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Physical and Mechanical Properties of Jute, Bamboo and Coir Natural Fiber

Subhankar Biswas[1,3], Qumrul Ahsan[2], Ahmed Cenna[3], Mahbub Hasan[1,4]*, and Azman Hassan[4]

[1]*Department of Materials and Metallurgical Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh*
[2]*Department of Engineering Materials, Faculty of Manufacturing Engineering, University Teknikal Malaysia, Malaysia*
[3]*Department of Mechanical Engineering, Faculty of Engineering and Built Environment, The University of Newcastle, Callaghan, NSW 2308, Australia*
[4]*Department of Polymer Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia*

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Abstract: A systematic study has been carried out to investigate the mechanical and physical properties of jute, bamboo and coir (brown and white) single fibers. The tensile properties (tensile strength, Young's modulus and strain to failure) were determined by varying span length. Scanning electron microscopic analysis was also carried out to determine the physical properties of fibers in order to correlate with its strength, Young's modulus and strain to failure. The Young's modulus and strain to failure were corrected using newly developed equations. The study revealed that with increasing test span length the Young's modulus increased and tensile strength as well as strain to failure decreased. This is because no extensometer could be used in this test set-up and machine displacement (denoted by α) was used for the modulus determination. It is also attributed that larger span length helps to minimize the machine displacement compared to smaller ones due to the reduced relative effect of slippage in the clamps. Among all fibers, the Young's modulus of bamboo fiber was the highest. Jute fiber had smoother surface compared to other three examined fibers.

Keywords: Jute, Bamboo and coir fiber, Span length, Tensile properties, Scanning electron micrographs

Introduction

Recently the use of polymer matrix composites reinforced with fibers such as glass, carbon, aramid etc. is steadily increasing in applications because of their favorable mechanical properties [1-9]. Due to their high cost, synthetic fibers are being replaced by natural fibers such as jute, bamboo, coir, flax, hemp etc. to fabricate moderate strength composites [10,11] and this is gaining acceptance. Natural fibers also favor the 'go green' technology in composite fabrication system due to their biodegradable and renewable properties [12-14]. The prominent advantage of natural fibers includes acceptable tensile properties, low cost, high toughness, good thermal properties and so on. In the present study, the specific objectives are to characterize jute, bamboo and coir (brown and white) fibers and to determine their mechanical and physical properties from experimental results. The tensile properties of jute, bamboo and coir fiber were evaluated with the help of a newly developed method using a mini tensile/compression testing machine. The developed method reduced the slippage effect of the grip of the tensile machine on the tensile properties. As a result it provided more accurate results compared to existing fiber tensile test methods.

*Corresponding author: mahbubmmebuet@gmail.com

Materials and Methods

Materials

Jute fibers (*corchorus olitorius*) (extracted by mechanical process) were collected from Bangladesh Jute Research Institute (BJRI). Bamboo fibers are extracted out of the culms from bamboo plants by steam explosion method. The fiber used in this study was extracted by steam explosion method and supplied by the Hanoi University of Technology, Vietnam. Coir fiber is extracted out of the husk (*mesocarp*) of coconut, which are grown extensively in tropical countries. Fibers can be extracted mechanically from unripe nuts and are then called 'white coir', while 'brown coir' is extracted after ripening of the coconut. Both brown and white coir fiber was also provided by the Hanoi University of Technology, Vietnam.

Methods

Tensile testing of jute, bamboo and coir (brown and white) single fiber (span length of 5 mm, 10 mm, 15 mm, 25 mm & 35 mm) was performed by using a mini tensile/compression testing machine. The machine registered the displacement of the clamps and the force applied on the fiber. It was developed Katholieke Universiteit, Leuven, Belgium. It worked as a normal tensile testing machine. The purpose of using the machine was to fit small load cell in it. Initially fiber (randomly taken) was cut down to the required length and weighed (for bamboo and coir fibers). The fiber was glued in between two paper frames (Figure 1) to conform a good

Figure 1. Specimens for tensile test.

gripping and straight direction to the test clamps. This paper frame was clamped in the machine at the top and the bottom. The paper was cut in the middle carefully just before testing. For every span length, 10-15 fibers were tested and the average values were calculated. Samples that broke near the edge of the clamps were excluded from the analysis.

The diameter of the jute fiber was measured using an optical microscope. The cross-head speeds used for jute, bamboo and coir fibers were 0.5 mm/min, 1 mm/min and 5 mm/min respectively. Again 200 N load cell was used for bamboo and coir fibers, while 5 N load cell was used for jute fibers.

Tensile strength was calculated by using equation (1):

$$\sigma = \frac{F_{\max}}{A} \tag{1}$$

Where σ is tensile strength, $F_{\max}$ is maximum load and A is cross-sectional area.

Cross-sectional area was measured by using equation (2) for jute fiber and equation (3) for bamboo and coir fiber:

$$A = \pi\left(\frac{d}{2}\right)^2 \tag{2}$$

$$A = \frac{m}{\rho^* L} \tag{3}$$

Where L is length, m is mass of fiber of length L, ρ is density and d is diameter.

The Young's modulus was measured from the linear portion of the stress/strain curve.

The surface morphology of jute, bamboo and coir fiber was studied by using an environmental scanning electron microscope (ESEM).

Results and Discussion

Tensile Properties

The stress/strain curves of jute, bamboo and coir (brown and white) fibers (25 mm span) are shown in Figures 2(a), (b), (c) and (d) respectively. The stress-strain curves for coir fiber (Figures 2(c) and (d)) have knuckle patterns unlike the other two fibers. Probably this knuckle indicates the start of plastic deformation in the case of coir fiber.

The primary characteristics of the mechanical behavior for the fibers are presented in Figure 3. Figure 3(b), (c) and (d)

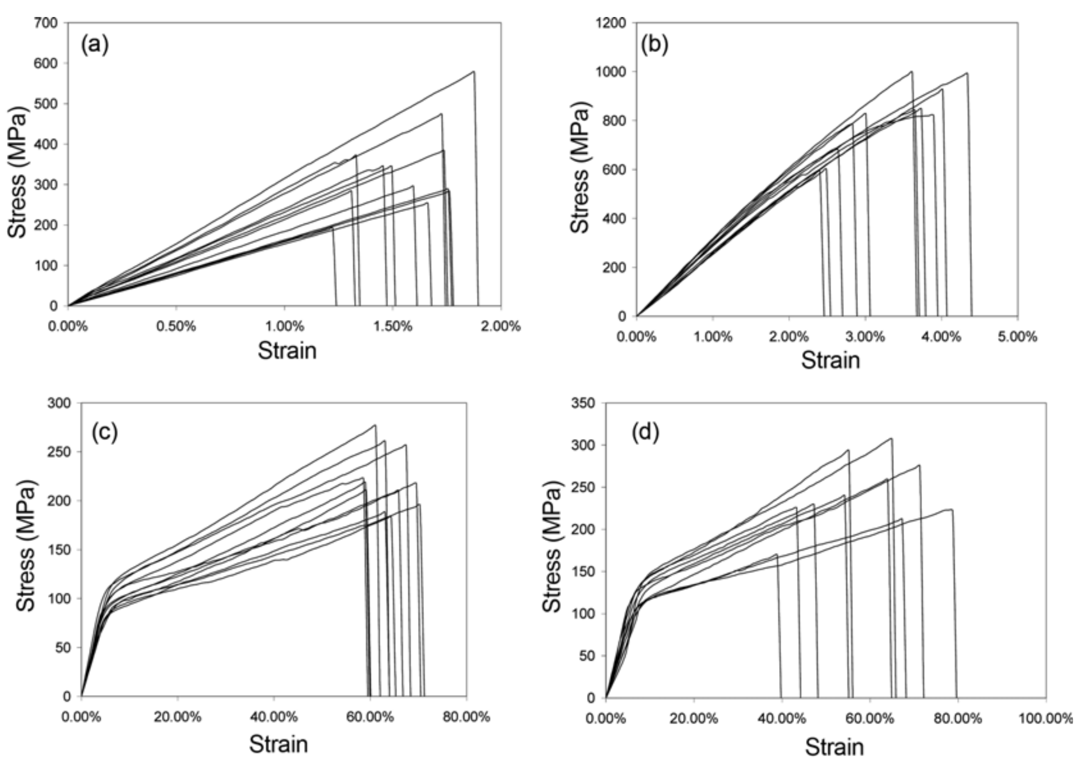

Figure 2. Stress/strain curves for (a) jute, (b) bamboo, (c) brown coir, and (d) white coir fiber at a span length of 25 mm.

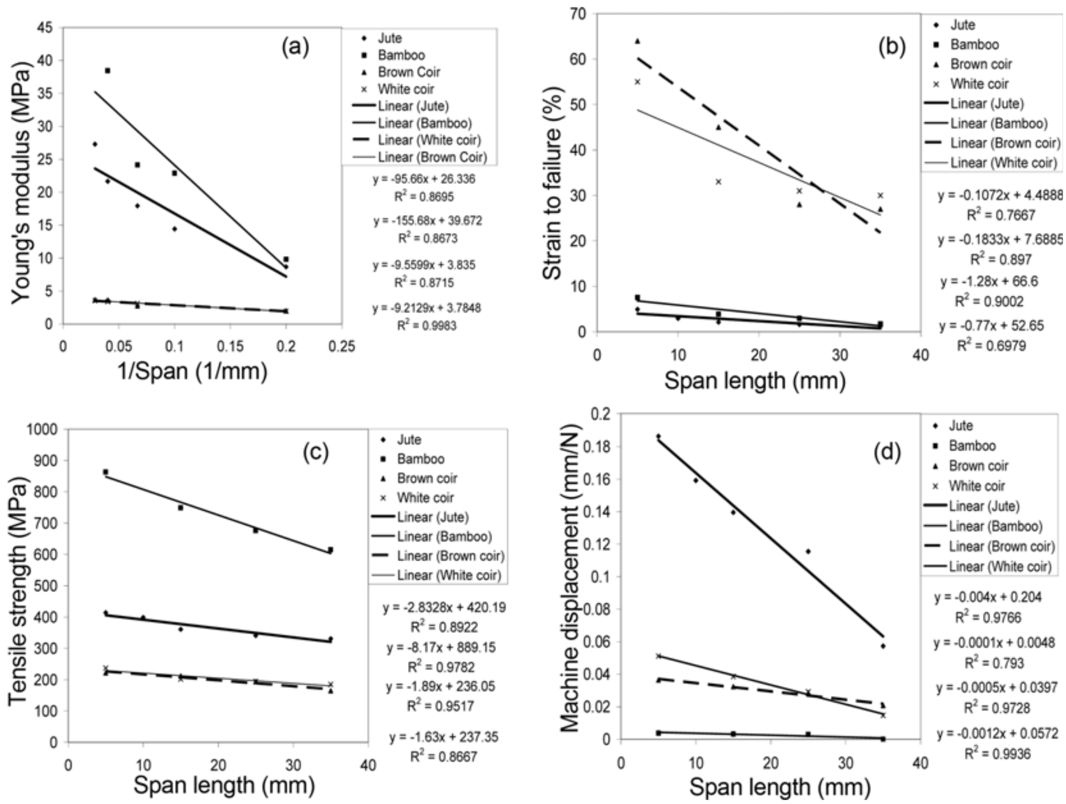

Figure 3. (a) The Young's modulus vs 1/span (uncorrected), (b) strain to failure vs span length, (c) tensile strength vs span length, and (d) machine displacement vs span length.

present the variations of strain to failure, tensile strength and machine displacement with respect to span length respectively. The variation of the Young's modulus has been presented in Figure 3(a) with respect to 1/span length. Results show that with an increase in span length, the Young's modulus increased (Figure 3(a)) for all fibers. As no extensometer was used in current set-up, machine displacement (displacement of the clamps) was utilized for the modulus determination. At longer gauge lengths the relative effect of slippage in the clamps will be smaller, thus increasing the Young's modulus value. On the other hand, the tensile strength and strain to failure decreased with an increase in span length. As mentioned by Bledski and Gassan [15], the longer the stressed distance of the natural fiber, the more inhomogenities (flaws) will be in the stressed fiber segment thus weakening the structure. As a result increasing fiber length inevitably reduces the strength of the fiber. It is also observed that at longer gauge lengths, the relative effect of slippage in the clamps was smaller (Figure 3(d)). This figure indicates that alpha, which is a factor estimating the influence of slippage and the test setup compliance also depends on span length. With increasing span length alpha values decreased slightly. Among all fibers the alpha values of bamboo fibers were the lowest (Figure 3(d)). It was because of the thicker diameter of bamboo fiber in comparison with other fibers. Jute fiber showed the highest alpha value as its diameter was smallest. Young's modulus regression equations in Figure 3 were used to find out the extrapolated values of the same. The extrapolated values were used later in equation (4). Strain to failure and tensile strength followed linear dependency with span length according to Figure 3.

Correction of Tensile Properties

Since machine displacement was used for the calculations of modulus, correction for the calculated values is required to exclude the systematic error introduced by the machine displacement. A Correction method to assess the actual fiber elongation from the measurement of clamp displacement has been presented in [16]. It has been done by subtracting the elongation of grip from the total fiber elongation. Corrected Young's modulus was found using the following steps:

a. $$\alpha_i = \frac{\Delta L_{total}}{F} - \frac{L_0}{E_0 \times A_i} \quad (4)$$

b. $$\frac{\Delta L_{total}}{F} = \frac{\varepsilon \times L_0}{\sigma \times A_i} = \frac{1}{E} \times \frac{L_0}{A_i} \quad (5)$$

c. $$\frac{\Delta L_{grip}}{L_0} = \frac{\alpha_l \times A_i \times \sigma}{L_0} \quad (6)$$

d. $$\frac{\Delta L_{fiber}}{L_0} < Corrected > = \frac{\Delta L_{total}}{L_0} - \frac{\Delta L_{grip}}{L_0} \quad (7)$$

Where α_i is machine displacement for each fiber, α_l is line value of α, L_0 is original span length, E is the Young's modulus for each fiber, E_0 is extrapolated Young's modulus, A_i is cross-sectional area for each fiber, F is force, ε is strain and α is stress.

The comparison between corrected and uncorrected Young's modulus for all fibers are shown in Figure 4. It is clearly observed that span length affects the Young's modulus. The Young's modulus had much scattered values for 5 mm span length, while the scattering was much lower for 35 mm span length (Figure 4). Again the average Young's modulus found was very close to extrapolated (modulus in infinite span length) values after correction.

Table 1 shows tensile strength, Young's modulus and strain to failure of all mentioned fibers with literature values [15,17]. Results show that all the fiber properties found are very close to their literature values. Among all examined fibers, tensile strength and Young's modulus of bamboo fiber were the highest, while coir fiber had the highest values in terms of strain to failure. Strain to failure to failure of both coir fibers are above 9 times higher than bamboo fiber and above 15 times higher than that of jute fiber.

ESEM Morphology

Environmental scanning electron microscope (ESEM) was used for physical analysis of jute, coir and bamboo fibers. Figures 5(a), (b), (c) and (d) show the longitudinal views of jute, bamboo and brown coir and white coir fiber respectively. It is clearly observed that jute fiber had smoother and more compact structure in comparison to bamboo and coir fibers. Bamboo fiber (Figure 5(b)) had rough structure because of

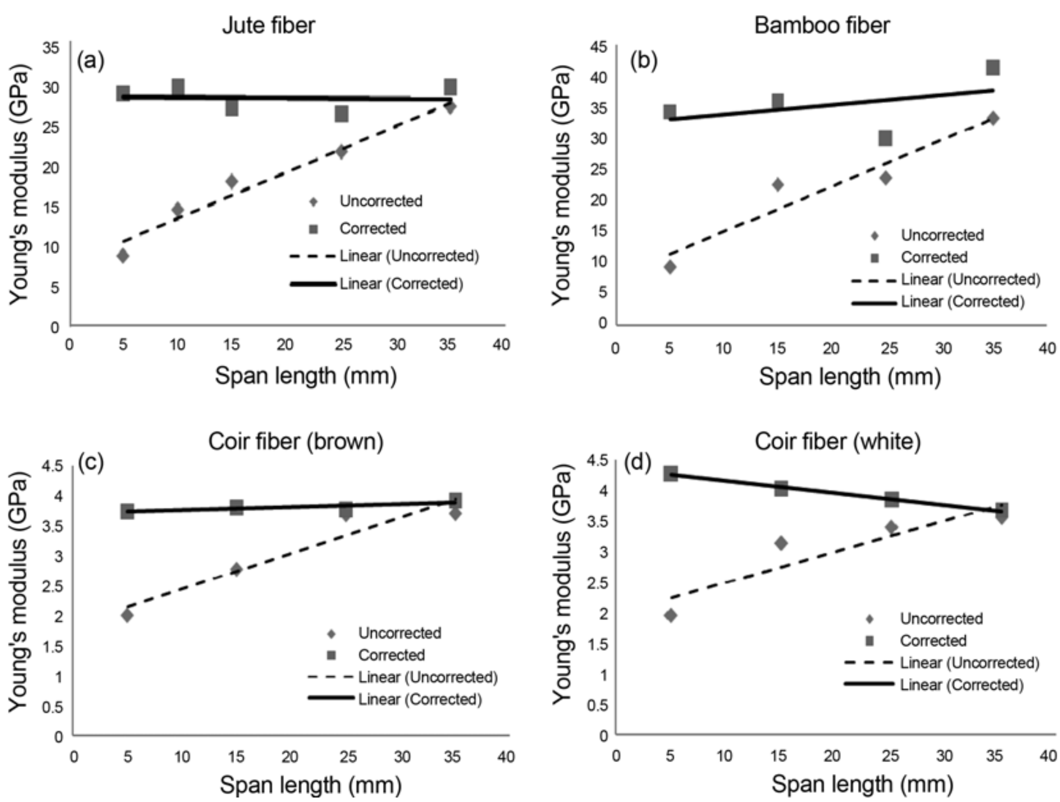

Figure 4. Corrected and uncorrected Young's modulus of (a) jute, (b) bamboo, (c) brown coir, and (d) white coir fiber.

Table 1. Tensile strength, Young's modulus (corrected) and strain to failure along with literature values [15,17]

Fiber species	Tensile strength (MPa)	Literature value (MPa)	Corrected Young's modulus (GPa)	Literature value (GPa)	Strain to failure (%)	Literature value (%)
Jute	331-414	393-773	28.43	13-54	2.56	1.5-1.8
Bamboo	615-862	450-800	35.45	11-30	4.11	1-3
Coir (brown)	165-222	175	3.79	4-6	40.95	30
Coir (white)	185-237	175	3.97	4-6	38.74	30

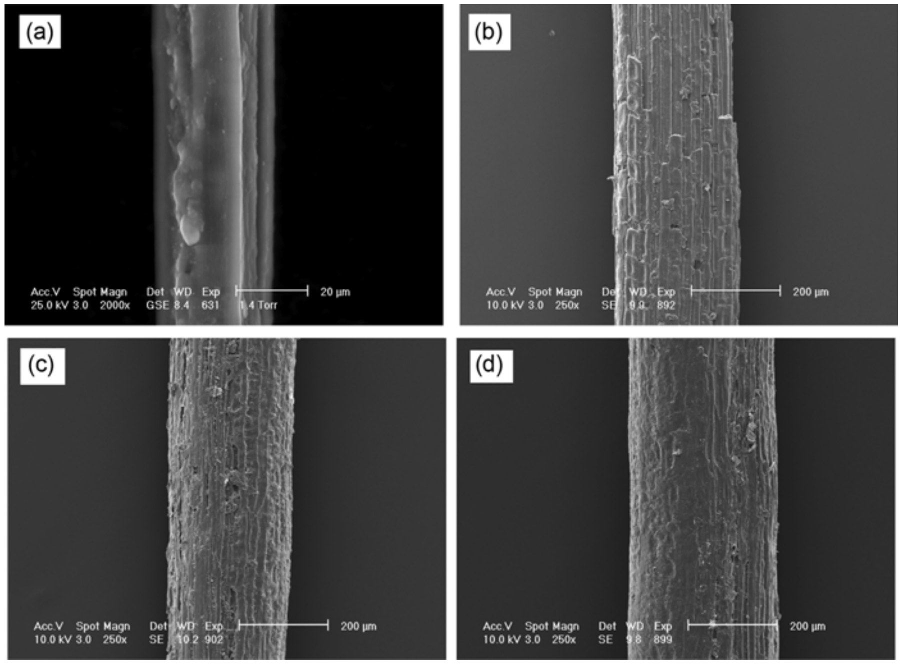

Figure 5. ESEM micrographs for the longitudinal direction of (a) jute, (b) bamboo, (c) white coir, and (d) brown coir fiber.

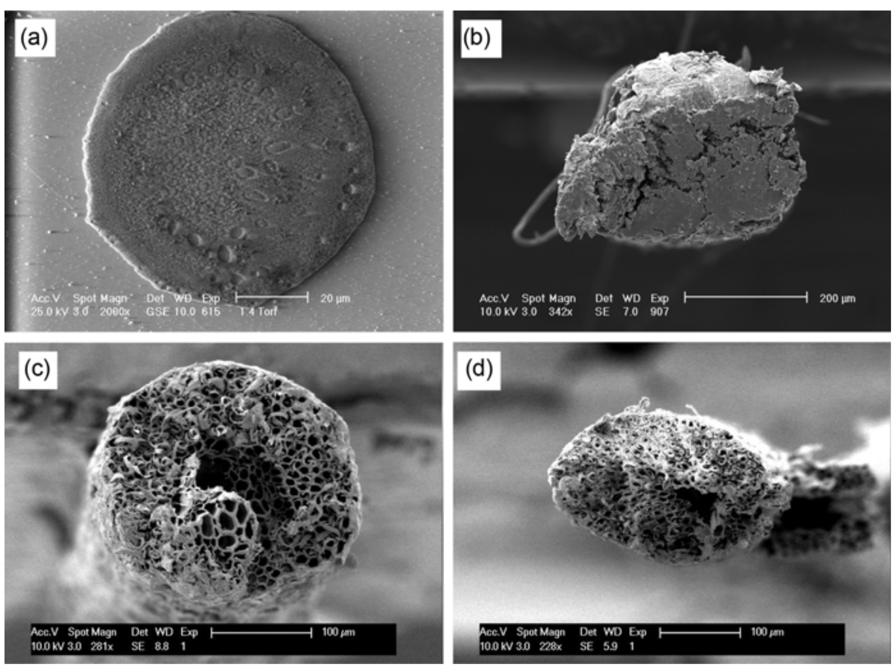

Figure 6. ESEM cross-sectional views of (a) jute, (b) bamboo, (c) white coir, and (d) brown coir fiber.

its extraction process. In case of two coir fibers, white one (Figure 5(c)) seemed denser compared to the brown one (Figure 5(d)).

The cross-sectional views of jute, bamboo, brown coir and white coir fiber are shown in Figures 6(a), (b), (c) and (d) respectively. It can be seen that all fibers had porosity in the middle portion of the cross-section. Among all fibers, bamboo had lowest porosity. In comparison between jute and coir fibers (both brown and white), jute fiber had low porosity, while both brown coir and white coir fibers had huge number of porosities. This is why tensile strength of coir fibers tested was the lowest compared to other fibers.

Conclusion

In the present study, tensile test was conducted on jute, bamboo, brown coir and white coir fibers using different span lengths. Morphology study using ESEM supports the characteristics of fibers determined through tensile test. Based on the experimental results, the following conclusions can be made;

· The Young's modulus increased with increased span length.
· With an increase in the span length, tensile strength and strain to failure decreased.
· Among jute, bamboo and coir fibers, bamboo fiber had the highest Young's modulus values.
· The surface of jute fiber found was smooth, while bamboo and coir fibers were rough.
· It is demonstrated that accurate properties of natural fibers can be determined by using newly developed analytical equations.

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