

Comparative Analysis of Curaua Fiber Density Using the Geometric Characterization and Pycnometry Technique

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Abstract One of today's biggest concerns has been environmental issues, which has motivated researches and the development of materials from renewable resources and environmentally friendly. Natural fibers have excelled in replacing synthetic fibers used in composites manufacturing, because natural fibers are biodegradable, abundance in the nature, low cost, low density, high strength, among others. Due to these qualities, some natural fibers are used for many purposes in automobile industry. However, the natural fiber has irregularities and pores in its structure which directly impact the density determination by geometric techniques and, accordingly, the volume of fibers used in composites. Therefore, the main objective is this study is to determine the density of curaua fiber by pycnometry and to compare it with the commonly used geometric technique.

Keywords Curaua fibers • Geometric density • Pycnometry

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Introduction

Composite materials refer to materials containing strong fibers—continuous or non-continuous—embedded in a weaker material or matrix. The matrix keeps the geometric arrangement of fibers and transmits to these fibers the load acting on the composite component. The composite material shows intermediate mechanical performance, that is, superior to those of the matrix but lower than those of the fibrous reinforcement [1].

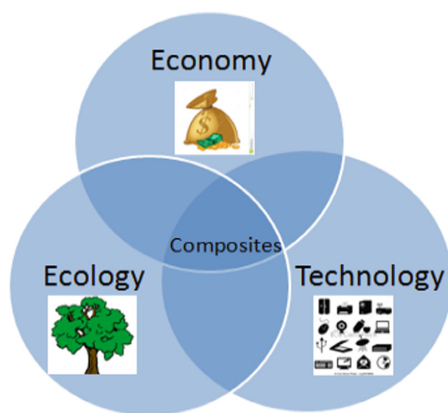
The applications to the composite materials include but not limited to electrical-electronics, building and public works, road transports, rail transports and maritime transports, cable transports, air transports, space transports, general engineering sector, sports and leisure, etc. [1].

Synthetic fibers are more common in composite materials but natural fibers (NF composites) offer benefits to the society from different points of view. According Agriculture and Consumer Protection, the benefits are regarded from an Economic, an Ecological and a Technical (E.E.T., see Fig. 1) [2].

In fact, the benefits that motivate the replacement of glass fiber for natural fiber in polymer composites [3], are also technical, economical and societal advantages [4, 5]. There are many reasons that favor the use of natural fibers, mainly those obtained from cellulose-based vegetables, also known as lignocellulosic fibers, such as cotton, flax, sisal, jute, hemp, wood, pineapple and curaua fiber. Actually, it is estimated that more than 500 lignocellulosic fibers are known and have potential to be used in engineering applications. Most of these fibers are native of tropical regions in Africa, South Asia, Central and South Americas. The plant cultivation, extraction and processing of lignocellulosic fibers represent an important source of income for people and countries in these regions.

Curaua fibers were used in this study. This fiber is extracted from the leaves of an Amazonian plant whose family is known as bromeliad and that resembles a pineapple plant. It has specific mechanical properties similar to inorganic fibers,

Fig. 1 E.E.T. (Economy, Ecology and Technology)
(adapted from Agriculture and Consumer Protection)



low-cost of production, offers relatively a high tensile strength level and is an important renewable raw material [6, 7]. Curaua fiber is composed of lignin (7.5%), glucan (66.4%), xylan (11.6%) and other materials, such as mannan (0.1%), galactan (0.5%) and arabinan (0.5%) [8].

Density is used in many areas of application to designate certain properties of materials or product and it is an important property of the fiber [9]. It is a standard physical term defined as weight (mass) per unit volume. SI units are kg/m^3 but it's common to use g/cm^3 [10]. Normally density of vegetal fibers is known through of the geometric characterization, but these fibers have pores and high density of defects on the surface of the fiber which significantly increase the probability of error in determination the fiber's density. In the other words, it is measured the apparent density of the fiber since apparent density is the mass per unit volume (or the weight per unit volume) of a material, including the voids which are inherent in the material [11, 12].

Density determination by pycnometers a very precise. It uses a working liquid with well-known density as water. It used for determining both the density of liquids and dispersion by simply weighing the defined volume, but especially for determination of the density of powders and granules. Pycnometers can also be used to determine the density of the solid phase in a porous solid [9, 13].

So, thinking about this problem, the aim of this work is compare the analysis of curaua fiber density using the geometric characterization and pycnometry technique.

Experimental Procedure

The curaua was obtained from Amazon Paper. The typical aspect of curaua plantation and a bundle of soft fibers are showed in Fig. 2.

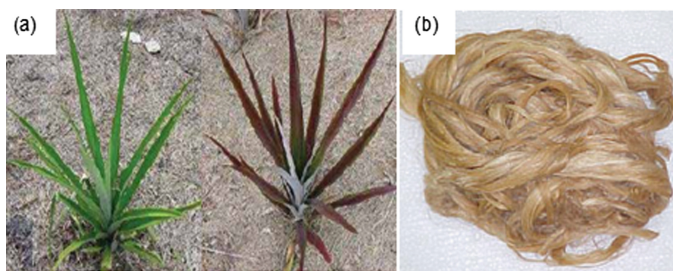


Fig. 2 a “White curua” and “purple curaua” plant respectively, b bundle curaua fiber [6]

Fiber Surface Analysis

The surface of representative specimen was analyzed by a Scanning Electron Microscope (SEM) SSX-550 Shimadzu.

Geometrical Characterization

The soft fibers were individually separated, for a statistical dimensional analysis. It was separate 100 (hundred) individual fibers and it was weigh each fiber (m_f) in a digital balance with 4 decimal places of the brand SHYMADZU and model AY220.

For determination of fiber diameter (d) was used a profile projector of the brand NIKON with magnification ($\times 50$). Each fiber was measured in 10 positions, five in a position and five turning the fiber in 90° .

The length of fiber (L_f) was measured with a metal graduated scale.

After obtaining the three measures described, were used the formulas of the density (1) and volume (2) to each fiber:

$$\rho_f = \frac{m_f}{V_f} \text{ (kg/m}^3\text{)} \quad (1)$$

where:

$$v_f = \frac{\pi d^2}{4} \times L_f \text{ (m}^3\text{)} \quad (2)$$

Ultimately, it was calculated average density (3):

$$\bar{\rho} = \frac{1}{n} \sum_{i=1}^n \rho_i \quad (3)$$

Pycnometry Technique

The fibers were dried in kiln at a temperature of 105°C and weighed (fiber mass - F_m) in a digital balance with 4 (four) decimal places of the brand SHYMADZU and model AY220. Also weighed the empty pycnometer (m_1) and the pycnometer with water (m_2).

In the dry glass pycnometer (50 mL) was inserted the fibers and added distilled water until to reach 90% in volume of the glass pycnometer. The pycnometer with distilled water and fiber was shaken to eliminate the air bubbles. So the pycnometer

was put in the desiccator linked with a vacuum pump with 400 mmHg suction applied. After 2 h with suction, it was removed to desiccator and shaken again.

The pycnometer was completed with water and placed the capillary cover. Dried the spare water that leaked through the capillary hole with a filter paper and measured total weight, that is, pycnometer + fiber + water (m_3).

The calculation was made with the density's equation (4):

$$\rho_{fibra} = \frac{m_f}{V_f} \text{ (kg/m}^3\text{)} \quad (4)$$

where, fiber volume (v_f) is equal the displaced water volume (V_d) due the presence of fiber into the fill pycnometer. Temperature depend of distilled water density $\rho_{H_2O}(W_d)$. So, to calculate the fiber volume was used the Eq. (5):

$$v_f = v_d = \frac{[(m_2 - m_1) - (m_3 - m_1 - f_m)]}{w_d} \quad (5)$$

Results and Discussion

Scanning Electron Microscopy—SEM

Figures 3 and 4 show the fiber imperfections. In Fig. 3, there are voids as indicated by the white arrow and in Fig. 4, it shows the irregularities in the all surface of the fiber.

Geometric Characterization

The measured distribution of 100 fibers revealed a dispersion interval in length from 150 to 164 mm, with an average of 157 mm (Fig. 5). Dispersion in diameter from 0.044 to 0.193 mm, with an average of 0.098 mm was also revealed (Fig. 6).

Fig. 3 Curaua fiber surface superior view with magnification ($\times 240$)

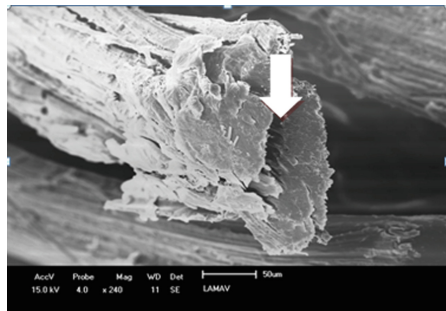
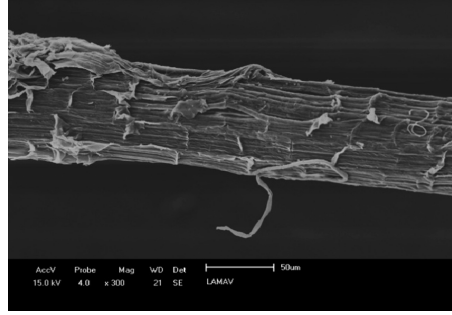


Fig. 4 Curaua fiber lateral view with magnification ($\times 300$)



Using Eq. 2 the volume of each fiber was obtained and using the equation, the density of each fiber was obtained. However, the final density was obtained through of Eq. 3:

$$\bar{\rho} = \frac{1}{100} \times 95.77 = 0.9577 \text{ (g/cm}^3\text{)} = 957.7 \text{ (kg/m}^3\text{)} \quad (6)$$

So, the density obtained was approximately 957.7 kg/m^3 .

Pycnometry Technique

It was used 3 samples to do this technique. In Table 1 is showed the fiber mass of each sample submitted to 105°C to eliminate the humidity, the mass of pycnometer, pycnometer + water and pycnometer + water + fiber respectively.

Using Eq. 5, obtain the displaced volume of fiber to each sample¹:

$$v_{f1} = \frac{[(80.333 - 28.065) - (80.503 - 28.065 - 0.601)]}{0.9962} = 0.432 \text{ cm}^3$$

$$v_{f2} = \frac{[(86.472 - 37.997) - (86.543 - 37.997 - 0.320)]}{0.9962} = 0.250 \text{ cm}^3$$

$$v_{f3} = \frac{[(90.678 - 37.869) - (90.835 - 37.869 - 0.553)]}{0.9962} = 0.397 \text{ cm}^3$$

So, applying the result in Eq. 4, obtain the density to each sample:

$$\rho_{f1} = \frac{0.601}{0.432} = 1.391 \text{ (g/cm}^3\text{)} = 1391 \text{ (kg/m}^3\text{)}$$

¹The water temperature was 28°C which corresponds to a density 0.9962.

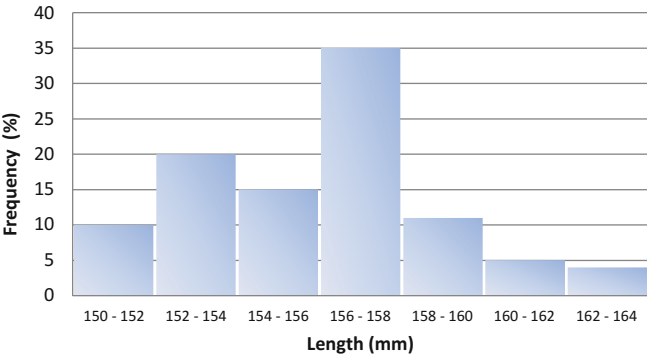


Fig. 5 Fiber length frequency graph

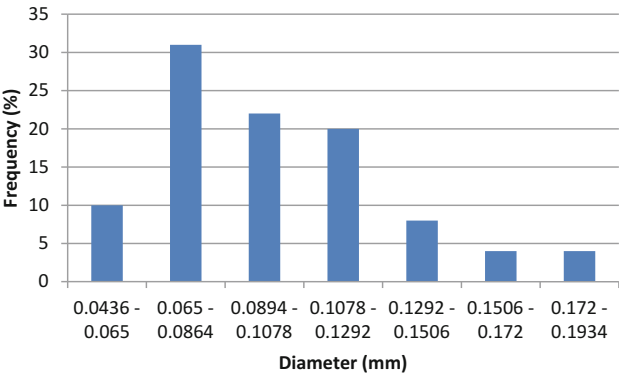


Fig. 6 Fiber diameter frequency graph

Table 1 Mass of the fiber, mass of the pycnometer, mass of the pycnometer with water and mass of the pycnometer with water and fiber

Sample	Dry fiber	Pycnometer (m_1)	Pycnometer + water (m_2)	Pycnometer + water + fiber (m_3)
	g	g	g	g
1	0.601	28.065	80.333	80.503
2	0.320	37.997	86.472	86.543
3	0.553	37.869	90.678	90.835

$$\rho_{f2} = \frac{0.320}{0.250} = 1.280 \text{ (g/cm)} = 1280 \text{ (kg/m}^3\text{)}$$

$$\rho_{f3} = \frac{0.553}{0.397} = 1.393 \text{ (g/cm}^3\text{)} = 1393 \text{ (kg/m}^3\text{)}$$

The average of the density is equal:

$$\bar{\rho} = \frac{(1.391 + 1.280 + 1.393)}{3} = 1.355(\text{g/cm}^3) = 1355(\text{kg/m}^3)$$

Conclusions

- From SEM observation, fiber has irregularities in its surface and voids/pores. So, the geometrical technique is not the best method because it does not identify the imperfections of the fiber;
- The fiber has approximately 29% of voids and pores;
- The result of the pycnometer was satisfactory because the density of the fiber is similar to density of the organic matter that ranging from 1300 to 1500 kg/m³.

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