Thermal conductivity of bamboo (*Guadua velutina*) in earthen construction of sustainable structures

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***Abstract*— It is important to enhance the use of natural materials in building construction to help environmental conservation while improving internal conditions of spaces inhabited by people according to the climate they live in. Earth construction helps to reduce impact in the area surrounding construction. However, it requires some plastered or natural cover which must be thermally isolating and effective. This paper describes the thermal results achieved using the species of bamboo *Guadua velutina* in construction. It shows that this material has a low thermal conductivity and a thermal model application to describe its behaviour is proposed. Some considerations are presented for the design and use of bamboo in earthen architecture, when used with other materials such as concrete and cemented bahareque to obtain a comfortable thermal construction.**

***Index Terms*—Earthen construction, thermal conductivity of bamboo, sustainable structures.**

I. Introduction

One of the main functions of living spaces is to provide indoor environments that are comfortable thermally for people. Understanding the needs of human beings and basic conditions that define comfort are essential for the design of buildings where users satisfy their comfort requirements with a minimum of mechanical equipment [1-4]. A suitable temperature is expressed by user satisfaction. The vertical elements in buildings produced with hearth base are now being re-explored as ecological techniques using natural materials are explored. Some examples of these techniques are rammed earth, compressed earth bricks and poured earth. Sometimes some natural reinforcement such as fibers or polymers from plants are used to improve compressed mechanical resistance. A bamboo specie: *Guadua velutina* is playing an important role because of its strength and structural advantages [6-7].

Generally, bamboo is constituted by longitudinal fibers in internodes and entangled fibers in its nodes that provide excellent resistance to various mechanical stresses. In
Mexico, bamboo can be found endemic or introduced and is easily cultivated. Unlike slow-growing trees, bamboo reaches its maximum height of from 10 to 15m with a diameter of 10 to 20 cm (in some species) in 4 to 6 months. It obtains adequate strength for construction use at 5 years and is a structure permanent crop, i.e. with no necessity to replant [2] This paper presents the experimental and theoretical results for *Guadua velutina* as a construction material and some considerations for its use and design in earthen architecture and cemented bahareque.

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II. Experimental Design

For the experimental design, bamboo specimens were cut with height equal to two diameters and they were covered with expanded polystyrene. As can be seen in Figure 1, holes were made in the bamboo specimens at different heights. The specimens were placed in a sand-bed electric heating system which had a temperature >60 ° C. Temperature was registered with infrared devices and recorded over time. The accuracy of the infrared sensors is ± 0.1 ° C
The average size of bamboo pieces was measured with a digital vernier with a precision of 0.10mm. Results were coupled to the theoretical model developed in [3], and normalized statistically.

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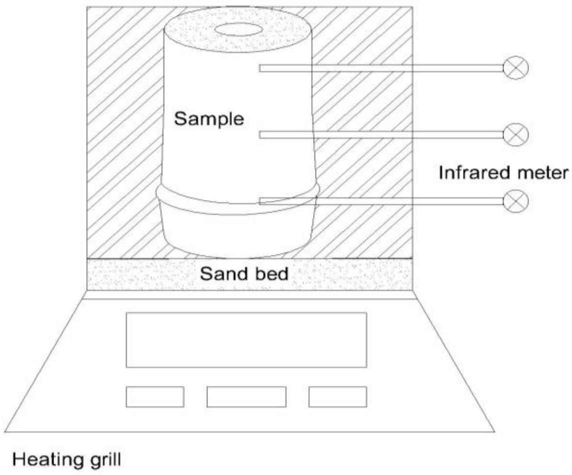

Figure 1. An experimental design according to [3].

III. Results and Discussion

Thermal models are important because they allow us to know specific characterization in design comfort, so that it is possible to propose some correlations that characterize materials [8,9].

Figure 2 shows the experimental results. It is observed that the temperature does not change significantly over time. The number at the end of each line shows distance in centimeters for the corresponding registered temperature

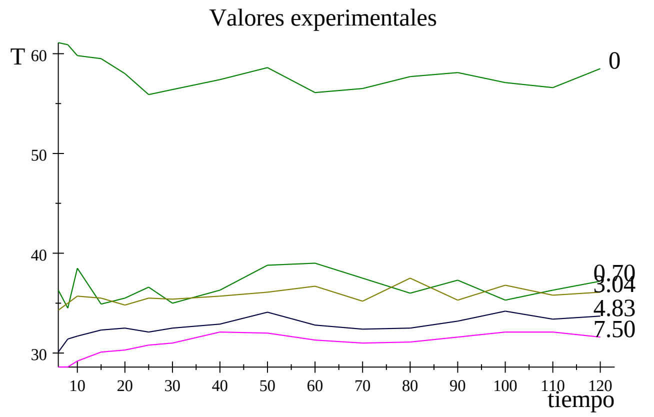

Figure 2. Experimental results obtained

Although temperature of the sand bed was about 60°C, a temperature of more than 20°C lower was observed at the next point registered.

All the results show a low slope which is not similar to other materials such as concrete, where the analysis of temperature over distance shows a curve that increases over time to stabilization. The results in all parts of the samples are similar, so that differences are not found between nodes or in the top or bottom of the pieces.

From the observed experimental results, a statistical model based on the method of Marquardt non-linear regression is proposed, yielding: [12]

$$T = 38.092 + 1.139\exp(-0.004t)\left(15.836 - 3.447x\exp\left(-0.093\left(\frac{x^2 - 46.735}{t}\right)\right)\right)$$

For a value of R^2 of 58.5289%.

These results show that thermal behavior of *Guadua velutina* does not change significantly over time.

Figure 3 shows behavior observed vs predicted results. It can be appreciated that results are agglomerated in some spaces, making it possible to reproduce the results in a better way at low temperatures. Mathematically, it is possible to predict changes of temperature over time for the species of bamboo analyzed in this work.

From the obtained model, parameters characterizing heat transfer are estimated. In this case we obtain:

$$\beta = \frac{U}{\rho C_p}$$

$$= 0.00486225\,\text{min}^{-1}$$

the adjusted statistical model has:

$$\frac{1}{4\alpha} = 0.0936645$$

From which is obtained the α value, so that:

$$\alpha = \frac{\kappa}{\rho C_p}$$

$$= 2.6691\frac{\text{min}}{\text{m}^2}$$

α and β are the characteristic parameters of thermal diffusivity.

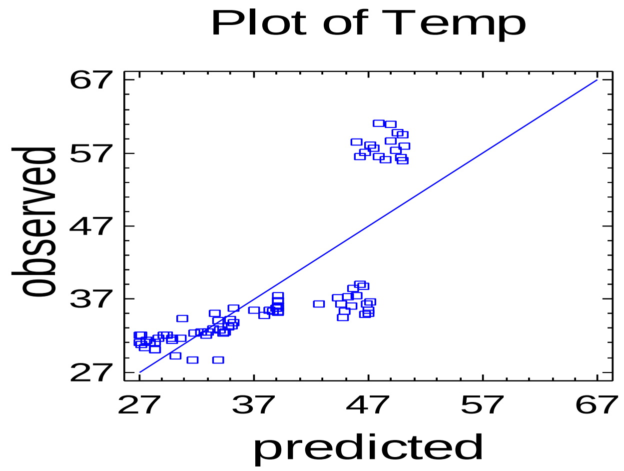

Figure 3. Experimental results against predicted

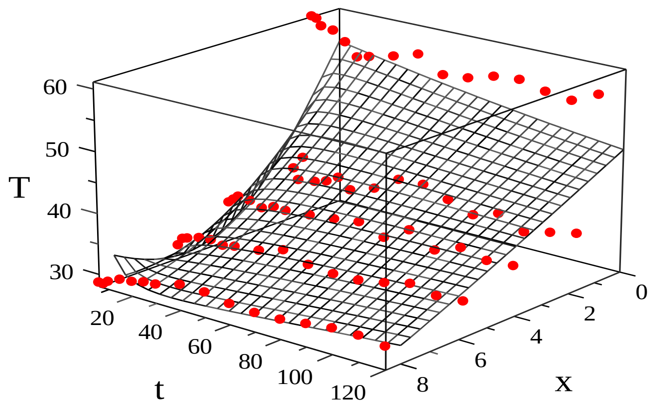

Figure 4. Comparison of the results obtained experimentally (points) and modeling (mesh)

This study compares bamboo to values found for other materials in the literature. The value found is below that reported in the literature and can be found in [3].

As is shown, the bamboo analyzed has a low thermal conductivity by a low thermal diffusivity, so it is possible to combine this bamboo species with other materials. Results with other species of bamboo used in a homogeneous mix with other solids, are presented in [10] and [11]. As it is presented in [12] we can use some materials separately. Here, a physical combination of both bamboo and soil for use in structures is presented.

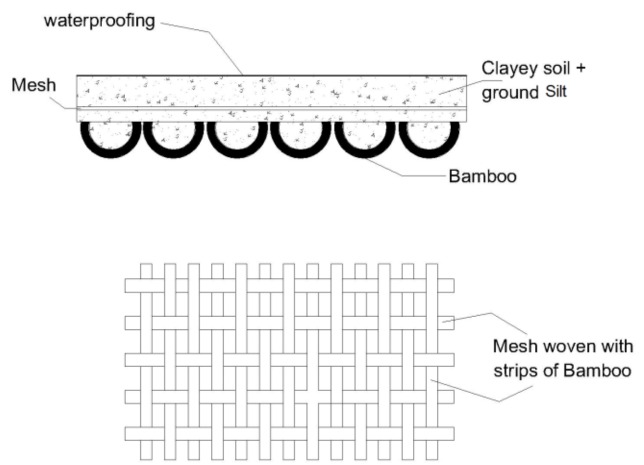

Figure 5. Proposed *Guadua velutina* slab

Figure 5 shows the placement of bamboo cut in half so that it has more grip. The outer side can be exposed to the sun, increasing temperature and, although a temperature increase must exist, it is stopped by the bamboo pieces. Reinforcement of the slab is necessary, which can be done by working with a mesh made with woven bamboo compressed between clay soil + silty soil. This mesh is made with strips obtained from the same rods of bamboo and intertwined in both directions to resist thermal contraction.

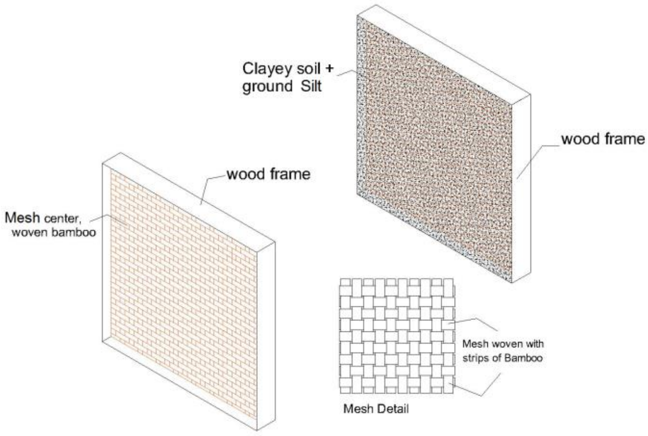

Figure 6. Proposed Guadua velutina wall.

Figure 6 presents a proposal to utilize *Guadua velutina* in walls, where a main structure or timber frame timber based on that observed above is used. A woven center mesh made from strips of bamboo would be placed so that space between strips is as minimal as possible. Filling the space or margin with clay soil + silty soil gives the frame or wooden structure an aesthetically uniform way to sustain both sides of that wall.

IV. CONCLUSION

It was found that the test species has low thermal diffusivity compared to other materials reported in the literature. The excellent mechanical properties of bamboo presented by other authors, together with the results obtained in this study, reinforce the integration of this material as part of sustainable building systems.

This study not only analyzed Guadua velutina from the perspective of structural safety, but from that of thermal comfort, which is a valuable feature in structural materials.

ACKNOWLEDGMENT

Special thanks to Hokmot Labs for their help in experimental part. Special thanks to Pedro Flores Becerra for help in experimental design and Lic. Lynda Kay Deckard Ramos for help with editing of this paper.

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