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LETTER

Uniformity of filament strength within a flax fiber batch

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Natural fibers are known to exhibit higher scatter of their mechanical properties than the synthetic ones. Fiber variety and agronomic practice [1], retting method [2], fiber location in the stem [3], as well as the presence [4] and amount of kink bands [5] in a fiber are shown to affect the strength of elementary flax fibers. The Weibull two-parameter distribution

$$P(\sigma) = 1 - \exp\left[-\left(\frac{\sigma}{\beta}\right)^{\alpha}\right] \quad (1)$$

is found to sufficiently accurately represent the fiber strength scatter at a fixed gauge length [6]. In Eq. 1, the Weibull scale and shape parameters are designated by β and α, respectively. When characterizing the strength and stiffness parameters of a fiber batch, the fibers for testing may come from only one location in the batch. Such data are normally representative for synthetic fibers due to uniformity of the batch ensured by the manufacturing process. In order to check the uniformity of fiber strength in a natural fiber batch, we tested fibers taken from different locations in a batch and subjected the results to statistical analysis.

The fibers produced by Ekotex (Poland) were tested. The test procedure of ASTM D 3379-75 Standard was followed. First, flax slivers were collected from three different locations of a fiber batch. The fibers were supplied in batches of 50 g. The material was packed in a plastic bag of approximate dimensions $150 \times 150 \times 50$ mm^3. The fiber samples were picked from the batch at roughly the same, largest possible within this volume of material, distance from each other. Single fibers were manually separated from fiber bundles. Fiber ends were glued onto a paper frame so that free fiber length amounted to 10 mm. Tension tests were carried out on an electromechanical tensile machine equipped with mechanical grips. During mounting, the specimens were handled only by the paper frame. Upon clamping of the ends of the paper frame by grips of the test machine, both sides of the frame were carefully cut in the middle. The tests were displacement-controlled with the loading rate of 1 mm/min. Fiber diameter was evaluated by optical microscopy, as the average of five apparent diameter measurements at different locations along the fiber.

For one of the locations within the flax fiber batch, the number of tests suggested by the standard ($\sim$50) was performed, while smaller number of fibers for testing was collected at the other two locations. The test results are shown in Table 1 and the empirical distribution functions plotted in Weibull co-ordinates in Fig. 1. The fracture probabilities here and in the following are evaluated via the median rank of the measured strength values using the following approximation

$$P = \frac{i - 0.3}{n + 0.4} \quad (2)$$

where i is the i-th number in ascendingly ordered strength data of the sample and n is the sample size (i.e., number of tests performed on fibers collected at the given location). It is seen that the means and standard deviations (STD) of strength exhibit little variation, and the distributions are quite close for most of the data range. Therefore we assume that the data sets come from the same distribution, and check this null hypothesis by a non-parametric test.

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Table 1 Mean value and standard deviation of fiber strength at different locations of batch

Location	Number of tests	Mean strength (MPa)	Strength STD (MPa)	$\|z\|$
1	49	721	267	–
2	19	741	344	0.33
3	18	704	290	0.01
Pooled	86	722	287	–

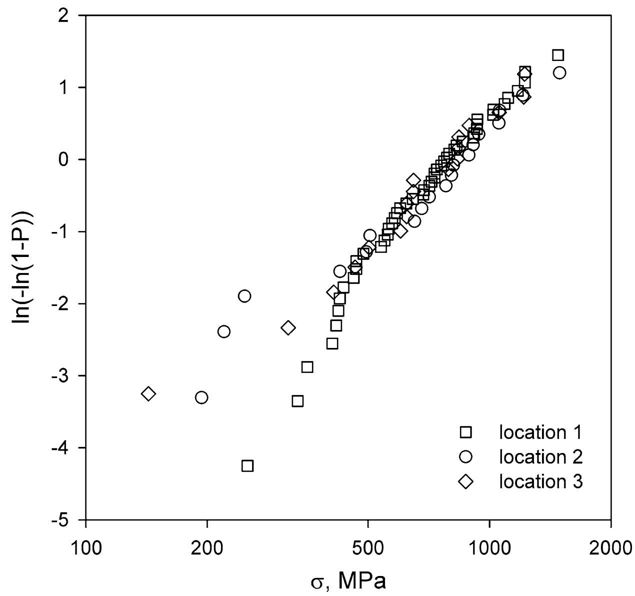

Fig. 1 Flax fiber strength distributions from three locations in the fiber batch, plotted in Weibull co-ordinates

We apply Mann-Whitney U test of rank sums (see e.g. [7]) used to assess if two samples come from the same distribution. The test is applied to strength data derived from locations 1 and 2, and locations 1 and 3. Test results from each of the two independent samples mentioned are first combined listing them in rank order. Then the value of test statistic U is determined as the number of times strength values in one sample precede those in the other sample in the ranking. It has been shown that for sufficiently large samples the distribution of U when null hypothesis is true becomes asymptotically normal with mean

$$\bar{U} = \frac{n_1 n_2}{2}$$

and standard deviation

$$s_U = \sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}}$$

where n_1, n_1 are the respective sample sizes (the numbers of fiber tests at each location). Then statistic

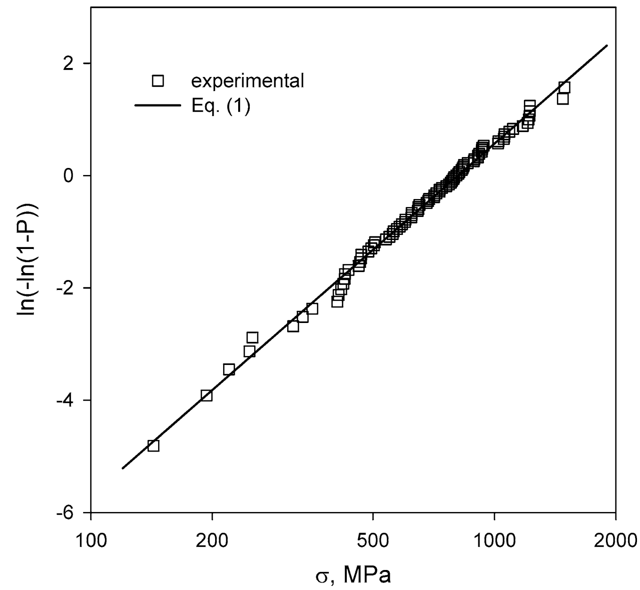

Fig. 2 Flax fiber strength distribution based on pooled data (markers) and Weibull distribution Eq. 1. The parameters of Eq. 1 are determined by MLM

$$z = \frac{U - \bar{U}}{s_U} \tag{3}$$

has a unit normal distribution (i.e., with zero mean and unity STD). Absolute value of z less than 1.96 indicates that the two samples come from the same distribution, at the 0.05 significance level, for a two-tailed test. z values calculated by Eq. 3 and presented in Table 1 show that the test criterion is met; hence null hypothesis is not rejected. Thus, we conclude that fiber strength distribution in the flax fiber batch can be considered uniform.

Pooling the strength data from all three locations considered and determining distribution Eq. 1 parameters by the maximum likelihood method (MLM), we obtain $\alpha = 2.7$ and $\beta = 812$ MPa. Empirical distribution of the pooled strength data (obtained using the combined strength data set with $n = 86$ and Eq. 2, as described above) is plotted in Fig. 2 along with Eq. 1 employing the parameter values obtained. The agreement of the graphs suggests that the flax fiber strength possesses the two-parameter Weibull distribution.

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