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BAMBOO – A CHALLENGING MATERIAL FOR ROMANIAN ENGINEERS
Part 1. Understanding the material

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Abstract: *The present paper is a part of an extensive study related to bamboo as a species with a great potential in wood industry, sustainable and eco-friendly. The study presents some anatomical, physical and mechanical properties of bamboo. The data were collected from the literature and compared with data for the most harvested Romanian species. The results are interesting and will open new paths for the research of this material.*

Key words: *Bamboo, anatomy, physical properties, mechanical properties.*

1. Introduction

Bamboo is an invaluable natural resource that has awakened an ever higher interest since the 80-ies. It has an "*unrivalled position in terms of diversity, distribution and uses"* [15]. In the light of botany, bamboos belong to *Angiosperm* group, *Monocot* subgroup. They are fast growing species, much faster than trees, each stem usually attaining its full height in one year and hardening over the following 2-5 years [9]. They naturally grow in tropical and subtropical regions where societies developed and evolved together. Eastern and South-Eastern Asia's peoples and cultures had a close association to bamboo, which became a contributor to their civilisation. From vegetarian food to houses, furniture, blowpipes and long-fibred pulp for paper making, bamboo was one of the earliest resources of existence. China is among the world's leading producers of bamboo.

In the last 20 years, peoples' concern for bamboo resources led to the formation of INBAR organisation (International Network for Bamboo & Rattan) which has the mission "*to improve the well-being of producers and users of bamboo and rattan in the context of a sustainable bamboo and rattan resource base by consolidating, coordinating and supporting strategic and adaptive research and development*" [32]. This network brings together organisations and individuals with similar goals, from countries with bamboo crops. 41 States of Asia, Africa, Latin America, North America and Oceania acceded to INBAR Establishment Agreement (Figure 1).

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Fig. 1. *Countries affiliated to INBAR [31]*

Out of the variety of bamboos, 20 species are defined as a priority for INBAR organization [33]. Not all species are appropriate for industrial uses. One of the most suitable bamboo species for manufacturing is a giant Moso Bamboo (*Phylllostachys pubescens*), originated from China.

In Romania, this material is not known very well. On the market, there are many importers that sell bamboo as sticks, posts of different diameters, parquet, furniture, decorative objects and pellets [29].

It is a distinct material that seems to be wood; yet is one of the most important *non timber* forest products in the world. Due to its macroscopic appearance comparable to wood, it is often confused with wood.

The present paper is an attempt to clarify this aspect and to summarise some anatomical, physical and mechanical properties of bamboo that are relevant in the industry sector. A short review of the literature related to bamboo vs. some usual Romanian wood species was done. Actually, the authors' effort was directed to understand this material.

3. Anatomical and physical-mechanical Properties of Bamboo

3.1. Bamboo Anatomy

Bamboos have about 1200-1500 species. Therefore, a macroscopic identification of the species according to the leaf type is very difficult to be done. Moreover, the blooming takes place after several years. Thus, the part available for identification is *culm* which represents a *jointed stem*.

Each culm segment begins and ends with a solid joint called a *node*.

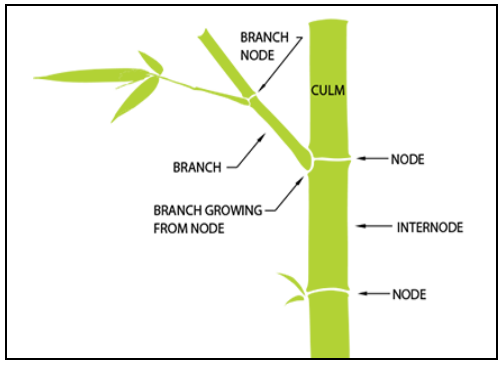


Fig. 2. *The main parts of the bamboo plant* [28]

The segments between the nodes are called *internodes*. From the nodes grow leaves and branches. Similar to the culms, the branches are also segmented with nodes and internodes (Figure 2). Aerial culms of bamboo are hollow (Figure 3a) except the node where lateral buds and leafy branches develop. Only few species have solid internodes [14]. In Figures 3b and c are illustrated these characteristics.

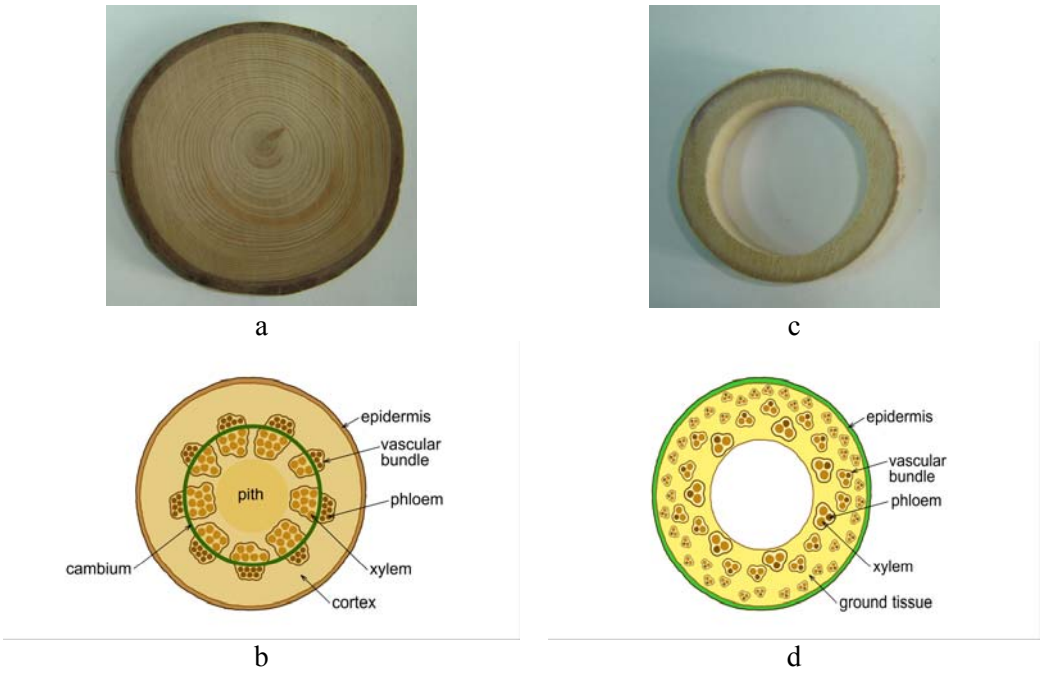
To illustrate the differences in the anatomic structure of wood and bamboo, Figure 4 is presented.

Wood and bark tissue grow in distinct, concentric annual rings, through secondary growth (Figure 4a).

A thin layer that covers the wood stem is epidermis. Between pith and epidermal layer, there is a cylinder of vascular bundles. Beneath the epidermis but outside of vascular bundles there is cortex made of parenchyma cells. The fundamental tissue that divides and generates xylem and phloem cells is cambium (Figure 4b).

a b c

Fig. 3. *Hollow stem (a) and the solid node area (b,c)*



a c

b d

Fig. 4. *General macroscopic and microscopic appearance of wood and Bamboo*

Bamboo produces only primary shoot, not secondary growth. Therefore, the anatomic structure is simpler (Figure 4c).

The stems of different bamboo species show in cross section a distinct epidermis on the outer area of cylinder, a ground tissue that contains parenchyma cells and big vascular bundles (Figure 4d). Vascular bundles are a combination of vessels and sieve tubes, with companion cells and fibers [1], [15].

The vascular system of bamboo is scattered with no particular arrangement as in case of wood, being composed of primary xylem and primary phloem tissue.

The cross appearance of the culms shows an outer area more dense and lignified, due to vascular bundles which are smaller and more numerous and the inner area where the vascular bundles are bigger and less numerous.

Few macroscopic and microscopic differences between bamboo and wood are presented in Table 1.

In the last 20 years, bamboo species from China, Singapore, India, Philippines and other countries were studied and identified according to multiple criteria [25]. Variation among bamboo species exists even if bamboo species are not so heterogeneous and numerous as wood species.

There are many studies based on light microscopy, digital image processing and pattern recognition techniques, SEM, TEM, that have simplified the bamboo identification [6], [11], [13], [15], [16], [20] and [23]. Moreover, similarly to wood, bamboo can be identified using *generic keys according to vascular bundles morphology* [25].

3.2. Physical and Mechanical Properties

The utilisation of bamboo is correlated with the properties of the culms. The different physical and mechanical properties in relation to their anatomical characteristics lead to establishing their suitability for various uses: construction applications, composites, design and furniture, etc. [3], [7] and [21].

A review of the properties mentioned in literature [1-26], [30] was done. The data are comparatively presented with the most harvested and used species in Romania.

Table 1

Macroscopic and microscopic characteristics of Bamboo vs. wood – data collected from the literature [2, 15]

<table>
<tr><th>Bamboo</th><th colspan="2">Wood</th></tr>
<tr><td>Hollow stem with internodes</td><td colspan="2">Solid stem</td></tr>
<tr><td>Only primary growth - No annual rings</td><td colspan="2">Secondary growth - concentric annual rings</td></tr>
<tr><td>No vascular cambium</td><td colspan="2">Vascular cambium</td></tr>
<tr><td>No radial cell elements</td><td colspan="2">Radial cells</td></tr>
<tr><td rowspan="7">Proportion of cells [15]
Parenchyma cells 52%
Fibers 40%
Conducting tissues (vessels, sieve tubes companion cells) 8%</td><td colspan="2">Proportion of cells [2]</td></tr>
<tr><td>Resinous</td><td>Hardwoods</td></tr>
<tr><td>Tracheids 87-96%</td><td>-</td></tr>
<tr><td>-</td><td>Vessels 2-65%</td></tr>
<tr><td>-</td><td>Fibers 13-80%</td></tr>
<tr><td>Parenchyma cells 2%</td><td>Parenchyma cells 2-75%</td></tr>
<tr><td>Rays 4-12%</td><td>Rays 1.2-50%</td></tr>
<tr><td>Resin canals 0-1.1%</td><td></td></tr>
</table>

Forest distribution in Romania indicates as preponderant species: the resinous, represented by spruce (*Picea abies* L. Karst.) and fir (*Abies alba* Mill.); the broadleaf, represented by beech (*Fagus sylvatica* L.), oak (*Quercus robur* L.) and other species, among which poplars (*Poplar spp*.) play an important role. The forest production cycle is 10-40 (60) years for young forests and 80-160 years for mature forests [24]. Conversely, bamboo can be harvested in less than 10 years [1], [6]. As a result, bamboo is managed as an agricultural crop (Figure 5).

Studies focused on physical [4], [14], [25] or mechanical properties [6], [10], [12] [14] [16-19], have shown interesting results. All authors have underlined the importance and potential of bamboo species for industry, as well as its competitiveness with other materials as wood, concrete or steel [22], [25].

For Romanian wood engineers, it is important to know some basic physical and mechanical properties of bamboo, to decide where bamboo can be placed as potential species for industrial uses, and whether the use of this material is economically efficient and opportune.

As a result, a few properties of bamboo are presented in Table 2, so as to better understand and compare them with those of indigenous species. The data for wood species are presented as a value range, and were selected from the Romanian literature [5], [8]. The specific gravity (ϱ_0) is expressed for oven-dry wood and mechanical properties are given for an equilibrium moisture content of 12%.

Considering the bamboo vs. the Romanian species, it can be assumed that the above-mentioned properties are generally comparable with the resinous species except the bending strength that is comparable with hardwoods.

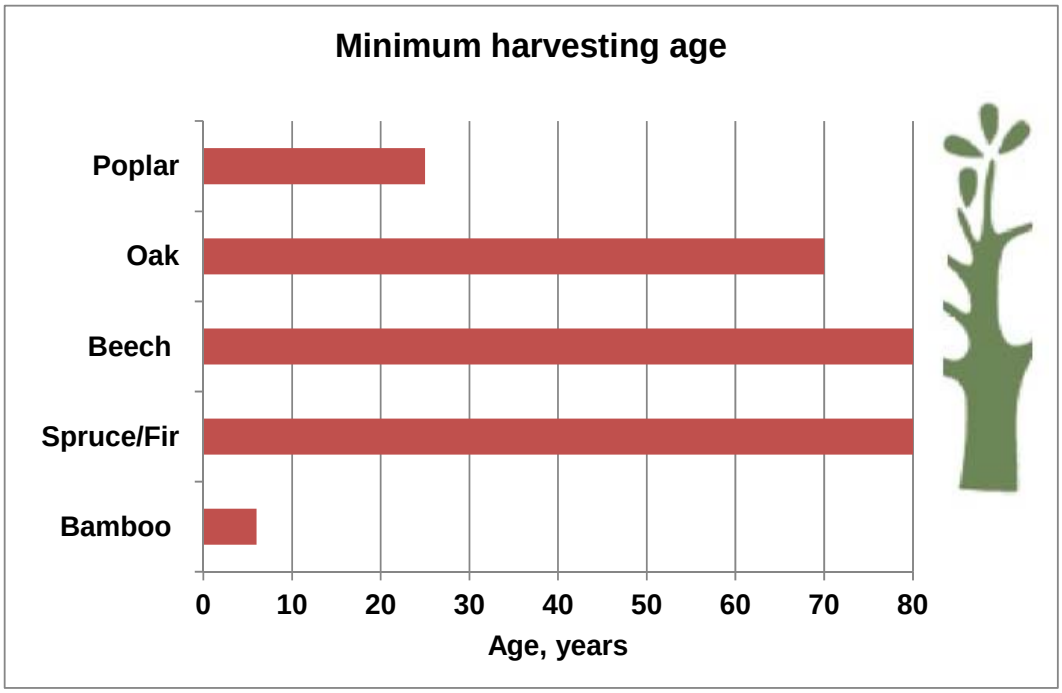


Fig. 5. *Harvesting age of Bamboo vs. some important Romanian species*

Table 2

Few physical and mechanical properties of Bamboo vs. Romanian species [3],[5],[8],[25]

Species	Specific gravity, ϱ_0 [g/cm^3]	Volume Shrinkage, βv [%]	Bending strength, [N/mm^2]	Compression parallel to the grain [N/mm^2]	Shear strength, [N/mm^2]
Fir (*Abies alba*)	0.400-0.500	10-12.5	65-85	45-60	<6.5
Spruce (*Picea abies*)	0.400-0.500	10-12.5	65-85	45-60	6-9
Beech (*Fagus sylvatica*)	0.650-0.800	15.5-18	110-140	60-80	6.5-9
Oak (*Quercus robur*)	0.650-0.800	10-12.5	60-80	85-110	11-14
Poplar *(Populus spp.)*	0.400-0.500	12.5-15.5	65	30-45	6.5-9
Bamboos**	0.500-0.550 0.700-0.900	11-13 (thickness) 6-7 (width)	130-200-270 270 (Outer part) 144 (Inner part)	36-45-60-80	8-11

Note: ** Data for bamboos are given as a value range for many species [3], [25]

As a result, the large utilisation of bamboo as building material is well justified. Its bending strength varies considerably between different species and the values are dispersed. Liese asserted that *the bending strength of the outer part is 2 - 3 times that of the inner part. Such difference becomes smaller with increasing height of the culm* [25].

Shear strength, compression parallel to the grain, and bending stress at proportional limit increased gradually with age and height [1].

The studied properties, in addition to other chemical and physical properties, compete as well to the utilisation of bamboo as a source of raw material for different products.

4. Arguments for and against Bamboo Utilisation

To complete the image of *what means bamboo?* a multitude of advantages were reported:

- It is one of the cheapest construction materials that combine the fast growing capacity with the properties of some hardwoods [26], [30];
- It is an alternative to timber wood as a wood substitute [25];
- All its parts can be used;
- It is strong, flexible, earthquake resistant due to its elastic properties [25].

Some disadvantages were also reported:

- Bamboo is a non-dimensional material because it is not uniform in shape and size [27];
- It is not a durable material. Generally, natural durability is 1-7 years, depending on exposure situation. It requires protective treatments [25];
- Some species can decay in green stands if are not harvested.

5. Conclusions

The present study is opportune, bamboo species not being sufficiently studied and known in Romania.

Before using bamboo, it is important to understand the material, the more so as this species is not specific for Romania.

There are sufficient arguments to investigate and promote bamboo as a species with a great potential in wood industry, sustainable and eco-friendly.

Some characteristics and properties presented in this paper, in addition to other physical properties have been tested in our

laboratories and will be presented and discussed in a second part of this paper.

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