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WEIBULL ANALYSIS OF THE DENSITY OF BAMBOO FIBER OF THE SPECIMEN DENDROCALMUS GIGANTEUS[1]

Lucas Barbosa de Souza Martins[2]
Frederico Muylaert Margem[3]
Sergio Neves Monteiro[4]
Rômulo Leite Loyola[5]

Abstract

Several economical, technical and environmental advantages are currently justifying the replacement of synthetic fibers by natural fibers. However, natural fibers obtained from plants, also known as lignocellulosic fibers, do not present the same dimensional uniformity. In fact, they sow large dispersion of values, as compared to the synthetic fibers. The specimen Dendrocalmus Giganteus type of giant bamboo is famous for its mechanical resistence, and works have been conducted to evaluate its mechanical properties. However, so far no work was carried out on the correlation between the diameter and the density of these fibers. Therefore, the objective of this work was to characterize the diameter of stripped bamboo fiber of the specimen dendrocalmus giganteus and to define by means of the Weibull statistic the diameter dependence of the density. The results haven't revealed an inverse correlation.
Key words: Bamboo fibers; Density; Diameter dependence; Weibull analysis.

ANÁLISE DE WEIBULL DA DENSIDADE DA FIBRA DE BAMBU DA ESPÉCIE DENDROCALMUS GIGANTEUS

Resumo

Várias vantagens econômicas, técnicas e ambientais justificam a substituição de fibras sintéticas por fibras naturais. No entanto, as fibras naturais obtidos a partir de plantas, também conhecidas como fibras lignocelulósicas, não apresentam a mesma uniformidade dimensional. Na verdade, elas apresentam grande dispersão de valores, em comparação com as fibras sintéticas. A espécie Dendrocalmus Giganteus de bambu gigante é famosa por sua resistência mecânica, e trabalhos têm sido realizados para avaliar suas propriedades mecânicas. No entanto, até agora nenhum trabalho analisou a correlação entre o diâmetro e a densidade destas fibras. Portanto, o objetivo deste trabalho foi caracterizar o diâmetro da fibra de bambu da espécie Dendrocalmus Giganteus e definir, por meio da estatística de Weibull, a dependência da densidade com o diâmetro. Os resultados não revelaram uma correlação inversa.
Palavras-chave: Fibras de bambu; Densidade; Dependência doe diâmetro; Análise de Weibull.

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[2] *Graduando, Eng. Metalúrgica e de Materiais. Lamav, CCT, Universidade Estadual do Norte Fluminense Darcy Ribeiro (UENF), Rio de Janeiro, Brasil.*
[3] *Eng. Eletricista. Pós-Doutorando, Eng. Metalúrgica, Lamav, CCT, UENF, Rio de Janeiro, Brasil.*
[4] *Eng. Metalúrgico, PhD, Professor Titular, Lamav, CCT, UENF, Rio de Janeiro, Brasil.*
[5] *Técnico em mecânica, Lamav, CCT, UENF, Rio de Janeiro, Brasil.*

1 INTRODUCTION

Bamboo is a well known grass-type plant with a hard and stiff stem or culm that can reach, in some species, more than 10 cm in cross section diameter and stand several meters height. Owing to its low density, approximately 0.9 g/cm^3, bamboo culms have been used in house construction from scaffoldings to panels. As an abundant natural resource in tropical and temperate regions, specially in Asia and South America, bamboo is also a substitute for wood and plastics in furniture and lightweight parts of automobile.[(1,2)] The cylindrical shape of the culm is, however, a limitation for its direct use in engineering systems. Consequently, research works have been conducted on bamboo fibers stripped off from the culm as reinforcement of polymer composites.[(1-12)] According to Shin et al.[(3)] bamboo fiber-epoxy laminates can be made into specific sizes and shapes, preserving the natural microstructural properties. These fiber composites overcome the limitation of the culm's cylindrical macrostructure. As a further advantage, Shin et al.[(3)] indicated that cracking and bioerosion caused by insect pests is prevented.
Works on the mechanical properties of polymer composites reinforced with culm-stripped bamboo fibers[(3-5,12)] reported mechanical strength and modulus that could vary significantly with the amount of incorporated fiber, the type of polymeric matrix and the fiber disposition (short-cut, continuous, aligned, mat-arranged). In spite of all these efforts, no investigation on the influence of the fiber diameter in the density has yet been carried out. Owing to the oriented lignocellulosic structure, as in other natural fibers,[(13-16)] it is relevant to investigate how the density of the bamboo fibers is affected by its cross section diameter.
Depending on the specialist ability and cutting technique, the manual culm stripping off process produces bamboo fibers with different diameters. Therefore, the objective of this work was to investigate the bamboo fiber density dependence on its diameter using a Weibull statistic analysis.

2 EXPERIMENTAL PROCEDURE

The basic material used in this work was the culm of bamboo (*Dendrocalmus Giganteus*) supplied by a producer of the north region of the state of Rio de Janeiro, southeast of Brazil. Large bamboo bushes (Figure 1a), occur naturally in the region. Fibers were manually stripped off from dried culms, Figure 1b with a sharp razor blade. The longitudinal direction of the fiber coincides with that of the culm and corresponds to the natural direction of the bamboo cellulose fibrils. Different cross section diameters were obtained (Figure 1c), in spite of the apparently uniform manual stripping procedure. From randomly selected 100 fibers, the equivalent diameter corresponding to the average between the larger and smaller (90º rotation) cross section dimensions at five locations for each fiber, was measured in a profile projector.

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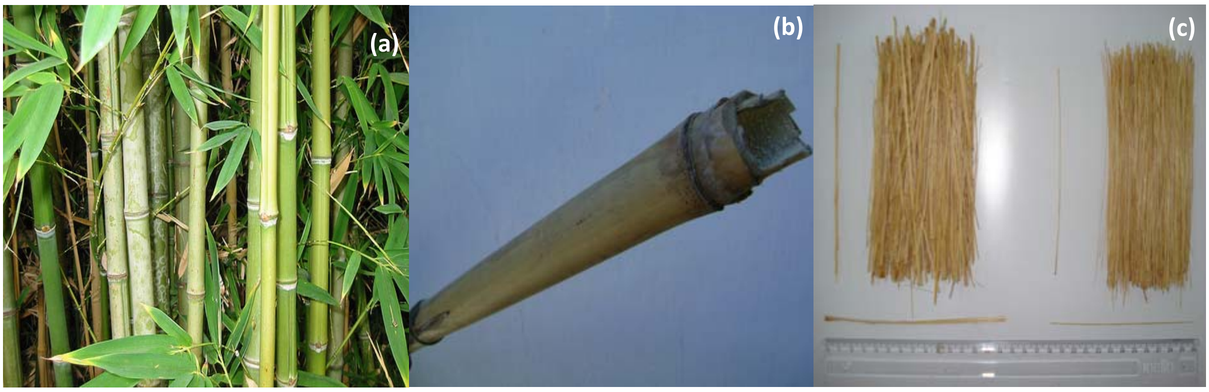

Figure 1. (a) Bamboo trees; (b) dried bamboo culm; and (c) its fibers longitudinally stripped with different diameters.

The histogram in Figure 2 shows the frequency of diameter distribution of stripped bamboo fibers used in the present work. Based on this histogram, an average diameter of 0.4 mm was calculated within the interval from 0.1 mm to 0.7 mm.
The as-stripped bamboo fibers (Figure 1b), were dried in a laboratory stove at 60 C for 24 hours to remove humidity. For each interval of equivalent diameter in Figure 2, 20 fibers were selected and their diameter and length was individually measured by profile projector machine model Pantec PJ3150 and their weight was measured in a precision balance in appropriated laboratory. As known, the natural fibers, basically, have a circular cross section, so, the density of each fiber was calculated considering a cylinder volume of the fibers, by the relation:

$$\rho = \frac{4m}{\pi d^2 l} \qquad (1)$$

Where: m = mass; d = diameter; l = length; and ρ = density.
Values obtained for the density were statistically interpreted by means of a *Weibull Analysis* computer program.

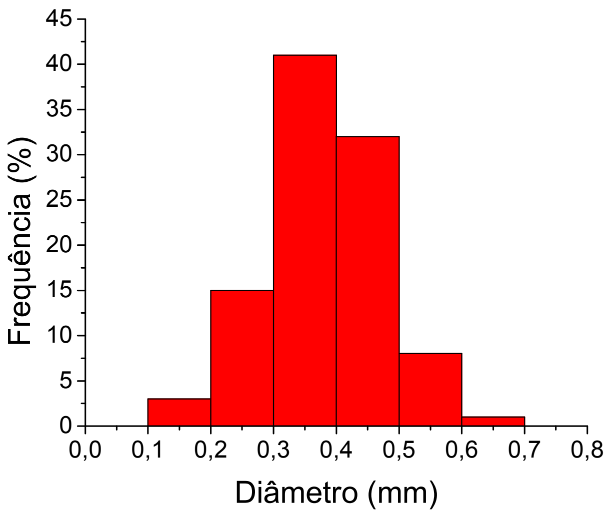

Figure 2. Distribution frequency for the stripped bamboo fibers equivalent diameter.

3 RESULTS AND DISCUSSION

Based on the values of weight and volume, one value of density was obtained for each fiber, and then these values were statistically analyzed by means of the Weibull

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method for the 20 fibers associated with each of the six diameter intervals shown in the histogram of Figure 2. The *Weibull Analysis* program provided the probability plots of reliability vs. location parameter shown in Figure 3 for all diameter intervals. Here it should be noted that all plots in Figure 3 are unimodal, i.e. with just one single straight line fitting the points at each interval. This indicates similar behavior of density of fibers within the same diameter interval.

In addition, the program also provided the corresponding characteristic density (θ), the Weibull modulus (β) and the precision adjustment (R^2) parameters. The values of these parameters as well as the average density and associated statistical deviations, based on the Weibull distribution, are presented in Table 1.

Table 1. Weibull parameters for the tensile strength of bamboo fibers associated with different diameters

Diameter interval (mm)	Weibull Modulus, β	Characteristic density, θ (g/cm3)	Precison Adjustment, R^2	Average density (g/cm3)	Statistical Deviation (g/cm3)
0.15	4,134	0,8865	0,8868	0,805	0,2192
0.25	4,571	0,9553	0,9515	0,8726	0,2169
0.35	5,506	0,8636	0,9639	0,7973	0,1672
0.45	5,307	0,8423	0,9676	0,776	0,1683
0.55	5,811	0,9489	0,8864	0,8787	0,1754
0.65	5,61	0,9997	0,9817	0,924	0,1905

The variation of the characteristic density with the average fiber diameter for each one of its intervals is presented in Figure 4. In this figure there isn't a regular tendency for the θ parameter to vary with the diameter of bamboo fiber. This means that density of that fiber is an undefined parameter, apparently presenting as random.

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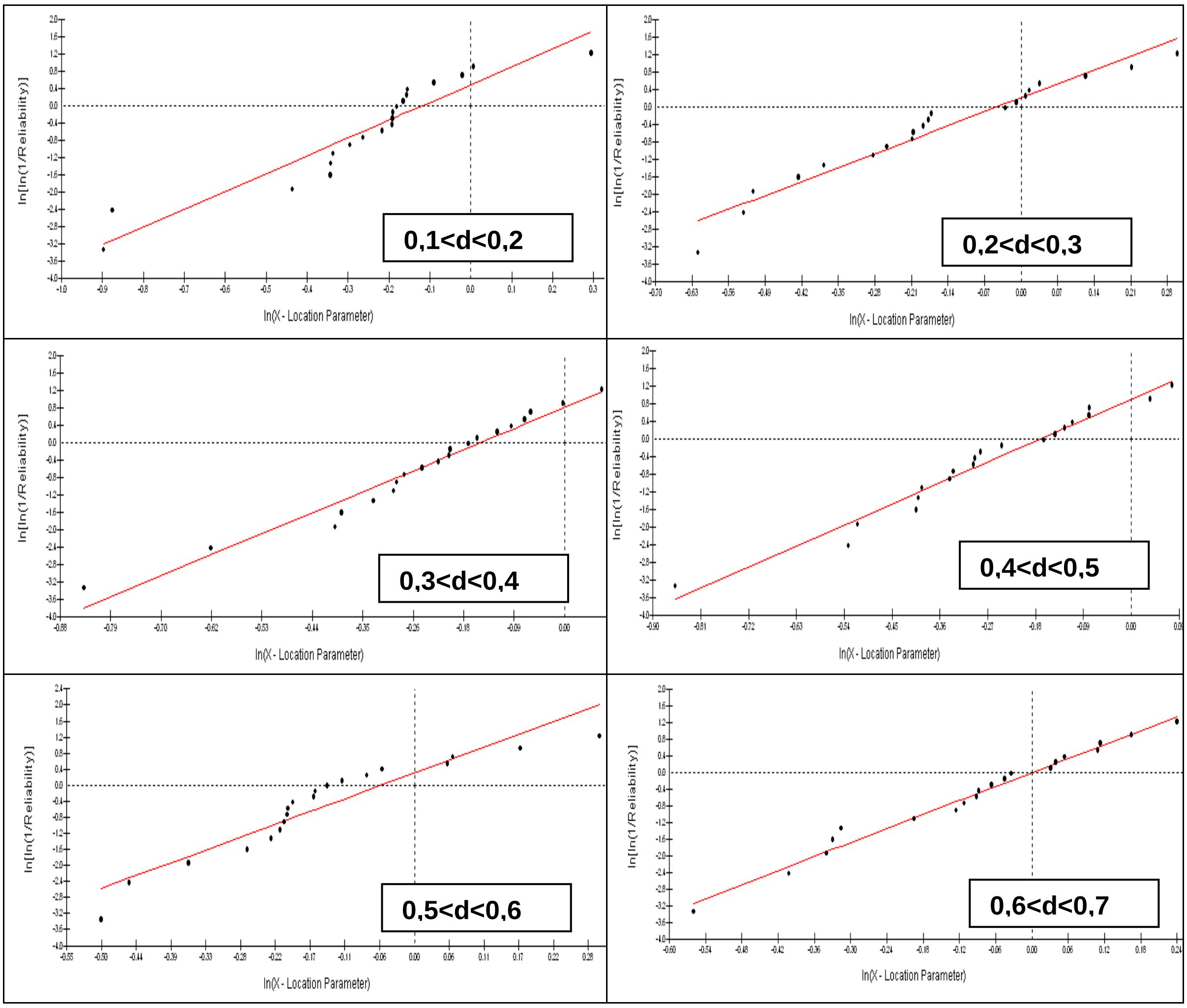

Figure 3. Weibull graphs for the different intervals in the histogram of Figure 2.

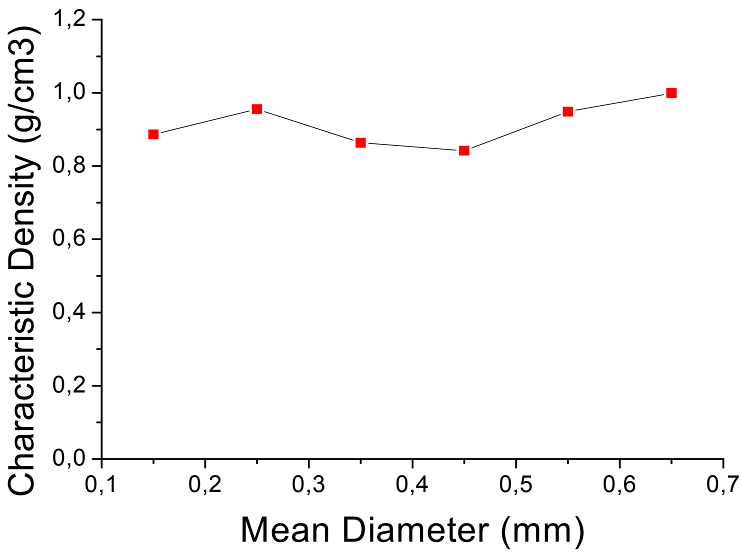

Figure 4. Variation of the characteristic density with the mean diameter for each interval in Figure 2.

In order to analyze better the physical meaning of the behavior of Figure 4, the average density evaluated in this work for the culm-stripped bamboo fibers was plotted as a function of the diameter in Figure 5. In this figure an independent correlation also exists between D and *d* where the error bars (statistical deviations) are too much close one to another, contemplating the values in the same interval, denunciating that the fibers have apparently the same density, independent from the diameter within the investigated limits. Here it is important to mention that these large dispersion (error bars) in the values of the density in Figure 5 is due to the heterogeneous characteristics and the randomly of the biological process of formation of any lignocellulosic fiber,(17) such as the bamboo in this work. As a consequence, it's only possible consider a horizontal line passing within the error bars as a better correlation between D and *d*, so, it's shown that the density would not vary with the diameter, presenting a unique value between 0,77 g/cm^3 and 0,93 g/cm^3. So, it is pertinent to consider that the values of D in Figure 5 are approximately constant, around 0,8423 g/cm3, for all of the fibers.

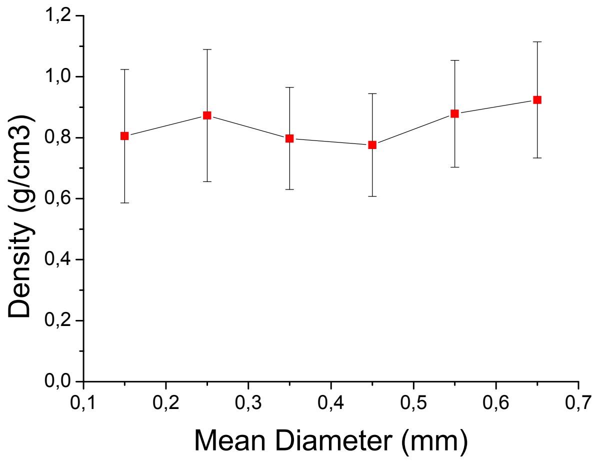

Figure 5. Variation of the average density with the diameter for each interval in Figure 2.

Based on Figures 4 and 5, it is suggested that these bamboo fibers (*Dendrocalmus Giganteus*), present a different behavior in the density comparing with others lignocellulosic fibers,(16,18) where a hyperbolic type of mathematical equation is the best statistical correlation between their properties.
As a final remark, it should be mentioned that the constant value of density of those bamboo fibers allow, in practice, a randomly selection of bamboo fibers to effectively reinforced polymer composites with improved mechanical properties, which makes that process much more easy.

4 CONCLUSIONS

- A Weibull statistical analysis of tensile-tested manually culm-stripped bamboo fibers revealed an independence between density and the fiber diameter;
- statistically, the organized distribution and formation of the structures of fibrils in different volumes of the fiber probably makes all fibers distribute themselves with the same relation, creating a uniform structured material.

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