

# Mechanical Characterization of *Angustifolia Kunth* and *Rayada Amarilla* *Guadua* Bamboo

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**Abstract.** *Guadua* is a Colombian endemic type of grass belonging to the bamboo family. It can be considered an alternative construction material due to its physical and mechanical properties, as well as a sustainable source of timber due to its fast growing process and high availability in tropical countries. The *Guadua* is composed by the stem petiole or lower part, the stem base, and the stem. In turn, the stem is divided into sections separated by diaphragms that form knots, called culms. The distance between knots and the structure of the longitudinal fibers in the culms depend on the age of the plant. This implies a difficulty when determining the mechanical properties of the stem, since there are not specific standards for this purpose. In this work the mechanical properties of young samples of *Angustifolia Kunt* and *Rayada Amarilla Guadua*, of around 6 years of growth, were characterized. To account for the natural variability introduced by the presence of diaphragms, cylindrical and prismatic samples were extracted without knot, with one knot in the middle, and with one knot at each end. Cylindrical samples were used to measure compressive strength parallel to the fiber direction, while prismatic samples were used to measure tensile strength also parallel to the fiber direction and flexural strength by three point bending. Methodologies from conventional construction materials were adapted for this purpose. The obtained results allowed concluding that the *Guadua* samples present different mechanical properties depending on the position of the knots. Samples with a knot in the middle are more resistant to compressive stresses, while the samples without knot are more resistant to flexural and traction stresses. The samples with one knot at each end presented a more balanced behavior, being efficient when exposed to compression, traction and flexural stresses.

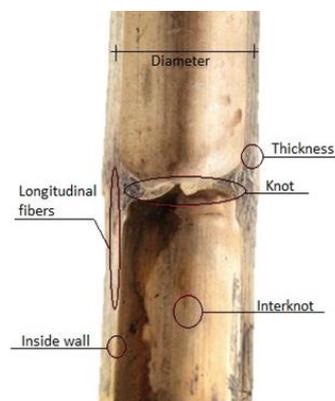
## 1 Introduction

The *guadua*, a type of bamboo native to Colombia, has been used as an alternative for sustainable construction since it is a resource found in several regions of the country [1]. It is a traditional material available in rural areas, and when properly transformed, it has quality and efficiency conditions to be economically and ecologically viable [2]. Colombia has *guadua* plantations distributed in the central mountain range and central area of the country in approximately 50,000 to 60,000 hectares, of which 95% are natural *guadales* and 5% come from crops [3]. *Guadua* can be used in civil construction; nevertheless, its potential as structural and non-structural elements is not fully exploited since 40% of the available material is used as raw material for the local industry [3].

The *guadua* between 3 and 6 years old, considered mature or adult, has its greatest strength and hardness and is most suitable for construction [4].

A cross section of a *guadua* culm detailing its internal parts is presented in Figure 1. Among all parts, fibers constitute the fabric that supports all the mechanical stresses to which the stem is subjected due to its own weight, wind loads, and other external factors. Bamboo

fibers, in general, are characterized by its thin shape, tapered on both sides and in some cases bifurcated at the ends [4].



**Figure 1.** Internal parts of a *guadua* culm.

Despite procedures and technical recommendations mentioned in the Colombian Seism Resistant Standard Regulation [5] and by local researchers on the subject [6-8], the use of this material as structural element is restricted, due in part to lack of knowledge of its mechanical properties. This work presents a mechanical

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Characterization of two Colombian guadua species, which contributes to the existing knowledge in the field.

## 2 Materials

In this work two types of guadua were characterized, *Angustifolia* Kunth (AK) and *Rayada Amarilla* (RA). Guadua culms were collected from a plantation in the municipality of Don Matías Antioquia, Colombia, at 2600 masl. The distance between knots for the AK guadua is 20 cm and for the RA guadua is 30 cm. Both types of guadua had on average a 10 cm external diameter and 1 cm of wall thickness.

## 3 Methods

To evaluate compressive strength, samples were cut from the culms taking into account the position of the knots. Samples were prepared: knots at the borders (NE), one knot in the middle (NM) of the section and without a knots (SN). Three samples were tested in each experiment.

For compressive strength full sections were [9] tested in a hydraulic compression machine with a 1200 kN load cell. Samples were cylindrical of 20 cm to 30 cm in length and 10 cm in diameter. Load was applied using a load rate of 6 MPa/s. Typical samples used in this test are presented in Figure 2 (a). To calculate this property the following formula is used:

$$RUM = \frac{P}{S} \quad [9] \quad (1)$$

*RUM*: Maximum unit stress, in kilograms force per square centimeter.

*P*: Load supported by the specimen, in kilograms force.

*S*: Cross-sectional area of the specimen calculated before the test, in square centimeters.

For flexural strength whole sections were used [7] testing in three-point bending (Figure 2(b)) Samples were of 50 cm to 100 cm in length and 10 cm in diameter. A hydraulic press adapted with a LVDT of 127 mm length was used to measure the displacement at mid-span using

a load application rate of 0.005 MPa/s. Flexural strength was measured from the stress at which the first crack was heard. The elastic modulus (MOE) of complete sections is determined determinant two points of the slope of the graph. To calculate this property the following formula is used:

$$\sigma = \frac{32 MD_1}{\pi(D_1^4 - (D_1 - 2t)^4)} \quad [7] \quad (2)$$

$\sigma$ : Ultimate bending stress, with an approximation of 0.5 MPa

*M*: Maximum momentum for each load application

*D<sub>1</sub>*: Average outside diameter (taking into account both ends of the specimen)

*t*: Average thickness (mm)

Prismatic sections were used to perform three-point bending [10] and direct traction [11] testing (Figure 2 (c)). Prisms 25 cm long with a cross-sectional area of 1 cm x 1 cm were evaluated in a universal hydraulic press with a 5 kN load cell. Five samples were tested for each knot arrangement. Three-point bending tests were performed using a controlled strain application at a speed of 1 mm/min using a LVDT at mid-span. Direct traction testing was performed at a deformation rate of 1.5 mm/min. Samples were fixed to the press by means of serrated pneumatic claws. To calculate this property the following formula is used:

$$ELPf = \frac{3P_1 L}{2b h^2} \quad [10] \quad (3)$$

*ELPf*: Unitary stress in the proportionality limit, in kilograms force per square centimeter.

*P*: Load in the limit of proportionality, in kilograms force.

*L*: Separation between supports, in centimeters.

*B*: Specimen width, in centimeters.

*h*: Specimen height, in centimeters

$$ELP = \frac{P_1 L}{Ad} \quad [11] \quad (4)$$

*ELP*: Unit stress to the limit of proportionality, in Newton per square centimeter.

*P<sub>1</sub>*: Load to the limit of proportionality, in Newton.

*Ad*: Area of the minimum section of the specimen, in square centimeters



**Figure 2.** Guadua samples used for (a) compression, (b) three-point bending in complete sections, and (c) three-point bending and direct traction in prismatic sections.

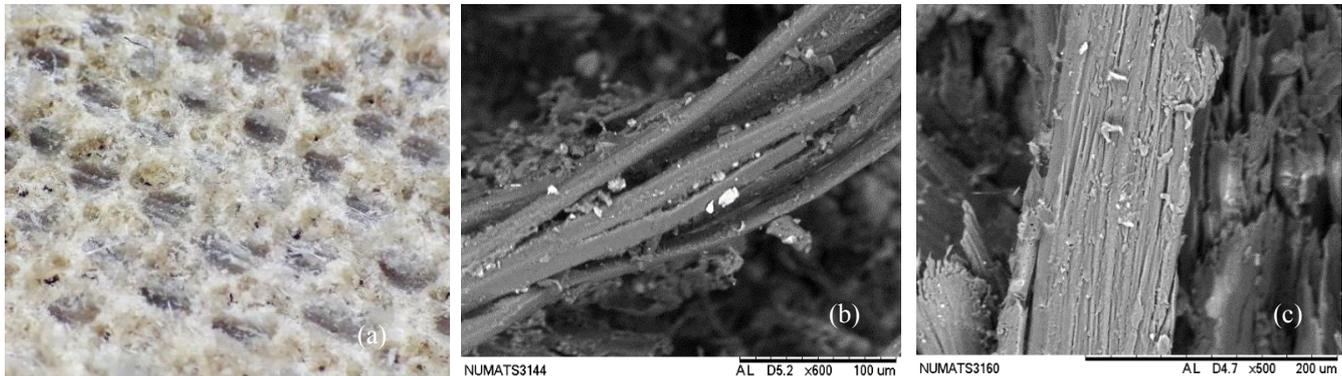
After mechanical testing, some samples of guadua were used for morphological characterization of their internal fibers.

This was done through stereoscopic microscope and a scanning electron microscope (SEM) operated in low vacuum mode at 15 kV. No conductive coating was deposited on the samples before performing imaging.

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## 4 Results

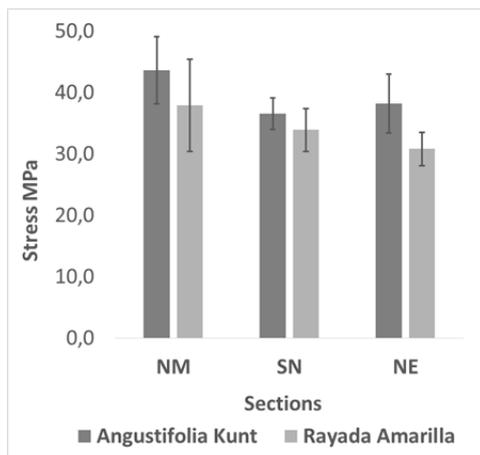
The internal structure of the guadua was characterized through a stereomicroscope (Figure 3(a)) and scanning electron microscopy SEM (Figures 3(b) and (c)), recognizing the orientation of the fibers in the



**Figure 3.** Morphology of fibers in guadua samples: (a). Sample observed through stereomicroscope variety RA. (b) sample observed through SEM variety AK, and (c) sample observed through SEM variety RA.

### 4.2 Compressive test in cylindrical sections.

Figure 4 presents the compressive strengths result for the different varieties of guadua. It was observed that the NM and NE sections obtained greater resistance compared to the SN sections in all the cases evaluated. Additionally, AK guadua obtained better performance compared to RA.



**Figure 4.** Compression strength (a) MPa of sections AK and RA with standard deviation.

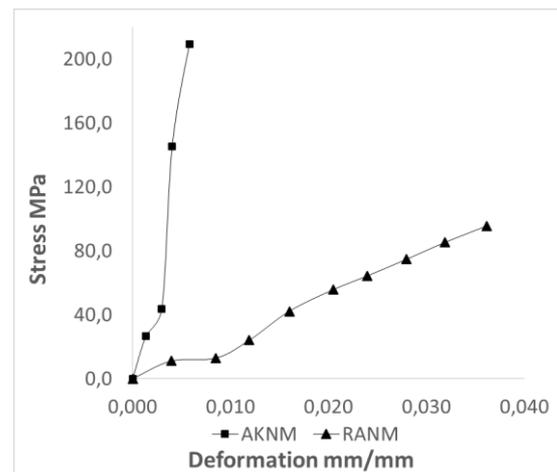
### 4.3 Bending test in cylindrical complete sections with knot in the middle.

In the bending tests of whole sections (Figures 5) maximum deformations of up to 0.050 mm/mm were identified. It was found from the stress-deformation curves that AKNM guadua presented a bending strength of 209.09 MPa, greater than 96.86 MPa obtained for RANM guadua.

### 4.1 Material morphology.

longitudinal direction in both varieties of guadua AK y RA, which coincides with what is reported in the literature [12].

Additionally, it can be seen that the RA guadua reached a much higher deformation at the maximum stress, indicating a higher elastic modulus.



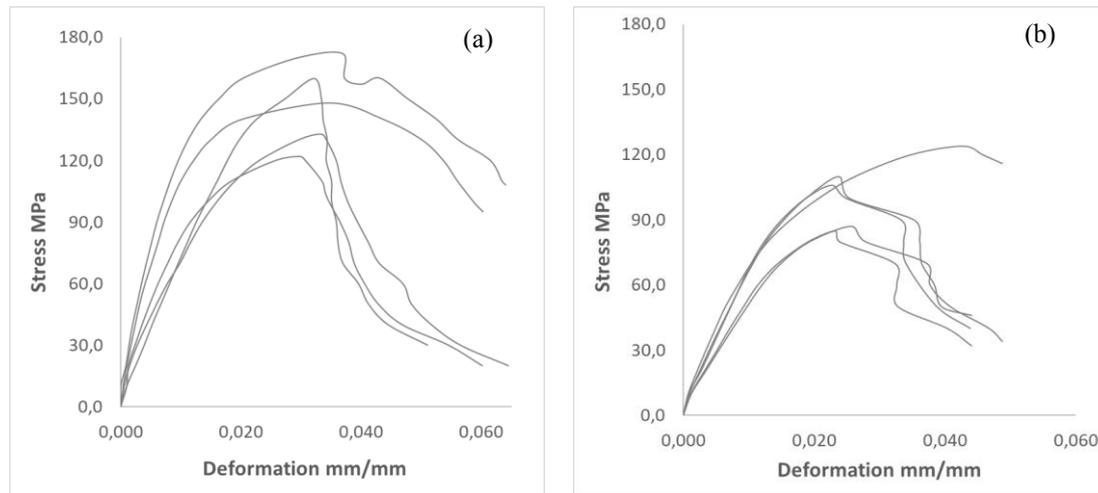
**Figure 5.** Typical curve of whole section section with knot in the middle evaluated in three-pint bending AK and RA.

### 4.4 Bending test in prismatic sections without a knots.

Three-point bending results are presented in Figure 6 for both types of guadua studied, without a knot. It was found that the bending strength of the AK variety ( $147.25 \pm 20.10$  MPa) is greater than in the RA variety ( $102.79 \pm 16.65$  MPa).

As found in the whole section, the prismatic samples of AK guadua reached a higher deformation than the RA guadua at the maximum stress

This indicates that the lower elastic modulus found for the RA guadua is an intrinsic property of the material and is not dependent on the presence of knots.



**Figure 6.** Stress - deformation curve (a) AK sections (b) RA sections.

#### 4.5 Tensile test on prismatic sections without a knot.

In the tensile test the AK guadua was measured, finding a value of  $143.13 \pm 15.66$  MPa. This value is much higher than compressive and flexural strengths due to the orientation of the fibers, parallel to the longitudinal axis of the prisms, along which the tensile load was applied.

### 5 Analysis and discussions

In the Tables 1 to 5 the results found in this work are compared with others reported by in the literature., It is possible to find agreement on the mechanical compression properties of the AK variety with values in the range of 38.2 MPa to 43.06 MPa. For the variety of RA in the range of 30.8 MPa to 37.9 MPa, even the values found for guadua RA have not been reported, but a consistent value is presented.

The sections that supported greater compression resistance were NM, then NE and SN in both species of guaduas, although the sections that had less resistance were the samples of guadua RA compared to AK. The SN sections that supported greater flexural strength were the samples of the AK variety compared to the guadua RA samples.

The authors [14] reported high MOE in prismatic sections compared to the values found in this study and those suggested by the standard however the current results are above the normative range (Table 3). In the evaluation of this property, it is striking that the values found in the prismatic sections and in the entire sections (Table 4) are similar values. On the other hand, the compressive, flexural and tensile strengths of this study are within the range suggested by the standard.

The MOE presents variability according to the cylindrical complete sections evaluated (Table 4) the result decreases while in prismatic sections it increases (Table 3). In general, the MOE is higher in guadua AK in sections SN and NM compared to guadua RA in sections SN.

**Table 1.** Compressive test results and comparisons

Variable	Caori, Gonzales (2007).[13]	Current results on cylindrical sections	
		Angustifolia Kunt	Rayada Amarrilla
Compressive strength (MPa)	50.6±9.0	NM 43.6±5.4 SN 36.5±2.5 NE 38.2±4.8	NM 37.9±7.4 SN 33.9±3.4 NE 30.8±2.7

**Table 2.** Bending strength results on prismatic and comparisons.

Variable	Pilco (2016) [14]	Current results on prismatic sections	
		Angustifolia Kunt	Rayada Amarrilla
Bending strength (MPa)	104.0±24.1	NM 103.5±23.1 SN 147.2±20.1	SN 102.7±16.6

**Table 3.** Elastic modulus (GPa) results on prismatic sections.

Variable	Pilco (2016) [14]	Current results on whole sections	
		Angustifolia Kunt	Rayada Amarilla
Elastic modulus (GPa)	15.8±4.1	SN 9.6±4.3 NM 7.8±1.7	SN 5.8±0.9

**Table 4.** Elastic modulus (GPa) results on whole sections.

Variable	Gonzales et al (2002) [15]	Current results on whole sections	
		Angustifolia Kunt	Rayada Amarilla
Elastic modulus (GPa)	10.7 ± 1.2	SN 3.65 NM 9.6	SN 6.6 NM 6.0

**Table 5.** Tensile strength results and comparisons.

Variable	Padilla (2018)[8]	Current results on prismatic sections
		Rayada Amarilla
Maximum average tensile stress (MPa)	198.4±59.2	143.1±15.6

## 6 Conclusions

After analyzing the characteristics of the guadua samples selected and evaluated for compression, bending and tensile tests of the varieties of AK and RA guadua, it is concluded that:

It was identified that the variety of AK guadua exhibits better mechanical behavior compared to RA guadua.

The mechanical properties are affected by the arrangement of the knots, the presence of NM in the compression sections was greater than in SN and NE sections.

In bending behaviors, it was evidenced that the section withstands greater effort in the SN section because the presence of NM is a discontinuity in the material, so that the stress supported is less.

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## References

1. W. Rodríguez Garzón, “Análisis del comportamiento de la producción y comercialización de la guadua y su efecto económico y social en el departamento de Santander.” Universidad de la Sale, Bogotá D.C, Colombia, 2007.
2. V. E. Avellán Cornejo, A. V. Donoso Sánchez, and L. A. González Espinoza, “Diseño de componentes

- constructivos con ecomateriales para edificaciones de la costa ecuatoriana. 1,” pp. 1–154, 2010.
3. D. C. Espinoza Pérez, “Cadena de la guadua en Colombia,” Bogotá D.C, Colombia, 2004.
4. M. Uribe Vallejo and A. Durán Contreras, “Estudio de elementos solicitados a compresión armados por tres guaduas.” Universidad Nacional de Colombia. Facultad de Ingeniería, Bogotá D.C, Colombia, 2002.
5. “Título G- Estructuras de madera y estructuras de guadua,” in *Reglamento colombiano de construcción sismo resistente NSR -10*, Bogotá D.C, Colombia, 2010, pp. G1–G158.
6. W. Gonzáles Avila, “Ensayos para determinar y comparar las propiedades físico-mecánicas de la guadua Angustifolia de Pacho Cundinamarca frente a la de Silvania Cundinamarca.” Universidad Militar Nueva Granada., Bogotá D.C, Colombia, 2016.
7. P. Luna, C. P. Takeuchi Tam, G. Granados, F. Lamus, and J. Lozano, “Metodología de diseño de estructuras en guadua Angustifolia como material estructural por el método de esfuerzos admisibles,” *Rev. Educ. en Ing.*, no. June 2011, pp. 66–75, 2011.
8. W. Padilla Martínez, “Comportamiento a tracción del bambú guadua Angustifolia teniendo en cuenta el deslizamiento en la interfaz fibra - matriz,” Universidad Nacional de Colombia. Facultad de Ingeniería., Bogotá D.C, Colombia, 2018.
9. Comisión Panamericana de Normas Técnicas, “Método de determinación de la compresión axil o paralela al grano,” in *Norma panamericana COPANT 466*, 1972, pp. 7–10.
10. Comisión Panamericana de Normas Técnicas COPANT, “Método de ensayo de flexión estática,” in *Norma panamericana COPANT 555*, 1973, pp. 19–26.
11. Comisión Panamericana de Normas Técnicas COPANT, “Método de ensayo de tracción paralela al

- grano,” in *Norma panamericana COPANT 742*, 1975, pp. 27–33.
12. J. A. Osorio Saraz, A. Espinoza Bedoya, and E. A. García Bedoya, “Evaluation of mechanical properties of the internal structure of the guadua with mathematical modelling.,” *ResearchGate*, no. October 2014, pp. 169–178, 2008.
  13. C. P. Takeuchi Tam and C. E. Gonzáles, “Resistencia a la compresión paralela a la fibra de la guadua *Angustifolia* y determinación del Módulo de Elasticidad.,” vol. 11, no. 1, pp. 89–103, 2007.
  14. E. P. Pilco Díaz, “Estudio de las propiedades físico-mecánicas de la *Guadua Angustifolia* Kunth de Loja, e implementación de este como material de construcción.,” Loja, Ecuador, 2016.
  15. E. González C, J. A. Osorio S, and E. A. García G, “Resistencia a la flexión de la guadua *Angustifolia* Kunt a escala natural,” *Rev. Fac. Nac. Agrar. Medellín*, vol. 55, no. 2, pp. 1555–1572, 2002.