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BAMBOO – A CHALLENGING MATERIAL FOR ROMANIAN ENGINEERS
Part 2. An experimental study on its anatomy and some physical and mechanical properties

Emanuela BELDEAN[1] Mihaela POROJAN[1]
Maria C. TIMAR[1]

Abstract: *The present paper is the second part of a study related to bamboo, which presents the experimental results regarding its anatomical, physical and mechanical properties. The obtained results for the tested properties are comparable with the literature data and represent the authors' important contribution to the knowledge and understanding of bamboo as a potential material for substituting wood.*

Key words: *Bamboo, microscopy, swelling, capillarity, compression strength.*

1. Introduction

Bamboo is a versatile material and can replace a variety of woods that are used for construction today. In the first part of this paper, some anatomical, physical and mechanical properties of bamboo, which are relevant for the industry sector, were summarised based on literature data [1]. The author's objective was to compare the properties of bamboo with the ones of common Romanian wood species. The obtained data represented a useful starting point for further studies presented in this paper.

The authors focused on the testing of some properties that were considered to be important for Romanian wood engineers. The aim of this study was to supply data and knowledge, in order to facilitate and promote the use of bamboo in modern constructions, furniture and other potential applications in Romania.

Anatomical structure, which directly affects physical and mechanical properties, was a first step in our investigations.

The physical and mechanical properties of bamboo also depend on many factors, such as age, culm height, growth location etc. [2], [8], [11], [14]. The properties considered in this study for bamboo were: moisture content, density, water absorption and swelling in two different tests: total immersion in water and capillarity test.

The challenge was even greater, as it is not an indigenous species for Romania and therefore it is not known very well.

2. Materials and Methods

Two types of commercial bamboo sticks

[1] Department of Wood Processing and Design of Wooden Products, *Transilvania* University of Brasov, Str. Universitatii, no.1, 500068, Brasov, Romania.
Correspondence: Emanuela Beldean, e-mail: ebeldean@unitbv.ro.

and poles (no specification for species or genus) with diameters of 22 mm and respectively 45 mm, were used for experiments (Figure 1). The material for the tests was procured from Romanian importers that sell bamboo in different forms [16]. This was conditioned in the laboratory, in normal atmosphere at about 20 °C and 55 RH for 14 days before testing.

Fig. 1. *Bamboo sticks and poles used for experiments*

2.1. Bamboo Anatomy

Microscopic investigation was employed for determining the anatomic structure.

The methodology for sample preparation was similar as for wood. A small sample from a bamboo stick was boiled in water until softening (Figure 2a). Fine transparent sections were cut by hand microtome (Figure 2b). Then, micro sections were coloured in Safranin 1% for 5 min (Figure 2c). Excess stain was washed off with water.

a b c

Fig. 2. *Sequences for micro slides preparation*

The samples were fixed on microscope slides and observed at different magnifications with a stereomicroscope Optika SZM fitted with a camera for image capture. The images revealed the microscopic appearance of bamboo in cross or longitudinal sections until 90x magnification.

2.2. Physical Properties

Bamboo is a lignocellulosic, anisotropic material like wood. It shows a notable difference in the anatomical structure, compared to the one of wood species, so that its morphology, macroscopic characteristics, physical and mechanical properties also differ from those of wood.

a. Moisture Content and Density

The moisture content and the density are important indicators for processing, strength properties, durability, and also for further utilisation of the material [3].

From the same stick of 45 mm diameter, six samples (rings) of 10 mm height were cut from the internode area for each moisture and density tests.

The initial weight of the samples was measured with an accuracy of 0.001g, then oven dried at 103 ±2°C, until the mass was constant. The moisture content was calculated with the formula:

$$U = (m_i - m_f)/m_f \times 100, [\%] \quad (1)$$

where:

m_i = initial mass of the sample [g];

m_f = final oven dried mass of the sample [g].

Fig. 3. *Samples for moisture content test*

The density is defined as mass per unit

volume. Considering that samples had irregular shape, the method employed was based on determining the volume of the samples as the volume of the liquid displaced. Toluene was employed as liquid into which the weighed samples were totally immersed (Figure 3). The density was calculated according to the formula:

$$\rho = m/V, \text{ [g/cm}^3\text{]} \quad (2)$$

where:
m = mass of the sample [g];
V = volume of the liquid displaced [cm^3].

Fig. 4. *Density experiment*

b. Water Immersion Test

Bamboo is a hydrophilic and hygroscopic material, which can absorb water as a liquid and adsorb water vapours from the atmosphere.

From each bamboo ring of 45 mm were cut 4 samples. 10 samples resulted from different rings for the immersion test. Each was coded, weighted and measured in three points situated at 5 mm from the margins and in the centre of the sample (Figure 5). Bamboo samples were then placed in a water bath at 20°C and maintained for a period of 72 hours, with intervals of weighing and measuring after: 1h, 2h, 24h, 48h and 72h. The samples were rapidly removed from the water bath, superficially dried with blotting paper to absorb excess water, weighted and measured to determine the water uptake (WA) and partial thickness swelling (α). The calculation formulas were used:

$$WA = (m_f - m_i) / m_i \times 100, \text{ [\%]} \quad (3)$$

where:
mf – final mass after immersion test [g];
mi – initial mass [g].

$$\alpha = (a_f - a_i)/a_i \times 100, \text{[\%]} \quad (4)$$

where:
a_f – thickness measured after immersion [mm];
a_i – initial thickness before test [mm].

a b c d

Fig. 5. *Sequences of water immersion test*
(a. – codification, b. – measuring, c. – weighing, d. – immersion)

c. Capillarity Test

Bamboo is a capillary, porous material. This property will influence the adhesion properties, ability for different treatments, finishing, chemistry of surfaces, etc. Furthermore, water absorption by capillarity thorough open cross-cut section could be critical in some applications (i.e. bottom part of chair legs).

Six bamboo samples obtained from bamboo rings of 10 mm height were placed in a glass, above a sponge saturated with distilled water and left for periods of: 1, 2, 24, 48, 72 hours (Figure 6).

Fig. 6. *Capillarity test*

To maintain saturation throughout the test periods, on the surface of the sponge was added water with a pipette. Before and after each testing period, the samples were weighted and measured in thickness, in three points, similar with samples for water immersion test.

The water adsorption and swelling were calculated with the same formulas (3, 4).

2.3.Mechanical Properties-Compression Strength Parallel to the Grain

The mechanical properties are correlated with density and anatomical structure. Age is another factor for development of strength properties. The bamboo culm usually serves practical purposes, as an axial load bearing member of a structure. Therefore, the tested mechanical property of bamboo was the compression parallel to the grain.

The samples were extracted from the same stick of 22 mm in diameter, without defects. Tests were performed on 10 samples taken from the internode area and 10 samples from node area (Figure 7a). The samples diameters and length were measured with digital calliper. The length of samples was 60 mm.

a

b

Fig. 7. *Samples from internode and node area (a) and compression fracture (b)*

The testing equipment was the universal machine type ZDM 5t/51 from the Laboratory of Wood Mechanical Testing. The set of tests involved compressive axial loading where samples were stressed to beyond fracture (Figure 7b). The compression stress was registered on the C scale of equipment (0-5000 daN). The loading speed was set to 6mm/min. In order to calculate the compression strength, the following formula was used:

$$\sigma_{c\parallel} = F/A, \text{ [N/mm}^2\text{]} \qquad (5)$$

where:

F – the axial loading [N];

A – the cross section of the sample (circular) [mm^2].

3. Results

The appearance of the macroscopic cross cut of the culms shows (Figure 8a) an outer area denser and more lignified, due to the vascular bundles which are smaller and more numerous, as well as an inner area where the vascular bundles are bigger and less numerous.

The microscopic investigation of bamboo indicated a vascular system with no particular arrangement as in case of wood.

Vascular bundles, highlighted in Figure 8b by a red mark, are a combination of vessels and sieve tubes, with companion cells and fibres [10]. They provide mechanical support and nutrient transport. As shown in Figure 8b, the vascular system of bamboo is composed of primary xylem vessels (*1*) and primary phloem tissue *(2*). The vascular bundles are embedded in the parenchyma ground tissue (*3*) and fibres areas (*4*). These cells represent almost 90% from the total number of the anatomic elements [2].

The moisture content and density of samples tested in this study are shown in Table 1.

Physical properties Table 1

Property	**Moisture content, %**	**Density, g/cm^3**
Mean Value	9.35	0.56
St dev	*0.71*	*0.01*

According to the literature [2, 4, 5, 6, 7, 10] the basic density of bamboo is 0.400/0.500-0.900 g/cm^3. It depends on species, anatomic structure, location of sample along the culm, age, moisture content, etc. The obtained value of 0.56 g/cm^3 was situated within the interval specified in the literature.

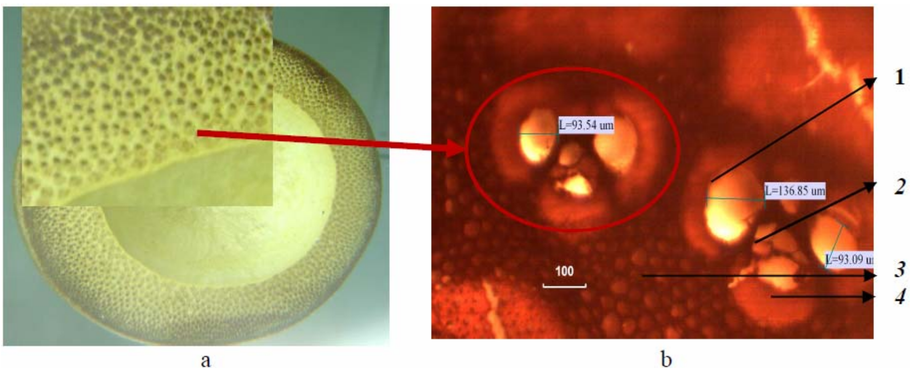


Fig. 8. *Macroscopic appearance (a) and microscopic cross section (b) of bamboo (magnification 90x)*

The water uptake and swelling after immersion and capillarity tests are shown in the diagrams of Figure 9. As noticeable, water absorption increased with the immersion time, until 77% for 72 hours of exposure. The same situation is revealed for thickness swelling. The value of the swelling after 72 hours of water immersion was 12%, which is close to the value of 13% mentioned in the literature.

Considering the capillarity test, the dynamic of water adsorption is slightly slower, but at the end of the test, the value is comparable with that for immersion test. This behaviour is directly influenced by the bamboo anatomy and the porous structure of the material. The value of thickness swelling was lower in this case: 8%, compared to 12% for immersion.

The compression tests performed for two types of samples originated from internode and node area are illustrated in Figure 10.

Comparing the compression strength values determined on samples of the node and internode areas these are very similar. It should be mentioned, however, that the standard deviation for the compression strength was higher for the internode area (8.54 comparing with 3.56 for node area).

The value indicated in the literature for 15% moisture content is 50-53MPa. The authors concluded in their study that *the strength on node and internode were almost similar of all mechanical properties tested,* including compression parallel to the grain [12]. It is well known that good strength is associated with decreasing moisture content [13].

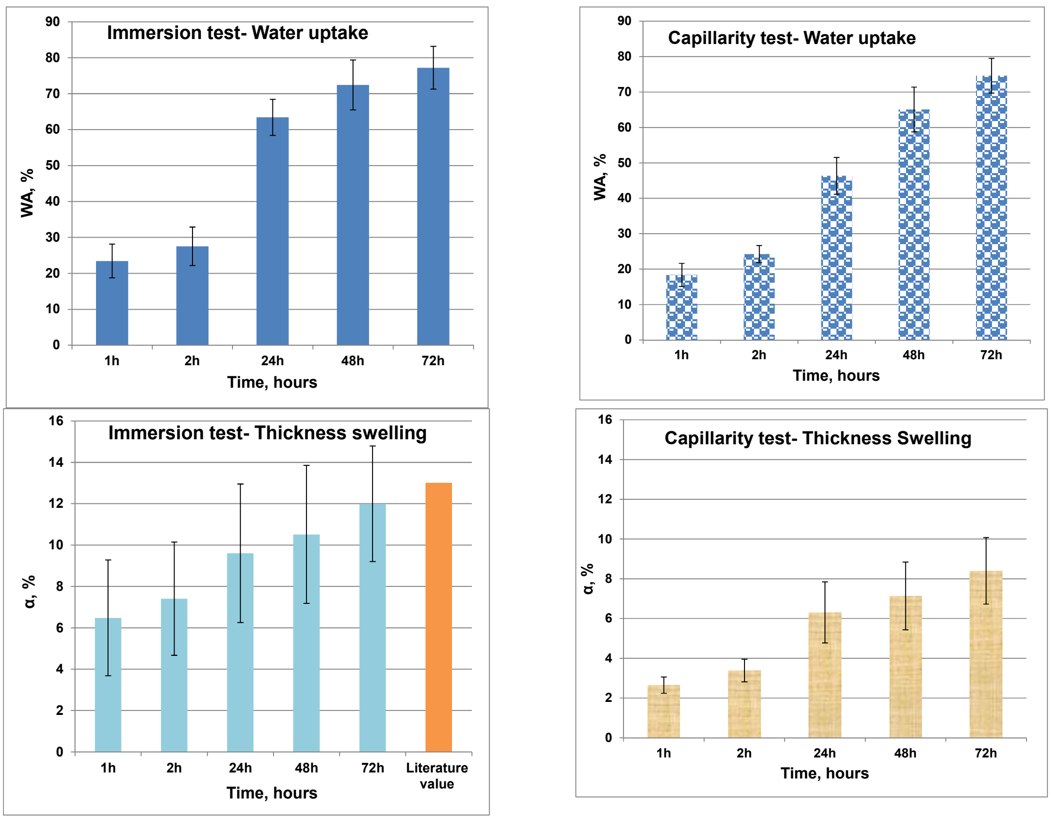


Fig. 9. *Results after water immersion and capillarity test (water uptake and swelling)*

The mechanical properties of bamboo decrease with increasing moisture content; although bamboo in an 'oven dry' condition also has lower strength than that in an 'air-dry' condition [15]. Another author mentioned [9] that *mechanical properties decreased as bamboo absorbed moisture in the hygroscopic range*. Therefore, the strength values of 65-66 MPa (Figure 10a) for air dried bamboo at 9.35% moisture content are considered accurate.

When compression was applied parallel to the grain it produced stress that shortened the cells along their longitudinal axis (Figures 10b and 10c). At failure, large deformations occurred.

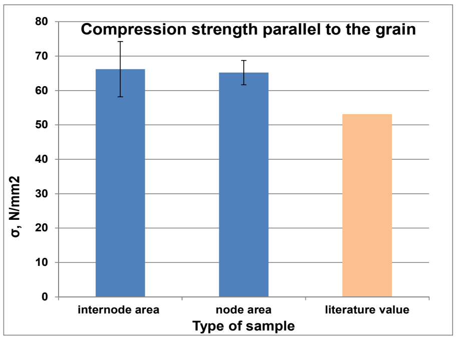
4. Conclusions

The present study brings a contribution to the knowledge and understanding of bamboo anatomy and its physical-mechanical properties, important to the engineering and design of bamboo products. For this purpose standard testing methods and adapted or original methods were employed.

The physical and mechanical properties determined indicate that bamboo can successfully compete with wood in diverse applications.

Though not investigated in this research it can be assumed that bamboo can be employed for production of biocomposites and could address applications where other materials from non-renewable resources such as concrete, plastics and metals (aluminium, steel) are employed [7].

To conclude, bamboo represents a fast growing renewable resource and its intelligent utilisation can serve sustainability. Further research is required on other bamboo properties, cost-effective technologies and resource management, for this purpose.



a

b

c

Fig. 10. *The compression strength parallel to the grain (a. – experimental results, type of fracture for internode area (b) and node area (c)*

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