Mechanical characterization of the rachis fiber obtained from the African palm elaeis guineensis

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Abstract. In the present work, experimental tests are carried out to determine the tensile strength of the fiber obtained from the African palm clusters. The tests were performed on a MTS BIONIX universal test machine under the ASTM standard, which characterizes the tensile strength and stiffness of the fiber in relation to its weight. Once the mechanical properties of the fiber are characterized, it is proposed to carry out studies as a reinforcement material in composite materials, reducing the amount of waste which generates health problems in this industry. Organic fibers have mechanical properties such as lightness, high mechanical strength and durability, for these reasons it has been used as a reinforcing element in polymeric matrices, being a potential replacement for some materials in the industry in general. By 2015, Colombia had 466000 hectares of African palm planted, highlighting the potential for acquiring this fiber in Colombia, to achieve positive results in the application of the fiber, a whole series of new industrial products can be developed with the social and economic impact that this represents.

1. Introduction
One of the current challenges of engineering is the search for new materials, especially those with a low environmental impact [1–4]. African palm is mainly grown in Malaysia, Indonesia, Thailand and in West and Central Africa [5]. The development of this crop in Colombia has maintained a constant growth. In the decade of the 60’s, there were 18,000 hectares seeded [6] and, today, there are more than 220000 hectares with this crop in 73 municipalities of the country [7,8]. In the African palm industry, the oil is extracted from the pulp portion of the fruit by several conventional operations, these operations produce a large amount of lignocellulosic scraps from leaves, empty bunches, palm kernel flavor, and fibers from shells [9]. For this industry, the final disposal of this waste generated during the production process represents a great challenge, because it may receive treatment before being discarded [10]. Currently, the amount of empty bunches or rachis has created an environmental problem since it produces contamination by combustion, generation of fungus and flies in accumulated wastes [11].

Many researches have been developed with the purpose of finding a useful meaning to African palm oil empty bunches. In [12], the pulp production was studied to obtain paper from the bunches of the African palm, it was concluded that, from the properties analyzed, only the tensile strength and scratch showed values near to pine paper sheets. In [13], researchers concluded that it was feasible to use fiber in grafts to improve the mechanical properties in cardboards with commercial reference 620 kgf/m and 720 kgf/m, as well as, the shelf life of the packaging and the final disposal in landfills.
The present investigation is focused on the analysis of organic fibers to be used as reinforcement material [14,15]. Experimental tests are carried out under ASTM D3822M-14 [16], using the universal testing machine MTS BIONIX [17], to characterize the mechanical properties of the fiber.

2. Materials and methods
For this research, fibers from the bunches of African palms that were received from the oil extraction process were used. In its initial condition, the fibers were obtained by manual extraction and the dimensions ranged between 5 cm and 30 cm of length, as shown in Figure 1. The ASTM standard establishes at least one sample composed of 10 data. A total of 14 continuous fibers were selected, which are sized to 15 cm of length. The mean diameter of the fiber was determined to be 0.5±0.02 mm. Due to the diameter of the fiber, it was necessary to create a head for the clamping to the machine. This head presented the following dimensions: 25 mm x 20 mm x 4 mm, as shown in Figure 2, with a working length of 100 mm.

The head was made by molding epoxy resin R-744, using a mold of wood, the leaks were treated with clay to seal the mold. The tests were performed in an MTS BIONIX universal machine, which allows to apply constant load and has a data acquisition equipment, Figure 3. We obtained the magnitude of the load and the elongation that suffered the specimens. The speed of application of the load was defined using ASTM D3822M-14 [16], and was fixed to constant value of 2 mm/min.

The Young’ modulus, or elastic modulus, $E$, is the constant of the constitutive relation $\sigma = E\varepsilon$ that indicates the elastic response of the material, being $\sigma$ is the stress on the area of the cross-section of the
element, and the strain $\varepsilon$ is the unit deformation understood as the relation between the length change with respect to the initial length [18].

![Figure 3. Universal testing machine, MTS BIONIX, with test sample.](image)

### 3. Result and analysis

The data obtained during the test were: force (N), displacement (mm), and time (s), the Young's modulus of the fiber, as well as, the tensile strength or ultimate stress. The results were analyzed by statistical methods in order to determine the approximate values.

Young's modulus is the slope of the stress-strain curve in the elastic zone, as shown in Figure 4. The corresponding stress-strain relationship for fiber # 4 of the sample gives the slope with a value of 960 MPa, this being the estimated Young's modulus for this fiber.

![Figure 4. Stress vs. strain.](image)

The results obtained for each of the fibers are shown in Table 1. Notice that Young’s modulus values range between the 889.45 MPa and 1088.67 MPa. The mean value was determined $E = 960$ MPa as the value of Young's modulus of the studied material, with a standard deviation of $S = 60$ MPa, as shown in Figure 5. The ultimate stress $\sigma_u$ corresponds to the maximum value of stress that can be applied to the material. When the applied stress approaches the ultimate stress, the accelerated striction (the cross...
section become thin compared to the initial condition) followed by the fracture begins. Table 1 shows the values of the ultimate stress within the range of 77.29 MPa to 144.49 MPa. The mean ultimate stress was 110 MPa, with a standard deviation of $S$: 25 MPa.

### Table 1. Test results.

| Fiber sample | Young’s modulus (MPa) | Ultimate stress (MPa) |
|--------------|------------------------|-----------------------|
| 1            | 904.13                 | 108.75                |
| 2            | 974.72                 | 115.28                |
| 3            | 985.56                 | 93.31                 |
| 4            | 1088.67                | 104.70                |
| 5            | 980.56                 | 139.72                |
| 6            | 955.86                 | 78.45                 |
| 7            | 925.09                 | 127.32                |
| 8            | 1018.68                | 144.75                |
| 9            | 889.45                 | 144.49                |
| 10           | 891.89                 | 77.29                 |

![Figure 5. Standard deviation of the elastic modulus.](image)

Table 2 summarizes the properties obtained for the fiber obtained from African palm bunches, *Elaeis guineensis*, which were experimentally estimated in this investigation.

### Table 2. Mechanical properties.

| Fiber          | Diameter (mm) | Density (g/cm³) | Deformation (%) | $\sigma_{u\text{prom}}$ (MPa) | $\sigma_{u\text{max}}$ (MPa) | $\sigma_{u\text{min}}$ (MPa) | $E_{\text{prom}}$ (MPa) | $E_{\text{max}}$ (MPa) | $E_{\text{min}}$ (MPa) |
|----------------|---------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| *Elaeis Guineensis* | 0.48-0.52     | 1.25            | 8 - 10          | 110             | 144             | 77              | 960             | 1089            | 889             |

### 4. Conclusions

Comparing the mechanical properties obtained for the African palm bunches with other organic fibers, it was observed that it is within the average values of 0.5 GPa to 3.5 GPa, but with a low cost and weight. The elastic modulus is 960 MPa and the ultimate stress is 110 MPa. The fiber presents the behavior of a ductile material achieving significant deformations of 8% to 10% before breaking. The strength of the fibers is affected by the humidity. In this research, a drying process was developed, but this parameter was not measured, thus, it is recommended for future investigations to take into account this variable. Fiber from palm oil bunches is a potential material to use as reinforcement fiber for composite materials.
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