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Study of the Mechanical Properties of Giant Reed as a Green Building Material

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***Abstract*— In the building sector advances are being made using natural green materials for the manufacture of building elements that are environmentally friendly and sustainable. Traditionally, in this sector, local materials with low energy cost and low environmental impact were used. In the Mediterranean Countries giant reed was used as a building material until the 1960´s, being replaced afterwards by other modern materials like concrete. Nowadays, in rural areas, inhabited dwellings made with giant reed can still be found. The reeds are used for ceiling, flooring, slabs, false ceilings and walls. The aim of this study was to investigate the mechanical properties of the giant reed to provide technical data to support the utilization of this green material for sustainable building. The results showed that the giant reed behaves mechanically like a softwood structural timber, having at the same time lower thermal conductivity than wood. Thus it can be used as a sustainable building material.**

***Keywords*— Giant reed, Arundo donax, modulus of elasticity, sustainable building, low thermal conductivity.**

I. Introduction

Climate change is one of the major issues of this century. Over the last few years, the environmental and energy policies of the world´s most industrialized countries have been adressed to promote the construction of sustainable buildings, i.e. buildings that are environmentally friendly throughout their life cycle: from the choice of the construction site, to their design, from construction to management and maintenance and, finally, to their deconstruction [1,2].

Arundo donax L (giant reed) is a perennial grass species (Poaceae) that posseses hollow stems. Althought it is thought to have originated in Asia , it is also considered as a native species in the countries surrounding the Mediterranean Sea. From this area, it has become widely dispersed by man into all of the subtropical and warm-temperate areas of the world, due to its multiple uses [3]. The giant reed was used as a building material in many countries around the Mediterranean Sea [4]. In the Southeast of Spain it was used in all kind of buildings until the beginning of the twentieth century, mainly being part of the floor and ceiling slabs. Until the 1960´s giant reed was used in single-family dwellings and in livestock accommodation. The slabs of these buildings consisted in mats of culms laying on top of timber beams. To form these mats, the culms were placed in parallel and then tied two at a time facing the the thinner end of one culm with the thicker end of the other. The culms were then tied together with a rope made of esparto grass. After this, a layer of plaster mortar was used to cover the slabs and the walls of the buildings. Fig 1. shows a piece of mat formed with reeds.

Figure 1. A piece of a mat made of culms of *Arundo donax* L.

Nowadays, in rural areas, there are lots of inhabited dwellings made with this technique that remain intact through the years. Therefore the objective of this study has been to study the mechanical properties of the giant reed to provide technical data to support the utilization of this green material for sustainable building.

II. Materials and Methods

A. *Materials*

The material used was culms of giant reed. They were collected from the River Segura basin and they were left outdoors for drying during 12 months until they reached an 8% relative humidity. The average culm height was 6 m and the average culm diameter was 3 cm. The culms of giant reed are morphologically heterogeneus and consist of two botanically distinct parts: nodes and internodes. According to Shatalov and Pereira [5], the nodes are composed of a nodal diaphragm, embedded inside the hollow cylinder of the stem, and the adjacent transition regions. In order to get the most homogeneus material, samples with different lengths were cut from the culms avoiding the nodes, only internodes were used for the tests. Twenty specimens were made for the tests.

B. *Methods*

The mechanical properties measured were the bending strength, and the compression strength along the longitudinal and the transversal directions. Furthermore, the thermal conductivity of a mat of reeds was also measured.

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In order to characterise the mechanical strengths, four parameters were defined: (I) maximum stress σ_r, (II) strain at maximum stress ε_r, (III) stress at elastic limit σ_e, and (IV) strain at elastic limit ε_e. The modulus of elasticity E was then calculated applying "(1)". The modulus of elasticity is the tangent of the slope of the stress/strain curve along the elastic zone.

$$E = \sigma_e / \varepsilon_e \quad (1)$$

Modulus of elasticity, also known as Young´s Modulus, measures how a material or structure will deform and straim when placed under stress. Materials deform in a different form when loads and stresses are applied, and the relationship between stress and strain varies typically. The ability of the matter to resist or transmit stress is important, being this property often used to determine if a particular material is suitable for a specific purpose.

Compression tests were carried out on a universal testing machine (Controls S.L.R. Milan, Italy). Flexion tests were carried out on a IMAL universal testing machine (Imal, model IB 600, Modena, Italy). The length of the samples was twice their width.

The thermal conductivity was also determined using the method of the heat flow meter (EN 12667, 2001) [6].

Tests for the thermal conductivity were performed on a heat flow meter instrument (NETZSCH instruments, Inc, USA). The samples used for the latter test were mats of reeds measuring 300x300 mm, and were disposed as shown in Fig.2.

Figure 2. Sample for the thermal conductivity test.

III. Results and Discussion

The results of the mechanical tests are shown in Table I. The values of the compression strength parameters are higher in the direction of the fibres (longitudinal direction) than perpendicular to the fibres (transversal direction) as expected. These values are similar to those of woods used in construction. For example, a structural timber class D30 (hardwood) [7] has a characteristic value of bending strength (σ_r) of 30 N/mm^2; a value of compression parallel to grain (σ_r) of 8 N/mm^2; and a value of modulus of elasticity of 10,000 N/mm^2. The giant reed meets some of these requirements of class D30. The classification of softwood (conifers) goes from C14 to C30. The giant reed meets all the requirements of C14.

TABLE I. AVERAGE RESULTS OF THE PROPERTIES TESTED OF GIANT REED

The average value of thermal conductivity of the mats of giant reed was 0.0733 W/mK. This value is in accordance with those of commercial insulating materials from renewable vegetable resources as it can be deduced from Table II. Structural timber has a thermal conductivity value of 0.12 W/mK. It can be concluded that the giant reed is a good insulating material.

Test	E [N/mm^2]	σ_e [N/mm^2]	ε_e	σ_r [N/mm^2]	ε_r
Compression Longitudinal axis	6,290	39.25 (4.74)	0.0062 (0.0049)	52.28 (4.84)	0.018 (0.005)
Compression Transversal axis	289	4,821 (0.41)	0.0167 (0.0063)	6.03 (1.15)	0.031 (0.012)
Flexion (bending)	13,252	35.78 (1.73)	0.0027 (0.0002)	74.68 (17.07)	0.006 (0.002)

TABLE II. AVERAGE RESULTS OF THE PROPERTIES TESTED OF GIANT REED

Materials	Thermal Conductivity W/mK	Source
Mats of reeds (Arundo donax L.)	0.069-0.077	Present study
Particleboard made of Washingtonia robusta palm tree	0.075-0.090	García-Ortuño et al (2011) [8]
Insulating board of bagasse	0.049-0.055	Panyakaew and Fotios (2011) [9]
Insulating board made of Kenaf	0.051-0.058	Xu et al. (2004) [10]
Insulating board made of cotton stalks	0.058-0.081	Zhou et al. (2010) [11]

IV. Conclusions

The mechanical properties achieved by the giant reed under stress make this green material suitable for its use in construction. It can be classified as C14 (strength classification for softwood) reaching also some of the requirements for D30 (Hardwood). It can be used for sustainable building and eco-housing, and to refurbish buildings made with reeds, were concrete slabs would overload the structures.

The giant reed is a good insulation material, similar to insulating boards made from agro-residues and better than wood.

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