent loss of tensile and bending properties of the samples due to

Table 5. The percent loss of mechanical properties of control and K$_2$Cr$_2$O$_7$ treated jute-PP composites due to soil burial

Time (days)	Control				5.0 % C$_{K(OA)}$				0.5 % C$_{K(SA)}$			
	TS	BS	TM	BM	TS	BS	TM	BM	TS	BS	TM	BM
5	7.6	7.14	6.2	5.7	3.9	3.6	3.16	2.7	4.7	4.0	4.0	3.4
10	10.8	9.5	8.1	7.1	6.0	5.4	4.5	4.1	7.0	5.8	5.1	4.8
15	14.8	14.0	10.8	10.1	8.0	7.3	6.3	5.6	8.8	7.6	7.3	6.2
20	18.7	17.5	13.13	12.2	10.8	9.7	8.24	7.6	10.9	10.0	9.2	8.0
25	22.4	20.0	16.0	14.6	13.5	12.8	10.2	9.8	13.0	12.6	12.1	10.8
30	25.6	23.4	18.4	17.5	16.4	15.8	12.6	12.2	16.8	15.7	14.7	14.0

Table 6. The percent loss of mechanical properties of control and $K_2Cr_2O_7$ treated jute-PP composites due to simulated weathering

Time (hrs)	Control				5.0 % $C_{K(OA)}$				0.5 % $C_{K(SA)}$			
	TS	BS	TM	BM	TS	BS	TM	BM	TS	BS	TM	BM
50	15.4	14.8	12.3	11.0	10.7	9.75	8.6	7.8	11.6	11.0	9.2	8.0
100	18.3	17.0	15.7	14.0	14.2	12.0	11.2	10.5	15.7	14.6	12.0	11.4
150	21.4	19.4	19.0	17.6	16.9	14.9	14.0	12.6	18.0	17.0	15.0	14.0
300	29.8	26.0	25.5	24.0	21.3	20.0	19.0	18.5	22.8	21.6	20.0	18.8
600	36.5	33.0	31.8	29.6	25.8	24.0	22.5	21.6	27.0	25.7	23.3	22.8

weathering is shown in Table 6. The experiment reveals that the reduction in tensile and bending properties of the composites due to weathering increases gradually with increasing exposure time. The percent loss of TS, BS, TM and BM of the control composite within the maximum period of observation is about 36.5, 33.0, 31.8 and 29.6 % respectively. The loss of TS and BS observed for $C_{K(OA)}$ is 25.8 and 24.0 %, for $C_{K(SA)}$ is about 27.0 and 25.7 % respectively. The loss of TM and BM for $C_{K(OA)}$ is 22.5 and 21.6 %, for $C_{K(SA)}$ is 23.3 and 22.8 %, respectively. During simulating weathering experiment, the degradation effect is more pronounced in control composite than that of the treated composite samples. Due to UV exposure under the environmental conditions in the weathering tester may be responsible for the loss of the mechanical properties of the composites. During weathering, leaching of lignin and water soluble products from the samples [31,32] as well as, absorption of water during the water spray and condensation cycle can occur. It is observed that both strength and modulus decrease with increasing duration of weathering. The reduction of strength and modulus could be due to degradation of fiber and fiber-matrix interfacial bonding. The most likely oxidation reaction [33] is caused by the UV radiation where O_2 is used up before it can diffuse to the interior. The degradation is concentrated near the surface, even in fibers in which high UV levels are present in the interior. The photo-oxidation process also takes place mainly in amorphous regions because of their higher permeability to O_2. The properties of the composite are also likely to have been affected by the embrittlement of the matrix. During weathering, chain scission of PP occurred along with formation of surface cracks results in embrittlement of the matrix [33,34]. Thus, leaching of lignin or water soluble products, absorption of water in particular at the interface and embrittlement of PP can occur simultaneously during weathering [35] which might have caused reduction in the strength and modulus of the composites.

Conclusion

The treatment of jute fabric with $K_2Cr_2O_7$ brought an important change in the mechanical and thermal properties of the composites. The study revealed that composite prepared with $K_2Cr_2O_7$ treated jute fabric in 5.0 % oxalic acid medium had better mechanical properties and thermal stability than that of the control composite and of the composites prepared with $K_2Cr_2O_7$ treated jute fabric in sulphuric acid medium. Thermal analytical data also revealed that thermal stability of the composites either treated or untreated was higher than that of PP or jute fabrics. The diffusion of water molecules into the $K_2Cr_2O_7$ treated jute-PP composites was less than that of the control sample. The prepared composites lost their mechanical properties to a greater extent when they are placed under different environmental conditions. The treated jute composites retained much of its mechanical properties under water, soil and simulated weathering conditions compared to the control composite. The mechanical properties of the composites were affected largely under the simulated weathering conditions.

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