Water Absorption And Kinetics Of Treated Woven Jute Fiber-LDPE Composites

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Abstract **- Natural fiber reinforced polymeric materials have grown appreciable amount of attention among academia and researchers. The eco-friendly nature, low cost and sustainability of these natural fibers are the main advantages. However, one major disadvantage which needs to be addresses is the hydrophilic nature of this fiber which provides weak interfacial adhesion between the natural fiber and polymeric material. To overcome this, woven jute fibers were treated with sodium hydroxide followed by Trimethoxy(propyl)silane to convert the fiber from hydrophilic to hydrophobic nature. In this study, both untreated and treated woven jute fibers were reinforced with low-density polyethylene (LDPE) matrix using compression moulding technique. The composite samples were prepared as sandwich of woven jute fiber and LDPE sheets. The effects of chemical treatments on the water absorption behaviour of woven jute fiber/LDPE composites were investigated. Further, mathematical investigation is done to find the diffusion kinetics. The results showed that the water resistance of the woven jute fiber reinforced LDPE composite improved after the chemical treatments. The composite having silane treated woven fiber demonstrated superior water resistance, indicating strong fiber-matrix adhesion.**

Keywords **- Woven jute fiber, Polymer composite, Water absorption, Hydrophilic**

I. INTRODUCTION

Over the past two decade, natural fiber based polymeric composites have gained an appreciable amount of attention. There is no denying that synthetic fibers like glass fiber offers relatively much better mechanical, thermal and water resistance properties, however, owing to the environmental concerns, cost and sustainability associated with these natural fibers, academicians and researchers are getting diverted to natural fibers. Synthetic fibers have various problems associated with them: as they are difficult to decompose, reclamation processing leads to a myriad amount of environmental load; it’s extremely difficult to conduct appropriate disposal processing [1]. Among various natural fibers like hemp, sisal, banana, coir etc. jute fibers have gained particular interest in India as the composite made using Jute fiber gives moderate tensile and flexural properties in comparison to those of others [2]. However, one major disadvantage is the hydrophilic nature of jute fiber which provides weak interfacial adhesion between the natural fiber and polymeric material. To overcome this, it is necessary to convert fiber from hydrophilic nature to hydrophobic nature. Chemical treatments to the natural fibers helps to remove non-cellulosic components as well as make improve its water resistance, which leads to provides better bonding between the natural fiber and the polymeric matrix. To improve resistance towards water absorption, alkali treatment (NaOH) and Trimethoxy(propyl)silane (silane) can be employed [3-5]. The optimum conditions for NaOH treatment is observed with the treatment of jute fiber with 5 % NaOH solution for 4h [6]. NaOH treatment results in disruption of hydrogen bonding and removal of non-cellulosic components (lignin, hemicelluloses etc.) which yield to better adhesion in composite material. Silanes are known for their sound efficiency as coupling agents and have been successfully applied with natural fiber filled polymer composites [7].

This paper deals with the development of the low-density polyethylene (LDPE) composite reinforced with woven jute mate. The composite samples were prepared as sandwich of woven jute fiber and LDPE sheets. The effects of chemical treatments (NaOH and Trimethoxy(propyl)silane) on the water absorption behaviour of woven jute fiber/LDPE composites were investigated and compared. Further, mathematical investigation is done to find the diffusion kinetics. In addition, to analyze the effects of various treatments on jute fiber has been investigated using Scanning Electron Microscopy (SEM).

II. EXPERIMENTAL

a. Materials

Jute fiber was used as reinforcement and Low-density polyethylene (LDPE) was used as matrix in this work. Sisal fiber was purchased from the local resource. It comprises of 59-61% cellulose, 12-13% lignin, 21-24% hemicellulose, 0.2-1.5% pectin etc [8]. LDPE was purchased from the M/s Rapid Engineering Company Private Ltd., India having density 0.945 g/cm^3 and melt flow index 34 g/10 min (2.16 kg at 230^{o}C). Sodium hydroxide (NaOH) and Trimethoxy(propyl)silane (silane) was for the modification of the jute fiber was procured from Sigma Aldrich.

b. Jute fiber treatment

i. *Untreated Jute Fiber:* Jute fiber mat were washed using distilled water to remove impurities. Washed fiber mat was then oven-dried at 60^{0}C for 48 h to obtain untreated jute fiber mat (U-JFM)

ii. *NaOH Treatment:* 5 % NaOH solution was used to treat the jute fiber mat for 4h. After that, jute fiber mat was thoroughly wasted with distilled water. Washed fiber mat was then oven-dried at 60^0C for 48 obtain alkali treated jute fiber mat (A-JFM).

iii. *Silane Treatment:* A-JFM was soaked in a solution of ethanol/water (50/50 by volume) with a 1% silane concentration for 2 hours and then cleaned with ethanol and then oven-dried at 60^0C for 48 h to obtain silane jute fiber mat (S-JFM)

c. Fabrication of Composites

The composite samples were prepared as sandwich of woven jute fiber mat and LDPE sheets. Composite samples were prepared maintaining fiber mat/matrix ratio of 3:7 (w/w). Jute fiber mat was sandwiched between LDPE sheets and placed in the mold between two Teflon sheets for the easy removal of the sample. Composite samples were prepared by placing mold in the compression moulding machine at around 180^0C and 20 MPa pressure for 10 min. Then the samples were taken out after complete cooling at room temperature.

III. CHARACTERIZATION

a. Scanning Electron Microscopy (SEM)

Morphological study of treated and untreated woven jute fiber mats were studied using scanning electron microscope (Model LEO-435VP). Prior to SEM evaluation, the fibers were coated with gold using a sputter coater.

b. Water absorption behaviour

The water absorption of composite samples was done as per ASTM D570-98 standards. The specimens were first oven dried at 50 ^{o}C till the weight of the sample become constant. This oven dried weight was termed as weight of dry sample (w_o). Then the oven dried specimens were dipped in distilled water at ambient temperature to study the kinetics of water absorption. The specimens were taken out periodically and weighted immediately and termed as w_t (weight after soaking into water after time t). The water absorption percentages were calculated by using following Eq.:

$$Water\ absorption\ (\%) = \frac{w_t - w_o}{w_o} \times 100 \qquad (1)$$

The diffusion coefficient is one of the most important parameter for the understanding of water absorption behaviour of any material. Diffusion coefficient shows the ability of the water molecules to penetrate inside the material structure. To identify diffusion behaviour following equation can be used:

$$\frac{M_t}{M_m} = kt^n \qquad (2)$$

where M_t is the moisture content at time *t*, M_m is the moisture content at equilibrium, and *k* and *n* are the kinetic constants calculated by taking the natural logarithm of above equation:

$$log\left(\frac{M_t}{M_m}\right) = log(k) + nlog(t) \qquad (3)$$

where *k* is the constant characteristic of the sample which indicates the interaction between the composite sample and water and *n* represents the diffusion characteristics. The values of *n* represents different behavior between the cases; for Case I (Fickian diffusion *n* = 0.5) while for Case II (non-Fickian diffusion $n > 1$). Moisture absorption in the natural fiber based composites usually follows the case I Fickian behavior, where the water absorption increases linearly with square root of time. The diffusion coefficient (D) for the water absorption can be calculated from the following equation:

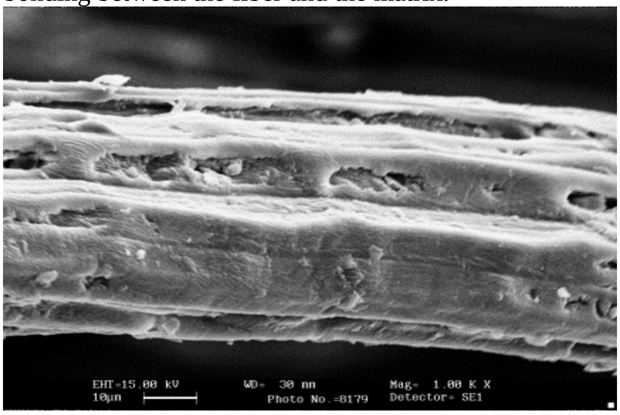
$$\frac{M_t}{M_m} = \left(\frac{Dt}{\pi h^2}\right)^{1/2} \qquad (4)$$

where *h* is the thickness of the specimens. The value of D gives the rate of water absorption of diffusion coefficient which can be obtained from the slope of the initial plot M_t versus square root of time t [9].

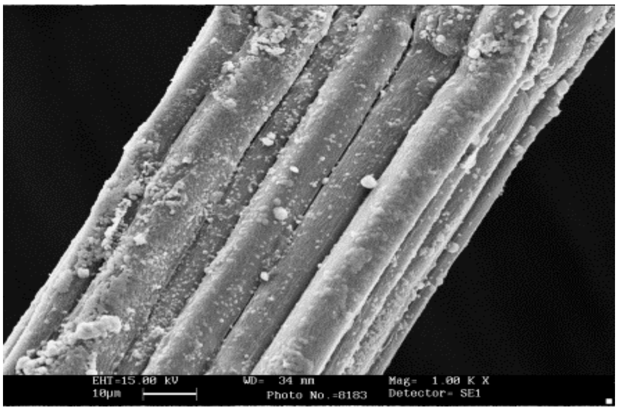
IV. RESULT AND DISCUSSION

a. Morphological study of fiber mats

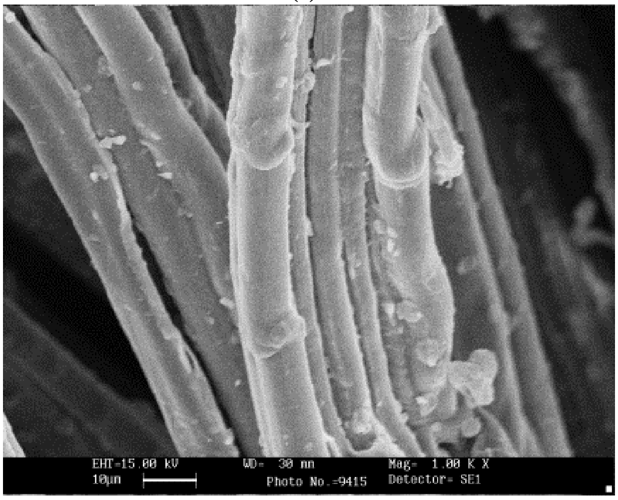
SEM was performed to examine the effect of NaOH and Silane on the morphology of the fiber mat. Figure 1 (a-c) shows the SEM micrographs of U-JFM, A-JFM and S-JFM. Figure 1c showing the SEM micrographs of U-JFM shows a smooth surface due to the presence of fatty acid, waxy and globular particles. A-JFM micrograph (Figure 1b) appears to rough and exposed micro-fibrils. This happens due to the removal of unwanted impurities and some part of non-cellulosic components like hemicelluse and lignin. The micrograph of S-JFM (Figure 1c), the morphology indicated a separation of the micro-fibrillar of the structure probably due to the delignification. The chemical treatment shows increased effective surface area, therefore facilitating better interfacial bonding between the fiber and the matrix.



(a)



(b)



(C)

Figure 1. SEM micrographs (a) U-JFM (b) A-JF (c) S-JFM

b. 4.2 Water absorption behaviour

Water penetration into the natural fiber based composites is also very important property to understand. Figure 2 tells about the percentage of water absorbed by untreated and treated jute fiber mat (JFM) reinforced composite. It is clear from the Figure 2 that water absorption increases at a considerable rate for first 10-12 days and then appreciable fall is observed in the rate of absorption which tends to zero after 5-6 days. The exposure of composite samples in water ageing resulted in slight deterioration of the surface texture in the form of colour fading. This was less apparent for the composite samples reinforced with alkali and silane treated fibers. Water absorption considerably decreases after silane treatment which is in accordance with the literature that reports alkali and silane treatment as effective ways to reduce water absorption in composites [6-8]. The moisture penetration into the composite samples is only resulted through the fiber, fiber/matrix interface, voids and cracks of the composites. The composite reinforced with untreated fiber mat, showed poor water resistance than the composite reinforced with treated fibers. Similar result has been also observed by Beg and Pickering [9] and Munoz and García-Manrique [10].

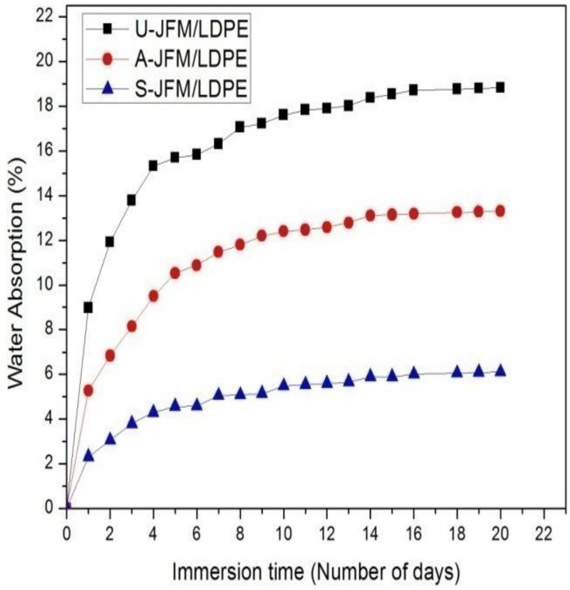


Figure 2: Water absorption (%) as a function of immersion time (number of days)

From the Figure 3 and Table 1, it is revealed that the diffusion coefficient of the A-JFM and S-JFM reinforced composites reduced considerably as compared to the U-JFM composites. From the statistical analysis (presented in Table 1) for both treated and untreated fiber mat composites it is clear that they followed Fickian mechanism of diffusion as *n* values are coming close to 0.5. The best result has been obtained for the S-JFM reinforced composites, which is confirmed by 57.7% reduced diffusivity compared to U-JFM reinforced LDPE composites. The value of silane treated fiber showed less value of diffusivity which justify improved water resistance. This improvement in water resistance may be corresponded to the removal of hydrophilic content and also due to the better adhesion between the fiber and the matrix which leads to the elimination of the voids between the fiber and polymer matrix. Similar behaviour is observed by Espert et al. [11] and Joseph et al. [12].

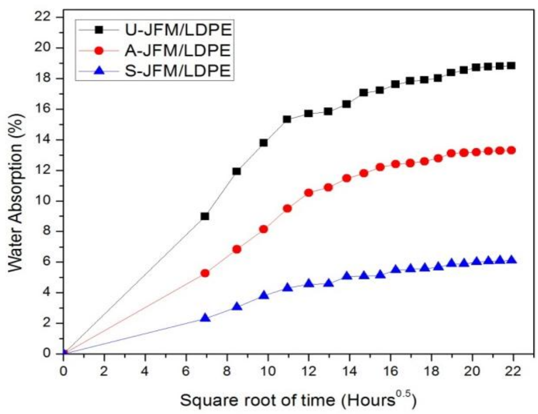


Figure 2: Water absorption (%) as a function of square root of immersion time

TABLE 1: THE VALUES OF KINETIC PARAMETERS (*K* AND *N*) AND DIFFUSIVITY (D) FOR JUTE FIBER MAT-LDPE COMPOSITES

Composite samples	*n*	*k*	D (mm^2/s)
U-JFM/LDPE	0.2756	0.6022	3.17E-06
A-JFM/LDPE	0.3073	0.5232	1.65E-06
S-JFM/LDPE	0.3880	0.4236	1.34E-06

V. CONCLUSION

In this study, the effect of alkali and silane treatment on the water absorption behaviour of jute fiber mat/LDPE composites has been studied. Alkali treatment results in the improvement of water resistance. With the silane treatment, further improvement in water resistance absorbed. This improvement in the water resistance is mainly observed due to the improved bonding between the fiber and the matrix which inhibits the water absorption process. The water absorption behaviour in all studied composite samples was found to follow the kinetics of Fickian diffusion theory.

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