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EFFECTS OF PROCESS PARAMETERS ON TENSILE STRENGTH OF JUTE FIBER REINFORCED THERMOPLASTIC COMPOSITES

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Abstract:

For Environmental concern on synthetic fibers (such as glass, carbon, ceramic fibers, etc.) natural fibers such as flax, hemp, jute, kenaf, etc. are widely used. In this research work, jute fiber reinforced polypropylene matrix composites have been developed by hot compression molding technique with varying process parameters, such as fiber condition (untreated and alkali treated), fiber sizes (1, 2 and 4 mm) and percentages (5%, 10% and 15% by weight). The developed jute fiber reinforced composites were then characterized by tensile test, optical and scanning electron microscopy. The results show that tensile strength increases with increase in the fiber size and fiber percentage; however, after a certain size and percentage, the tensile strength decreases again. Compared to untreated fiber, no significant change in tensile strength has been observed for treated jute fiber reinforcement. Fractographic observation suggests the fracture behavior to be brittle in nature.

Keywords: Natural fiber, Jute fiber, Polypropylene, Composite, Tensile strength.

1. Introduction

Now-a-days, newer polymer matrix composites reinforced with fibers such as glass, carbon, aramid, etc. are getting a steady expansion in uses because of their favorable mechanical properties. However, they are quite expensive materials. For this, natural fibers such as jute, flux, hemp, etc. can be alternately used to reduce the cost of the composites (Mohanty et al., 2002). Moreover, production of environmentally friendly materials is another important issue. Natural fiber composites focus well into this ecological image. The use of natural fibers, derived from annually renewable resources, as reinforcing fibers in both thermoplastic and thermoset matrix composites provide positive environmental benefits with respect to ultimate disposability and raw material utilization.

The prominent advantages of natural fibers include acceptable specific strength properties, low cost, low density, high toughness, good thermal properties, and so on. Low specific weight, which results in a higher specific strength and stiffness than glass is a benefit especially in parts designed for bending stiffness. In the fields of automotive industries, reduction of energy consumption in production of motor vehicles and improvement of their day to day fuel economy are growing upwards due to accelerating use of natural fiber composites.

In the case of thermoplastic composites, adhesion between the hydrophilic fiber (such as jute fiber) and hydrophobic matrix (such as polypropylene) is poor (Karmaker and Youngquist, 1996). Therefore, the bond between them needs to be improved. This may be improved by alkali treatment. It is believed that the alkali treatments results in an improvement in the interfacial bonding by giving rise to additional sites for mechanical interlocking, hence promoting more matrix/fiber interpenetration at the interface (Gassan and Bledzki, 2000).

In this project, jute fiber reinforced polypropylene composites were prepared under various processing parameters using hot compression molding technique. The goal of this work is to understand the changes of tensile strength under various process parameters. Optical microscopy was done to show the conditions of fiber with increased fiber loading. Fracture surfaces of tensile test specimens were examined under scanning electron microscope to get an idea about the fracture behavior.

2. Experimental

2.1 Materials

The composites were produced using treated (jute fibers were treated by Bangladesh Jute Research Institute, Dhaka, Bangladesh, with 20% sodium hydroxide) and untreated jute fiber and polypropylene pellets. The treated

and untreated jute fibers were chopped into various lengths of 1, 2 and 4 mm. For all lengths of fibers, composites were developed with 5, 10 and 15% (by weight) of jute.

2.2 Methods

2.2.1 Composite Fabrication

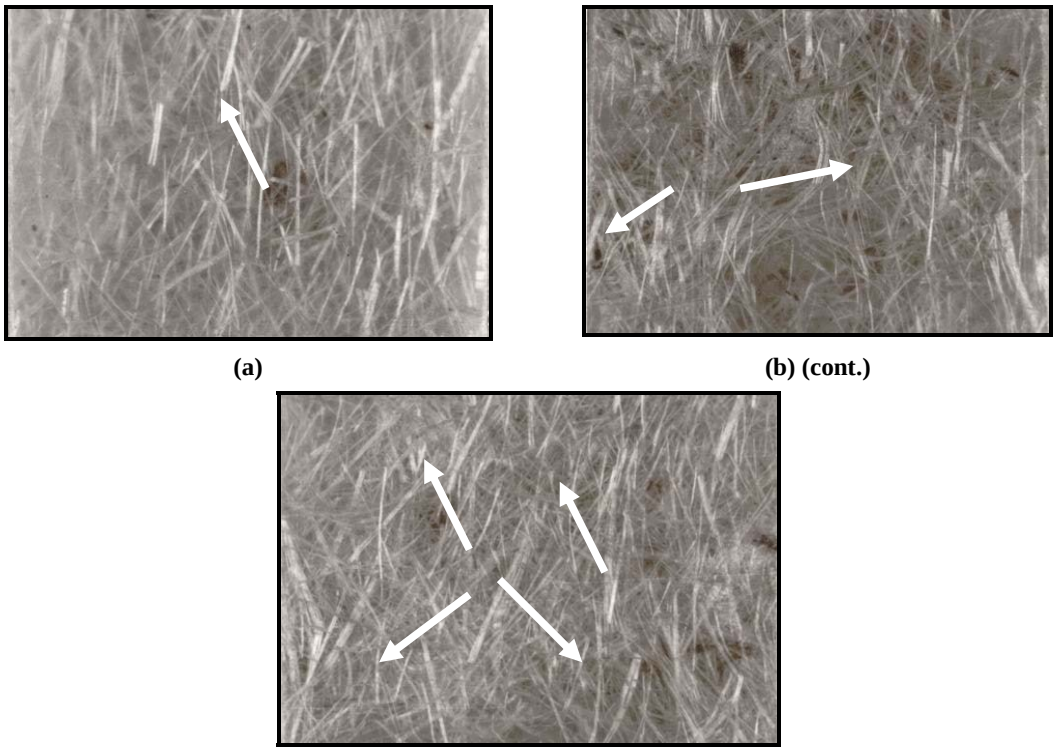
The chopped fibers were sieved with 1, 2 and 4 mm sieves for obtaining the desired variation in jute fiber length. The fibers were conditioned at 110 ^{0}C for 24 hours to remove moisture and polypropylene was also conditioned at the same temperature. Proper proportion of fibers (5, 10 and 15% by weight for each of 1, 2 and 4 mm length) and polypropylene were then properly blended in the blender to get a homogeneous mixture for each length type. The mixture was placed in a mold and composites were made with 50 kN load at 180 ^{0}C.

2.2.2 Tensile Test

Tensile testing of the specimens was performed according to ASTM D 638-98 on a universal test machine operated at a crosshead speed 3 mm/min. Three test specimens from every composition (combination of predefined fiber length and wt percentage with polypropylene) were tested at the same time and the averages of results were used.

2.2.3 Metallography and Fractography

Conventional metallography of selected specimens was done under metallurgical microscope. Fracture surfaces of the tensile test specimens were observed under Philips XL - 30 Scanning Electron Microscope operated at 10 kV. Samples were mounted with carbon tape on aluminum stubs and then sputter coated with gold for 30 seconds to make them conductive.



(a) **(b) (cont.)**

(c)

Fig. 1: Optical microscopy of jute fiber reinforced polymer composites reinforced with various fiber wt. percentages. (a) 5% Fiber (b) 10% Fiber (c) 15% Fiber. Entanglement of fibers is shown by the arrow. It is clear that 15% fiber composite has highest fiber entanglement compared to 5 & 10% fiber composites

3. Results and Discussion

In this research work, at first selected specimens were observed under metallurgical microscope. Then tensile specimens were prepared according to ASTM specification and were tested. Using a Scanning Electron Microscope, fracture surfaces of the tested specimens were observed.

3.1 Metallographic observation

The examination under metallurgical microscope shows the variation of fiber wt. percentages in different jute fiber composites (Fig. 1). As evident from the figure, with the increase of fiber percentage in the composite, probability of entanglement of fiber increases. This is due to strong inter-hydrogen bonding between fibers (Alam et al., 2004).

3.2 Tensile strength

The typical load-stroke curve obtained from the tensile test is shown in Fig. 2. From this curve, it can be predicted that the failure behavior of the jute fiber reinforced thermoplastic composite is brittle type.

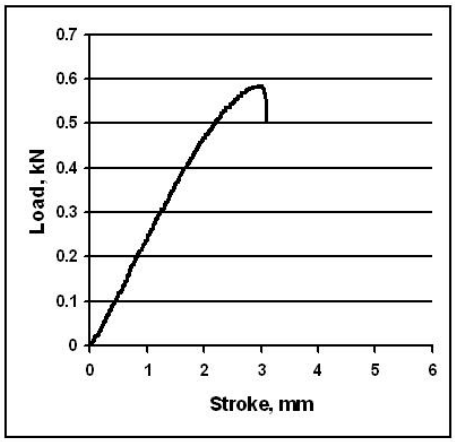


Fig. 2: An observed load-stroke curve obtained from tensile test

The tensile test results have been plotted in Figs. 3 & 4 as a function of fiber length. From these figures, it is clear that as the fiber length increases, the value of tensile strength increases and then decreases. This observation is true for almost all cases (with exception in the case of 5% treated specimens).

Figs. 5 & 6 represent the relationship between fiber percentage (wt %) and tensile strength value. As per these plots, in general, as the fiber percentage increases, the tensile strength also increases and then decreases.

As observed from the curves, tensile strength was increased to a maximum at 2 mm fiber length and then dropped. Also, tensile strength was found to increase to a maximum at 10% fiber (by weight) and then decreased. 2 mm & 10% treated fiber composites gave better results than untreated fiber composites but not so distinguishable.

Fiber length has profound impact on the properties of composites. Besides holding the fibers together, the matrix has the important function of transferring applied load to the fibers. The efficiency of a fiber reinforced composite depends on the fiber-matrix interface and the ability to transfer stress from the matrix to the fiber (Karnani et al., 1997). In small fiber size (here, 1 mm), tensile strength is low due to the fact that length may be not sufficient enough for proper distribution of load. As proper length is not available for stress distribution, failure occurs easily.

On the other hand, for the composites of longer fiber size (here, 4 mm), tensile strengths were decreased compared to 2 mm fiber reinforced composites. The probable reason is that a long fiber may not become compatible with the matrix properly. Thus improper bonding occurs between the fibers and the matrix. Moreover, fibers may be folded and there is no bonding between the folded and unfolded portion of fiber which resulted in a lower strength. Fiber entanglement may also contribute to reduce the strength (Joseph et al., 2002). For 5% treated fiber composites, the exceptional behavior is probably that 4 mm size of fiber is still not enough to create fiber entanglement or folding inside the matrix.

In phenol formaldehyde/banana fiber composites, with the increase of fiber length tensile strength was found to be increased (Joseph et al., 2002). The trend of increase followed by decrease of tensile strength observed in current project was found in sisal/polypropylene composites (Jayaraman, 2003).

According to Figs. 5 & 6, after 10 wt. percent fiber as reinforcement in the composites, tensile strength was decreased with higher percentages of fiber. The incorporation of fibers into thermoplastics leads to poor dispersion of fibers due to strong inter fiber hydrogen bonding which holds the fibers together. Improper adhesion hinders the considerable increment of tensile strength (Beckermann et al., 2004). Thus, as fiber percentage increases, gathering of fibers takes place instead of dispersion and melted polypropylene can not wet

them properly due to non entrance of melt through the adjacent two fibers. Since no adhesion is present between the fibers and fibers are also not bonded with matrix, failure occurs before attaining the theoretical strength of composite. Thus high fiber content was limited by the incompatibility issue unless coupling agent is used (Wollerdorfer and Bader, 1998).

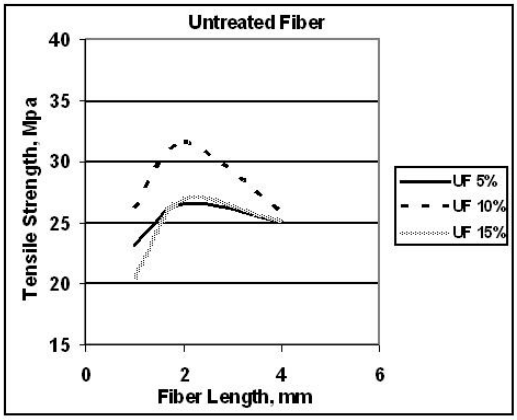


Fig. 3: Tensile Strength of Untreated Jute Fiber Composites at Different Lengths*****

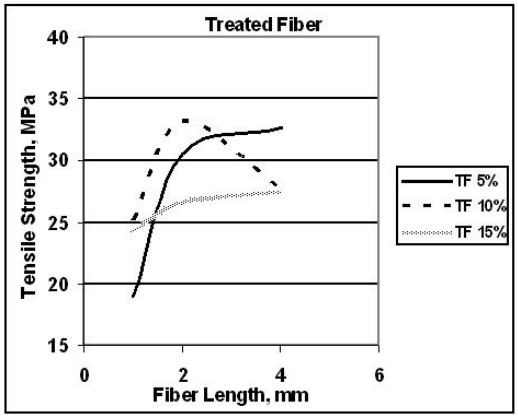


Fig. 4: Tensile Strength of Treated Jute Fiber Composites at Different Lengths*

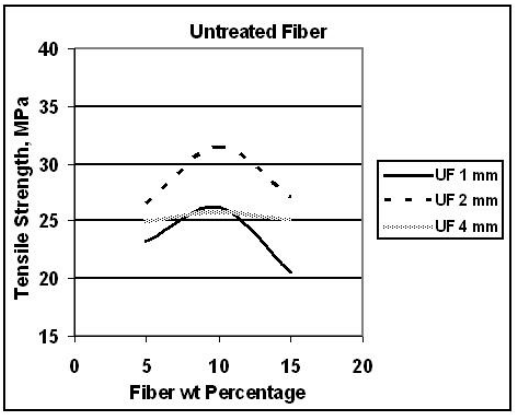


Fig. 5: Tensile Strength of Untreated Jute Composites at Different Fiber wt. Percentages*

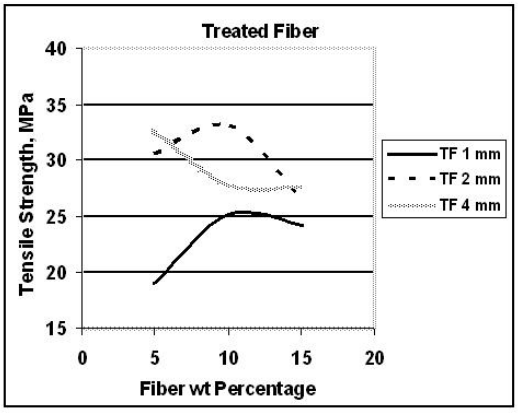


Fig. 6: Tensile Strength of Treated Jute Fiber Composites at Different Fiber wt. Percentages*

** (UF: Untreated Fiber, TF: Treated Fiber)*

It has been reported that initially strength may decrease after a slight increase in strength and then at very high fiber content it may again increased (Wambua et al., 2003, Jayaraman, 2003). In polypropylene/wood composites, tensile strength was found to decrease after a certain percentage of fiber (Beg and Pickering, 2004).

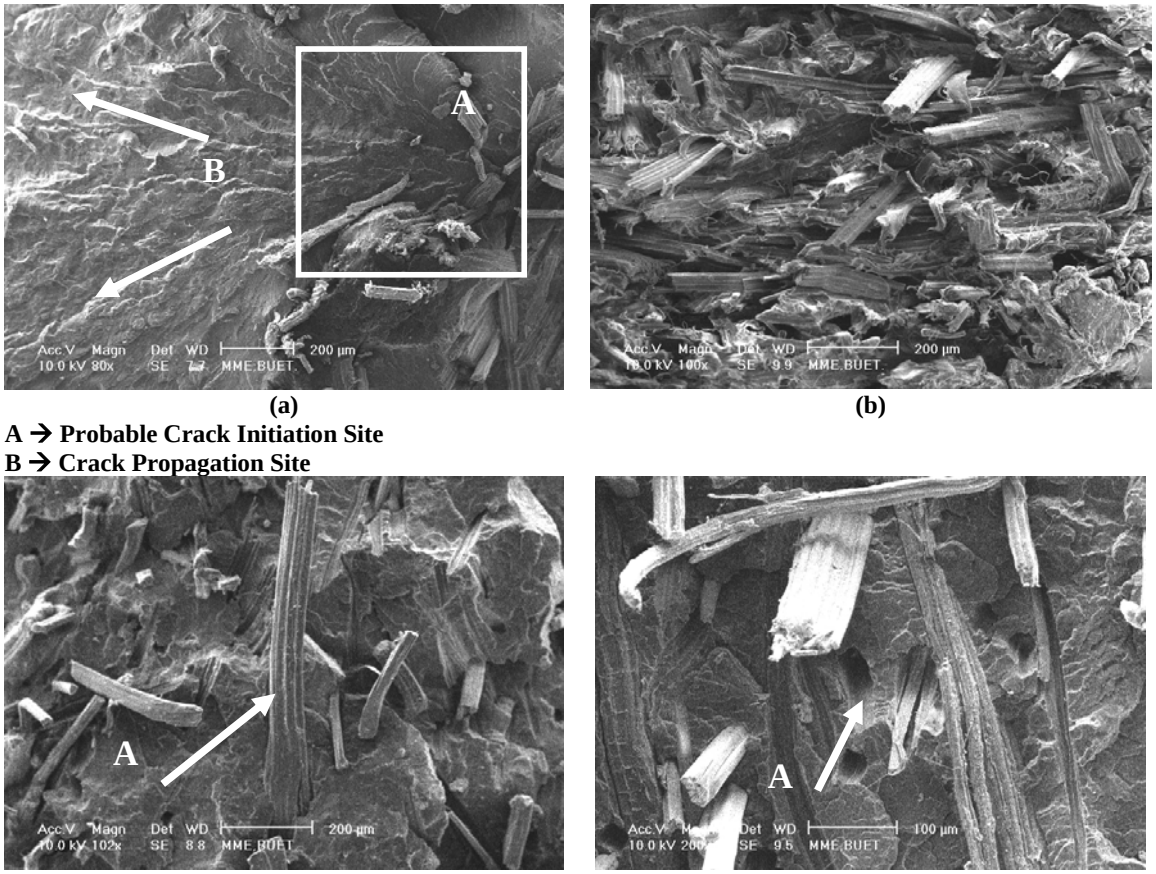
The tensile strengths of the uncoupled composites have values in close range for all fiber percentage levels (Karmaker and Schneider, 1996, Rowell and Stout, 1998). Without coupling agent, fiber content and fiber length do not have significant effects on composite tensile properties (Sameni et al., 2003). There exist incompatibilities between the different surface properties of the polar fibers and non-polar polypropylene. Due to presence of hydroxyl and other polar groups in various constituents of natural fiber, the moisture uptake is high for dry fibers. All these lead to poor wettability with matrix and weak interfacial bonding between the fiber and relatively more hydrophobic matrices. To improve affinity and adhesion between fiber and thermoplastic, chemical coupling agents can be used so that tensile strength increases (Khan et al., 2001, Saheb and Jog, 1999). As a coupling agent, MAPP may be used to enhance interfacial adhesion that may react or interact favorably with the hydroxyl group on the fiber surface (Mohanty et al., 2004). Use of coupling agent reduces the number of fiber pull-out (Gassan and Bledzki, 1997).

As evident from Figs. 3-6, tensile strength was not significantly improved by alkali treatment. But, alkali treatment generally increases the strength of natural fiber composites (Dieu et al., 2004, Gañán and Mondragon, 2004, Razera and Frollini, 2004). A strong sodium hydroxide treatment may remove lignin, hemicellulose and other alkali soluble compounds from the surface of the fibers to increase the numbers of reactive hydroxyl groups on the fiber surface available for chemical bonding. So, strength should be higher than untreated fiber

composites. The probable cause of this unlike phenomenon may be, alkali react on the cementing materials of the fiber specially hemicellulose which leads to the splitting of the fibers into finer filaments. As a result, wetting of fiber as well as bonding of fiber with matrix may improve which consequently make the fiber more brittle. Under stress, these fibers break easily. Therefore, they can not take part in stress transfer mechanism (Ray et al., 2001). So, high concentration of sodium hydroxide may increase the rate of hemicellulose dissolution which will finally lead to strength deterioration. Moreover, unnecessary extra time in treatment may also cause increment of hemicellulose dissolution.

3.3 Fractography

The main reason for poor mechanical properties in jute fiber composites is weak bonding between the fiber and matrix. This is evident in the micrographs obtained from scanning electron microscopy (Fig. 7). The important feature of these micrographs is that a clear picture of fracture is shown. There is a clear evidence of brittle failure in Fig. 7 a. Also crack initiation site and propagation through the matrix were observed in Fig. 7a. According to the SEM fractographs (Fig. 7b-d), fiber pull-out and debonding predominate in fracture surfaces with fairly clean and recognizable fiber surface without matrix adherence. In Fig. 7b, clear fracture surface shows poor fiber/matrix interfacial bonding. Fiber pull-out was also clearly seen in Fig. 7c. Fiber debonding was observed in Fig. 7d.



(a) **(b)**

A → Probable Crack Initiation Site
B → Crack Propagation Site

(c) **(d)**

A → Fiber Pull-out **A → Fiber Debonding**

Fig. 7: Scanning Electron Microscopy of Fracture Surfaces of Jute Fiber Composites after Tensile Test. Evidence of Brittle Fracture (a). Indication of Poor Interfacial Adhesion: Clean Fracture Surface (b), Fiber Pull-out (c) and Fiber Debonding (d)

4. Conclusions

a. Optical microscopy clearly shows that with the increase of fiber wt. percentage, entanglement of fibers occurs.
b. In the case of fiber length, 2 mm jute fiber composites give better tensile strength over 1 & 4 mm jute fiber composites.

c. In the case of fiber amount, 10 percent fiber (by weight) composites has better tensile strength compared to 5 & 15 wt. percent fiber composites.
d. Scanning electron microscopy of fracture surfaces indicates the fracture behavior to be brittle type.

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