Measuring the effects of humidity on the mechanical properties of bamboo fibres

Introduction

There is a growing interest in replacing synthetic fibres with natural fibres such as bamboo, coir, cotton, flax, hemp, jute, kenaf, oil palm and sisal[1]. This is driven in part by the market requirement to reduce the use of fossil fuel derived fibres and their associated risk to the climate. In addition, natural fibres have many favourable properties including low cost, low density, durability, biodegradability, sustainability, good thermal insulation and high toughness[1,2,3].

Recently, there has been increase in using bamboo fibres as a viable, more renewable alternative to glass fibres. Bamboo fibres are already used in the textile industry, the construction industry, and in the paper industry[4,5].

Compared to other lignocellulosic (dry plant matter) fibres, bamboo has a high lignin percentage (32.2%) and a small microfibrillar angle (2° to 10°). The combination of these two factors results in a high tensile strength, flexural strength (stress at failure in bending), and rigidity of the fibre wall[2], all of which are desirable properties when considering the uses of bamboo fibres in the construction industry.

However, it is well known that natural fibres, including bamboo, can undergo significant swelling when exposed to humid environments. For instance, Jakovljević *et al.*[6] tested the effects of humidity on two different species of whole bamboo culms, Pseudosasa amabilis and Pleioblastus amarus, showing that the tensile, compressive, and bending strength of the bamboo was statistically significantly reduced (95% confidence limits) after the bamboo was kept at a humidity of 60% for three weeks[6].

This study examines the effects of humidity on single bamboo fibres, with the aim of better understanding how humidity affects their diameter and their tensile mechanical properties. This is important to assess because if bamboo fibres swell within a composite material, it can lead to cracking and weakness[7].

Methodology

The study was conducted on wet spun bamboo fibres using Dia-Stron's Fibre Dimensional Analysis System (FDAS770) and Linear Extensometer (LEX820).

Dimensional

Bamboo fibres were randomly selected from a bundle, mounted into Dia-Stron's bespoke one-part plastic tabs and secured into place using Dymax UV-curing adhesive. The V-shaped alignment feature of the tabs increases consistency during testing, speeds up the mounting process and reduces accidental damage to the samples. Twenty samples each of 20mm and 30mm gauge lengths were mounted into cassettes and equilibrated for three hours in a temperature and humidity-controlled cabinet. The dimensional measurements of the fibres were measured using the FDAS770, a high-frequency Laser Scanning Micrometer for accurate, non-contact dimensional measurement of fibres with fully automated sample rotation and translation. The average diameter was determined from five cross-sectional measurements of each fibre. The temperature was kept at a constant 20°C ± 2°C and the humidity increased for each successive set of measurements, from 35% relative humidity (RH) to 50%, 65% and 80% respectively, all ± 2%RH.

Tensile

An additional eighty 20mm samples were dimensionally measured and tested for tensile strength. Twenty of these samples were kept at each of the aforementioned humidities and pulled to break using the LEX820, with an extension rate of 1mm/min. A further twenty samples were measured at 4mm and 30mm for each humidity, in order to calculate the compliance correction of the system (using ASTM C1557-20).

Shapiro Wilks tests were used to determine whether the data was normally distributed. Normally distributed data were tested for statistical significance using a pairwise t-test, nonparametric data was tested using a paired Wilcoxon signed rank sum test. In all cases a p-value of <0.05 was used to determine statistical significance.

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Results

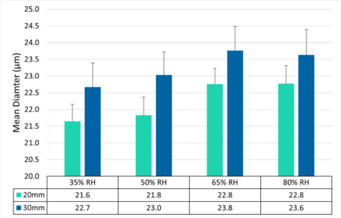
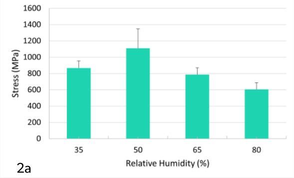


Figure 1: *Showing the mean diameter of the bamboo fibres, in μm, across the range of humidities.*

The average diameter of the bamboo fibres increased with increasing humidity, in both groups. The fibres at 35%RH had the smallest average diameter, with an increase through 50%RH to 65%RH (Figure 1). Above 65%RH there was no significant change in fibre diameter, as the fibres seemed to have reached their swelling capacity. The mean diameter of the 20mm bamboo fibres increased from 21.6μm to a maximum of 22.8μm, a 1.2μm increase (5.6%). The mean 30mm bamboo fibre diameter increased from 22.7μm to a maximum of 23.8μm, a 1.1μm increase (4.8%).



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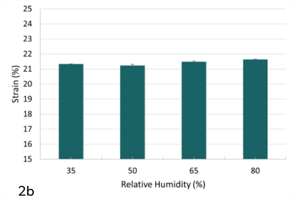

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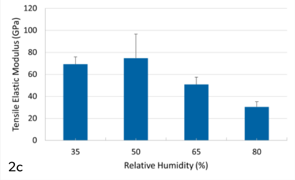

2c

Figure 2: *Over the range of relative humidities, showing the (a) strength in megapascals, (b) strain in % and (c) tensile elastic modulus in gigapascals. The error bars show standard error.*

The strength showed no statistically significant change between 35%RH and 50%RH, with a p-value of 0.3762. The strength significantly decreased as the humidity continued to increase, to a mean value of 605MPa at 80%RH, compared to 1100MPa at 50%RH (Figure 2a). The strain showed no significant differences with changes in humidity (Figure 2b). The tensile elastic modulus followed the same trend as the strength, with no significant change between 35%RH and 50%RH, but significantly decreasing as the humidity rose beyond 50%. The tensile elastic modulus declined from 74.8GPa to 30.5GPa, a decrease of 59.2% (Figure 2c).

Conclusion

In this study, it was seen that increasing humidity significantly decreases the tensile strength and elastic modulus of bamboo fibres, but does not affect the strain to break. Higher humidities result in the bamboo fibres swelling, with the increase in diameter plateauing between 65%RH and 80%RH. There is scope for further studies using the FDAS770 to investigate the humidity at which bamboo fibres reach their maximum diameter, and the addition of the Dynamic Swelling Module to explore the swelling profiles of fibres immersed in water. Additional applications of the LEX820 include determining whether the tensile elastic modulus continues to decrease beyond 80%RH, and whether repeatedly cycling the fibres through high and low humidities weakens them further.

References:
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