Conference Paper

Influence of Hydroxyethyl Cellulose Treatment on the Mechanical Properties of Jute Fibres, Yarns, and Composites

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Jute yarns were treated by tap water with and without tension at room temperature for 20 minutes and then dried. Fibre and yarn strength were measured before and after treatment. Unidirectional (UD) composites were made by both treated and untreated yarns with and without applying hydroxyethyl cellulose (HEC) as size material. Water-treated jute yarns without tension and composites made of those yarns showed decreased strength, and water treated jute yarns with tension and composites made of those yarns showed increased strength with respect to raw yarns and composites made of raw yarns. However, no specific trend was noticed for fibre tensile strength and tensile modulus. HEC sized yarns showed up to 12% higher failure load with respect to unsized yarns, and composites made of HEC sized yarns showed up to 17% and 12% increase in tensile strength and tensile modulus, respectively, compared to composites made of similar types of unsized yarns.

1. Introduction

Cellulose-based fibres can be an ideal source of reinforcement material for composite production due to their abundant production and supply. Cellulose fibres are plant-based, and nearly 1000 types of plants produce useable cellulose fibres [1]. Each year plants produce about 180 billion tons of cellulose around the world [2]. Cellulose has excellent specific properties (tensile modulus 138 GPa and tensile strength >2 GPa [3]). However, natural fibre composites (NFC) suffer some limitations such as lower tensile and impact strength [4]. Plant-based fibres contain different quantity of cellulose (Table 1 [1]). Cotton contains a very high percentage of cellulose, and it secures the first position according to production among the important cellulosic fibres. However, it has limited use in composite production due to moderate mechanical properties [5] and high level of ecological impact for cultivation of cotton [6]. Cultivation of jute needs little or no fertilizer and almost no use of pesticides. Jute is a cheap fibre, and the position of jute is second according to yearly production worldwide (Table 1) among important usable

cellulosic fibres. It has very good mechanical properties (tensile modulus 32 GPa and tensile strength 550 MPa [7]) and has the versatility to use in different textile preforms. All these attractive properties developed interest to choose jute fibre for this research work.

All natural fibres are discontinuous except silk, which makes them challenging to use directly for composite production. Therefore, a preform is helpful to use staple natural fibres in composite manufacture. Different textile preforms such as yarn [8], nonwoven fabric [9], woven fabric [10], knitted fabric [11], multiaxial fabric [12], and 3D fabric [13] are very common for composite production. To explore the strength of reinforcement in composites, proper alignment of fibre is very important [8]. Among different types of preforms, unidirectional (UD) fibre matt gives better alignment of fibres [8]. Textile yarn is generally used to make the UD fibre matt. Sewing, use of adhesive, and lino weaving may be some possible ways of forming UD matt from textile yarn. In this work hydroxyethyl cellulose (HEC), an adhesive material, was used to bind the UD matt. It is a natural cellulose-based product which is soluble in water. It is cheap, nontoxic, and

TABLE 1: Annual production of some of the commercially important fibre sources and their chemical composition [1].

Fibre type	World annual production (10 ³ Tonnes)	Cellulose %	Hemicellulose %	Lignin %	Pectin %
Cotton	18,450	92	6	—	<1
Jute	2,850	72	13	13	
Flax	830	81	14	3	4
Sisal	378	73	13	11	2
Hemp	214	74	18	4	1
Coir	650	43	<1	45	4
Ramie	170	76	15	1	2
Straw	—	40	28	17	8
Kapok	123	13			

easy to apply [4]. Stirring by mechanical stirrer for 10 minutes gives a homogenous viscous solution to use as binding material. Before applying this binding material extensively, it is important to investigate its effect on composite properties.

Natural fibre composites (NFC) are now used for non-structural or semistructural purposes and find limited use in structural application. To improve mechanical properties, researchers have studied fibre surface modification, matrix modification, and the use of coupling agents [14]. Among these well-established methods, physical or chemical fibre surface modification is very popular. Physical methods include stretching, calendaring, thermal treatment [14], and production of hybrid yarns [15]; chemical treatments include alkali treatment and the use of coupling agents [16]. To perform chemical treatment on natural fibre, researchers normally treat it in a water-based chemical solution. As water-based treatments are popular, it is very important to understand if there is any effect on natural fibre composites due to water treatment under different conditions.

2. Materials and Methods

2.1. Materials. In this experimental work, tossa jute yarn was used, supplied by Janata Sadat Jute Mills Ltd., Bangladesh. Unsaturated polyester, trade name polylite 420-100 by Reichhold UK Ltd., was used as the matrix material.

2.2. Preparation of Yarn for Water Treatment, Sizing, and Composites. Yarns were lightly wound on a perforated plastic tube under tension neither to allow any slackness nor to apply any stretching. Yarn winding tension was approximately 1.5 gm/Tex. After water treatment, these yarns were described as water-treated yarn with tension. Loose yarns dipped in water were described as water-treated yarn without tension. All yarns to be sized were wrapped closely together on a plastic sheet in a single ply. Sizing enabled yarns to form UD matt. UD matt of unsized yarns was made by wrapping it on a square steel frame. The dimension of the frame was 260 mm × 260 mm × 1 mm. Width of the arms of frame was 10 mm, and yarns were wrapped on it closely together. Care was taken to avoid under tension or overtension to minimise any slack and to avoid stretching of the yarns.

2.3. Water Treatment. Loose yarns and yarns wrapped on the perforated tube were dipped in tap water at room temperature for 20 minutes. Yarns were then taken out of the water bath, squeezed and pressed gently, and dried in an oven at 105°C for one hour.

2.4. HEC Sizing. HEC solution was made with 0.6% HEC (w/w) with tap water. A homogenous solution was made with the help of a mechanical stirrer. Stirring was done for 10 minutes at 200 revolutions per minute. This solution was then applied to the wrapped yarns on plastic sheet by brush. Yarns were then dried at 105°C for one hour.

2.5. Preparation of Composites. Vacuum assisted resin transfer moulding (VARTM) was used to manufacture composites in this work. In VARTM, resin is infused in a closed mould with vacuum which helps to avoid trapped air bubbles. Fibre volume fraction and dimensions of the composite plaque can be closely controlled. This is a compatible and relatively cheap method for infusing long fibre like jute. Considering the advantages, VARTM was chosen.

UD matt of sized yarn was cut according to the inside dimension of a picture frame (250 mm × 250 mm), and the weight of the UD yarn sheet was measured to calculate fibre volume fraction. Unsized yarns were infused whilst wrapped on the frame. A different inside dimension (260 mm × 260 mm) picture frame was used to form the edge of the mould. 0.20% (by weight) accelerator NL-49P (cobalt (II) (2-ethylhexanoate) 1% CO in diisobutyl phthalate) and 0.8% (by weight) butanox catalyst (methyl ethyl ketone peroxide 35% in phthalate plasticizer) were mixed with resin.

In this experiment, first accelerator was mixed with resin with a hand stirrer and then catalyst to avoid any accident. After infusion the tool was closed overnight for cure. The composite plaque was then postcured for 6 hours at 60°C inside an oven. To avoid any sort of deformation during postcuring, the composite plaque was placed between two pieces of glass fibre composite with some weight added to it.

2.6. Single Fibre Preparation for Tensile Test. Single jute fibre extracted from yarns was attached on a rectangular paper frame with araldite adhesive. The dimension of the paper

frame was 35 mm × 20 mm. A rectangular hole having dimension 25 mm × 10 mm was cut inside the paper frame with reference to BS ISO 11566: 1996. The diameter of each fibre was measured using an optical microscope. The diameter was measured at three places (both the ends and middle) of each fibre to be tested, and the mean value was taken as the effective fibre diameter. Practically, the width was considered as fibre diameter assuming that the fibre has circular cross-section.

3. Testing

3.1. Single Fibre Tensile Test. Single fibres were tested in tension according to BS ISO 11566: 1996. The fibre attached on rectangular paper with araldite was mounted to the jaws of a Hounsfield machine. Vertical arms of the rectangle were burnt carefully by an electric burner after mounting. 5N load cell was used with 1 mm extension/min. Load and extension were then recorded up to failure. 25 specimens were tested for each sample. Mean values were calculated for tensile strength and tensile modulus.

3.2. Single Yarn Tensile Test. HEC sized and unsized raw yarns and water treated yarns with and without tension were used for tensile testing. This test was done with reference to BS ISO 3341: 2000. The specimen length was 250 mm, and the result was calculated from 10 tests.

3.3. Composite Test. The tensile tests for composites were carried out with reference to BS EN ISO 527-4: 1997. Plaques were tested along the longitudinal direction of yarn. The dimension of sample for tensile test was 250 mm × 15 mm. After cutting the composite plaque to the required size for testing, both cut edges were polished by sand paper. Then, width and thickness of the composite strip were measured at three places (both the ends and middle) to find the mean value of width as well as thickness of the strip, to calculate the stress. Strain was measured by using an extensometer. 50 KN load cell was used, and the rate of extension was 1 mm/min. 5 tests were done for each sample to calculate the mean values of tensile strength and tensile modulus. Tensile modulus was calculated at 0.025 to 0.1 percent strain range, as this region exhibited the highest value of stiffness for plant-based composites [4].

4. Results and Discussion

4.1. Fibre Test Result. Tensile strength and stiffness of single jute fibres are presented in Figures 1 and 2, respectively. These results did not show any specific trend; however, a large value of standard deviation was noticed in all cases. Experimental results showed that the surface treatment studied in this research work did not affect the tensile properties of jute fibre. High values of standard deviation may be due to inherent properties of single jute fibres [17].

A large variation of jute fibre diameter, tensile strength, and tensile modulus has been observed in previous studies [7, 18].

FIGURE 1: Tensile strength of single jute fibre (error bars indicate standard deviation).

FIGURE 2: Tensile modulus of single jute fibre (error bars indicate standard deviation).

4.2. Yarn Test Result. Yarn test results (Figure 3) showed an increase in failure load for HEC sized yarn apart from respective unsized yarn. This is a well-cited [19, 20] phenomenon since the size material has an adhesive property which binds fibres in the yarn close together (Figures 4, 5, and 6) making the yarn stronger. However, HEC sized raw yarn did not show any increase in failure load. This may be due to some deficiencies such as variations in linear density, incursion of faults, variation of fibre quality, or impurities in the yarn. A decrease in yarn failure load was found for water-treated yarn without tension, whilst water-treated yarn with tension showed an increase in failure load with respect to raw yarn. This behaviour may be due to some reorientation of fibres in the yarn as a result of water treatment. The jute spinning process involves a series of operations including drawing, drafting, and twisting. All of these operations induce a level of stretching on fibres, and stretched fibres tend to relax

FIGURE 3: Failure load of single jute yarn (error bars indicate standard deviation).

FIGURE 4: Water-treated yarn without tension and HEC sized.

FIGURE 5: Raw yarn HEC sized.

FIGURE 6: Water-treated yarn with tension.

FIGURE 7: Water-treated yarn without tension.

FIGURE 8: Raw yarn.

FIGURE 9: Water-treated yarn with tension.

when load is removed. Dipping yarn without tension in water enabled fibres to achieve this relaxed state, and at this stage fibres shrank but all fibres did not shrink to the same extent, and the result was an open structure yarn (Figure 7) with respect to raw yarn (Figure 8), and yarn also got wavy configuration. Due to this open structure, cohesive force reduced, and this may be the reason for the lower yarn failure load for water-treated yarn without tension. During water treatment of yarn under tension (Figure 9), yarns could not shrink, but tendency to shrink may have helped fibres to become oriented towards the yarn axis which increased yarn failure load.

4.3. Composites Test Result. From the test results good correlation was found between failure load of yarn and tensile strength of composites, supporting the observations by other

researchers [21] that composites follow the yarn property rather than fibre property. Composites made of sized yarns showed 9–17% higher tensile strength (Figure 10) and 5–10% higher tensile modulus (Figure 11) with respect to composites made of the same type of unsized yarns. Use of sizing material increased the strength of yarns, and stronger yarns produced stronger composites. As mentioned earlier, water-treated yarns without tension exhibited an open structure as well as a wavy configuration. Composites made of these yarns without applying HEC size showed 10% lower tensile strength (Figure 10) and 11% lower tensile modulus (Figure 11) with respect to composites made of raw yarns. The change in yarn structure affected the alignment of fibres in the yarn, and fibres became wavy and curly, which may have reduced composite properties. Composites made of water-treated yarns applying tension but no HEC size showed 7% higher

FIGURE 10: Tensile strength of composites (error bars indicate standard deviation).

FIGURE 11: Tensile modulus of composites (error bars indicate standard deviation).

tensile strength (Figure 10) and 1% higher tensile modulus (Figure 11) with respect to composites made of raw yarns. As mentioned earlier, due to application of tension during yarn wetting, fibres may aligned better towards yarn axis, and composites made of these yarns showed higher tensile properties.

5. Conclusion

Application of HEC size and water treatment had no effect on the properties of jute fibre.

All types of HEC sized yarn studied in this research showed higher failure load with respect to similar types of unsized yarn. Water treatment of jute yarn without tension reduced yarn failure load, and water treated yarn under tension showed higher failure load with respect to raw yarn.

Composites made of HEC sized yarn showed higher tensile strength and tensile modulus in all cases with respect to composites made of similar types of unsized yarn. Composites made of water treated yarn without tension showed lower tensile strength and tensile modulus, and composites made of water-treated yarn with tension showed higher tensile strength and tensile modulus with respect to composites made of raw yarn. This behaviour is very important for

water-based chemical treatment of natural textile yarn for composite manufacture. As yarn properties and composites properties are affected due to wetting yarn with and without tension.

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