

Artículo de investigación

COMPRESSION RESISTANCE AND SHEAR STRENGTH OF *Guadua angustifolia* CULMS AFTER DRILLING OF THE NODE DIAPHRAGM**Resistencia a la compresión y al corte de culmos de *Guadua angustifolia* después de la perforación del diafragma del nudo****Titulo Corto: Culm strength and diafragm – Resistencia del culmo y diafragma**

Keywords: Absorption, bamboo, boron and boric acid, commercial culms, maturity, preservation, moisture content.

Palabras clave: absorción, bambú, boro y ácido bórico, culmos comerciales, preservación, madurez, humedad.

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ABSTRACT

The preservation of guadua (*Guadua angustifolia*) culms is an important process which affects their quality after harvesting and their subsequent utilization as a raw material in handicraft, furniture and construction. Boron and boric acid are frequently used in the preserving solution (PS). To ease the adsorption the culm diaphragm is usually drilled before immersion in the PS. We performed a factorial experiment to determine the possible effects of drilling the culm diaphragm on compression and shear strength. Two measures of culm maturity were considered. The traditional measure is defined by the external features of the culms and another is based on the time since culm emergence. Variance analyses did not show any significant ($p > 0.05$) difference in mechanical properties when the diaphragm was drilled. Nevertheless, those culms with maturity defined using the traditional approach had significantly lower values of compression and shear strength. In addition, culms with higher moisture content were significantly stronger.

RESUMEN

La preservación de culmos de guadua (*Guadua angustifolia*) es un proceso fundamental que contribuye a garantizar su calidad de estos cuando

luego de ser cosechados son usados en distintas aplicaciones como muebles, artesanías y especialmente estructuras. El uso de boro y ácido bórico, es una de las prácticas más comunes para preparar soluciones preservantes. Para facilitar la absorción de la solución preservante durante la inmersión, el diafragma de los culmos es perforado. En este estudio, mediante un experimento factorial, se evaluó el posible efecto que puede tener la perforación del diafragma en la resistencia al corte y a la compresión de los culmos. Adicionalmente, su madurez fue incluida como otro factor, considerando dos formas de definirla: el método tradicional, a partir de características externas, y otro, mediante la selección de culmos marcados previamente (hace 4 años) al momento de haber emergido del suelo. Los análisis de varianza no mostraron ningún efecto o cambio significativo ($p > 0.05$) en las propiedades mecánicas evaluadas, cuando se evaluaron culmos perforados y no perforados. No obstante, aquellos cuya madurez fue definida mediante el método tradicional mostraron en promedio menor resistencia al corte y a la compresión que los previamente marcados. Por otro lado, la humedad de las probetas mostró un efecto significativo ($p < 0.05$) cuando fue incluida en el modelo de análisis de varianza como covariable y valores más altos de esta variable se asociaron a mayor resistencia de los culmos.

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INTRODUCTION

About 1200 of bamboo species distributed around the world has been identify (Lobovikov *et al.*, 2005). Some of them are successfully employed for obtaining raw material for different application such as furniture, housing, handicraft (Londoño, 1998) and also mainly in Asia, bamboo species edible are an important source of incomes for rural communities (ie. Bhatt *et al.*, 2003).

The species *Guadua angustifolia* Kunth (guadua) is a woody bamboo naturally distributed at north of South America and part of Central America (Panama, Costa Rica) and introduced to Mexico, Guatemala and Honduras (Londoño, 1998). This specie is widely utilized for structural application due to high strength and dendrometric attributes (ie. culm diameter and culm length), in fact guadua houses, bridges and roofs for rural housing are worldwide recognized. Therefore this bamboo species can be used for structural applications (Takeuchi *et al.*, 2009; Correal & Arbeláez, 2010).

As a significant step of the preindustrial process, bamboo culms must be treated with preserving solutions in order to avoid the insect attacks (Morales & Tistl, 2007). A validated method, even accepted in the framework of forest certification by the Forest Stewardship Council (FSC) is the use of boron and boric acid solution. This solution has resulted effective for avoiding the attack on insect when culms are employed in structures (Morales & Tistl, 2007), when other procedures such drying and the selection of mature culms have been properly carried out. However, to guarantee the absorption of the preserving solution the diaphragm of the node, the membrane between the internodes is usually drilling. The anatomical structure and mechanical properties of the culm internode are relatively well studied, nevertheless fewer details are available of the culm node Lybeer *et al.* (2006).

In bamboo culms elongated, the node may support the bending forces Niklas (1998), which is evidenced in the diameter and the chemical composition (Lybeer *et al.*, 2006). Although Liese (1998) mentioned the probable influence of diaphragm on bending behavior, Gonzalez *et al.*, (2008), did not find

any effect of the lack of culm diaphragm when the compression strength was assessed. On the other hand, Rusinque & Takeuchi (2007) found a decreasing on bending when the diaphragm was drilled.

According to the experiences above referenced and additionally considering the maturity of culms as a factor that might influence their strength, the aim of this paper was to assess the behavior of compression and shear strength of the culms after drilling their diaphragm and when their maturity was defined by different approaches.

MATERIALS AND METHODS

AREA OF STUDY

The bamboo forest of guadua where the samples were collected are located in the farm Yarima in Pereira, Colombia, at 1150 masl with an annual rainfall of 2500 mm per year on average and mean temperature of 22 °C. The soils are mainly Alfisols, with higher bases saturation (over 30%), sometimes limited by a layer of clay between 0.6 and 100 cmm of depth and on a undulating topography.

In Yarima farm the bamboo forests of guadua have a total surface of 26 ha, with an average density of 5 100 culms per ha, average culm diameter of 12 cm and a total length of 22 m. These forests have been commercially harvested since 1950 and currently are certified by FSC. The reason of working with culms from only one farm was to avoid the probably effect of site conditions on the variables analyzed (Camarago, 2006). Besides, this area may be considered as representative of the farms which are doing additionally treatments of preservation to the commercial culms.

EXPERIMENTAL DESIGN, SAMPLING AND ASSESSMENT OF MECHANICAL PROPERTIES

A factorial experiment 2² was defined, with two factors and two levels. The factors were the maturity of the culms (traditional method and known maturity) and the drilling of the diaphragm of the



Figure 1. Samples test



Figure 2. Mature culm with lichens



Figure 3. Labelling culms according the stages of maturity



Figure 4. Drilling of culm diaphragm

node (drilled and undrilled). The response variables were the shear strength τ_{ult} (MPa) and the compression strength σ_{ult} (MPa) of the culms.

For each mechanical property to be assessed, 120 samples for testing were obtained from the commercial section of 40 culms (three per culm). This section was defined according to the criteria utilized in the market for the commercialization of bamboo culms, where the pieces more sold are those between 3 m and 9 m of the culm height. In addition, because the probably changes on the moisture of the culms along the different sections of the culms may influence the behavior of mechanical properties (Wakchaure & Kute, 2012).

It was established as a criterion for each sample test, of two nodes in the central part of the sample. Therefore the height of them varied between 35 and 70 cm (Figure 1). The culms were randomly selected, 20 using the traditional method to identify the

maturity which is based on external features such a color and the presence of lichens (Figure 2) and 20, with maturity known (five years after emerging) which is determined by marking the culm when it emerges or determined according to the position of the culm within the sequence conformed by culms joined throughout the rhizomes (Figure 3), being the fourth culm after the shoot (the youngest culm) five years older (Rodriguez *et al.*, 2010). After cutting the culms, the test samples were extracted according to the criteria defined and then the treatment of drilling the diaphragm of the node was applied on the half of the samples (60) (Figure 4). Thereafter, all samples for testing were sent to the Lab for measuring the mechanical properties.

The shear strength τ_{ult} (MPa) and the compression strength σ_{ult} (MPa) were measured on a total of samples sent to the Lab. These tests were carried out according to ISO/TR 22157-2 (2004) and NTC 2007,

internationally standardized methods, in the Material Lab of the National University of Colombia at Manizales. The moisture of the samples for testing was measured as a possible source of variation; this is in fact required in the ISO and NTC methods.

ANALYSES

Descriptive statistics were calculated for both response variables. Additionally, a normality tests of Kolmogorov-Smirnov and Lilliefors as well as Shapiro Wilk and the Levene's test of variance homoscedasticity, were performed in order to corroborate the assumptions of the variance analyses (ANOVA). Thereafter, an ANOVA and a covariance analyses were performed to determine the probable effect of factors on the response variables analysed. The Statistica 7.0 (StatSoft, 2008) was used for these analyses.

RESULTS

The τ_{ult} and σ_{ult} values obtained were consistent with those registered for guadua (Takeuchi, 2005; Camargo,

2006; Gonzalez *et al.*, 2008; Correal & Arbelaez, 2010). These values also resulted comparable with those registered for other species (Table 1).

After the normality tests of Shapiro-Wilk, Kolmogorov-Smirnov and Lilliefors, the τ_{ult} as well as the σ_{ult} were significant ($p < 0.05$). Therefore the original data were transformed in order to fulfil with the assumptions of ANOVA analysis. The τ_{ult} fit well ($p > 0.05$) with the square root while σ_{ult} with $1/X$ ($p > 0.05$), being $X\sigma_{ult}$. On the other hand, the Levene's test performed for the original and the transformed values of both depending variables showed the homoscedasticity of the variance ($p > 0.05$).

BEHAVIOUR OF SHEAR STRENGTH T_{ULT} AND THE COMPRESSION STRENGTH Σ_{ULT} UNDER THE FACTORS ASSESSED

The principal effect of drilling the diaphragm of the node did not show a significant ($p > 0.05$) effect on τ_{ult} and σ_{ult} as well as the interaction with the method to define the maturity. Whereas, the values τ_{ult} and σ_{ult} (MPa) significantly increased ($p < 0.05$)

Table 1. Average value of shear strength τ_{ult} (MPa) and the compression strength σ_{ult} (MPa) of *Guadua angustifolia* culms and other bamboo species

Property	Bamboo species	Mean	Reference
Shear strength (Mpa)	<i>Guadua angustifolia</i>	3.08 (± 0.67)	In this study
	<i>Gigantochloa scortechinii</i> ²	4.52	Mohmod <i>et al.</i> (1990)
	<i>Bambusa vulgaris</i> ²	4.53	Mohmod <i>et al.</i> (1990)
	<i>Bambusa blumeana</i> ²	4.81	Mohmod <i>et al.</i> (1990)
	<i>Guadua angustifolia</i>	7.53	Camargo (2006)
	<i>Guadua angustifolia</i>	4.7-5.1	Takeuchi (2005)
	<i>Guadua angustifolia</i> ³	7.3	Correal & Arbelaez (2010)
Compression strength (Mpa)	<i>Guadua angustifolia</i>	41.6 (± 9.9)	In this study
	<i>Guadua angustifolia</i>	30.1	Gonzalez <i>et al.</i> (2008)
	<i>Bambusa blumeana</i> ²	27.08	Mohmod <i>et al.</i> (1990)
	<i>Bambusa vulgaris</i> ²	28.17	Mohmod <i>et al.</i> (1990)
	<i>Gigantochloa scortechinii</i> ²	28.79	Mohmod <i>et al.</i> (1990)
	<i>Guadua angustifolia</i>	30.7	Camargo (2006)
	<i>Guadua angustifolia</i> ³	35.2	Correal & Arbelaez (2010)
	<i>Phyllostachys pubescens</i> ¹	86.5	Li (2004)

1 = Measured in culms of five years age, compression strength parallel to the fiber; 2 = two meters of free light of the element; 3 = Average value of culms three years age ; 3 = Average value of culms five years age

when the method to define the maturity was the known maturity, 2.67 ± 0.5 vs. 3.5 ± 0.6 for τ_{ult} and 35.3 ± 5.2 vs. 47.8 ± 9.4 for σ_{ult} (Figure 5 and 6).

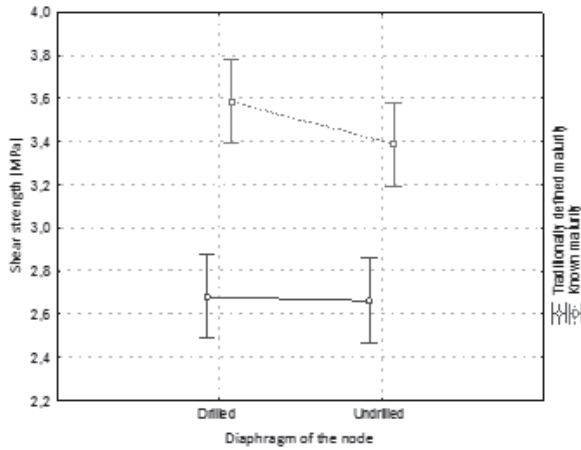


Figure 5. Behaviour of shear strength τ_{ult} (MPa) of *Guadua angustifolia* culms with drilled and undrilled diaphragm and with two approaches to define the maturity. Vertical bars denote 0.95 confidence intervals

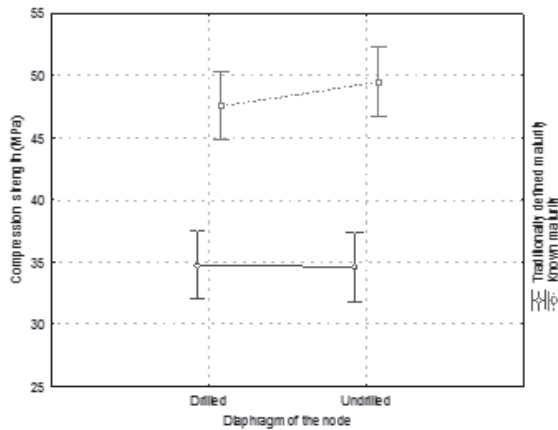


Figure 6. Behaviour of compression strength σ_{ult} (MPa) of *Guadua angustifolia* culms with drilled and undrilled diaphragm and with two approaches to define the maturity. Vertical bars denote 0.95 confidence intervals

The moisture of the test samples varied between 13 to 45% and it was 26% (± 0.7) on average. This variable also did not fit well with the normal distribution ($p < 0.5$) according to the test of Shapiro-Wilk, Kolmogorov-Smirnov and Lilliefors, therefore in order to perform an ANOVA analysis, the original values were transformed to the square root of moisture for those test samples used to assess τ_{ult} and σ_{ult} . After this procedure the assumption was fulfilled ($p < 0.05$). In addition, the Levene's test to

corroborated the homoscedasticity of the variance was also accomplished ($p > 0.05$).

The moisture of the test samples was significantly ($p < 0.05$) higher in those culms with maturity known and any significant ($p > 0.05$) relationship was evidenced with the drilling of the samples (Figure 7 and Figure 8). However, when moisture was included as a covariate within the ANOVA analysis, its effect resulted significant ($p < 0.05$). It is probably due to the higher moisture within the samples of culms with known maturity which also showed influence on τ_{ult} and σ_{ult} , as it was above described.

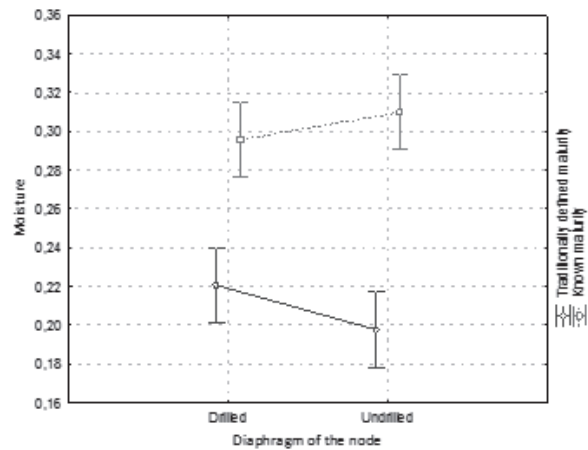


Figure 7. Relative value of moisture of the test samples used for assessing shear strength τ_{ult} (MPa). Test samples include those with drilled and undrilled diaphragm and two approaches to define the maturity. Vertical bars denote 0.95 confidence intervals

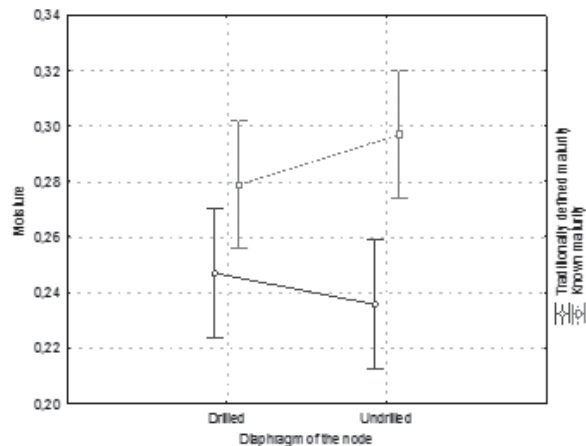


Figure 8. Relative value of moisture of the test samples used for assessing compression strength σ_{ult} (MPa). Test samples include those with drilled and undrilled diaphragm and two approaches to define the maturity. Vertical bars denote 0.95 confidence intervals

DISCUSSION

According to the node morphology vascular bundles in the node are connected by the peripheral part of the culm (Liese, 1998). The culm structure in this part is less organised and the transverse distribution of water and nutrients occurs mainly in the nodal region (Lybeer *et al.*, 2006). The diaphragm is a part of this node structure (Liese, 1998), however it does not seem to be associated with the culm strength which would be defined by those fibres located mainly in the peripheral part of the culm where most of the bundles are located.

Although authors such as Gonzalez *et al.*, (2008) for guadua and Wakchaure & Kute (2012) for *Dendrocalamus strictus* found evidence on the reduction of σ_{ult} when moisture of the samples test increased, this pattern was not evidenced in this study. When the moisture was correlated with the values of τ_{ult} and σ_{ult} , a weak relationship ($R=0,3$) although significant ($p<0.05$) was evidenced with of τ_{ult} . While with σ_{ult} , any correlation was observed ($P>0.05$). According to the results shown in figures 5 and 6, the effect of the method to define the maturity of the culms is considerable. Therefore, the relationship between moisture and τ_{ult} might be more associated with maturity of the culms and not with the moisture. Indeed, Gonzalez *et al.*, (2008) found that older culms (more mature) had higher σ_{ult} , even though in this case the maturity was assigned to the culms tested by traditional method. In the case of the study carried out by Wakchaure & Kute (2012), there was any variability on the maturity (age) of the culms, because all were 3 years old.

The effect of maturity on the mechanical properties of guadua culms is widely documented (ie. Gritsch, C., *et al.*, 2004; Correal & Arbelaez, 2010; Rodriguez *et al.*, 2010; Henao & Rodriguez, 2010) and also for other bamboo species (i.e Mohmod *et al.*, 1990; Li, 2004; Liese, 2004; Hisham, *et al.*, 2006). The traditional method for defining maturity might be relatively efficient and improper especially when humid conditions are extremes (very wet or very dry) because the external attributes employed to define the maturity do not follow any specific

pattern and maturity might be in fact totally wrong defined (Rodriguez *et al.*, 2010). In this case, probably non culms were used when the traditional method was applied.

CONCLUSIONS

The drilling of the diaphragm of culms does not influence mechanical properties of the culms such as shear strength τ_{ult} (MPa) and the compression strength σ_{ult} (MPa). Apparently this membrane does not fulfil any function to support to culm internodes and therefore does not increase the strength of bamboo culms when are subjected to strength of compression and shear. In order to consider other possible response to this change, it could be interesting to assess other mechanical properties such as bending (Rusique & Takeuchi, 2007) or tensile properties. However, in terms of compression and shear strength, the drilling of bamboo culms is a proper practice the might be used for improving the absorption of the preserving solution.

On the other hand, the definition of culm maturity is a key factor to guarantee the quality of culms for structural applications. The traditional method might sometimes be not the best approach to define the maturity. Therefore, strategies such as the labelling of culms when they emerge, should be implemented as a part of the silvicultural practices employed in order to avoid that young and immature culms are harvested with their consequent lesser strength.

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