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# Mechanical and physical characterization of *Guadua angustifolia* 'Kunth' fibers from Colombia

# Caracterización Física y mecánica de fibras de *Guadua angustifolia* 'Kunth' provenientes de Colombia

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## ABSTRACT

Fibers of natural origin have been implemented as reinforcement materials in different areas; hence, it is important to know their properties. In this paper, the results of the physical, chemical, and mechanical characterization of natural fibers of guadua are shown; to achieve this, scanning electron microscopy (SEM), atomic force microscopy (AFM), moisture absorption, apparent density and fiber stress tests were used. The aim was to analyze the general behavior of guadua fibers and to determine their viability as reinforcement in composite materials for construction. From the characterization, it was determined that guadua has an excellent tensile strength and can be used as reinforcement in polymer matrices because of its roughness; that is, it has adhesion, is light, and has excellent absorption in comparison with other fibers.

**KEYWORDS:** Natural fibers; SEM; AFM.

## RESUMEN

Fibras de origen natural se han implementado como material de refuerzo en distintas áreas; por ello la importancia de conocer sus propiedades. En este trabajo se muestran los resultados de la caracterización física, química y mecánica de fibras naturales de guadua; para lograrlo, se emplearon técnicas de Microscopía Electrónica de Barrido (SEM),

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Microscopia de Fuerza Atómica (AFM) y ensayos de absorción de humedad, densidad aparente y tensión en las fibras. Esto con el fin de analizar el comportamiento en general de las fibras de guadua, para determinar su viabilidad como refuerzo en materiales compuestos para la construcción. A partir de la caracterización se determinó que la guadua tiene una excelente resistencia a tensión, que puede ser utilizada como refuerzo en matrices poliméricas debido a su rugosidad; es decir, tiene adherencia, es liviana y presenta una excelente absorción en comparación con otras fibras.

**PALABRAS CLAVE:** Fibras naturales; SEM; AFM.

## 1. INTRODUCTION

As a result of the environmental and economic problems that the planet is currently undergoing, there has been increased interest in developing research aimed at using renewable and natural resources, which can replace or supplement conventional materials used in construction and which have a lower environmental, economic, and energy cost [1-3]. Accordingly, composite materials have taken on great importance in minimizing these problems, and this has encouraged deeper study of the mechanical properties and the ways of producing these compounds [4-6]. From this, the idea of studying the fibers of *Guadua angustifolia* 'Kunth' has arisen, because it has been shown that these natural fibers are abundant and have adequate mechanical properties to be used as reinforcement in polymeric composites [2, 7-15]. However, it is difficult to extract guadua fibers with uniform length, so many studies have been carried out with the aim of extracting the desired fibers in a simpler way [2].

The natural fibers of *Guadua angustifolia* 'Kunth' consist of cellulose microfibers that are aligned along the length; this provides multiple benefits relative to other plant fibers, such as recyclability, abrasion during production, low density, low cost, thermal insulation, acoustic insulation, high mechanical strength, stiffness, and high growth rate [16-20]. These properties have made guadua an attractive material for various applications [7].

In this study, the physical and mechanical properties of *Guadua angustifolia* 'Kunth' fibers were determined by implementing two characterization techniques, scanning electron microscopy (SEM) and atomic force microscopy (AFM), to identify each of the properties that could be used for the reinforcement of polymer matrices.

## 2. MATERIALS AND METHODS

### 2.1. Extraction of fibers

The used fibers were extracted from clusters of *Guadua angustifolia* with an average age of 5 years [6, 21], from the municipality of Peñón, department of Cundinamarca, Colombia. Before being processed for fiber extraction, guadua clusters were selected that were without knots and had an outer diameter of 8.8cm and a wall thickness of 0.8cm.

The removal of fibers was performed with a mechanical process, which consisted of extracting the fibers manually with directed pressure to the inner part of the column. The fibers were then sieved and the fraction corresponding to sieve numbers 30 and 40 was taken to obtain the natural fibers [6, 7, 16]. Subsequently, the fibers were surface-treated with 5% sodium hydroxide for 30 minutes to remove impurities; the fibers were then washed with distilled water at neutral pH value and dried at a temperature of 105°C for 12 hours [6, 7, 22].

### 2.2. Scanning Electron Microscopy

Eight of the extracted fibers were coated with gold so that the samples were conductive for analysis with a scanning electron microscope (model JSM 6490-LV). ImageJ software was implemented for digital image processing, and the average fiber diameter, cross-sectional area, and percentage of voids were measured.

### 2.3. Atomic Force Microscopy

A fiber was used to visualize the topographic changes of the surface morphologies and the roughness of *Guadua angustifolia* 'Kunth' fibers [23]. To achieve this, a model team, CYPHER ESTM ASYLUM RESEARCH, was implemented. The strategic point of the guadua fiber was identified, and the topography was measured.

### 2.4. Mechanical characterization

Figure 1 shows the dimensions of a fiber. Thirty *Guadua angustifolia* 'Kunth' fibers were selected from the outside of the cluster, and the stress test was performed on the basis of the ASTM D1557-03 method. Each fiber was mounted on a support board and was fastened by employing a rigid epoxy resin at each end [7, 15]. Once the fiber was fixed, the mechanism was mounted at a speed of 0.36mm/sec, and the applied force was recorded. From the transverse area measured by SEM, the average tensile strength of the guadua fibers was obtained [24, 25].

## 2.5. Physical characterization

The humidity content was determined by weight differentiation on the basis of the ASTM D4442 method. In addition, the percentage of humidity absorption was measured on the basis of the ASTM D5229 method. Finally, the bulk density was determined by volume displacement on the basis of the ASTM D3800 method, by taking into account the weight of the sample and volume dislodged [7, 13, 26].

## 3. RESULTS AND DISCUSSION

From the characterization by SEM, it can be observed that a cross-section of one of the guadua fibers studied inside the column (Figure 1) has an average diameter of 236.431 $\mu$m, from which a transverse area of 40903.4571 $\mu m^2$ is obtained. It is also shown that the section presents a plane with a void percentage of 0.61% because of the number of holes in the fibers (Figure 2), which give the guadua a low density relative to other fibers, such as jute or coconut [16].

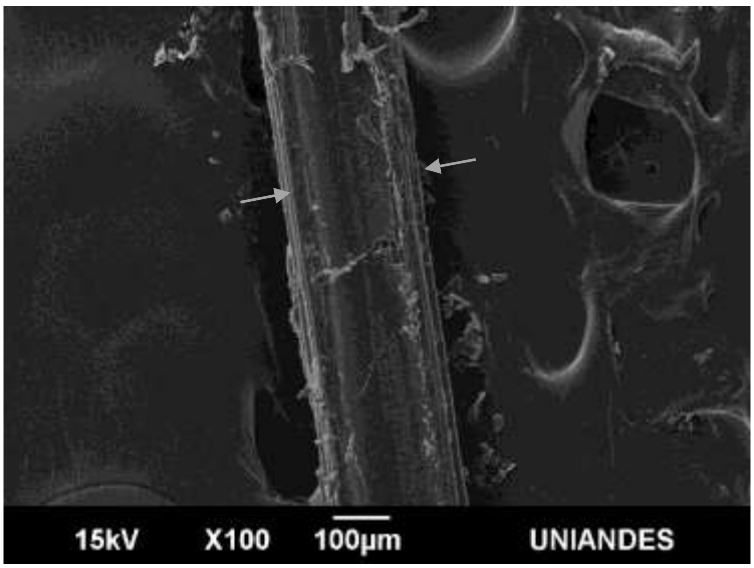


**Figure 1**. Guadua fiber composed of aligned cellulose microfibers.

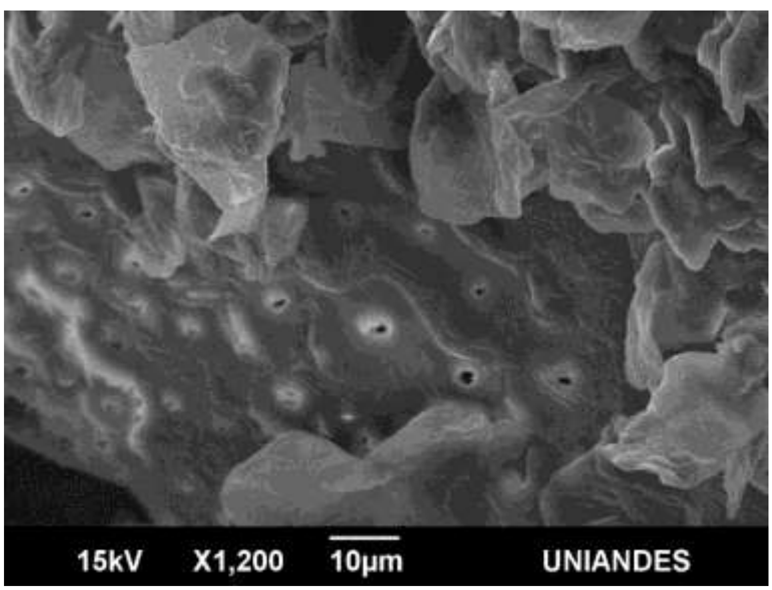


**Figure 2**. Cross-section of a *Guadua angustifolia* 'Kunth' fiber.

Longitudinally, the guadua fibers have a rough surface (Figure 1). It can also be observed that *Guadua angustifolia* 'Kunth' is a composite material, which consists of long cellulose fibers aligned in the direction of the axial axis of the fiber and immersed in the woody material (Figure 3) [7, 19, 20]. This causes the guadua to have a low tensile strength in the direction transverse to its longitudinal fibers and a high strength along the longitudinal axis [15, 19, 27].

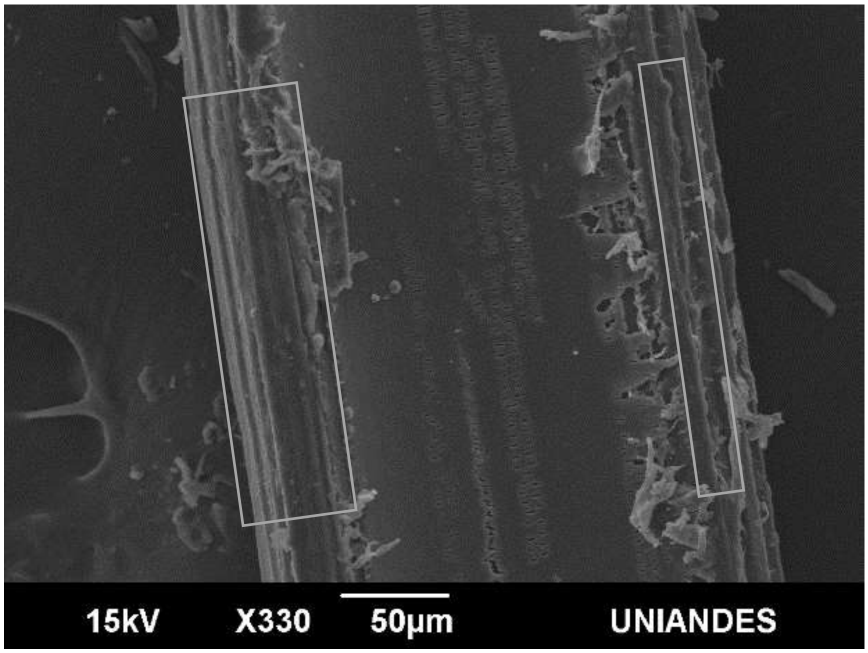


**Figure 3**. Example of a longitudinal section of a *Guadua angustifolia* 'Kunth' fiber.

From the AFM characterization, a micrograph was obtained for a section, with dimensions of 2µm×2µm, parallel to the axial axis of the fiber (Figure 4). From this, it is possible to observe variations as a result of crests and undulations that make a quite nonuniform texture of the topography. This characteristic of iregularity provides greater adhesion between polymer matrices and fibers [26].

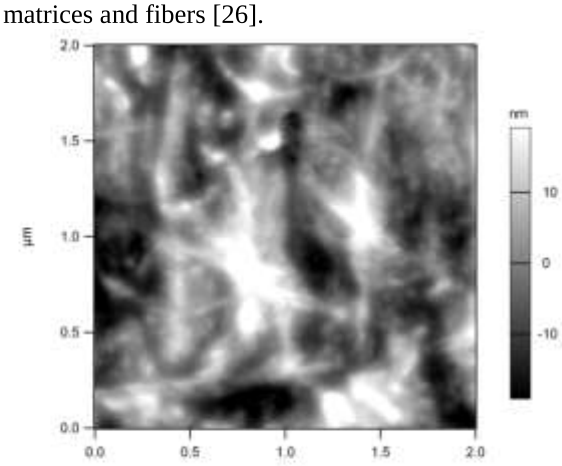


**Figure 4**. Surface morphology of a section of the longitudinal section of a *Guadua angustifolia* 'Kunth' fiber.

The nonuniform surface shown in the AFM micrograph of the *Guadua angustifolia* 'Kunth' fibers can also be seen in the SEM images (Figure 2 and Figure 3). Thus, it was determined that the guadua has a surface roughness of 9.51nm, a product of the ripples marked on the surface layer [23].

From the apparent density test, it was determined that the *Guadua angustifolia* 'Kunth' fibers have a density of 0.69g/cm$^3$. This is a lower value than that of artificial fibers, such as carbon, which gives an advantage for use in light materials.

From the humidity content test of the fibers extracted from the *Guadua angustifolia* 'Kunth' culm, a value of 8% was found, which is in accordance with the findings of other authors [1, 7, 28]. However, Gutiérrez and Takeuchi showed that the humidity content in which the material is used as a structural element does not affect the tensile strength of the fibers [1]. From the water absorption test of the extracted fibers, a value of 56.33% was found.

The values of water absorption and density are relatively low, which reflects in important properties that allow *Guadua angustifolia* 'Kunth' to be implemented as reinforcement for polymer matrices [26].

In Figure 5, the results of the microtension tests are observed, with the aid of a graph plotted against the number of fibers tested. A small variation in the results is shown because of the difference between the diameters of each of the fibers extracted, as a consequence of the complicated extraction process. The highest resistances correspond to the regions closest to the outer surface, which correspond to the highest densities of the column cross-section, whereas the lowest resistances correspond to the regions farthest from the outer surfaces with the lowest fiber densities [29].

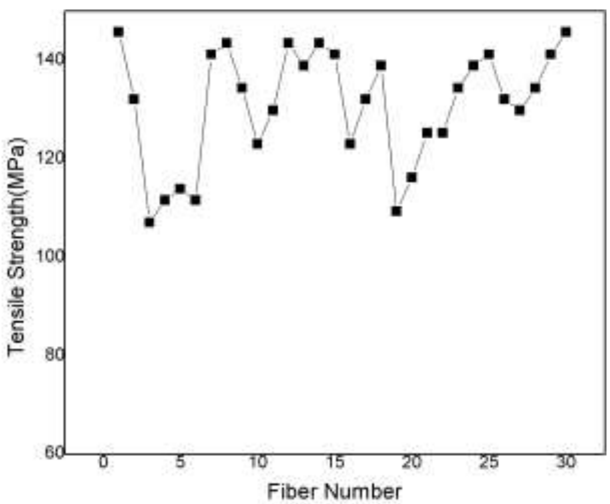


**Figure 5**. Tensile strength of each of the *Guadua angustifolia* 'Kunth' fibers tested.

The longer the fiber length for the tensile strength test, the greater the number of critical sites and, therefore, the greater the probability of failure. It has been mentioned by other authors that the critical defects can originate from imperfections developed during growth and defects introduced during extraction [24, 30].

## 4. CONCLUSIONS

As a result of the closed and compact structure of the column of guadua, the process of extracting the guadua fibers is complicated and produces critical sites in the fibers, which produce a greater probability of failure in tensile strength tests.

On the longitudinal surface, the topography of the fibers is irregular. This irregularity is important because it provides the material with adhesion at the interface between the fibers and polymer matrices, which gives these fibers an advantage over other natural fibers with less roughness.

Guadua presents attractive properties, such as its low density, absorption, and moisture content, which make it a light material. It also exhibits high tensile strength, which indicates the potential of these fibers as a reinforcing material for polymer composites with applications in the construction industry and as an environmentally friendly engineering material.

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