CORRELATION BETWEEN THE DIAMETER AND THE DENSITY OF HEMP FIBER USING THE WEIBULL STATISTIC METHODOLOGY

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ABSTRACT

Economical, technical and environmental advantages justify the substitution of glass fiber for lignocellulosic fibers in polymeric composites. However the uniformity of the glass fiber dimensions and composition contrast to the lignocellulosic fibers heterogeneity. In this work, a statistical analysis of the correlation between the diameter and the density of hemp fiber using the Weibull methodology was performed. The diameter was obtained by profile projector measurements, while the density used precise determinations of the fibers mass and volume. The results revealed an inverse dependence between the hemp fiber diameter and its density.

Key words: Hemp fiber, Weibull methodology, Diameter, Density.

INTRODUCTION

In recent years, there has been an increase application of natural fibers as reinforcement of polymer matrix composites in several industrial sectors, with special participation in automobile components (1-3). In fact, not only environmental benefits are motivating the substitution of natural fibers for glass fiber in polymer composites(4), but also technical, economical and societal advantages(5). A number of reasons favor the use of natural fibers, mainly those obtained from cellulose-based vegetables, also known as lignocellulosic fibers. The motivation to perform the correlation between density and diameter is that a previous work, which was carried out using a Weibull statistical analysis, found an inverse relationship between the
tensile strength of hemp fibers with their diameters\(^6\). Furthermore, a recent work correlated the density and the diameter for bamboo fibers \(^7\).

The lignocellulosic fiber for this work was extracted from the plant \((Cannabis sativa)\). Such fibers have been incorporated into polymer composites to manufacture industrial components, especially in the automotive industry as car dashboards and stuffing. The dimensional heterogeneity and the large dispersion of the values of the diameter of lignocellulosic fibers are limitations to its use in composites \(^8\)-\(^10\), this study conducted a statistical analysis by Weibull \(^11\), on the influence of diameter in resistance traction of hemp fibers.

**EXPERIMENTAL PROCEDURE**

The basic material used in this work was untreated hemp fiber. Statistical analysis were performed on one hundred fibers randomly removed from the as-received lot. These fibers were then measured in ten different points along the length, and were 90\(^\circ\) 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. Figure 1 shows the histogram for the distribution of hemp fiber diameters by considering 6 diameter intervals. From this distribution, presented elsewhere\(^6\) an average diameter of 0.065mm was found for the as-received lot.

![Histogram of hemp fiber diameters](image)

**Figure 1.** Histogram of the frequency of the hemp fiber for each diameter interval.

After the statistical analysis, each diameter interval was completed with 20 or more fibers for density measurements that would allow a Weibull analysis. Table 1 presents the number of hemp fiber measured in each diameter interval.
Table 1. Diameter intervals and number of fibers obtained for density measurements.

<table>
<thead>
<tr>
<th>Diameter interval (mm)</th>
<th>Number of fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.035&lt;d&lt;0.045</td>
<td>20</td>
</tr>
<tr>
<td>0.045&lt;d&lt;0.055</td>
<td>20</td>
</tr>
<tr>
<td>0.055&lt;d&lt;0.065</td>
<td>24</td>
</tr>
<tr>
<td>0.065&lt;d&lt;0.075</td>
<td>23</td>
</tr>
<tr>
<td>0.075&lt;d&lt;0.085</td>
<td>7</td>
</tr>
<tr>
<td>0.085&lt;d&lt;0.095</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 2 shows a small amount of hemp fiber with different diameters, which were used in this work. These hemp fibers were dried at 60°C in a stove for 24 hours to remove humidity.

Figure 2. A small bundle of hemp fibers.

For each interval of equivalent diameter in Table 1, the selected hemp fibers had their diameter and length individually measured using a model PANTEC PJ3150 profile projector and each was weighed in a precision balance. The density of each fiber was then calculated considering a cylindrical volume of the fibers, by the relationship:

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

Where: m – mass; d – diameter; l – length; \(\rho\) – density.
RESULTS AND DISCUSSION

Based on the values of weight and volume, an average value of density was obtained for each fiber. These values were statistically analyzed by means of the Weibull method for at least 20 fibers associated with each of the seven diameter intervals. The Weibull Analysis program provided the probability plots of reliability vs. location parameter shown in Fig. 3 for all diameter intervals.
Figure 3. Weibull graphs for the different diameter intervals.

Here it should be noted that not all plots are unimodal, i.e., with just one single straight line fitting the points at each interval. This may indicate distinct behaviors for the density of hemp fibers within the same diameter interval. In spite of this small Weibull discrepancy inside the diameter intervals, only one straight line was assign for each graph. Based in these straight lines, the program provided the corresponding characteristic density ($\theta$), the Weibull modulus ($\beta$) and the precision
adjustment ($R^2$) parameters. The values of these parameters as well as the average density and associated statistical deviations, taking into account the Weibull graphs in Fig. 3, are presented in Table 2.

Table 2. Weibull parameters for the density of hemp fibers associated with the different diameter intervals.

<table>
<thead>
<tr>
<th>Diameter interval (mm)</th>
<th>Weibull Modulus, $\beta$</th>
<th>Characteristic density, $\theta$ (g/cm$^3$)</th>
<th>Precision Adjustment, $R^2$</th>
<th>Average density (g/cm$^3$)</th>
<th>Statistical Deviation (g/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.035&lt;d&lt;0.045</td>
<td>9.833</td>
<td>1.266</td>
<td>0.9177</td>
<td>1.204</td>
<td>0.1471</td>
</tr>
<tr>
<td>0.045&lt;d&lt;0.055</td>
<td>5.021</td>
<td>1.086</td>
<td>0.9480</td>
<td>0.9974</td>
<td>0.2276</td>
</tr>
<tr>
<td>0.055&lt;d&lt;0.065</td>
<td>6.865</td>
<td>0.887</td>
<td>0.9596</td>
<td>0.8295</td>
<td>0.1419</td>
</tr>
<tr>
<td>0.065&lt;d&lt;0.075</td>
<td>7.319</td>
<td>0.9601</td>
<td>0.9600</td>
<td>0.9002</td>
<td>0.1451</td>
</tr>
<tr>
<td>0.075&lt;d&lt;0.085</td>
<td>5.912</td>
<td>0.7993</td>
<td>0.9242</td>
<td>0.7409</td>
<td>0.1455</td>
</tr>
<tr>
<td>0.085&lt;d&lt;0.095</td>
<td>5.266</td>
<td>0.9133</td>
<td>0.9376</td>
<td>0.8411</td>
<td>0.1837</td>
</tr>
</tbody>
</table>

The variation of the characteristic density with the average fiber diameter for each one of its intervals is presented in Fig. 4. This figure presents a regular tendency for the $\theta$ parameter to vary with the inverse of the hemp fiber diameter. This means that the density of the hemp fiber holds an inverse correlation with the fiber diameter. This correlation adjusts to a hyperbolic equation of the type:

$$\theta = 0.029/d + 0.503$$  \hspace{1cm} (2)

From the Table 2 it is also possible to plot the graphs for the average density against the diameter, shown in Fig. 5. This figure confirms the inverse correlation between the density and the diameter found in Fig. 4. However, the corresponding mathematical adjustment provides the following hyperbolic equation:

$$\rho =0.029/d + 0.44$$  \hspace{1cm} (3)
Figure 4. Variation of the hemp fiber characteristic density, $\theta$, from the Weibull analysis with the corresponding diameter.

Figure 5. Diameters of the hemp fibers and their respective average densities.
A comparison between Eq. (2), Fig. 4, and Eq. (3), Fig. 5, indicates a definite tendency for the hemp fiber density to markedly vary with the inverse of the fiber diameter.

CONCLUSIONS

- The analysis of more than 100 fibers of hemp showed an inverse dependence between the density and fiber diameter, so that the larger the diameter the lower the density.
- The Weibull analysis show some inconsistency on the unimodal graphs construction that can be attributed to large dispersion of natural fibers. In hemp fibers, flaws and defects are present in large quantities, because its structure and composition.
- Statistically, the organized distribution and structure formation for the fibrils creates this kind of mechanism and reaction.

REFERENCES
