INFLUENCE OF STRESS FREQUENCY ON DEFORMATION PROPERTIES OF THREADS

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Abstract
Our contribution deals with an experimental analysis of the influence of the stress frequency on the deformation properties of the thread. The textile material (the threads) is exposed different ways of the stress during a processing. For example, warp threads are stressed cyclically with a relative high frequency during a weaving. We have to solve a problem of a determination of a modulus of rigidity and additional deformation parameters of the thread for this condition. The standard devices for testing of textile materials (for example: Instron) do not allow for the extension of threads at the frequency of extension due to the weaving process. Therefore, the special testing device (VibTex) for simulation of the textile materials stress during the weaving process has been designed in the Weaving Laboratory of the TU-Liberec. The contribution describes a way of the modulus of rigidity determination by using measurements on the standard device Instron and the special device VibTex for the concrete textile material (the thread). The modulus of rigidity values are compared in the conclusion part of this contribution. This part includes a discussion of these results and answers on questions about the influence of the stress frequency on the modulus of rigidity of the thread and concrete way for modulus of rigidity determination from the point of view of the weaving process.
Key words: VibTex, modulus of rigidity, deformation properties, weaving process

1. Introduction

Do the frequency and velocity of extension of linear textiles influence their deformation properties? This article is concerned with experimental analysis of this problem. During its processing, the textile material (linear textiles) is subject to varied stress regimes. For example during the weaving process, warp threads are extended cyclically at a relatively high frequency. What experimental tools can be employed for determination of modules of rigidity in such a way that their values might correspond to a given technological process?

In the present article, the answers to above-mentioned questions are found experimentally. First of all, the chosen textile material (linear textile: 42 x 2 tex, 640 S, 100% PES) has been subject to a standard strength test on the device *Instron 4411*; on basis of the measured data, there has been determined the module of rigidity as the slope of the regression straight line. This value corresponds to very slow (static) extension of threads. Next, the given textile material has been subject to a test on special device *VibTex*, which allows extending textile materials at high frequencies (see [1], [2] and [3]). In this case, the threads have been extended harmonically, with maximum elongation 5 mm and frequency 10Hz. In final section of the article, the modules of rigidity established on basis of measuring on the devices *VibTex* and *Instron* are compared mutually and they are discussed.

2. Parameters of the used linear textile

For measuring purposes, there have been used two-fold twisted polyester threads of the fineness 42 tex x 2. The ply twist has been measured by means of twist meter *Y220B*, on which clamping length 250 mm and preload 150 mN have been set up. A total of 30 measurings have been realised, and resulting values are shown in the following table:

Table 1: Ply twist Z [m^{-1}]

	Number of measurings	Average value	95% conf. interval	Standard deviation
Z [m^{-1}]	30	640	(633 ; 646)	16,91

Further parameters of the concerned linear textile have been determined by means of the instrument *Uster Tester IV-SX* , on which testing speed 400 m/min and measuring time 1 min have been set up. Three measurings have been realised successively, with following results:

Table 2: Selected results of measuring on the device Uster Tester IV-SX

	Number of measurings	Average value	95% conf. interval	Standard deviation
U [%]	3	5,35	(5,20 ; 5,5)	0,061
CV [%]	3	6,71	(6,51 ; 6,90)	0,079
CV_{1m} [%]	3	2.74	(2,54 ; 2,94)	0,081
CV_{3m} [%]	3	2,28	(2,08 ; 2,47)	0,076
CV_{10m} [%]	3	1,85	(1,61 ; 2,09)	0,095
Number of thin places –50% [km^{-1}]	3	0		0
Number of thick places +50% [km^{-1}]	3	1,67	(0,54 ; 3,90)	1,443
Neps +280% [km^{-1}]	3	0.83	(0,14 ; 2,67)	1,443
Hairiness [-]	3	5.5	(5,45 ; 5,55)	0,021

As indicated above already, the thread strength has been determined by standard measuring (in accordance with Standard ČSN EN ISO 2062) on the device *Instron 4411*, setting up there clamping length of the thread 500 mm, velocity of the cross-tie 300 mm/min and preload 200 mN. The value of preload here does not correspond to the value determined by the Standard, but to the value adjusted during measuring on the device VibTex (because of mutual comparison of measuring results). A total of fifty measurings have been realised, with the following results:

Table 3: Strength and breaking elongation of threads

	Number of measurings	Average value	95% conf. interval	Standard deviation
Strength [N]	50	22,57	(22,27 ; 22,87)	1,09
Relative strength [cN/tex]	50	26,87	(26,51; 27,24)	1,29
Breaking elongation [%]	50	18,99	(18,77; 19,21)	0.79

3. Determination of the module of rigidity on basis of static strength tests

3.1.Deformation properties of threads till the break

Among outputs of the device *Instron 4411* there range tension curves, i.e. dependence of the tensile force on the elongation (see fig. 1).

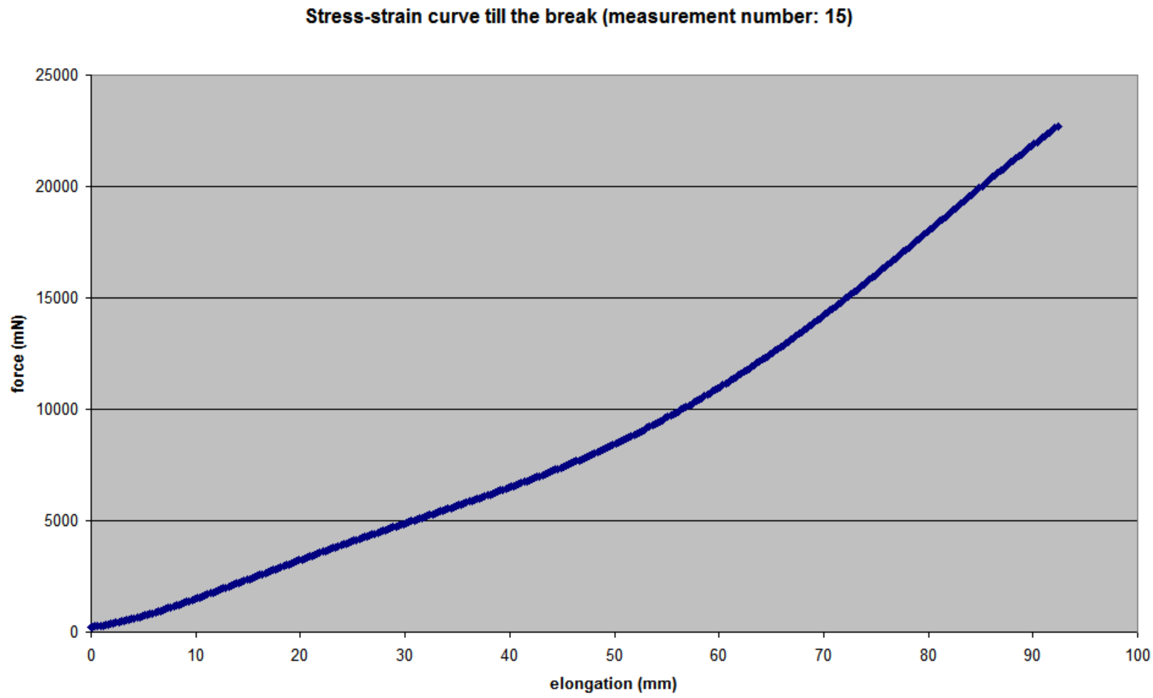

Figure 1: Stress-strain curve till the break

In our case, twenty stress-strain curves have been chosen at random from fifty realised measurings, and in the spreadsheet program Excel, the straight line $y = K_{NT}.x + q$ has been laid through the measured data by the least square method. The symbol x represents here elongation of the thread, and the symbol K_{NT} represents the slope of the regression straight line, i.e. the module of thread rigidity. Furthermore, there has been calculated the square of the correlation coefficient R^2_{NT}, which characterises the "degree of linearity" of deformation properties of the given linear textile till the break (see fig. 2):

Figure 2: Stress-strain curve and its regression straight line

The resulting values of the module of rigidity (slope of regression straight line) K_{NT} and the square of correlation co-efficient R^2_{NT} are shown in the following table:

Table 4: Static module of rigidity established as the slope of regression straight line, and correlation coefficient

	Number of measurings	**Average value**	**95% conf. interval**	**Standard deviation**
K_{NT} [N.m^{-1}]	20	203,25	(199,03 ; 207,47)	9,63
R^2_{NT}	20	0,96098	(0,958103 ; 0,963857)	0,006565

3.2. Deformation properties of threads at an elongation up to 5 mm

In the following, we shall concentrate on analysis of deformation properties of linear textiles at deformations up to 5 mm. From the stress-strain curve, we select the data which correspond to elongation of threads up to 5 mm only, we lay the regression straight line $y = K_N.x + q$ through this data again, and we calculate the corresponding correlation coefficient R^2_N (see fig. 3). The symbol K_N represents here the slope of the regression straight line, i.e. the module of thread rigidity at deformations up to 5 mm.

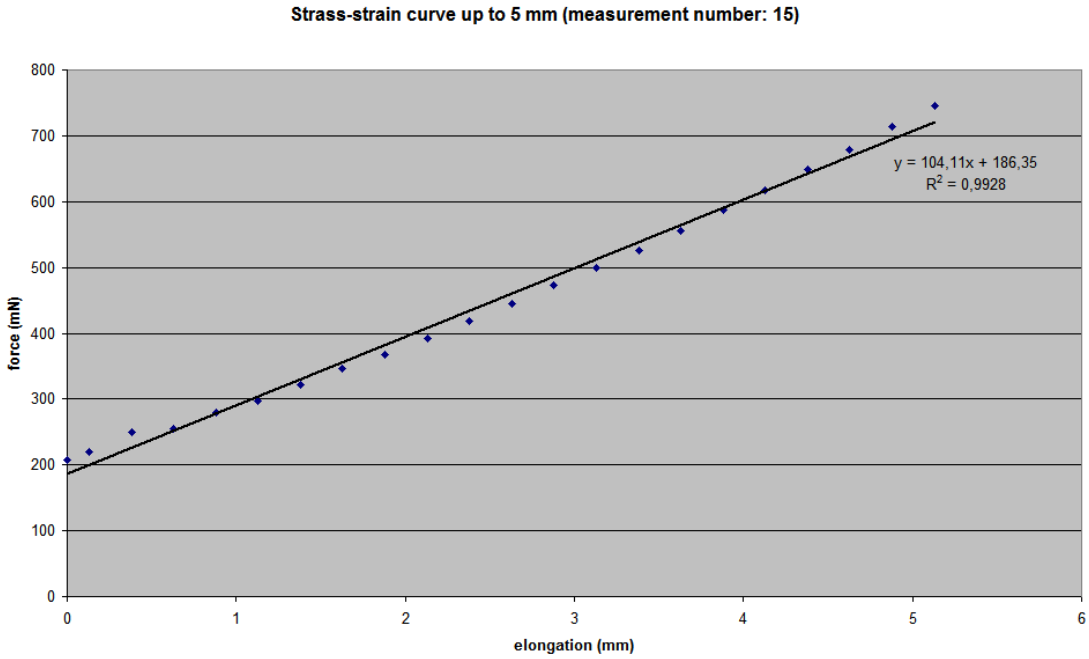

Figure 3: Stress-strain curve up to 5 mm and its regression straight line

The resulting values of the module of rigidity (slope of regression straight line) K_N and of the square of correlation co-efficient R^2_N are shown in the following table:

Table 5: Static module of rigidity, established as slope of regression straight line at deformations up to 5mm, and correlation coefficient

	Number of measurings	**Average value**	**95% conf. interval**	**Standard deviation**
K_N [N.m^{-1}]	20	101,21	(93,1 ; 109,32)	17,33
R^2_N	20	0,995335	(0,99426 ; 0,99641)	0,002452

4. Determination of dynamic modules of rigidity

On the special device *VibTex*, the design of which is described in detail in the literature [1], [2] or [3], there has been realised experimental measuring, with the thread clamping length 500 mm, preload 200 mN and harmonic course of extension with frequency 10 Hz and maximum elongation 5 mm. Among the outputs of the device *VibTex*, there ranges the dependence of the tensile force on the elongation, both during extension and loosening of threads (see fig. 4).

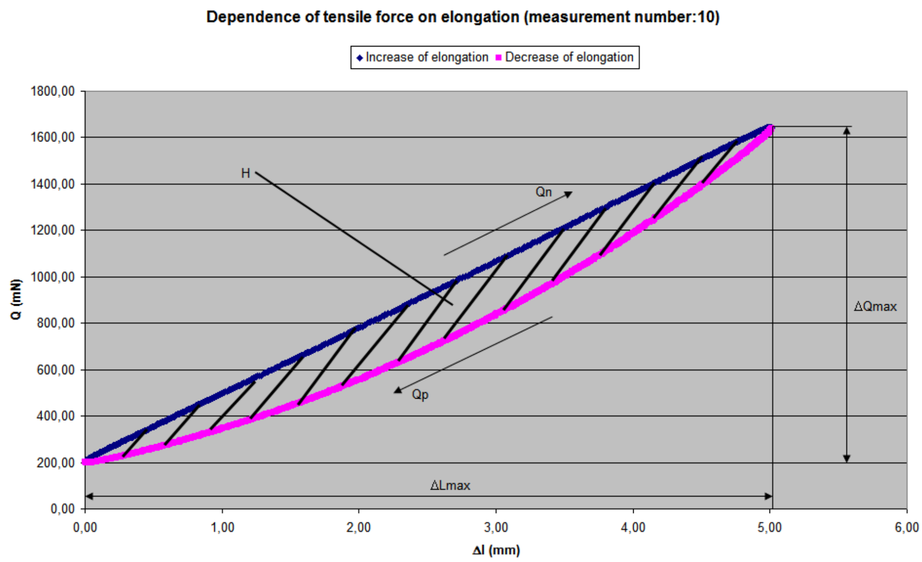

Figure 4: Dependence of tensile force on elongation during extension and loosening of threads

The measurings realised in this manner allow determining the module of rigidity as the slope of the regression straight line both during extension ($y=K_N.x+q$) and loosening ($y=K_P.x+q$) of the thread, and respective squares of correlation coefficients R^2_N *a* R^2_P (see fig. 5):

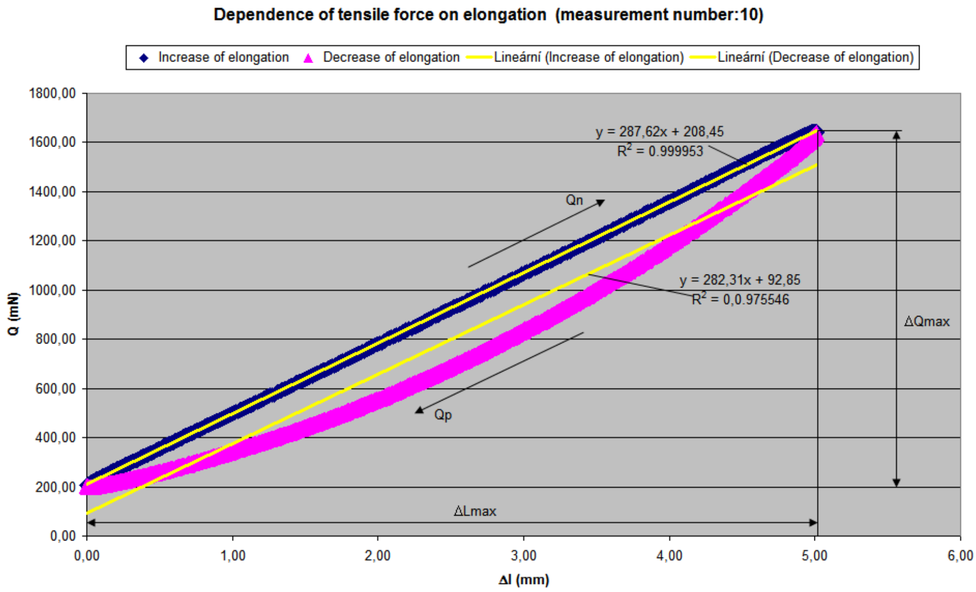

Figure 5: Dependence of tensile force on elongation (measuring No.10)

Furthermore, it is possible to establish the dissipation of energy (hysteresis) during one cycle:

$$H = \int_0^{\Delta L_{max}} Q_N(\Delta l).d\Delta l - \int_0^{\Delta L_{max}} Q_P(\Delta l).d\Delta l \qquad (1)$$

The integral is solved numerically by trapezoidal method.
A total of twenty measurings have been realised successively, and resulting values both for extension and loosening of the thread are arranged in the following table:

Table 6: Dynamic modules of rigidity, correlation coefficients and hysteresis

	Increase of elongation		**Decrease of elongation**		
No. of measurings : 20	**K_N (N/m)**	**R^2_N**	**K_P (N/m)**	**R^2_P**	**H (mN.mm)**
Average value	306,02	0,999931	301,64	0,978755	823,62
95% conf. int.	(298,01;314,03)	(0,999914;0,999948)	(293,63;309,65)	(0,977962;0,979548)	(811,13;836,11)
St. dev.	18,27	0,000038	19,67	0,001808	28,49

5. Conclusion and discussion

5.1 Deformation properties of the given textile material

The results of experimental measurings prove a high degree of linearity of deformation properties of the given textile material. The values of squares of correlation coefficients during extension in the areas up to 5 mm are high both during static extension ($R_N^2 = 0{,}995335 \pm 0{,}001075$) and dynamic extension ($R_N^2 = 0{,}999931 \pm 0{,}000017$). When loosening the thread, the linearity of deformation properties is lower ($R_P^2 = 0{,}978755 \pm 0{,}000793$). The results of static extension during the strength test also indicate a relatively high degree of linearity of deformation properties of the given textile material during its extension till its break ($R_{NT}^2 = 0{,}960980 \pm 0{,}002877$), and the dissipation of energy at cyclical stress is relatively low (H=$823{,}62 \pm 12{,}49 (mN.mm)$).

5.2 Effect of the frequency of extension on the module of rigidity

The realised measurings have proved the effect of the extension frequency on the module of rigidity of the thread for the given textile material. In case of static strength test on the device *Instron 4411*, the module of rigidity during elongation up to 5 mm is expressed by the value $K_N = 101{,}21 \pm 8{,}11 (N/m)$, and in case of dynamic elongation on the device *VibTex* by the value $K_N = 306{,}02 \pm 8{,}01 (N/m)$. This behaviour of textile materials is probably due to their rheologic properties (see literature [4] and [5]). Therefore, it is evident that in spite of a high degree of linearity of deformation properties of the given textile material, a mere substitution with an ideal spring in the whole area of frequencies is not possible, and it is necessary to look for a suitable rheologic model, which might characterise this behaviour of the concerned textile material. In case of determination of specific modules of rigidity, it is necessary to take into consideration the regime of the stress exerted on textile materials during their processing. Because of these facts, the employment of standard methods (e.g. stress-strain curves from the strength tests) for determination of modules of rigidity of warp threads on weaving loom results impossible.

6. References

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