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Tensile Strength of Untwisted Fibre Streams Measured at Dynamic Conditions

Abstract
The tensile strength of cotton sliver was analysed under dynamic conditions with the use of an F460 Stick-Slip Friction Tester apparatus from the Zweigle company. In order to obtain measuring data, the fibre stream is directed through the drawing apparatus at constant velocity and constant drawing ratio. Changes in the force created as a result of drawing the fibre stream were continuously recorded with the use of a measuring gauge placed between the pair of drawing rollers. For the purpose of this investigation, the tests were carried out after the second drawing zone for a sliver of central-Asiatic cotton with linear density of 3.4 ktex.

Key words: *cohesion of fibres, unit cohesion, tensile force, tensile strength of the sliver.*

Introduction

The tensile strength of an untwisted fibre stream is an important parameter, because maintaining its appropriate value at the accepted technological conditions prevents uncontrolled drawing from occurring over the whole technological process. Opposition to the tensile strength applied to the fibre stream comes from friction forces acting between fibres.

The anisotropic, visco-elastic character of the fibre material causes fibre friction not to satisfy the classical law of Amonton-Coulomb [1] which is characterised by the feature that the friction coefficient μ is a constant value:

$$T = \mu \cdot N \quad (1)$$

where:
T - friction force,
N - force of normal pressure.

The character of the mechanical properties of the fibre material causes the friction coefficient to depend on the value of the normal pressure force, the value of the area of the acting fibre surfaces, and their sliding velocity [1]. Therefore the majority of researchers publish the equation determining the friction force in the following form:

$$T = H + \mu \cdot N \quad (2)$$

where:
H - cohesion of fibres.
According to Kragielski [1], those friction forces which are independent on the force of normal pressure are called cohesion, whereas those friction forces which depend on this force are called forces of the sliding friction.

The dependence of friction forces on the forces of normal pressure is presented in Figure 1. The segment AB characterises the cohesion H of fibres that, as can be seen, is independent of the forces of normal pressure. The segment BC is a visualisation of the equation $T=\mu N$, and depends on the fibre friction coefficient $\mu = tg\gamma$.

In an untwisted fibre stream, the force of normal pressure equals zero or has a value near zero; thus the friction force which arise during fibre sliding depends almost entirely on the cohesion H of fibres, which as seen in Figure 1 is constant.

Monfort [2] analysed the phenomena occurring during the drawing of an untwisted fibre stream (Figure 2), and distinguished some drawing zones in the breaking force-elongation curve:

- Segment OA - the fibres do not slide in relation to each other, and the fibre stream is tensioned. The abscissa a_f is equal to 20% of the maximum sliding elongation, whereas the ordinate F_f is about 30% of the maximum force F_{max}.
- Segment AB - as before, the fibres further do not slide to each other. This segment is approximately a straight line and is related to the area of Hook's law. The co-ordinates a_h and F_h are equal to 75% of the sliding elongation and 80% of the maximum force.
- Segment BC is the beginning of fibre sliding; the fibres move in relation to each other up to the moment when they achieve the breaking zone.
- Segment CD - beginning from point C the tensile force decreases. The progress of the curve is often irregular, which is characteristic of the phenomenon of fibre sliding. In this zone the number of fibres which are in mutual contact decreases down to the final extension which corresponds with the sliver's break.

According to Budnikow [1], the cohesion of fibres can be presented as:

$$H = h \cdot \lambda \quad (3)$$

where:
H - cohesion of fibres in cN,
h - unit cohesion of fibres in cN/mm, and
λ - average length of the sliding fibre ends during sliver drawing, in mm.

The analysis of the phenomenon of fibre sliding in relation to each other can be carried out on the basis of the drawing process of an untwisted stream of fibres (of the sliver) [3,4]. However, the assumption should be accepted that all fibres have the same lengths equal to the average fibre length l. If two forces F, equal and sufficiently high, acting in opposite directions are applied to the sliver, then in the cross-

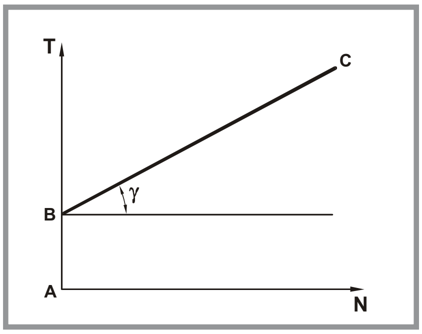

Figure 1. Friction force in dependence on normal pressure [1].

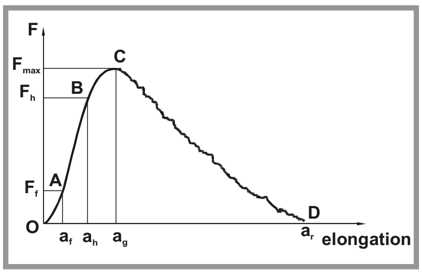

Figure 2. Breaking force in dependence on elongation of the untwisted fibre stream.

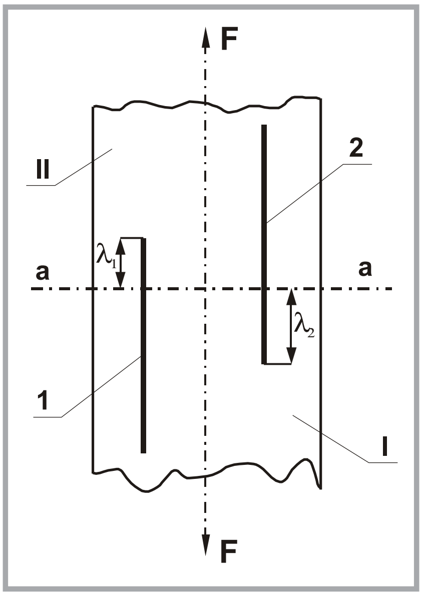

Figure 3. *Fibre sliding during drawing of an untwisted fibre stream.*

section a-a of the fibre stream (shown in Figure 3) a mutual sliding of fibres occurs.

All fibres which pass through the cross-section a-a can be divided into two parts. This fibres presenting by fibre 1 (in Figure 3) and which have their longer segments in the lower part of the sliver (I) slide with their shorter ends λ_1 in relation to the fibres consisting of the sliver part II. Those fibres presented by fibre 2 move to the upper part of segment II, and slide with their shorter ends λ_2 in relation to the fibres remaining in the lower part I. When the unit cohesion between any fibre is equal to h, than the quantity of force F_1, which has to be applied to the fibre 1 to draw out its shorter end λ_1 from between the other fibres surrounding it, must surmount the cohesion H_1 of the fibres:

$$F_1 = H_1 = h \cdot \lambda_1 \qquad (4)$$

The total force F for all fibres that move through the cross-section a-a, which must be applied to achieve the displacement of these fibres, is equal to the sliver's tensile strength, and equals:

$$F = \sum_{i=1}^{n_w} F_i = \sum_{i=1}^{n_w} h \cdot \lambda_i \qquad (5)$$

where:
F - the tensile strength of the fibre stream in cN, and
n_w - the number of fibres in the cross-section of the fibre stream.

The length of the sliding fibre ends λ_i can change within the range from 0 to l/2. On the assumption that all fibres have the same length l, and that in every selected cross-section of the fibre stream a constant number of fibre ends exists, the average value of the sliding fibre ends equals 0.25 l. In this case, the tensile strength of the untwisted fibre stream is described by the equation:

$$F = 0.25 \cdot h \cdot l \cdot n_w \qquad (6)$$

Considering the number n_w of fibres in the cross-section of the fibre stream as the ratio of the particular linear densities Tt_{sw} and Tt_w, equation (6) can be transformed into equation (7):

$$F = \frac{0.25 \cdot h \cdot l \cdot Tt_{sw}}{Tt_w} \qquad (7)$$

where:
Tt_w - linear density of the single fibres,
Tt_{sw} - linear density of the fibre stream,
l - average fibre length.

As can be seen from equations (6) and (7), the tensile strength of an untwisted fibre stream depends on the unit cohesion of the fibres, the average fibre length and the number of fibres in the cross-section of the fibre stream.

Aim and Subject of Investigation

The aim of these investigations was to estimate the influence of the F460 Stick-Slip Friction Tester apparatus's working parameters on the value changes of the sliver's drawing forces. The subject of our investigation was an analysis of the tensile strength of a cotton sliver measured under dynamic conditions with the use of the F460 Stick-Slip Friction Tester. The tests were carried out for a sliver with a linear density of 3.4 ktex, consisting of central-Asiatic cotton with fibres of 24.5 mm length and a linear density of 1.7 dtex. The data were obtained after the second drawing zone.

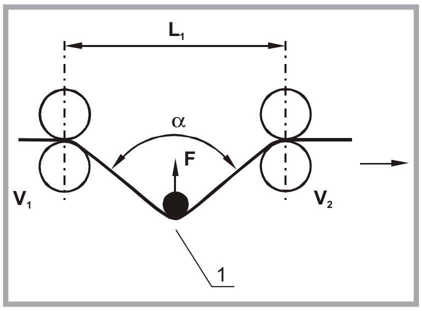

Figure 4. *Schema of the drawing apparatus with measuring roller of the F460 Stick-Slip Friction Tester.*

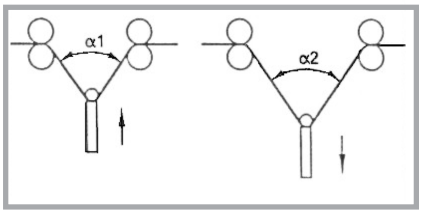

Figure 5. *Position of the measuring roller in dependence on the length of the drawing zone.*

The F460 Stick-Slip Friction Tester from the Zweigle company, which we used in our tests, is designed for measuring tensile strength of slivers and rovings [5]. The apparatus consists of the following parts:
- a mechanical unit working on the principle of a single-zone drawing apparatus,
- a drawing force measuring gauge placed

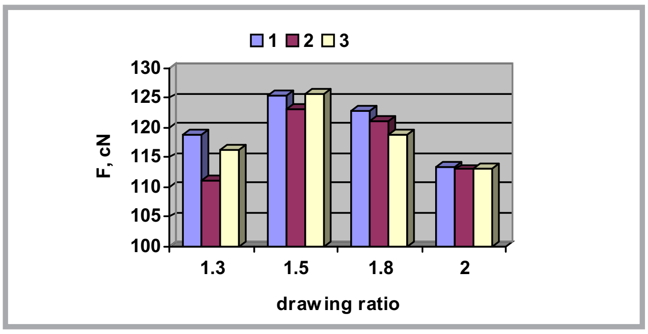

Figure 6. *Drawing force F of the sliver in dependence on drawing ratio and pressure at sliver moving velocity of 5 m/min.*

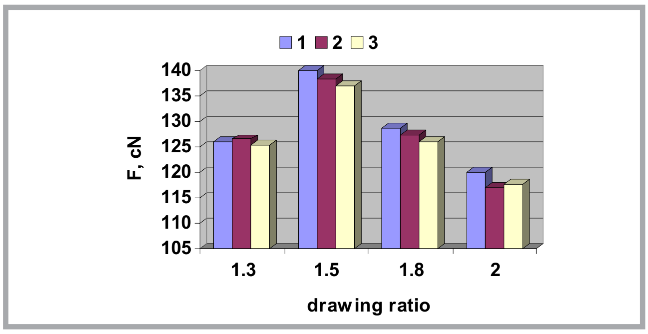

Figure 7. *Drawing force F of the sliver in dependence on drawing ratio and pressure at sliver moving velocity of 10 m/min.*

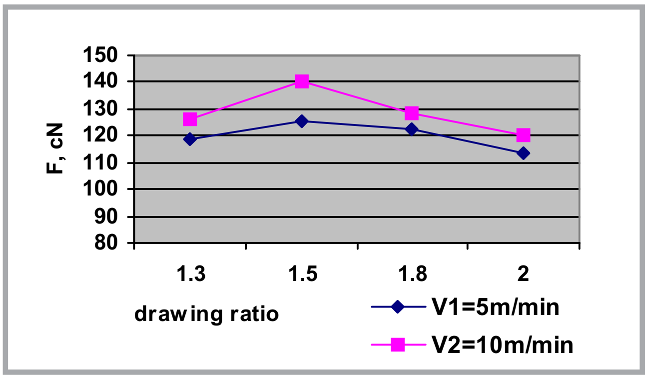

***Figure 8.** Drawing force F of the sliver in dependence on drawing ratio and sliver moving velocity v [m/min] at a pressure of 1 bar (100 kPa).*

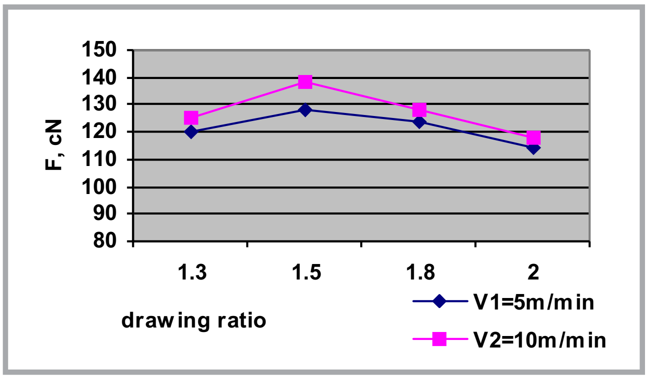

***Figure 9.** Drawing force F of the sliver in dependence on drawing ratio and sliver moving velocity v [m/min] at a pressure of 2 bar (200 kPa).*

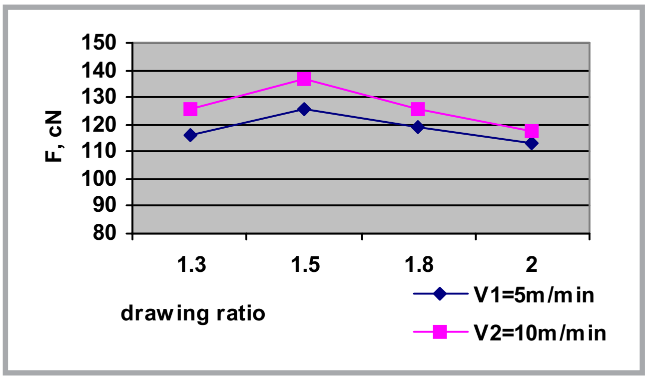

***Figure 10.** Drawing force F of the sliver in dependence on drawing ratio and sliver moving velocity v [m/min] at a pressure of 3 bar (300 kPa).*

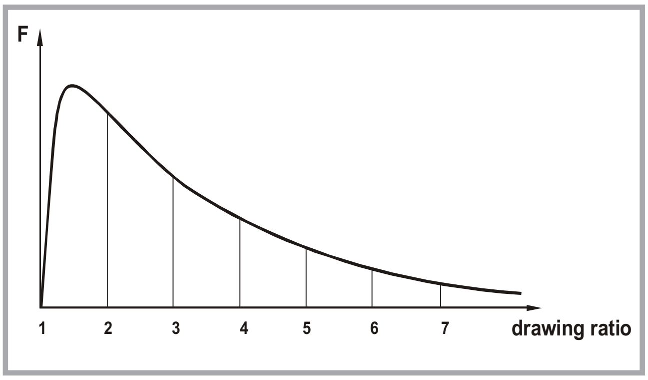

***Figure 11.** Drawing force of the fibre stream in dependence on the value of the drawing ratio applied.*

in the zone of the drawing apparatus,

- a PC computer equipped with an additional card for velocity control of the apparatus, with a START-STOP function and an A/D converter,
- a monitor, keyboard, and printer, and
- F460 software for the graphic presentation of data obtained and for control of the apparatus.

While testing a sliver or roving, the force created as the result of drawing the fibres is continuously measured. Over the time of measurement, the fibre stream passes over the drawing apparatus at a constant velocity and drawing ratio. Drawing is achieved as the result of the difference in velocity between the feeding and the output rollers ($v_1 < v_2$). The force F is measured with the use of a measuring roller placed between both pairs of drawing rollers (Figure 4). The force changes are recorded.

The position of the measuring roller (1) can be altered, but it must be selected in relation to the length L_1 of the drawing zone. The angle α in the triangle: pair of feeding rollers - measuring roller - pair of output rollers (Figure 5) must be constant in every position of the roller (the rule $\alpha_1 = \alpha_2$ must be preserved).

The measurements can be conducted at different settings of the apparatus within the following ranges:

- moving velocity of the fibre stream selected with the use of the F460 PC software: 5, 10, 15, and 20 m/min;
- drawing ratio: 1.3, 1.5, 1.8, and 2.0;
- length of the drawing zone L_1: 100, 150, 200, 250, and 300 mm; the length of the drawing zone should be selected in dependence on the length of the processed fibres;
  - for short fibres with lengths of 40, 60, and 80 mm the drawing zone should have a length of 100, 150, and 200 mm respectively;
  - for long fibres with lengths of 80, 100, and 120 mm, 200, 250, and 300 mm respectively;
- the pressure of the upper rollers of the drawing apparatus which are pressed by pneumatic cylinders to the lower rollers is determined by the value of the air pressure settings; the pressure of the rollers can be selected within the range: 44.2, 88,4, 133, 177, 221, and 265 N at air pressure set in the apparatus at 1, 2, 3, 4, 5, and 6 bar respectively (100-600 kPa).

Measuring Results and Discussion

The experiments were conducted at a drawing zone length of 100 mm. The full range of drawing ratios (1.3, 1.5, 1.8, and 2) and two velocities of the sliver (5 and 10 m/min) were applied at three different pressures of the drawing apparatuses' upper rollers: 44.2, 88.4, and 133 N, obtained as the result of following pressure settings: 1, 2, and 3 bar (100, 200, and 300 kPa).

Figure 6 presents the influence of the drawing ratios and pressures applied during tests on the drawing force F of the sliver tested at a moving velocity of 5 m/min, whereas in Figure 7 the same as above is shown at a velocity of 10 m/min. The graphs shown in Figures 8-10 present the values of force F obtained at different drawing ratios, sliver moving velocities and pressures of the drawing apparatuses' rollers.

For the majority of measurement results obtained, the increase in pressure related to the increase in loading the drawing apparatuses' rollers causes a decrease in the force *F* which is necessary to overcome the resistance of the fibre sliding during the drawing of the sliver.

An increase in the fibre stream's moving velocity from 5 m/min up to 10 m/min causes an increase in force *F*, while maintaining the same drawing ratios in the zone of the drawing apparatus. Applying greater drawing ratios preliminarily results in an increase in force *F*, but next in a permanent drop.

The maximum force *F* was achieved at a drawing ratio of 1.5 for all parameters applied during the tests we carried out . This conforms with the information published [6-8] that the drawing force equals zero at a drawing ratio R=1. This force rises fast within a range of small drawing ratios, and achieves its maximum at drawing ratios of 1.1-1.7 [7]. Furthermore the force gradually decreases, aiming asymptotically at zero. The drawing ratio value at which the force achieves its maximum and the value of the maximum force depend on the drawing conditions, firstly on the kind of fibres, the linear density of the fibre stream feed, the lengths of fibres, the distance between the gripping points of the drawing rollers, and on the surface properties of the fibres. At a constant drawing ratio setting, the drawing force only changes within certain limits, which results from the irregularity of the linear density of the fibre stream drawn. The higher the irregularity of the fibre stream's linear density, the greater the dispersion of the drawing forces.

The changes of the drawing force in dependence on the drawing ratio have been presented graphically by Sewstianow [8], and are shown in Figure 11. This curve only illustrates the general shape of the dependencies, and not any characteristic values.

During the preliminary drawing interval, the fibres are stretched; small elongations and displacements of the fibres cause an impact rise of the drawing force. As the fibre stream is not twisted, a further drawing increase leads to a decrease in the cohesion between fibres; the number of stretched fibres decreases, and as an effect the drawing force also decreases.

Considering the character of the drawing force changes in dependence on the drawing ratio in the feeding zones of drawing apparatuses, application of a drawing ratio near R=1 or higher than R=1.5 is recommended.

Summary

- An increase in drawing ratio of the drawing apparatus causes a rapid increase in drawing force, and subsequently its permanent drop.
- For 3.4 ktex cotton yarn, the greatest force *F* appears at a drawing ratio of 1.5.
- An increase in the sliver moving velocity also causes an increase in the drawing force (at constant drawing ratio in the zone of the drawing apparatus).
- A pressure increase which influences the increase in loading of the drawing apparatus' rollers causes a decrease in the drawing force of the fibre stream.

Conclusion

The computerised F460 Stick-Slip Friction Tester allows us to measure the drawing forces of untwisted fibre streams under dynamic conditions.

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