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Engineered bamboo scrimber: Influence of density on the mechanical and water absorption properties

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HIGHLIGHTS

- Influence of bamboo scrimber density on the tensile strength and tensile modulus properties.
- Effect of bamboo scrimber density on the compressive strength and compressive modulus properties.
- The flexural strength and flexural modulus of bamboo scrimber were evaluated.
- Long term water absorption by bamboo scrimber.

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ABSTRACT

Engineered bamboo scrimber has processed from the raw bamboo culm into a compressed or laminated product with thermosetting resin in the density range of 800–1200 kg/m^3. The present work investigates the mechanical properties of commercially available engineered bamboo scrimber and compares the results of present work with the existing results in the literature. The main aim of this work is to investigate the influence of bamboo scrimber densities on the mechanical properties. The strength and modulus properties in tensile, compression, shear and flexural were evaluated using the specimens of three different densities. The dynamic modulus of elasticity of bamboo scrimber beams were evaluated using ultra-sonic pulse method. According to the present results it can be concluded that the density have significant influence on the mechanical properties of bamboo scrimber. The long term water absorption was also conducted to analysis the weight gained by the bamboo scrimber having different densities and the results revealed that density of specimen's influences the water absorption.

1. Introduction

Bamboo and bamboo-based panels would be the ideal source, to fulfil the demand of wood in construction sector. Bamboo is a rapidly-renewable resource; it regenerated for harvesting in three to eight years [1,2]. Due to the hollowness and the longitudinal fibers direction makes bamboo as an efficient natural structural design [3]. In the recent years bamboo attracted significant scientific research for the sustainable building material development since it possesses similar mechanical properties to those of structural wood products and bamboo is more renewable compare to wooden products due to its fast growth rate [3].

Bamboo is an orthotropic material with high strength along and low strength transversal to its fibers [4]. Bamboo having comparable tensile strength, compressive strength, Young's modulus and shear strength on a weight to-weight basis to conventional materials such as low-carbon steel and glass-reinforced plastics [5–8]. Bamboo fibers have various applications in the material development such as bio-composites with polymer matrix [9,10], reinforced material for concrete [11,12]. There are mainly three types of engineered bamboo products those being used as structural building material: laminated bamboo, reconstituted densified bamboo, and bamboo board [13]. Reconstituted densified bamboo also known as strand woven bamboo or bamboo scrimber. The word "Scrimber", originally proposed by Coleman [13], means

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Nomenclature

$f_{t\parallel}$	tensile strength parallel to grain direction [MPa]
$f_{t\perp}$	tensile strength perpendicular to grain direction [MPa]
$E_{t\parallel}$	tensile modulus parallel to grain direction [GPa]
$f_{c\parallel}$	compressive strength parallel to grain direction [MPa]
$f_{c\perp}$	compressive strength perpendicular to grain direction [MPa]
$E_{c\parallel}$	compressive modulus parallel to grain direction [GPa]
$\tau_{\parallel}$	shear strength parallel to grain direction [MPa]
f_f	flexural strength 3-point bending [MPa]
E_f	flexural modulus 4-point bending [GPa]
$MOE_{D\parallel}$	dynamic modulus of elasticity parallel to grain direction [GPa]
$MOE_D\perp$	dynamic modulus of elasticity perpendicular to grain direction [GPa]
CBT	control bamboo treatment oven dry at 85 °C
SST	saturated steam treatment
HDAT	hot dry air treatment
THMDB	thermo-hydro-mechanically densified bamboo
PSL	parallel strand lumber

numerous wood splinters bonded together, latter it was adopted for crushed bamboo culms bonded together with adhesives (phenol formaldehyde resin) and compacted together up to twice of its density using cold and hot pressing [13]. The density of a bamboo scrimber can be increased to 1050–1250 kg/m^3, to improve the bonding strength and the bamboo scrimber has been successfully commercialized and rapidly developing in China [14,15].

Yu et al. [16] described the fabrication and characterisation bamboo scrimber (1150 kg/m^3) with different weight percentages of phenol formaldehyde [PF] resin and different heat treatments of bamboo bundles. They revealed that the influence of PF resin loading on water swelling and mechanical properties of bamboo scrimber. Sharma et al. [17] investigated the commercial bamboo scrimber mechanical properties with density 1163 kg/m^3 and compared the mechanical properties with laminated bamboo sheets. They investigated the mechanical properties of bamboo scrimber in parallel to fiber direction only and do not evaluates the modulus of elasticity. Yu et al. [18] investigated the mechanical properties of bamboo fiber reinforced composite (BFRC) comparing with those of commercial bamboo scrimber and laminated bamboo lumber (LBL). They presented the tensile, compressive and shear strength of bamboo scrimber of 1100 kg/m^3 density. Shangguan et al. [19] developed a 2D model for compressive parameter of bamboo scrimber and the model predicted the influence of compressive loading angle to fiber direction on compressive property of scrimber. Guan et al. [20] fabricated the composite bamboo scrimber using two different bamboo species i.e. Moso bamboo and Muli bamboo (*Melocanna baccifera*) and compare their mechanical properties. The existing literature has presented limited data on the mechanical properties of bamboo scrimber and has not considered the influence of density on properties of bamboo scrimber as the density varies between 800 and 1200 kg/m^3 [19].

The present study investigates the influence of density on the mechanical properties such as tensile, compressive, shear, and flexural strength as well as modulus of elasticity of commercial bamboo scrimber and evaluates long term water absorption.

2. Materials and methodology

2.1. Materials

In the present study commercially produced bamboo scrimber also known as strand woven bamboo supplied from China was used. The bamboo scrimber are produced commercially using Moso bamboo (*Phyllostachys pubescens*) along with phenol formaldehyde resin, and the thermal treatment using saturated steam (SST) was also employed during fabrication process. Fig. 1 shows the schematic presentation of bamboo scrimber commercial production; the bamboo culms were process minimally to remove the few millimetre of outer and inner skin. The supplied bamboo scrimber having 40 mm × 40 mm × 620 mm dimensions and density varies between 1000 and 1220 kg/m^3. The received bamboo scrimber were conditioned in a chamber at 65% ± 5% relative humidity and 20° ± 2 °C temperature for one month to maintain the final moisture content around 7%. Further, the conditioned bamboo scrimber were trimmed into different dimensions as per standard requirement for mechanical property analysis and again conditioned for two weeks prior to testing in chamber at 65% ± 5% relative humidity and 20° ± 2 °C temperature.

The foil linear strain gauges (type 20/120 LY41, temperature response matched to steel with α = 10.8 [10^{-6}/K]), with the later applications of bridge for connection the cables, were purchased from the company HBM (Hottinger Baldwin messtechnik) GmbH.

2.2. Mechanical properties testing

The mechanical properties were measured with a universal testing machine (LabTest 4.100SP1, Czech Republic) using load cell of 100 kN capacity.

2.2.1. Dynamic modulus of elasticity (ultrasonic pulse method)

Ultrasonic impulse measurement was conducted using Tico apparatus. The measurements were conducted in both longitudinal (parallel to grain) and perpendicular (across the grain) directions, as shown in Fig. 2. The ČSN 73 1371 [21] was employed to determine the modulus of elasticity non-destructively and calculation process is given below and the dimensions of bamboo scrimber 40 mm × 40 mm × 620 mm was used.

$$\rho = \frac{m}{V}\ (\text{kg/m}^3) \tag{1}$$

The transit speed of impulse:

$$V_i = \frac{L}{T}\ (\text{K.m/s}) \tag{2}$$

where; $T = t_1 - t_{corr.}$

Coefficient of dimensionality of the environment:

$$K = \frac{V_i}{f}\ (\text{mm}) \tag{3}$$

-- consideration of unidirectional environment $\rightarrow$k = 1

$$MOE_D = \frac{\rho \times V_i^2}{K}\ (\text{MPa}) \tag{4}$$

2.2.2. Compressive strength

The compressive strength of engineered bamboo scrimber were evaluated in parallel to grain directions as per ČSN 490110 [22] and perpendicular to grain directions as per ČSN 490111 [24] standards. Two foil linear strain gauges were pasted using epoxy resin on the mid-span of samples for accurate measurement of force and linear displacement for calculation of modulus of elasticity. The