Physical and mechanical properties of Italian bamboo culms

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Abstract

This paper presents the values of some physical and mechanical properties of bamboo culms grown in Italy and belonging to *Phyllostachys Edulis* and *Phyllostachys Viridiglaucescens* species. Specifically, the geometrical properties, the density, the moisture content, the compressive strength, the tensile strength, the bending strength and the bending modulus are analysed in accordance with the International standards. The excellent properties make the plant of bamboo a likely resource for green buildings.

1. Introduction

The classical building materials such as concrete and steel are always more frequently substituted by timber and other natural materials that are defined green materials. A novel era of intelligent consumption and optimal usage of the natural resources will characterize the next decades. In this scenario, new materials characterize the actual research, with particular reference to the materials that are sustainable and have good mechanical properties. Many investigations and results on the mechanical properties of bamboo are presented in literature (Janssen 1991; Chung et al. 2002; Ahmad et al. 2005; Ghavami et al. 2005; Yu et al. 2008; Hamdan et al. 2009; Shao et al. 2010; Aiping et al. 2012). However, those values have been calculated through scientific research tests and so the available data on the bamboo's properties have been obtained by different methods. The small number of the values obtained through universal rules could makes sceptical many architects and civil engineers about the use of this plant as building material and it does not encourage them to design civil structures with the bamboo. The scope of this paper is to show some physical and mechanical properties of the Italian bamboo and to extend the number of the experimental results in accordance with the International standards (ISO 2004).

2. Physical and mechanical properties

The culms belonging to *Phyllostachys Edulis* (called here EG) were taken from a specialized nursery in bamboo plantation situated near Genova and they were 3-5 years old. The culms belonging to

Phyllostachys Viridiglaucescens species came from forests near Lucca (called here VV) and near Roma (called here VP). The former were 4-5 years old, whereas the age of the latter is not known. The number of culms at our disposal were 25 for EG with 1500 mm length, 9 for VV with 1000 length and 20 for VP with 800 mm length. The skin's colour of EG and VP were green, while VV were from ochre to brown colour. This variance of colour from EG-VP and VV could be due to the chemical treatment (boric acid) of VV. The culms were stored in a place without sunlight for three months before tests. The temperature was between 19 °C and 23 °C and the relative humidity (R.H.) was between 80% and 95%. This high value of the R.H. would provide very safety values of the strength to design with the bamboo. The specimens for our research were taken from the part of culm between 1.0 m and 5.0 m (Figure 1).

2.1 Physical properties

In this report, the geometrical characteristics of the bamboo culms are the external diameter, the wall-thickness and the cross-section area. The values of the moisture content (MC) and the density (ρ) in bamboo culms were evaluated by taking specimens from three part of an individual culm, i.e. from the two ends of culm and from the middle. Four culms of each of the species were selected for the moisture content and the density evaluation. Therefore, the total number of the specimens for each species were 12. The moisture content and the density of each specimen were calculated by the following expressions

$$MC = \frac{(- {}_0)}{} \cdot 100 \qquad (1)$$

$$\rho = \frac{}{} \qquad (2)$$

where is the mass of the specimen, $_0$ is the mass of the dried specimen and is the volume of the specimen. These values were calculated in accordance with ISO22157-1 and ISO22157-2.

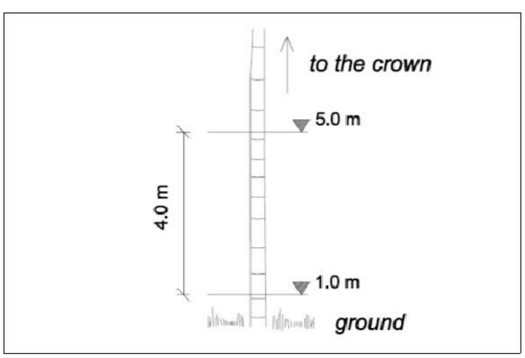


Figure 1

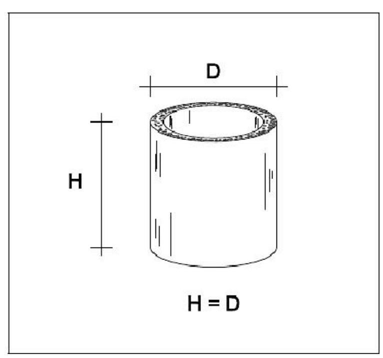


Figure 2

2.2 Mechanical properties

The compression strength ( ), the tensile strength ( ), the bending strength ( ), and the bending modulus ( ) of the bamboo culms were evaluated. Every test was carried out on a universal testing machine (*Metrocom*, capacity 600 kN) equipped with *Zwick Roell* control system (*testControl* electronics).

2.2.1 Compression strength

In this section the compressive strength is evaluated ( ) and it is referred to the longitudinal direction (parallel to the direction of the fibers). The specimens for the compression tests were 12 for each species and they were taken directly from the culm with a height ( ) equal to external diameter ( ) (Figure 2). The specimens were both with and without the node. Each specimen were placed between two steel plates that pressed both extremities of the specimen. The upper plate was equipped with a hemi-spherical bearing that provided a uniform distribution of load over the ends of the specimen. The compression tests were carried out without the intermediate layer (Teflon). The ultimate compression strength was evaluated as

$$ - \qquad (3)$$

where is the maximum load obtained from test and is the cross-section area of the specimen as specified below

$$= [\ ^2 - (\ -\ )^2] \qquad (4)$$

where and are the average radius and the average wall-thickness as specified in ISO22157-1 and ISO22157-2.

2.2.2 Tensile strength

In this section the tensile strength is evaluated ( ) and it is referred to the longitudinal direction (parallel to the direction of the fibers). The specimens for the tensile tests were 4 for each species (no tests were carried out on VP). The shape of the specimens for the tensile tests are not defined univocally in the ISO recommendations since three profiles are suggested. In our research, the form of the specimen was similar to a dog-bone shape (Figure 3). The length of the specimen was 500 mm, whereas the reduced section was 140 mm. The radius was 80 mm and the height was 30 mm. The thickness of the specimen was equal to the wall-thickness of the bamboo culm. Every specimen had a node in the reduced section (Figure 4). The ultimate tensile strength was evaluated as

(5)

where is the maximum load obtained from the test and is the cross-section area of the specimen in the reduced section.

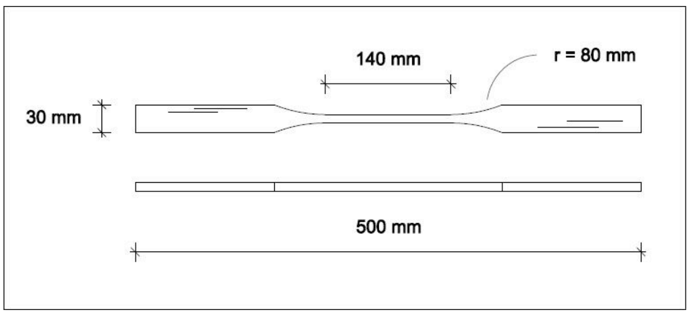


Figure 3

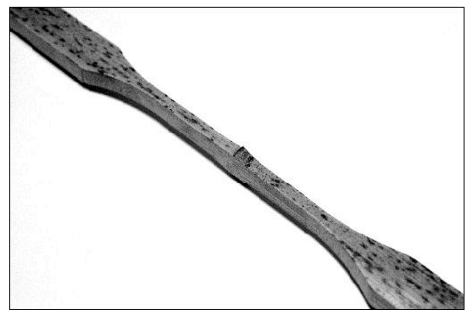


Figure 4

2.2.3 Bending strength

In this section the bending strength ( ) and the bending modulus ( ) are evaluated. The specimens for the bending tests were 12 for each species (no tests were carried out on VV and VP because they were too short for the test). They were tested by a four-point test bending (Figure 5). To avoid local crushing of the bamboo specimen during the tests, four wood saddles at the supports and at two load-points were placed (Figure 6). Furthermore, the shear strength of the cross-section was improved by hose clamps placed at the support and at load-points. The ultimate flexural stress was defined as

(6)

where is the ultimate applied load with the bending test, is the distance between the load point and the support, is the radius of the culm and is the moment of inertia of the culm as specified in the ISO standards. The bending modulus was calculated by the following expression

$$= \frac{23}{1296}\;\frac{3}{}\;\left(\frac{_{,80\%}\;\;-\;\;_{,20\%}}{_{80\%}-\;20\%}\right) \qquad (7)$$

where and are respectively the load and mid-span deflection related at 80% of , whereas $_{,20\%}$ and $_{20\%}$ are respectively the load and mid-span deflection related at 20% of .

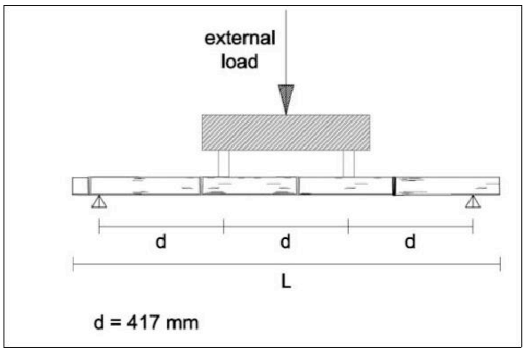


Figure 5

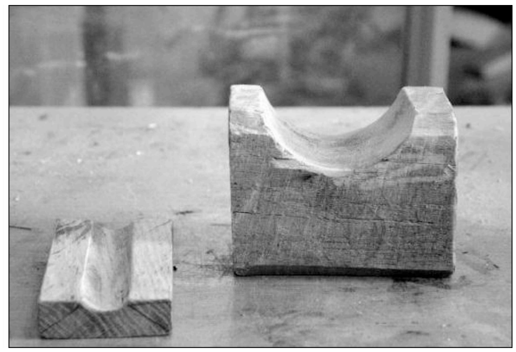


Figure 6

3. Results

3.1 Physical properties

The results of the geometrical properties, the moisture content and the density are reported in the tables below (Tables 1-3).

Table 1 - Species: *Phyllostachys Edulis* (EG)

	Max	Min	Average	St. Deviation
External diameter [mm]	89.7	61.9	74.8	6.8
Wall-thickness [mm]	10.0	5.1	7.5	1.1
Cross-section area [mm^2]	2466	915	1595	350
Moisture content [%]	65.5	26.9	43.7	12.6
Density [kg/m^3]	927.7	655.2	765.3	83.6

Table 2 - Species: *Phyllostachys Viridiglaucescens* (VV)

	Max	Min	Average	St. Deviation
External diameter [mm]	67.0	46.0	57.7	6.8
Wall-thickness [mm]	7.2	4.1	6.1	0.9

Cross-section area [mm^2]	1347	578	1001	245
Moisture content [%]	36.6	20.0	24.9	5.8
Density [kg/m^3]	-	-	-	-

Table 3 - Species: *Phyllostachys Viridiglaucescens* (VP)

	Max	Min	Average	St. Deviation
External diameter [mm]	63.1	42.4	51.4	6.5
Wall-thickness [mm]	8.9	5.2	6.8	0.8
Cross-section area [mm^2]	1489	622	958	199
Moisture content [%]	39.4	25.1	32.7	5.0
Density [kg/m^3]	880.8	755.3	804.9	39.3

3.2 Mechanical properties

The results of the compression tests, the tensile tests and the bending tests are reported in the tables below (Tables 4-6).

Table 4 - Species: *Phyllostachys Edulis* (EG)

	Max	Min	Average	St. Deviation
Compressive strength [MPa]	59.0	51.1	55.7	1.9
Tensile strength [MPa]	166.8	80.3	126.7	36.2
Bending strength [MPa]	118.4	72.1	97.3	13.6
Bending modulus [MPa]	15452	11625	13215	1116

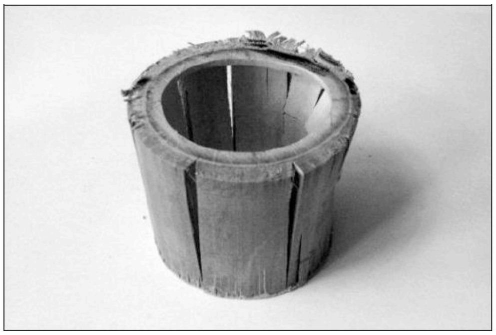
Table 5 - Species: *Phyllostachys Viridiglaucescens* (VV)

	Max	Min	Average	St. Deviation
Compressive strength [MPa]	66.2	46.4	56.8	7.6
Tensile strength [MPa]	172.0	145.4	159.0	13.0
Bending strength [MPa]	-	-	-	-
Bending modulus [MPa]	-	-	-	-

Table 6 - Species: *Phyllostachys Viridiglaucescens* (VP)

	Max	Min	Average	St. Deviation
Compressive strength [MPa]	81.2	50.2	69.3	9.1
Tensile strength [MPa]	-	-	-	-
Bending strength [MPa]	-	-	-	-
Bending modulus [MPa]	-	-	-	-

In most cases, the failure mode during the compression tests was “end-bearing” mode. Only a few cases showed “splitting” mode as failure mechanism (Figures 7-8). The node did not affect the ultimate strength of bamboo. It restricted the deformations of the specimens in directions of the plane (radially) perpendicular to the direction of the compression, i.e. the node limited the Poisson's effect on the specimens (Figure 9). During the tensile tests, the failure occurred in a brittle way on the node or close to that (Figure 10). In some specimens, the failure was determined by initial cracks in the opposite part of the skin (Figure 11). This fact depends on lesser density of the fibres in the inner part of the culm than in the outer part. During the bending tests, the failure culms was mainly characterized by a local crushing failure at the load-point (Figure 12). Some specimens showed a failure characterized by a longitudinal crack (Figure 13) or a total crushing of the culm (Figure 14). In that case, the ultimate strength was lower than the other cases.



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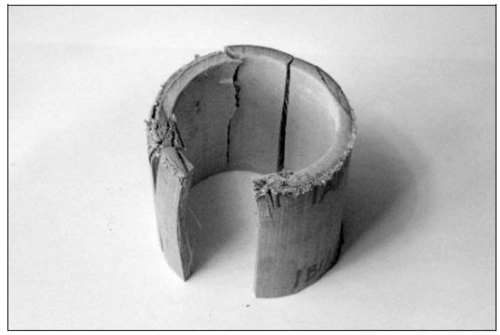
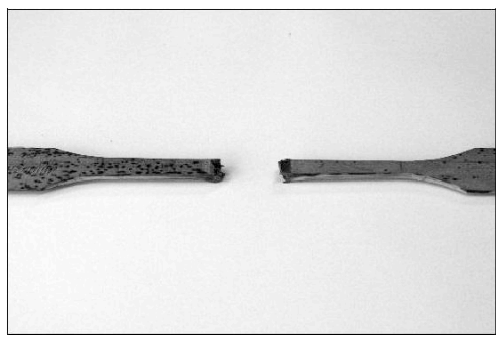


Figure 8

Figure 9



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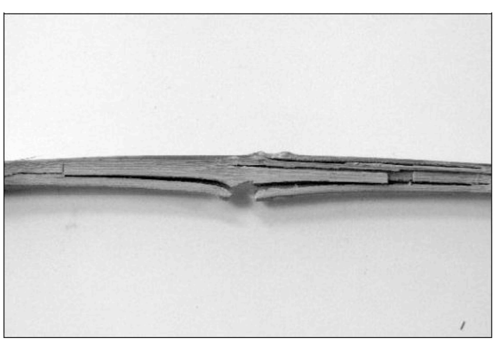
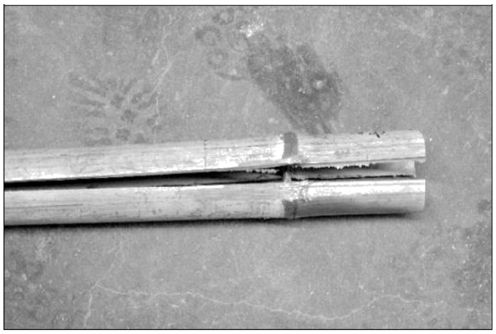


Figure 11

Figure 12



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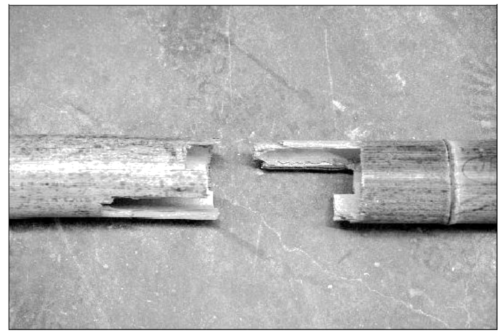

Figure 14

4. Conclusions

Our results show that the Italian bamboo can be a suitable material for building structures since its strength is comparable to the strength of the other classical building materials such as concrete and timber. We have to acknowledge that the results from our research are not enough for a real safety design with bamboo, since the mechanical behaviour of this material is not still understood completely. Then, additional tests are required for a wider knowledge of Italian bamboo's properties.

Acknowledgments

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