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Assessment of fire reaction and fire resistance of *Guadua angustifolia kunth* bamboo

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ABSTRACT

The main challenge for construction industry today is sustainability. Bamboo has properties that make it sustainable, but its fire behavior remains unknown. This paper presents an exploratory research on fire behavior of *Guadua angustifolia kunth* (*a.k.*) bamboo. Fire reaction was assessed through critical heat flux for ignition and flame spread while fire resistance through charring rate and strength variation with temperature. Fire reaction fall within standard limits used for structural woods, while fire resistance results are higher than that of plywood. Based on these preliminary results, *Guadua a.k.* would be adequate as structural and indoor finishing building material.

1. Introduction

Bamboo is probably one of the oldest and most versatile construction materials that has been used for more than 2000 years in Japan and China. Its high resistance-to-weight ratio, high renewability rate and wide availability [1], in addition to its low impact on the environment compared to other construction materials, turns bamboo into an excellent construction material. Today, bamboo is increasingly used for construction of minor structures, mainly in some countries in Latin-America and Asia.

Guadua angustifolia kunth (*Guadua a.k.*) is the largest bamboo in American and the third largest worldwide. Besides its large size *Guadua a.k.* is characterized by a high growth rate reaching its maximum strength after 3–4 years [2]. Moreover, *Guadua a.k.* contributes to capture carbon dioxide (CO_2) and releases oxygen like trees. Bamboo capture 40 times (per square meter per year) more CO_2 pine trees [3], which is a desirable characteristic for reducing the greenhouse effect. Consequently, *Guadua a.k.* becomes a promising construction material to be considered for sustainable development.

In spite of the aforementioned advantages of *Guadua a.k.*, its natural round shape presents irregularities in the transverse section, and its composition is not homogenous alongside culm, thus limiting its use in structures with long spans and heavy loads [4]. In order to overcome this limitation, glued laminated *Guadua* (GLG) has been developed and its mechanical properties prove to be as good as the engineered woods used in building construction [4]. Therefore, *Guadua* becomes a multipurpose material in construction works, either in its round or laminated form, for different applications as structural elements (wall panels, beams and columns), or as architectural finish (wood flooring, wall indoor veneer panels).

Even though *Guadua a.k.* is regarded as an excellent alternative material in construction, the lack of knowledge and understanding on its fire behavior may become a barrier for its mass use in structures. Similarly to some other forest species, *Guadua a.k.* is a combustible material, which faced to a certain amount of heat, generates gases derived from its chemical breakdown or pyrolysis. This phenomenon causes mass loss and reduction in strength [5]. Under such conditions, structures built with *Guadua a.k.* may become unstable, prone to collapse or jeopardize people safety. Consequently, proper characterization of *Guadua a.k.'s* fire behavior is essential to predict its response, so it can be adequately considered during design.

To the best of the authorś knowledge, there are no published results on bamboo fire behavior. This research presents for the first time a characterization of round and glued laminated *Guadua a.k.* fire behavior by means of a study focused on two aspects of material behavior: (1) fire reaction and (2) fire resistance. Fire reaction is associated to elements used for finishes and describes the ease with which a material can be ignited and spread fire under specific conditions [6]. Fire resistance involves structural elements and describes how an element is able to maintain its sealing and isolation capacity and/or structural resistance under fire conditions [7]. In order to properly analyze the experimental results, further comparisons were established between the fire behavior of round and glue laminated *Guadua a.k.* with plywood made of Radiata pine.

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2. Materials and methods

2.1. Guadua

A giant bamboo species called *Guadua angustifolia kunth,* native from Colombia (South America) was used in this research. Its botanical classification places it within *Poaceae* family, *Bambusoideae* subfamily, *Bambuseae* tribe, *Guaduinae* sub-tribe and *Guadua* gender. *Guadua* is one of the most important bamboo native genders in tropical America. It can be found from the south of United States down to the north of Chile and Argentina [3]. The main parts of the *Guadua a.k.* are shown in Fig. 1. Its hollow culm may reach up to 30 m in height and its wall thickness varies between 0.8 and 2.0 cm. The culm is divided into nodes, generating intermodal zones ranging from 10 up to 40 cm. The *Guadua a.k.* diameter vary widely; in the bulkier parts (bottom section), it can range from 10 to 18 cm while in the thinner parts (top section), it can range from 5 to 10 cm. Cepa (bottom), Basa (middle) and Sobrebasa (top) are used in the construction of the structures since its wall thickness and outside diameter are the most appropriate from the strength point of view [2].

The typical anatomical structure of bamboo, which is composed by parenchyma tissue, fibers and sieve tubes, is shown in Fig. 2. It is estimated that 51% by volume corresponds to parenchyma tissue, 40% to fibers, and 9% to sieve tubes [8]. Such distribution becomes relevant since fibers improve the mechanical properties of bamboo. In addition, the percentage of fibers is not uniformly distributed through the wall thickness, but decreases from the external to the internal zone; consequently the Parenchyma percentage at the internal zone is higher than the external zone. Physical characterization of *Guadua a.k.* [3] indicates that round *Guadua a.k.* has a density of 700 kg/m^3; whereas, laminated *Guadua a.k.* (GLG) has a density of 715 kg/m^3. Mechanical properties of round *Guadua a.k.* and GLG are shown in Table 1.

The current research focussed on round *Guadua a.k.* (Fig. 3a) as well as GLG (Fig. 3c) for different applications in construction. Due to requirements of some of the tests to be conducted, round *Guadua a.k.* shall be fitted into a panel, but keeping round surface characteristics (Fig. 3b). The panel was elaborated from longitudinal pieces of culm cut and glued in such a way they meet required dimensions. Consequently, round *Guadua a.k.* and GLG test specimens used in study are shown in Fig. 3b and c, respectively.

The fabrication process of laminated *Guadua a.k.* is divided into two steps: (1) elaboration of sheets and (2) elaboration of boards which are schematically shown in Fig. 4. The elaboration of sheets consists of cutting longitudinally culms of 1–1.5 m in length into eight slices. The slices are then passed through a grinding machine to remove the inner and outer layers and then dried in an oven. Dried slices are then further ground to flatten their surfaces and, then, impregnated with an adhesive resin (melamine–urea–formaldehyde) along the narrow faces and assembled to form *Guadua* sheeting. Once the bamboo sheets are finished, they are glued together on the wide faces in order to form boards in a hot press. Details of fabrication process can be found elsewhere [9].

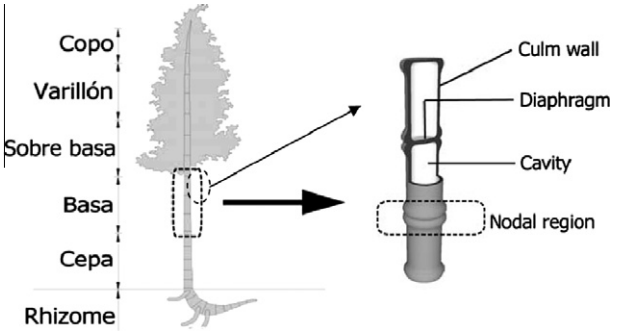

Fig. 1. Main parts of *Guadua a.k.* bamboo [3].

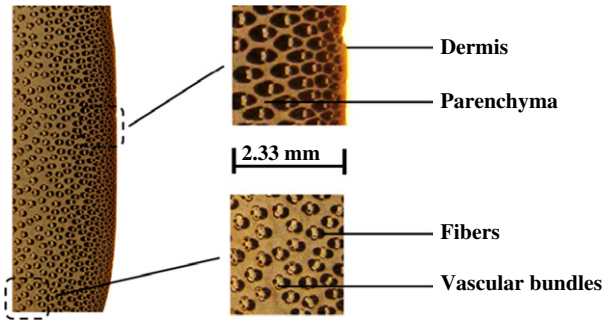

Fig. 2. Anatomical Structure of *Guadua a.k.* bamboo.

Table 1
Mechanical properties of round *Guadua a.k.* and GLG [3].

Mechanical properties in (MPa)	Round *Guadua a.k.*	GLG
Compression parallel to grain	18	48
Tension parallel to grain	63	132
Shear parallel to grain	7.5	9.4
Bending strength	49	87

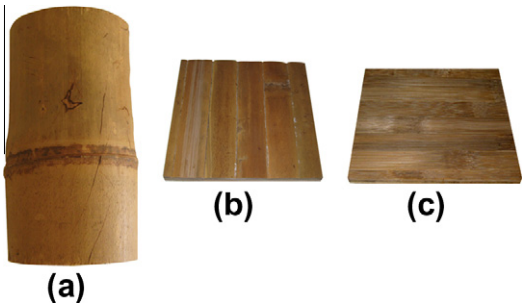

Fig. 3. (a) Round *Guadua a.k.* culm, (b) Round *Guadua a.k.* panel, and (c) GLG panel.

2.2. Experimental approach

Fire reaction was studied based on fire ignition and flame spread. Such parameters allow understanding of the way a material contributes to its own pyrolysis and spreads the fire. In addition, fire resistance was studied based on charring behavior and flexural strength at high temperatures. Although fire resistance is defined for assemblies, this paper focuses on the material's level. Both fire reaction and fire resistance help to understand the capacity of structural elements during fire.

Besides round *Guadua a.k.* and GLG, plywood made out of Radiata pine tree was also investigated. Plywood, a widely used material in construction, provides a reference material to analyze *Guaduás* behavior under the same test conditions, considered very useful due to the exploratory nature of this investigation. All test conducted in this study are shown in Table 2 and comparisons with plywood were developed for each of the parameters under study.

2.2.1. Ignition

A wood element exposed to fire develops chemical decomposition processes that facilitate gas emissions and charring of the exposed surface. Gases emanating from the surface are likely to turn into flames; thus, generating an ignition phenomenon [10]. Flame spread is especially dangerous when the material is used for indoor finish or for lining applications in a given structure because it represents an immediate danger for occupants and contributes to the spreading of fire in a room. In order to characterize a material from an ignition point of view, ASTM E1321 [11] suggests to determine the ignition critical flux that corresponds to the heat flux below which ignition does not take place [12]. The critical heat flux (also known as the lower thermal load per unit area) is obtained by exposing the material to a constant heat flux and determining the relation between heat flux received by the material surface and the time before ignition takes place. This procedure considers the use of a LIFT device (Lateral Ignition and Flame spread Test), which provides the heat flux received by material surface. The test specimen sizes were 155 mm in length, 155 mm in width, and 9 mm in thickness.

2.2.2. Flame spread

Flame spreads along the surface of the material affecting the whole element. Flame spread consists of the horizontal displacement of a flame due to the inherent combustibility of forestry elements which is a relevant factor for fire spread in buildings [12]. Fire spread rate will depend on the heating rate at the material surface and on the contribution of the own material to the combustion process. Faster flame propagation will take place on those materials with lower thermal inertia (i.e., materials that heat rapidly), which are also the most likely to develop an ignition phenomena [13]. Thus, materials with low critical flux generate higher risk situations for occupants than materials with higher critical flux to spread a flame. The fire spread rate for *Guadua a.k.* was determined using the LIFT device as required by ASTM E1321 [11]. The test specimen sizes were 800 mm in length, 155 mm in width, and 9 mm in thickness.