INFLUENCE OF STRUCTURE OF THE YARN ON MECHANICAL CHARACTERISTICS OF YARNS EXPOSED TO DYNAMIC STRESS

Petr Tumajer¹, Petr Ursíny¹, Martin Bílek², Eva Mouckova¹, Martina Pokorna¹

¹Technical University of Liberec, Faculty of Textile Engineering, Department of Textile Technologies, Liberec, Czech Republic

²Technical University of Liberec, Faculty of Mechanical Engineering, Liberec, The Czech Republic
Studentská 2, 461 17 Liberec 1, Telephone: +420 48 535 3259, +420 48 535 3426; Fax: +420 48 535 3542
E-mail: petr.tumajer@tul.cz; petr.ursiny@tul.cz; martin.bilek@tul.cz; eva.mouckova@tul.cz; martina.pokorna@tul.cz

Abstract:

This paper is a direct follow-up of the paper [1] describing in detail the VibTex equipment, which facilitates testing of textiles in a wide range of frequencies of their extension, as well as the determination of corresponding dynamic modules and loss angles. This equipment has been employed for testing polyester yarns of concordant fineness manufactured on ring and rotor spinning frames. At the same time, the material concerned has been subjected to a standard strength test. Therefore, the results of experimental measuring published in this paper allow us to assess the effect of the chosen spinning technology upon the mechanical properties of polyester yarns both at their static and dynamic loading. The introductory section of the paper contains a theoretical analysis of the effect of the chosen manner of spinning upon the mechanical characteristics of yarns. The experimental section indicates the results of measurements at static and dynamic loading, and the final section of the paper confronts the obtained pieces of knowledge with theory. This paper is part of a larger group of publications concerned with the behaviour of various linear textiles when exposed to dynamic loading (see [1], [2], [4], [5], [6]).

Key words:

Dynamic characteristic, cyclical stress, mechanical properties, testing device, VibTex.

Introduction

In the course of processing, linear textiles are exposed to various types of stress. As an example, we can indicate the weaving process, during which warp threads are extended cyclically at a relatively high frequency [2]. Standard devices for testing of textiles do not allow the corresponding frequencies to be reached; therefore, the VibTex equipment has been constructed, which is able to elongate textiles at a relatively wide range of frequencies [1]. Consequently, in our workplace we are able to analyse experimentally the behaviour of textiles both at their static loading (employing standard instruments) and at their dynamic loading (employing the VibTex equipment), and to confront the mechanical characteristics corresponding to these two regimes.

Another possibility of ascertaining and analysing mechanical properties of yarns is the method of measuring on running yarn. In this case, the measuring is carried out under conditions close to operating conditions, e.g. in the phase of preparation for weaving. Deformation properties of the yarn can be studied not in dependence on the action of force only, but also in dependence on a kinematic quantity, the velocity of advance of the running yarn. Consequently, in addition to static and dynamic conditions, we study these properties in dependence on kinematic conditions as well. In this respect, in our workplace we are able to realise experimental measurements and analyses. The complex research issues referred to are solved in the frame of the research project concerned with the level and variability of characteristics of the yarn under conditions simulating the mechanics of processing procedures. The objectives of the presented paper are partial issues of this larger overall subject.

The assessment of mechanical properties of specific textiles is important from the point of view of their modelling (mathematical models) during their processing, as well as from the point of view of solving various technological problems. At present, two principal spinning methods are used in the manufacture of yarns: ring spinning and rotor spinning. Does the manner of spinning affect the mechanical properties of yarns at static and dynamic loading? These are the issues with which this paper is concerned.

Theoretical part

This section addresses the theoretical conditions of the mechanical characteristics of ring-spun and rotor-spun yarns when exposed to dynamic loading. The mechanical properties of yarns under dynamic loading depend on the mechanical properties of the fibres and on the structure of the respective yarn. We will examine the effect of the geometrical structure of yarn, considering the same applied fibre material.

The most common spinning technology is ring spinning. The ring-spun yarn of cotton type has many positive properties. The ring spinning system realises the principal spinning processes, namely the attenuation of the supplied product (the roving, or the sliver) by a mechanical drafting motion, followed by reinforcement of the refined fibre band by a twist imparted by the traveller in the traveller – ring – spindle system, and at the same time the traveller, together with other motions, provides for winding of the final yarn. From the point of view of characteristic structure, the most important aspect is the effect of the drafting motion, which provides for a relatively high parallelism and straightening of fibres. Of similar importance is the effect of the system that imparts a twist to the fibre band,

thus forming the final geometrical structure of the ring-spun yarn.

The rotor spinning system is a completely different spinning technology. It belongs to the group of spinning systems based on the open-end technological principle (so-called OE-spinning). The system is characterised by separation of the twisting motion and the winding-up motion. The supply sliver is fed into the spinning unit, and fibres are loosened by actuation of the opening roller, which transports the fibre flow, and subsequently, the same passes into an air transport channel. Next, the flow of fibres is taken over by the collecting surface of the spinning rotor, where the fibre flow is converted into a fibre band through the cyclical doubling system. The spinning rotor imparts a twist to the drawn-off fibre band, and the yarn produced passes through draw-off ways, pulled by take-off rollers; next, there follows the winding-up motion, producing the final cylindrical or conical cross-wound winding. From the point of view of the characteristic structure of the rotor-spun yarn, the opening motion is of the decisive importance in a broader sense, and particularly one of its parts, namely the transport channel which realises the air transport of the fibre flow. Subsequently, the fibre flow is taken over by the collecting surface of the spinning rotor. The twist imparted by the spinning rotor also has an important effect here. As a rule, the value of the twist density is usually higher than that of a comparable ring-spun yarn.

As mentioned before, with the given fibrous material the geometrical structure determines the end-use properties of the yarn. It determines the effect which the dynamic characteristics of fibres will have in the final yarn and its dynamic characteristics. Therefore, it is evident that the relation between the length deformation of fibres and the length deformation of the yarn will play an important role.

It is necessary to state here that with a model yarn, represented by a helical model of the geometrical arrangement of fibres in the yarn structure, irregularities in length deformations of fibres are apparent, resulting from the twist structure of the yarn. The helical model has been applied in modelling the geometrical structure of ring-spun yarn, and on its basis the relation between the twist density of the yarn and the yarn fineness (the so-called Koechlin's relation) has also been deduced.

Nonetheless, even this model arrangement shows the following irregularities concerning the length deformation of fibres.

Length deformation of fibres due to twisting

On the basis of geometrical relations, following from the helical model, it is possible to indicate equation (1) (see [3]):

$$\varepsilon_v' = s \cdot \sqrt{1 + 4\pi^2 r^2 Z^2} - 1 \quad (1)$$

where: ε_v' - relative elongation of the fibre after twisting of yarn, s - shortening of the yarn due to twisting, r - radius of the helix [m], Z - twist density of yarn [m⁻¹].

From equation (1) it follows that the relative elongation of the fibre at given parameters Z , s is a function of the radius on which the helically laid fibre lies. From this condition follows an initial uneven pretension of fibres in dependence on the radius r .

Length deformation of fibres at a given length deformation of the yarn

On the basis of the helical model, equation (2) applies (see [3]):

$$\varepsilon_v = \frac{\varepsilon_p}{1 + 4\pi^2 r^2 Z^2} \quad (2)$$

where ε_v - relative elongation of the fibre at the relative length deformation of the yarn ε_p .

From equation (2) it follows that with the model yarn exposed to relative length deformation ε_p , at the given twist density Z , the fibres will be longitudinally deformed to the value ε_v in dependence on the radius r . Even the model yarn, represented by the helical geometrical structure, shows uneven length deformations, and consequently, uneven pre-tension in the loading of fibres, thus creating conditions for certain imperfections in the utilisation of the fibrous substance. With the real ring-spun yarn, we can add further factors increasing the above-mentioned unevenness, in particular the migration of fibres, for which there are geometrical and mechanical reasons.

By contrast with the ring-spun yarn, with the rotor-spun yarn the decisive factor is a reduced degree of parallelism and straightening of fibres in the fibre band [4], transferred after the twisting operation in the final yarn as well. The rotor-spun yarn is also distinguished by a characteristic twisting structure. The outer layers contain so-called belt fibres, and/or fibres with a considerably different twist factor (the effect of the so-called connecting zone on the collecting surface).

From the above it follows that the yarn, as a fibre formation exposed to length deformation, will react with a force response determined by the characteristic fibrous structure of the yarn. The transfer of the length deformation to individual fibres is highly uneven, and at a certain degree of length deformation of the yarn, the individual fibres participate in the force response to a highly uneven degree, some of them not at all. On the other hand, a sufficient pre-tension of the yarn and the subsequent static (relatively slow) length deformation causes the yarn structure to be modified to a more suitable form from the mechanical point of view. However, the same cannot be expected in a dynamic process with considerable frequency, when high-frequency deformation produces force responses corresponding to the original inconvenient yarn structure. Owing to the real inner structure of the rotor-spun yarn, the force response is given by a lower portion of loaded fibres than in comparable ring-spun yarn.

Therefore, in comparison with the ring-spun yarn, with the rotor-spun yarn in the static deformation process, with a certain level of relatively small deformations it is possible to expect rather insignificant differences both in the force response and in the level of rigidity modules. On the contrary, in the dynamic process the structural differences will show as considerably, and it can be expected that the dynamic modules of the rigidity of rotor-spun yarn will be considerably lower statistically than those of the ring-spun yarn.

Experimental part

Experimental measurements are realised on polyester yarn, manufactured on ring and rotor spinning frames. Both types of yarn have been manufactured from the same sliver; for the

Table 1. Selected parameters of material and yarn.

Yarn	Average fibre length [mm]	Average fibre fineness [dtex]	Nominal yarn count [tex]	Twist coefficient α [ktex ^{1/2} .m ⁻¹]	Nominal yarn twist [tpm]	Spindle/Rotor speed [rpm]
Ring	38	1.5	50	105	470	7000
Rotor				132	590	77300 (rotor Ø37 mm)

Table 2. Basic characteristics of yarn mass irregularity and hairiness.

Parameter		Ring yarn	OE yarn
U [%]	Average value	6.25	8.10
	95% confidence interval	(6.11 ; 6.39)	(8.00 ; 8.21)
CV [%]	Average value	7.87	10.22
	95% confidence interval	(7.70 ; 8.04)	(10.12 ; 10.32)
CV(1m) [%]	Average value	3.23	3.27
	95% confidence interval	(2.69 ; 3.77)	(3.06 ; 3.49)
CV(3m) [%]	Average value	2.70	2.53
	95% confidence interval	(2.18 ; 3.23)	(2.19 ; 2.89)
CV(10m) [%]	Average value	1.80	1.80
	95% confidence interval	(1.41 ; 2.20)	(1.39 ; 2.21)
Thin places -50% [km ⁻¹]	Average value	0	0
	95% confidence interval	0	0
Thick places -50% [km ⁻¹]	Average value	2,83	2,5
	95% confidence interval	(1.26 ; 5.48)	(1.04 ; 5.03)
Neps +280% [km ⁻¹]	Average value	1.67	0
	95% confidence interval	(0.54 ; 3.89)	0
Hairiness H [-]	Average value	6.17	6.4
	95% confidence interval	(5.57 ; 6.67)	(6.36 ; 6.44)

Figure 1. Longitudinal view of yarn samples: A - rotor yarn ; B – ring yarn; magnification: 50x.

manufacture of the ring-spun yarn, the sliver has undergone the roving operation on a flyer frame. The manufacture of the yarn used a mixture of 3 types of polyester fibres, with the largest portion of Grisuten 11 fibres. The selected basic parameters of the yarn are shown in Table 1. Fig. 1 shows longitudinal views of the yarns, scanned by the VEGA-TESCAN electronic microscope.

Before the main experiment, the yarns were measured for unevenness and hairiness on the Uster-Tester IV-SX instrument, with the aim of verifying whether the yarns show any significant deviations in these monitored characteristics. The measurement was carried out at a velocity of 400 m.min⁻¹ for a period of 1 min. The results are indicated in Table 2. In the case of thick places and neps[CMA4], which is relatively low, a 95 % confidence interval was established in accordance with Poisson distribution [7].

From Table 2 it is evident that the rotor-spun yarn shows a considerably higher short-term irregularity than the ring-spun yarn. This fact confirms the results of current research studies carried out at the Technical University of Liberec, which prove that the rotor yarn spun on high-speed spinning frames shows more short-term irregularities [8]. The reason is the necessity to reduce the diameter of the rotor with increasing frequency of its revolution, thus reducing the degree of cyclical doubling, with a consequential impairment of mass unevenness of rotor-spun yarns.

Table 3. Conditions of measuring on the Instron instrument.

Number of measurements	Clamping length [mm]	Pre-tension [mN]	Velocity of the transverse beam [mm/s]
50	500	800	4.2

Table 4. Measurements of strength and elongation at break on the Instron instrument.

Yarn	Strength [N]		Relative strength [cN/tex]		Elongation at break [%]	
	Average value	95% confidence interval	Average value	95% confidence interval	Average value	95% confidence interval
Ring spun yarn	18	(18.1 ; 18.7)	36.6	(36.2 ; 37.5)	15.5	(15.3 ; 15.6)
Rotor spun yarn	12.9	(12.8 ; 13.1)	25.9	(25.5 ; 26.3)	14.9	(14.8 ; 15.1)

Mechanical characteristics under static loading

Using the Instron 4411 instrument, a standard strength test was conducted (in compliance with the conditions of the relevant standard CSN EN ISO 2062 (80 0700)). Therefore, the clamping lengths of the yarn of 500 mm were employed in the tests, and for evaluation purposes, only those tests only in which the time till the break exceeded the value 17 s were considered. A different value (required by the standard) was employed in the case of the pre-tension only, in order to facilitate comparison of measuring results at static and dynamic loading. The pre-tension was set to a value of 800 mN. The measurements were realised under standard climatic conditions (temperature: 22°C, relative humidity: 65%). The conditions of measuring on the Instron instrument are shown in Table 3; the results are indicated in Table 4.

The results of the strength tests are also the tensile curves which express the dependence of the tensile force on the

Figure 2. Example of a tensile curve of ring-spun yarn till the break. **Figure 3.** Example of a tensile curve of ring-spun yarn till 4 mm.

elongation (see Fig. 2). From the standpoint of the comparison of mechanical properties (modules of rigidity) during static and dynamic loading, the area of elongation till the value of 4 mm is of importance (during dynamic loading, the yarn was extended harmonically, with a maximum elongation of 4 mm – see below). Therefore, we define the static module of rigidity as the slope of the regression straight line, the equation of which is determined by the method of least squares. The straight line is interpolated through the values that determine the tensile curve in the area of elongation till 4 mm (see Fig. 3). From among the realised measurements, 10 tensile curves were chosen at random, and on the basis of the above-described procedure we established the static values of rigidity modules K_p (slopes of regression straight lines) and coefficients of determination R^2 for both ring-spun and rotor-spun yarns, (see Table 5).

Mechanical properties at dynamic loading

Dynamic tests were realised on the VibTex equipment (see [1]). Yarn with a clamping length of 500 mm was extended harmonically with maximum elongation 4 mm, pre-tension 800 mN and varied frequencies: 20 Hz, 40 Hz, 60 Hz, 80 Hz and 100 Hz. The measurements were realized under standard climatic conditions (temperature: 22°C, relative humidity: 65%). For the purposes of statistical processing, at each frequency 10 measurements were realised, with various yarn sections. The measuring conditions are summarised in Table 6.

The measured data were processed by means of the VibTex Soft program which, by means of the algorithms described in [1], calculates the values of dynamic modules and loss angles for individual measurements. Table 7 shows these parameters for ring-spun and rotor-spun yarns. Examples of tensile curves of yarns at a frequency of 40 Hz are shown in Fig. 4.

Figure 4. Examples of tensile curves of ring-spun and rotor-spun yarns at frequency 40 Hz.

Table 6. Conditions of measuring on the VibTex equipment.

Frequency of extension [Hz]	20	40	60	80	100
Average velocity of extension [mm/s]	80	160	240	320	400
Number of measurements	10	10	10	10	10
Clamping length [mm]	500	500	500	500	500
Maximum elongation [mm]	4	4	4	4	4
Pre-tension [mN]	800	800	800	800	800

Table 7. Dynamic modules of rigidity.

Frequency of extension [Hz]			20	40	60	80	100
Ring-spun yarn	Dynamic module of rigidity C_P [N/m]	Average value	628	624	606	617	617
		95% confidence interval	(612; 644)	(610; 638)	(585; 627)	(594; 640)	(598; 636)
	Loss angle [°]	Average value	2.9	3.1	3.3	4.2	5.4
		95% confidence interval	(2.7; 3.1)	(3.0; 3.2)	(3.2; 3.4)	(4.0; 4.4)	(5.3; 5.5)
Rotor-spun yarn	Dynamic module of rigidity C_P [N/m]	Average value	508	510	504	494	514
		95% confidence interval	(503; 513)	(504; 516)	(488; 520)	(485; 503)	(504; 524)
	Loss angle [°]	Average value	3.1	3.0	3.3	4.3	5.1
		95% confidence interval	(3.0; 3.2)	(2.8; 3.2)	(3.1; 3.5)	(4.2; 4.4)	(4.9; 5.3)

Conclusion

The mechanical properties of ring-spun and rotor-spun yarns at dynamic loading are influenced by the inner structure of the yarns. This was demonstrated by an analysis of theoretical assumptions of the geometrical arrangement of fibres in the structures of ring-spun and rotor-spun yarns, and by an analysis of the manifestation of the mechanical characteristics of fibres under conditions of dynamic and static stress on the yarns. Subsequently, experimental measuring and mathematical and statistical evaluation of the results confirmed an important effect of the differing structures of ring-spun and rotor-spun yarns. The static modules of rigidity of ring-spun

and rotor-spun yarns did not show a statistically important difference. On the other hand, the dynamic modules of these yarns showed a statistically important difference; namely that the characteristic structure of rotor-spun yarn has brought about a lower level of the dynamic module of rigidity of this yarn (Fig. 5).

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Figure 5. Comparison of static and dynamic modules of rigidity of ring-spun and rotor-spun yarns.

variability of deformation properties of yarn in conditions simulating the mechanics of treatment processes'.

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