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MECHANICAL PROPERTIES OF FLAX FIBRES

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A b s t r a c t. The applicability of stress relaxation measurement for describing the mechanical properties of flax fibres has been studied. The curves of measured values have been fitted by of a logarithmic relaxation equation, which already has proved successfull with a series of organic substances.

K e y w o r d s: flax fibres, mechanical properties

INTRODUCTION

The fibre flax belongs to those crops currently under intensive investigation for their technological applicability. Flax fibres can be used as row materials for fabric as well as filler for plastics and resins. In each case the most accurate measurement of their mechanical properties is required. This refers to the fibre strength, which is made up of the strength of the single fibre bunch. This also refers to such difficult--to-define properties like suppleness or suitability for spinning [1].

As measuring method the stress-strain measurement is used most, either on conventional material testing machines or on special devices like the Stelometer [2].

THEORY

A general objection against stress-strain measurement of agricultural materials is its mobility to their visco-plastic behaviour, which always overlaps the - normally predominant - elastic material properties. This is valid for the flax fibres under investigation too, as can be seen from Fig. 1 (in the pure elastic case the curve must not show hysteresis).

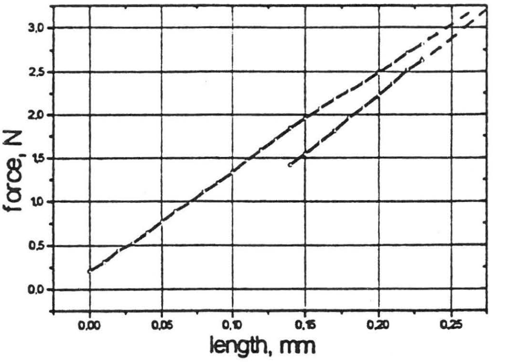

Fig. 1. Force-elongation-diagram of flax fibre (variety Marina, exp. No. 0007). Test data: maximal force 3 N, deformation speed 0.4 mm/min, load range 50 N.

A measuring method which besides stress and strain explicitly includes the time lets expect the more exact values right from the beginning. For this purpose the stress relaxation is a suitable and often used method. Here the test specimen will be linearly deformed and after stopping the test machine the stress built up in the specimen will be recorded as a function of time, producing a monotonic decreasing function (Fig. 2).

This curve completely represents the complex visco-elastic-plastic material behaviour. The essential thing now is to extract the contained material parameter by means of a suitable approach. An often used way is

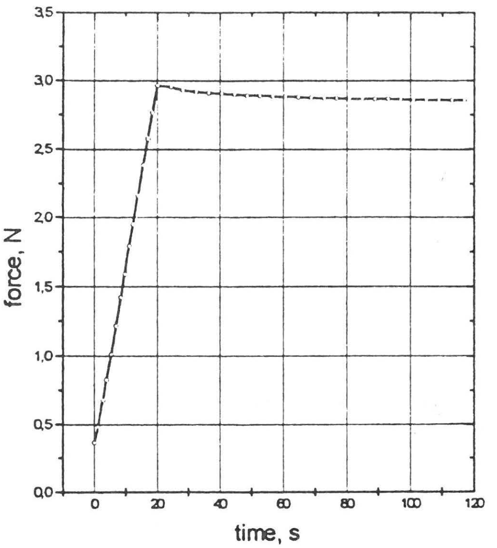

Fig. 2. Stress relaxation in flax fibres (variety Marina, experiment No. 0003) Test data: initial load 3 N, deformation speed 0.4 mm/min, time basis 100 s, load range 50 N.

fitting the relaxation curve by a sum of exponential functions. We used a logarithmic function in the following form:

$$\frac{F}{F_0} = 1 - \frac{1}{C} \ln (bt + 1) \qquad (1)$$

where F - force, F_0 - initial force, t - time, C,b - relaxation coefficients.

The logarithmic approach delivers with a smaller number of parameters equally good, mostly better results then the exponential sum method [3].

The logarithmic approach is based on the reaction-rate theory, which describes deformation processes by means of the thermal activated flow of microscopic structures under external mechanical stress. Besides an exact fitting of the relaxation curves this approach allows because of its physical background under certain circumstances a more far reaching interpretation of the occurring deformation processes, too (cf. [3], p. 54). In each case it avoids inaccuracies inevitably caused by ignoring the time dependence in the stress-strain experiment.

MATERIALS AND METHODS

The investigations were aimed at testing the applicability of the stress relaxation method to examine the mechanical properties of flax fibres. To this end some test measurements of flax, variety Marina were carried out on a Zwick material testing machine.

The deformation speed was adjusted to 0.4 mm/min, the initial force of relaxation was 3 N, resulting in a strain of approximately 0.5...1 %. The samples were natural fibres of 25 mm length and an estimated diameter of 50...180 μm, which were clamped into the grips as gently as possible. In order to avoid premature rupture 10 fibres were measured.

The force-time curves at constant strain (relaxation curves) have been linearized and the relaxation coefficients C and b calculated by linear regression analysis (Fig. 3).

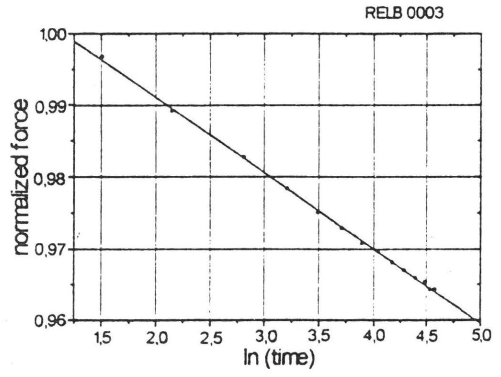

Fig. 3. Normalized stress relaxation curve of flax fibre with regression line (variety Marina, experiment No. 0003). Linear regression data: Y=A+B·X, A= 1.01211, B=- 0.01052, R=- 0.99959.

From the relaxation coefficients the Young's modulus of the fibres was calculated using the following equation (cf. [3], p.18):

$$M = \frac{b \cdot \sigma_0}{C \cdot \dot{\varepsilon}_A} \qquad (2)$$

with C, b - relaxation coefficients, σ_0 - initial stress, $\dot{\varepsilon}_A$ - deformation speed and compared with that value, which was calculated from the deformation phase of the relaxation experiment, i.e., from the stress-strain experiment.

Finally a correction was done taking into account the stiffness of the testing machine (Fig. 4; cf. [3], p.54).

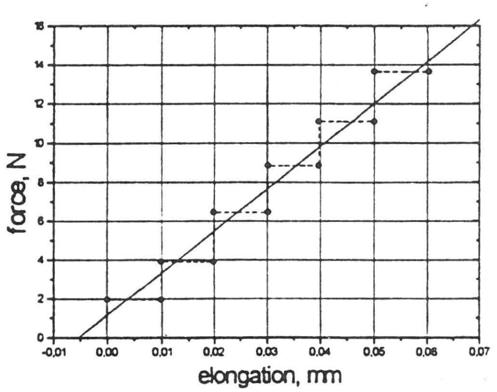

Fig. 4. Force-elongation-diagram of the Zwick testing machine (Institut für Landtechnik, Bonn). Test data: maximal force 14 N, load range 50 N, deformation speed 0.04 mm/min, minimal length resolution 0.01 mm.

RESULTS AND DISCUSSION

The results of the linear regression analysis are shown in Table 1. The high correlation coefficients indicate the good fitting of the selected approach into the measured values.

Table 1. Results of linear regression analysis. Y=A+B X (for A, B cf. Eq. (3))

Experiment No.	A	B	R
1	1.00902	-0.00856	-0.99425
2	1.01155	-0.01171	-0.99879
3	1.01211	-0.01052	-0.99959
4	1.00621	-0.00768	-0.99932
5	1.00166	-0.00791	-0.99932
6	1.00165	-0.00726	-0.99675
7	1.00588	-0.00741	-0.99685
8	1.01052	-0.00810	-0.99531
9	1.00782	-0.00979	-0.99785
10	1.00960	-0.01521	-0.99922

The relaxation coefficients C, b result from the regression analysis as follows:

$$C = -\frac{1}{B}$$

$$b = e^{C(1-A)} \qquad (3)$$

where A, B regression coefficients (Table 1) and are in the order of: C=95.06 and $b=0.3163\ s^{-1}$(experiment No. 003).

Since for linearizing the relaxation curves instead of Eq. (1):

$$\frac{F}{F_0} \approx 1 - \frac{1}{C} \ln (bt) \qquad (4)$$

was used, in order to fulfil the then necessary condition $b \cdot t \gg 1$ the first measured values from the beginning of the relaxation curve should not be included in the calculation (depending on the actual value of b).

The most exact measurement of the initial force F_0 is also important for the accuracy of the relaxation coefficients (esp. b).

The Young's modulus was calculated from the relaxation coefficients according to Eq. (2) estimating the fibre diameter to 50...180 μm. Its value is in the order of $1.8 \cdot 10^{10}..1.4 \cdot 10^{9}$ N/m^2, depending on the estimated diameter.

This however, does not produce the expected correspondence with the modulus calculated from the stress-strain diagram, showing values from $2.4 \cdot 10^{11}...1.8 \cdot 10^{10}$ N/m^2. The reasons for this deviation have to be investigated more closely.

For all measurements using material testing machines it has to be taken into consideration that specimen and gauge are in serial connection. Therefore the measured deformation (strain) has to be reduced by the amount of elastic deformation of the testing machine in order to get exact values for the Young's modulus of the material under investigation. This particularly applies to firm materials and low load ranges. In case of the flax fibres under investigation the calculated correction of the Young's modulus amounted to -8.5 % and is therefore no negligible quantity.

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