EVALUATION OF THE DIAMETER INFLUENCE ON THE TENSILE STRENGTH OF PINEAPPLE LEAF FIBERS (PALF) BY WEIBULL METHOD.

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ABSTRACT

Natural fibers are nowadays substituting the synthetic fibers, owing mainly to environmental issues. The lack of uniformity and large dimensional dispersion in natural fibers is, however, a disadvantage for these substitutions. In the case of the fiber extracted from the Pineapple leaf, little is known about its properties and dimensional characteristics. This is a drawback in terms of the application of these fibers in composite materials. Therefore, the present work evaluated the tensile strength of PALF fibers as a function of their dimensional characteristics, particularly the equivalent diameter, using a statistic method based on the Weibull distribution. The diameter was measured with precision by a profile projector. Tensile tests were conducted for each individual fiber to determine the mechanical strength. The results, interpreted by the Weibull statistical method, showed a correlation between the fiber strength and its diameter.

Keywords: PALF fiber, tensile test, mechanical strength, Weibull statistic method.
INTRODUCTION

Composites are presently the faster growing materials with engineered combinations of properties that cannot be achieved by simple conventional ceramics, polymers or metallic alloys (1, 2). This is particularly the case components with special requirements for aerospace application (3). Modern aircrafts demand lighter, stronger, tougher and stiffer structural parts that can only be made with carbon fiber reinforced composites. The space shuttle is a high-tech example of a vehicle using different types of expensive composites including carbon fiber reinforcing pyrolized graphite matrix composites. Less expensive, glass fiber composite is also used interior components of aircrafts in addition to an extensive application in many other products, from surfboards to automobile components. All synthetic composites like the mentioned ones reinforced with carbon and glass fibers are, however, associated with environmental drawbacks. Their production is energy-intensive and they cannot be easily recycled. Moreover, glass fiber is related to health problems like lung diseases.

While it has not been possible to replace sophisticated carbon fiber composites by another material with comparable properties, natural fibers are successfully substituting glass fiber in common composites, mainly in the automobile industry (4,5). The reasons for this preference comprise not only environmental aspects but also economical and technical advantages. For instance, lignocellulosic fibers extracted from cultivated vegetables such as sisal, jute, banana, coir, flax, hemp and many others are already being used in common composites (6). These fibers are recyclable and do not require as much energy to be processed as the glass fiber. Furthermore, lignocellulosic fibers are less expensive, lighter and softer than the glass fiber (7).

Less known natural fibers like piassava (8), ramie (9), curaua (10) and buriti (11) are currently being investigated for their potential as composite reinforcement. PALF is certainly the lignocellulosic fiber with least knowledge as far as mechanical properties are concerned. Even review works on the application of natural fibers in composites (6, 12-14) fail to report on PALF fibers. Since the heterogeneous characteristics of lignocellulosic fibers is a limitation for their use in composites, the present work carried
out a statistical analysis on the mechanical properties of PALF fibers. This analysis was performed through precise geometrical measurements in association with tensile tests.

EXPERIMENTAL PROCEDURE

The basic material used in this work was untreated PALF showed in fig.1. Statistical analysis were performed on one hundred fibers randomly removed from the as-received the lot. These fibers were then measured in five different points along the length, and were 90° rotated to be measured again, assuming a cylindrical structure for the fibers. The rotation guarantees the correct values of the mean diameter for each fiber. Fig. 2 shows the histogram for the distribution of PALF diameters by considering 6 diameter intervals.

![Figure 1. A small bundle of PALF.](image)

. For each interval of equivalent diameter in Fig. 2, 20 fibers were selected. All these fibers were then individually tensile tested at 25 ± 2ºC in a model 5582 Instron machine. Specials grips were used to avoid both fiber slippage and damage. The test length was 10 cm and the strain rate 2.1x10⁻⁴s⁻¹. Values obtained for the tensile strength, i.e. the ultimate stress, were statistically interpreted by means of a Weibull Analysis computer program.
RESULTS AND DISCUSSION

Based on the maximum load, the tensile strength ($\sigma_m$) was determined for each fiber. The values of $\sigma_m$ were then statistically analyzed by means of the Weibull method for the 20 fibers associated with each of the seven diameter intervals shown in the histogram of Fig. 2. The Weibull Analysis program provided the probability plots of reliability vs. location parameter shown in Fig. 3 for all diameter intervals. Here it should be noted that all plots in Fig. 3 are unimodal, i.e. with just one single straight line fitting the points at each interval. This indicates similar mechanical behavior of fibers within the same diameter interval.
In addition, the program also provided the corresponding characteristic stress ($\theta$), the Weibull modulus ($\beta$) and the precision adjustment ($R^2$) parameters. The values of these parameters as well as the average mechanical strength and associated statistical deviations, based on the Weibull distribution, are presented in Table 1.

Table 1. Weibull parameters for the tensile strength of PALF fibers associated with different diameters.
The variation of the characteristic stress with the average fiber diameter for each one of its intervals is presented in Fig. 5. In this figure there is a tendency for the θ parameter to vary inversely with the average PALF fiber diameter. This means that the thinner the fiber the higher tends to be the characteristic stress. Furthermore, the corresponding values of β and R², shown in Table 1, statistically support the inverse correlation between θ and the average diameter d (mm). By means of a mathematic correlation, a hyperbolic type of equation was proposed to fit the data in Fig. 4.

\[ \theta (\text{MPa}) = \frac{12.7}{d} + 34.7 \]  

(A)

Figure 4. Variation of the characteristic tensile strenght with the mean diameter for each interval in Fig.2.

In order to analyze the physical meaning of Eq. (1), the average tensile strength, \( \bar{\sigma}_m \), evaluated in this work for the PALF was plotted as a function of the diameter in Fig. 5. In this figure an apparent hyperbolic inverse correlation also exists between \( \bar{\sigma}_m \) and d within the error bars (statistical deviations) and investigated limits.

\[ \bar{\sigma}_m = \frac{11.9}{d} + 31.6 \]  

(B)
Here it is important to mention that the large dispersion (error bars) in the values of the tensile strength in Fig 5 is due to the heterogeneous characteristics and the randomly of the biological process of formation of any lignocellulosic fiber \(^{(17)}\), such as the PALF fibers in this work. As a consequence, one could also consider a hyperbolic line passing within the error bars as a possible correlation between \(\bar{\sigma}_m\) and \(d\). In this case, the tensile strength vary with the diameter. However, the variation of \(\theta\) with \(d\) in Fig. 5, suggests that an inverse correlation fits better the experimental results for the PALF fibers.

**Figure 5.** Variation of the average tensile strength with the diameter for each interval in Fig.2.

Based on Eq. (A) and (B) it is suggested that, as in others lignocellulosic fibers \(^{(15,16)}\), a hyperbolic type of mathematical equation is the best statistical correlation between the tensile strength and the diameter of PALF.

Finally, the filamentary nature of the PALF could also be responsible for the results in Fig. 5. As illustrated in Fig. 6, the thicker the PALF, the less compact is its microstructure. In other words, the thinner fibers tend to be more uniform with more close packed filaments. This contributes to resisting areas with less empty spaces and, consequently, higher stresses.
Figure 6. Microstructure of the PALF fiber: (a) 200X and (b) 1600X.

As a final remark, it should be mentioned that an inverse correlation such as that in Eq. (B), could allow, in practice, a selection of stronger thinner PALF fibers to effectively reinforced polymer composites with improved mechanical properties.

CONCLUSIONS

- A Weibull statistical analysis of tensile-tested PALF fibers revealed an inverse correlation between the tensile strength and the fiber diameter.
- This correlation indicates a possible hyperbolic mathematical equation to PALF fibers.
- SEM observations provided evidences that a thicker PALF fiber, with more fibrils than a thinner one, could undergo rupture at a comparatively lower stress.
- Statistically, the larger distribution of fibrils mechanical resistances of the thicker fiber allows a weaker fibril to rupture shortly than any of the fewer fibrils of the thinner fiber.

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REFERENCES


