Uses of Jute Fiber Reinforced Polymer Composites

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Abstract: Jute fiber is being used as a promising reinforcement material in polymer matrices for its biodegradable characteristic and some other properties desirable for composite fabrication. Polar jute fiber, like other natural fibers, exhibits inherent incompatibility with non-polar polyolefinic matrices. This drawback affects the physico-mechanical properties of the resulting composites. The compatibility between two different phases of the composite can be improved by modification of either of the components of the composite or both. Various types of modification such as chemical, ionizing or non-ionizing radiation techniques etc. were successfully applied to improve the interfacial adhesion between jute fiber and polymer matrices. For diversified applications and promotion of jute based composite products, the research is not now only confined in laboratory scale but is geared up for large scale production.

Keywords: Rreinforcement, Polymer Matrices, Composite, Iinterfacial Adhesion, Surface Modification

1. Introduction

Jute fiber is extracted from the stem of jute plant which belongs to the genus *Corchorus*, family*Tiliaceae*. Only two species of *Corchorus,* namely *C. capsular* L. and *C. olitorius*L., are grown commercially, although around 40 wild species are known. *Corchoruscapsularis* is called White Jute and *Corchorusolitorius* is called Tossa Jute. Olitorius and capsularis jute have almost similar chemical composition[1-2].Jute plant grows to about 2.5 to 3.5 meters in height at maturity. The long fiber runs along the whole length of the stem or stick as a lacework sheath. The fiber is removed from the stem by biological retting.

The major jute producing countries are Bangladesh, India, China and Thailand. Bangladesh provides over 90% of the world's raw jute and allied fiber exports. Bangladesh yarn supplies account for about 75% of world imports. Jute is a second most important vegetable fiber after cotton, in terms of usage, global consumption, production, and availability. It is one of the cheapest and the strongest of all natural fibers [2-3].

Jute fiber is fully bio-degradable and eco-friendly. Jute products are better than even their bio based counterparts in terms of energy use, green house gas emission, eutrophication and acidification. It is reported that one hectare of jute plants absorb 15 tons of CO_2 from the atmosphere and add 11 tons

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of O_2 during its life span of 120 days. Moreover, the decomposed leaves and roots of jute plants increase the fertility of the soil that reduces fertilizer cost of the next crops. It was reported that during the manufacturing process 1 kg fabric of jute shopping bag saves 80 MJ of energy in comparison to 1 kg of polyhydroxyalkanoid (PHA). In case of thermoplastic starch (TPS) and polylactic acid (PLA) the amount of saved energy is 20 MJ and 54 MJ respectively [4].Jute hessian cloth consumes lesser amounts of energy and emits negligible amounts of green house gas (GHG) in comparison to thermoplastic polypropylene resin (Table 1).

Table 1. Energy inputs and green house gas (GHG) outputs for PP plastic resin and Jute hessian [5].

Materials	Energy, GJ/1000 kg	GHG, Tones CO_2eq
PP	63	1340
Jute hessian	02	0.15

2. Composition and properties of jute fiber

The chemical composition of jute fiber is as follows: cellulose (61-71%), hemicelluloses (13.6-20.4%), lignin (12-13%)ash (0.5-2%), pectin (~0.2%),wax (~0.5%) and moisture (~12.6%)[6]. The different structural components of fiber play an important rule on the properties of the fiber. Jute fiber has high cellulose content and low microfibril angle (~8.0º)[6] which are the desirable properties of a fiber to be used as reinforcement in polymer matrix.Low microfibril angle makes the fiber more rigid, inflexible and mechanically more strong. The cellulose fibrils provide rigidity and maximum tensile and flexural strength. On the other hand, the large amount of hydroxyl groups in cellulose gives hydrophilic character to jute fiber. The hydrophilicity of fibers is responsible for poor compatibility with hydrophobic polymer matrices and also for dimensional instability. However, these hydroxyl groups make the fibers more reactive toward the different surface modifiers [Figure 1]. Hemicellulose is very hydrophilic, soluble in alkali and easily hydrolyzed in acids. Lignin is considered to be responsible for the UV degradation and also known to resist microbial degradation [7].

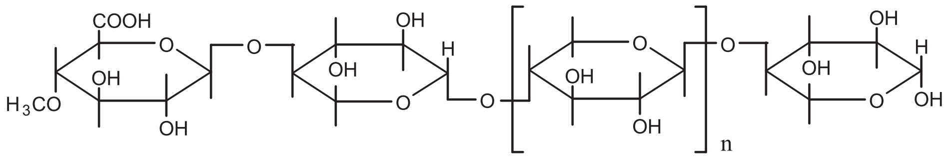


Figure 1. Structure of β-D-Xylopyranose with terminal α-D-4-O methylglucuronic acid, a main constituent of jute hemicellulose

Jute fiber has low density and is light compared to glass, carbon and aramid fibers. It causes no problem during dumping. Handling of jute fiber causes little concern in terms of health and safety and energy can be recovered from it in an environmentally friendly way. The additional advantages include chemical and sound resistance, high specific strength and stiffness. The various mechanical parameters of jute fiber are as follows: density (1.3-1.46 g.cm^{-3}), elongation (1.5-1.8%), tensile strength (393-800 MPa), Young's modulus (10-30 GPa), specific tensile strength (302-547MPa/ g.cm^{-3}) and specific Young's modulus (8-20.5 GPa/g.cm^{-3}) [8-10].The non-abrasive nature of jute fiber leads to advantages in regard to technical and recycling process of the composite materials. The decomposition of natural fiber-reinforced composites balances CO_2 release with respect to the assimilated amount during their growth. Jute fiber reinforced biodegradable polymers can be decomposed completely at the end of their life cycle at the most environmentally friendly way. So, the biodegradability of jute fiber can contribute to a sound ecosystem while its low cost, easy availability and high performance bears the economic importance. Jute fiber has already earned a testimony of success as reinforcing material in engineering markets such as in automotive, construction as well as in packaging industries [11-12].Recently sonali bag has been developed in Bangladesh from jute based cellulose as alternative for synthetic plastics based packaging materials[13].

3. Surface Modification of Jute Fiber

There are several disadvantages associated with jute fibers when they are used as reinforcement in polymer matrices. Due to presence of hydroxyl and other oxygen containing groups in the fiber constituting components, jute fiber becomes polar and hydrophilic in natural. Polymer matrices are mostly non-polar thermoplastics which result compounding difficulties with polar jute fibers. This makes poor inter dispersion or interfacial adhesion between two phases of fiber and matrix. This is a major disadvantage of jute fiber-reinforced composites. High moisture absorption is another drawback of jute fibers which results in poor mechanical properties and reduces dimensional stability of the composites. Jute fiber is vulnerable to degrade at higher processing temperature (above 250ºC) that restricts the choice of matrices. The property variations within the same fiber also creates problem in producing the uniform results of different parameters of composite properties. So, it is necessary to solve the aforesaid difficulties by developing strong interfacial adhesion between two different phases which is needed for an effective transfer of stress and load distribution throughout the interface. This situation leads to development of strategies for surface modification of jute fibers. The different types of surface modifications of jute fiber have achieved various levels of success in improving fiber strength and fiber/matrix adhesion in jute fiber composites [14-19].

4. Properties of Jute Fiber-reinforced Polymer Composites

The treatments of jute fiber contribute significantly on the tensile strength, modulus and elongation at break of the jute fiber. The enhanced properties of the fiber are the precursor for improving the mechanical properties of the fiber reinforced composites. The incorporation of others fiber into jute fiber also contributes appreciably on the properties of jute fiber-reinforced polymer composites.The parameters such as tensile strength (TS), bending strength (BS), impact strength (IS), tensile modulus (TM), and bending modulus (BM) are used to determine the mechanical properties of the composites.

A comparative study on the mechanical properties of UV and gamma treated jute fabric (Hessian cloth) reinforced polypropylene (PP) composites areshown in Table 2[20].

Table 2. Effect of gamma, UV and starch on the mechanical properties of the composites

Composites	TS (MPa)	BS (MPa)	TM (GPa)	BM (GPa)	IS (kJ/m^2)
PP	25.9	34.1	0.49	0.54	5.1
GPP	32.1	40.3	0.55	0.63	10.2
UVPP	33.9	44.4	0.63	0.65	10.4
UC	48.0	51.2	0.95	1.12	17.1
GC	57.9	62.4	1.24	1.58	24.2
UVC	59.6	65.3	1.32	1.62	26.1
SGC	63.2	72.2	1.35	1.64	31.5
SUVC	66.2	72.7	1.52	1.60	28.2

[PP- Polypropylene; GPP- gamma treated PP; UVPP- UV treated PP; UC- untreated composite; GC- gamma treated composite; UVC- UV treated composite; SGC- Starch and gamma treated composite; SUVC- Starch and UV treated composite.

The effects of various types of oxidizing agents on the mechanical properties of the composites are shown in Figure 2. Oxidized jute brought positive impact on the mechanical properties of the composites at optimal conditions[21-25].

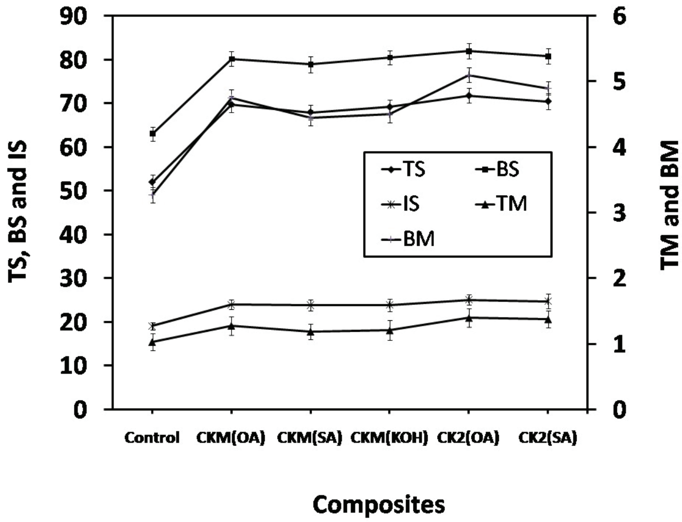
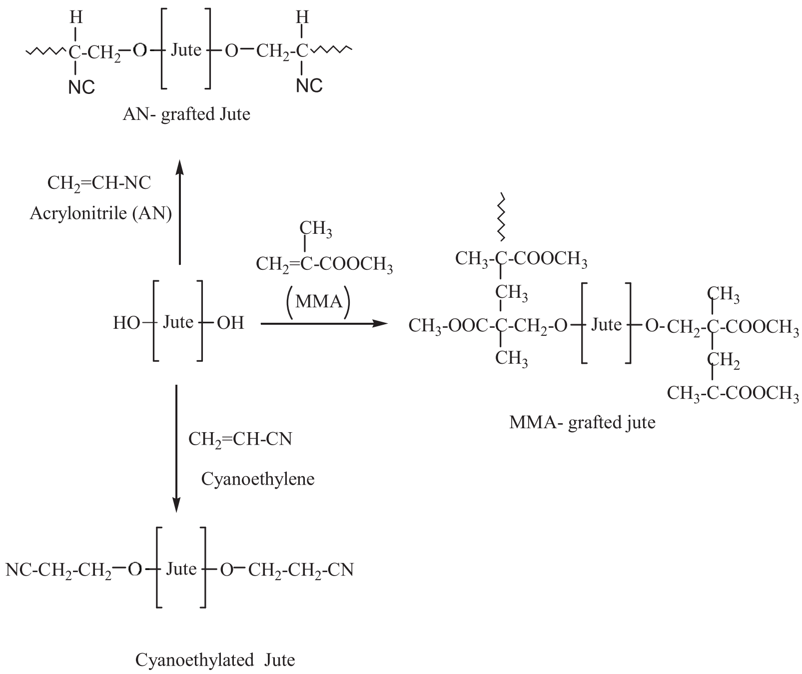


Figure 2. Effect of oxidizing agents on the mechanical properties of jute-PP composites.

[CKM (OA), CKM (SA), CKM (KOH) = jute fabric-PP composites treated with $KMnO_4$ in oxalic acid(OA), sulphuric acid (SA) and potassium hydroxide (KOH) media, respectively; CK2 (OA), CK2 (SA) = jute fabric-PP composites treated with $K_2Cr_2O_7$ in oxalic acid(OA) and sulphuric acid (SA) media, respectively]

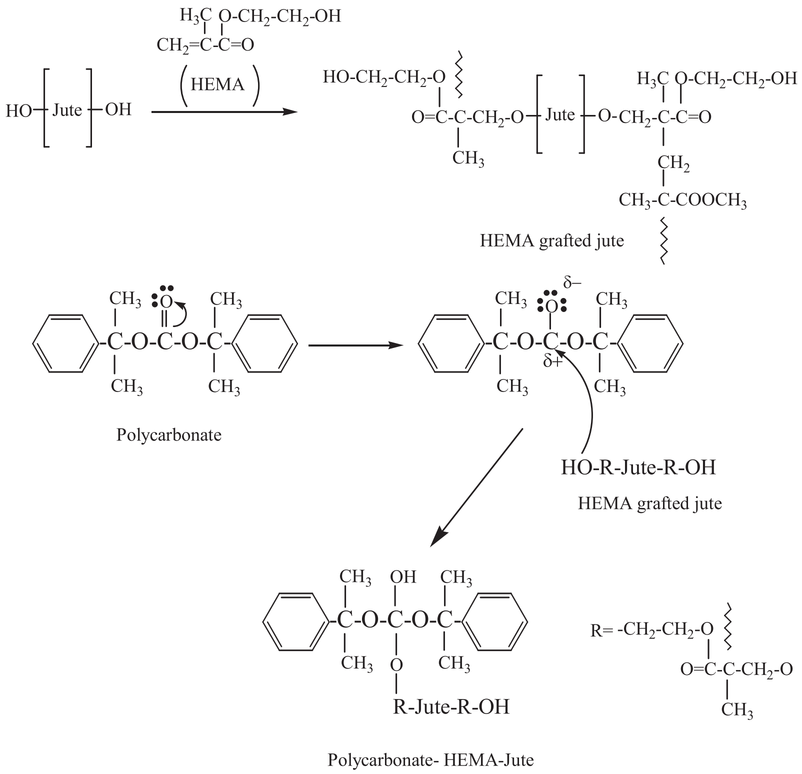
The mercerized jute-PP composite shows lower water uptake tendency due to better fiber-matrix adhesion, reduction of polar groups and removal of hemicelluloses from the fibers during mercerization. The mercerized jute composite also shows less degradable in soil, water and simulated weathering conditions[26]. The chemical surface modifications of jute fibers were carried out by the processes involving bleaching, dewaxing, alkali treatment, cyanoethylation and vinyl grafting[27-28]. The vinyl grafting improves the wettability and adhesion between fabrics and matrix through vinyl polymer moieties on the fiber surfaces during the fiber modification treatment (scheme1).



Scheme 1: Cyanoethylated, and acrylonitrile- and MMA-grafted jute fiber.

The different chemical treatments of jute fibers with alkali, alkali and methyl methacrylate, (MMA) and alkali and polyamide (PA) treatment were found to increase the interfacial adhesion between jute fiber and polypropylene [29].

Jute fabrics were modified with 2-hydroxyethylmethylacrylate (HEMA) and 2- ethylhexylacrylate (EHA) [30]. The investigation shows that the hydroxyl groups of HEMA react with carbonate groups of polycarbonate (PC) through nucleophilic addition (scheme 2). The better dispersion of HEMA treated fiber in PC and increased interfacial adhesion between jute and PC was reported.



Scheme 2: Reaction between polycarbonate and HEMA-grafted jute fiber.

Hybrid composites of glass and jute fabric modified by treatment with γ-aminopropyltrimethoxysilane (silane), isopropyl triisostearoyltitanate (titanate) and tolylenediisocyanate (tdi) were fabricated using unsaturated polyester resin (USP) [31]. An improvement in mechanical properties of laminates was observed when jute fabric was modified by titanate treatment. A number of hybrid composites was made with jute, mercerised jute, and high tenacity man-made cellulose tyre cord yarn Cordenka[32-33].The investigation showed that phase mixed domains formed in the hybrid networks and hybrid polymer networks retained higher modulus at lower and intermediate frequencies over the polyester resin.

5. Applications of Jute Composites

Jute reinforced thermoplastic laminates and composites have currently been utilized as promising substitution for thermoplastic and manmade fiber reinforced composites with high physical properties and excellent performance at low weights, i.e. high stiffness, high strength and low density. The automobile industry, footwear industry, in making building /construction materials, home/ garden furniture, toys, etc. were identified as the most potential area for use of jute based composites. Jute/PP composites are found to be cheaper, lighter, have strength properties comparable almost twice as stiff as glass fiber reinforced PP composites with some additional unique properties.

Bangladesh Atomic Energy Commission has successfully made a wide range of products from jute reinforced polymer composite (Figure 3). Jutin (jute + tin) has outstanding mechanical (Table 3), thermal (Table 4), and aging (Table 5) properties which make it suitable and ideal for roofing and wall cladding. It is durable, rust proof, saline resistant, light weight, heat resistant, environmental friendly and possesses higher mechanical properties [34].

Table 3. Mechanical properties of Jutin.

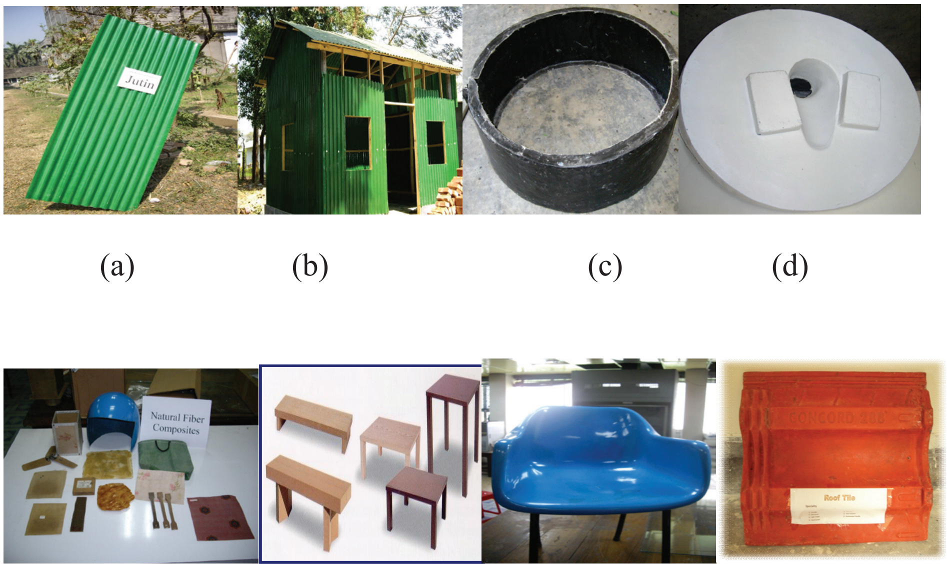
Properties →	TS (MPa)	BS (MPa)	TM (GPa)	BM (MPa)	IS (kJ/m^2)
Jutin	117	96	4	4.5	44
UV cured Jutin	150	140	6.5	5.2	68

Table 4.Thermal conductivity of different structural materials.

Materials →	Jutin	Brick	Concrete	Iron	Aluminium	Natural fiber	USP
Thermal conductivity W/mk	0.05-0.07	0.86	1.51	58.15	250	0.13-0.17	0.17

Table 5. The effect of thermal aging on tensile strength of Jutin.

Sample	Tensile strength (MPa)				
	Room temp.	0ºC	4ºC	50ºC	70ºC
Jutin	96	116	99.8	93	78



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 3. Various types of products from jute composites: (a) Jutin (b) a model hut (c), &(d) ring and pan of latrine, (e) helmet, fan, bag etc., (f)&(g) bench, table and chair (h)roof tile

Conclusion

Traditionally jute fiber has been used for making rope, hessian cloth, carpet, wall-mat, fancy bags etc. The use of jute fiber as reinforcement in polymer matrices has opened up a new dimension in the areas of structural materials as the synthetic fibers based materials face criticism from the environmental point of view. Despite the attractive features of applications, jute fibers have so far been utilized little as a reinforcement material in automotive sectors, advance or smart materials or nanocomposites production. So, fully exploit the potential of jute fibers, the future research plan should be conducted to develop high-quality jute composites both in scientific organizations as well as in industrial sectors.

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