RESEARCH ON THE ABILITY OF YARNS FOR TEXTILE PROCESSING

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Abstract: *The article is intended to study the destruction mechanism of yarns of different structures under different types of deformations that occur during their textile processing (weaving, knitting, etc.). Improving the wear resistance of yarns is one of the main ways to determine the causes of their destruction in textile processing with their subsequent elimination. The significance of this problem is determined by the fact that increasing the reliability and endurance of yarns is equivalent to increasing output without additional labor and material resources. The ability of yarns for textile processing is mainly determined by their mechanical characteristics in tension: tensile strength and elongation, endurance, longevity, cyclic elongation, and the like. In the regulatory documents, this ability is mainly assessed only by the indicators of tensile strength and elongation, which does not fully characterize their behavior in textile processing. Therefore, the study of the features of the yarn destruction under different types of mechanical interactions, as well as the impact of their structure on the process of destruction, is relevant for predicting their endurance and developing a new range of textile fabrics.*

Keywords: *textile threads, yarns, textile processing, wear resistance of yarns, breaking force, breaking elongation, breakage, complex method, endurance ratio.*

1 INTRODUCTION

The development of fashion requires the use of textile fabrics with new structures and properties for garment production. To ensure this, new types of threads and yarns with special structures and properties, which strongly influence their processing into textile fabrics, are used [1-9].

In textile processing, threads can withstand different interactions – repeated extensions, bending, abrasion, etc. One of the significant problems is yarn breakage in the textile manufacturing process (knitted and nonwoven fabrics). Knowledge of the ability of yarns for textile processing significantly accelerates the design of a new range of textile fabrics, as well as facilitates the definition of their use [3, 7, 8-12].

A significant amount of research has been devoted to the study of endurance and wear resistance of one of the types of textile threads – yarn [7, 10-14]. In addition, the features of the mechanism of yarn destruction under different types of extensions are understudied, which does not allow to more accurately predict its endurance and wear resistance.

To explain endurance and wear resistance of textile materials, it is advisable to follow S.N. Zhurkov's fluctuation kinetic theory of strength [12, 13] for polymeric materials that include different types of textile threads and yarns. The basic equation of the material endurance according to this theory is as follows:

$$\tau = \tau_0 \, exp \frac{U_0 - \gamma\sigma}{RT}, \qquad (1)$$

where τ_0 – the parameter (corresponds to the extension of one thermal oscillation of atoms (10^{-12} – 10^{-13})) does not depend on the nature and structure of the material; U_0 – the energy of destruction of interatomic bonds of the material; γ – structurally sensitive coefficient; σ – constant load acting on the material during tests; R – absolute gas constant; T – absolute test temperature.

Equation (1) contains a structurally sensitive coefficient γ that characterizes the inhomogeneity of load arising from the extension of the material in its volume and indicates how many times the true local load, under the action of which the failure occurs, exceeds the mean. Thus, all other things being equal, material endurance has a significant dependence on the material structure. Accordingly, knowledge of the structure of textile threads and yarns is essential for predicting their behavior in processing and operation.

The destruction of yarns during single and repeated extensions occurs in different ways [15-18]. Therefore, a comprehensive study of the impact of such types of extensions on the structure of yarns is important for predicting their behavior in the manufacturing of textile fabrics. An important

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element in determining the endurance and wear resistance of yarns in textile processing is to determine the mechanism of their destruction under different types of extensions.

The number of methods for determining the mechanical characteristics of yarns with different types of deformations is significant, but in most cases, they simulate one type of interaction (extension or bending). Most of the methods will require significant amounts of material and time. Comprehensive methods for determining the wear resistance of yarns, as a model for the main mechanical factors in wear – repeated extensions and bending, which is the most adequate to the real process of yarn wear during their processing. The use of such methods will make it possible to quickly compare yarns of different structures, predicting their operational properties [10, 14, 17, 15-23].

The purpose of the presented work was to study the features of the destruction process of yarns of different structures under different types of extensions and the combined actions of extension and bending as well. This is aimed at providing recommendations to the textile industry with the definition of technological parameters of the equipment, which leads to a reduction in yarn breakage and increases productivity and quality of manufactured products.

2 METHODS AND MATERIALS

All types of yarns mentioned in the research were made of the same raw materials: 50% – wool and 50% – polyester. Also, all of them were obtained by comb (worsted) spinning system and are used in textile production for the manufacturing of worsted suiting.

Yarns for each stage of the study were selected so that the degree of their twist for each stage of the study was the same. The specific values of the yarn structure for each stage of the study are given below. Mathematical processing of test results was carried out according to the standard methods and formulas [12-15].

At the first stage of the study, the relative breakage of a single-thread yarn under single and repeated extensions was compared. At this stage, a single-thread yarn of 19 tex with 750 tpm was studied. Only the places of yarn breakage were analyzed, which allowed determining the peculiarity of its destruction.

Analysis of the areas where yarn breakage occurred during single and repeated extensions was performed using a magnifying glass (20×) and a biological microscope of Biolam C-11 type (50×).

For greater differentiation of the areas of yarn breakage under extension, they were divided into 3 groups. These are the areas without any visible structure changes that are close to the nominal linear density with a stable nominal yarn cross-section, others are with thickenings <20% and sections with thinnings > 20 % of the nominal yarn cross-section. Accordingly, areas of yarn with thickenings < 20 % are 120 %, and with thinnings > 20 – 80 % of the nominal cross section of the yarn.

To determine these areas, 10 bobbins were selected from the batch of yarn. A strand of 100 m long was wound on a reel from each bobbin. Each turn of the yarn on the reel crown was separated from the other, which allowed for making a clear visual observation. Subsequently, the thinnest, thickest, and nominal areas of the yarn were determined with the help of a magnifying glass and marked with a contrasting marker. The number of thin, thick, and nominal areas of the yarn for each strand was 10 each. After that, these areas were cut out and fixed on the cover glass. Each group of areas was formed separately. The areas of the yarn cut in the places marked with a marker were in a free state, which allowed to compare them with the areas of the yarn that broke on the devices RM-3 and PN-5. Then, the cover glass with the areas of the yarn was placed under a microscope that had a micrometer ruler, which allowed to determine the value of the section for each area. After that, the obtained values were averaged. The total number of measurements of each area of yarn was 100. This further allowed to determine the value of the nominal cross-section of the yarn, as well as areas with thickenings < 20 % and areas with thinnings > 20 % of the nominal cross-section.

A single extension of the yarn was performed on an RM-3 tensile-testing machine and repeated extensions – on a PN-5 pulsator. Testing was carried out applying well-known methods [12-15]. The following parameters of the methods were set: the clamping length of the elementary sample on the RM-3 tensile-testing machine was taken equal to 500 mm. The extension speed of the yarn was chosen so that the breakage time was in the range of 10 to 20 s before breakage.

During repeated extensions on the PN-5 pulsator, the clamping length of the elementary samples was 500 mm. Static load on the yarn was determined to be equal to 25 % of the breaking. In textile processing, the yarn does not receive loads exceeding 25% of the breaking one, so this value of the static load on the yarn is optimal for research. The value of the specified cyclic deformation ($E_{s.c}$) was the same and equal to 2.6% of the breaking elongation. This elongation is almost equal to the cyclic deformation of the yarn on the loom. The frequency (speed) of extensions was 200 cycles per minute, which was the approximate frequency of cycles of the loom. At this stage, the study was conducted until the complete destruction of the yarn. The number of yarn tests on each device was 100. The comparison of mean values and determination of the significance of deviations were made using the Student's t-test with a confidence interval of 0.95 (Pd = 0.95).

To study the tips of the yarn fibers after their breakage on the devices RM-3 and PN-5, they were also cut and fixed on the cover glass. First, the tips of the fibers were examined at the breakpoints under a magnifying glass, and then under a microscope.

At the second stage of the study, the relative breakage of single-thread and twisted yarns was compared with repeated extensions on the PN-5 device. The parameters of the methods were similar to the first stage of the research. The single-thread yarn was similar to the yarn of the first stage, and the twisted yarn had a linear density of 19 tex×2 with a twist of 650 tpm. Twisted yarn is obtained from two single-thread yarns 19 tex with a twist of 750 tpm.

At the third stage, the comparison of the endurance of yarns of different production methods to repeated extensions at different values of cyclic deformation was made. At this stage, the yarn of a curtailed production method with the resulting nominal linear density of 44 tex (hereinafter – yarn A) and classic twisted yarn with a linear density of 22 tex×2 (hereinafter – yarn B), obtained by twisting two single-thread yarns (the twist of a single-thread yarn was 750 tpm), were used. The twist for both types of yarns was the same and was equal to 650 tpm. The yarn of a curtailed production method was obtained on a circular spinning machine by twisting two rovings (without the processes of crushing and twisting, which are characteristic of obtaining a classic twisted yarn). This yarn is similar to Sirospun yarn.

The tests were performed on a PN-5 pulsator. The strength of the yarns of both production methods was determined at the initial clamping length of 500 mm, a static load of 25% of the breaking one, and the frequency of extension cycles of 200 cycles per minute. The value of the specified cyclic deformation $E_{s.c}$ ranged from 2.6 to 3.8%. The number of samples at each value of $E_{s.c}$ was 50.

Reliability indicators were also calculated taking into account the correspondence of the distributions to the theoretical law (log-normal) according to the standard method [12].

At the fourth stage, changes in the semi-cycle breaking characteristics of the yarns depending on the number of cycles of their repeated extensions were studied.

The two types of semi-woolen combed twisted yarn mentioned in the third stage were used for the research. Studies of both types of yarns were performed on a pulsator PN-5 under the same conditions with the clamping length: l_0 = 500 mm, the given cyclic deformation - $E_{s.c}$ = 2.6 %, cyclic frequency - n_c = 250 cycles per minute, and static load of 25 % of the breaking one. The parameters of $E_{s.c}$ and n_c were taken close to the production cycle on the loom.

At the beginning of the tests, the samples of both types of yarns were subjected to extensions of 500 cycles, which was taken as conditional zero. Thus, the fibers in the yarn structure were pre-straightened.

Since in the process of weaving the warp yarn withstands about 5 thousand extension cycles before working in the fabric, their maximum number was taken as 5,000. After a given number of extension cycles (500, 1,000, 1,500, 2,000, 2,500, 3,000, 3,500, 4,000, 4,500, 5,000), the yarn (yarn should not be untwisted) was carefully removed from the device PN-5 and subjected to testing on an RM-3 tensile-testing machine with the clamping length of 200 mm. The number of tests for each type of yarn at each value of the specified number of extensions was 100.

At the last stage, devoted to the combined method of determining the ability for textile processing of yarns, the yarns, specified in the third and fourth stages of the study, were studied.

This technique simulates a complex set of simultaneous mechanical actions – repeated extensions, bending, and abrasion, followed by determining the change in the semi-cycle characteristics of the yarn. To do this, the device of Metrimpex company (Hungary) of 5-24-1 type was used [21, 23]. It can be used to simulate the textile processing of threads and yarns as a result of the simultaneous action of a set of mechanical deformations of extension, bending, abrasion, as well as, if necessary, changes in the test temperature. The clamping length of the sample was taken equal to 500 mm.

The degree of action of repeated extensions, bending, and abrasion, as well as the ratio of their modes, are chosen so that they in a relatively short time lead to well-evaluated results and at the same time were not very different from production and operating conditions. The number of cycles of repeated impact on the yarns is chosen according to the practical conditions of textile processing. The static load rate can be adjusted in a wide range, making it possible to bring the test conditions closer to real. The tests were performed at room temperature.

Before the start of multiple tests, the average breaking load P1 of a certain batch of threads on a tensile-testing machine of RM-3 or RM-30 type is determined. After repeated action of the combined types of deformations, the studied samples of yarns are released from the clamps (samples should not be untwisted) and determine their average breaking load P2. The clamping length of the sample was 200 mm. The number of cycles of multiple combined mechanical actions was assumed to be 10,000. The number of samples to assess the endurance (of yarns) by the standard is 5, and in our case to increase the reliability of the results the number of samples for both types of yarns was 10.

3 THE RESULTS OF THE STUDY OF THE DESCTRUCTION OF THREADS (YARNS) IN THE DIFFERENT TYPES OF EXTENSION

An important element in the study of the characteristics of yarn breakage in its textile processing is to find the areas where these breaks occur with different types of deformations. Since the most common type of deformation in the textile processing of yarns is their extension, much attention was paid to the study of the peculiarities of the yarn destruction during its single and repeated extensions in the presented article.

At the first stage of the study, a lot of different types of extension deformations were studied for combed single-thread semi-woolen (worsted) yarns for weaving purposes using the classic technology of spinning. Features of the yarn structure are given in Section 2.

Table 1 shows the results of studies of the relative number of breaks in different parts of the yarn. Single extension of the yarn was performed using an RM-3 tensile-testing machine, and repeated extensions – a PN-5 pulsator. The parameters of the methods are given in Section 2.

The results in Table 1 show that the smallest number of breaks in the yarn under different types of extensions are observed in the areas with thinning, and significantly greater in the areas with thickening. This is because the areas with thickenings have a more heterogeneous structure, so they loosen and break more easily when extended. It is especially true for multi-cycle extensions of a single-thread yarn, where almost half of all breaks are in the areas with thickenings.

It was also found under a microscope and magnifying glass that in the areas with thickenings there is a significant number of unbroken fibers in the places of breakage, which indicates less fiber tightness and stratification of the yarn structure in these areas under different types of extensions.

In the areas of the yarn with thinnings, there is some increase in the degree of fiber twisting compared to other areas. Therefore, in these areas, the degree of fiber bonding increases, and there is a decrease in the yarn breakage compared to the areas where there were thickenings and no damage to the structure. When examining the ends of the fibers under a microscope and a magnifying glass, it was determined that in the areas with thinning at the points of yarn breakage, a larger number of fiber ends are destroyed. The yarn breakage in the areas without any visible destruction of the structure is of mediocre importance under different types of extensions.

Table 1 shows that the number of breaks in thin places of a single-thread yarn is significantly greater under a single extension than under repeated ones. This may be due to the impossibility of rapid redistribution of load on each fiber under a single extension. Under repeated extensions, there is a loosening of the yarn structure and, therefore, redistribution of load on each fiber is more even; accordingly, its breakage in thin places decreases.

Twisted yarns are widely used for the production of textile fabrics in addition to single-thread yarns. In textile processing, yarns are mainly subjected to repeated extensions, so in further studies, attention was paid to this type of deformation.

At the second stage of the study, the peculiarities of the impact of repeated extensions on single-thread and twisted weaving yarns were determined. The features of each type of yarn are listed in Section 2. The study of areas with the yarn breakage was carried out similarly to Stage 1 of the study.

Table 2 shows the results of studies of the breakage of twisted yarns 19×2 tex with repeated extensions on the PN-5 pulsator.

The results given in Table 1 and Table 2 show that in the areas of the yarn with thinning and without any visible damage, the values of relative breaks under repeated extensions are much lower for a single-thread yarn than for a twisted one, and vice versa for the areas with thickening. This is due to the different structures of single-thread and twisted yarns and the peculiarity of their destruction in the process of repeated extensions.

For single-thread yarns, the breakage in different areas is explained by the same reasons as defined above and presented in the explanations in Table 1.

There is a slightly different trend for twisted yarns. The structure of twisted yarns consists of two interconnected (by twisting) single-thread yarns, each of which has its structure. Areas with different deviations (thinning, thickening, and without visible destructions) of each of the components of a twisted yarn are combined in its structure randomly, determining the peculiarity of its breakage under repeated extensions.

Table 1 The value of the relative number of breaks of a single-thread yarn during single and repeated extensions

Areas of yarn monitoring	The relative number of breaks [%]	
	RM-3	PN-5
Thinning (>20 % from the nominal cross-section)	29	13
Thickening (<20 % from the nominal cross-section)	44	51
Without any visible damage to the structure	27	36

Table 2 The value of the relative number of breaks of a semi-woolen combed single and twisted yarn on PN-5

Areas of yarn monitoring	The relative number of breaks [%]	
	19 tex	19×2 tex
Thinning (>20 % from the nominal cross-section)	13	31
Thickening (<20 % from the nominal cross-section)	51	23
Without any visible damage to the structure	36	46

Thus, in contrast to a single-thread yarn, the smallest number of breaks in a twisted yarn is observed in the areas with thickenings. This is mainly because in these areas there is a redistribution of loads between the components of the twisted yarn and the fibers in them, and there is a greater degree of fiber bonding in the structure of the twisted yarn. The number of fibers in the areas with thickenings is significantly greater than in others, enabling redistribution of the load between them.

Given the above, it can be noted that under single and repeated extensions of yarns of different structures, the nature of their breakage is different and depends on the homogeneity in the structure, order, and degree of fiber bonding.

At the third stage of the study, it was important to determine the ability for textile processing of yarns of the same raw material composition, linear density, and purpose, but different spinning methods were used to make a new range of suiting.

To compare the ability of yarns of different production methods and structures for the action of repeated extensions, there were adopted the yarn of a curtailed production method (yarn A) of the resulting nominal linear density of 44 tex and classic combed twisted yarn (yarn B) of similar fibrous composition and the linear density of 22 tex×2. The main characteristics of the yarn are presented in Section 2.

To more fully assess the test results, there was determined the correspondence of empirical distributions to theoretical laws: log-normal, Weibull, Rayleigh, Maxwell, exponential, χ^2 - square, beta, and gamma using the criteria λ and χ^2. It was determined that the log-normal law the most satisfies the empirical distribution of the test results of both types of yarns. The results of statistical processing are given in Table 3.

Table 3 shows that the yarn A endurance in terms of arithmetic mean and median at almost all the values of $E_{s.c}$ exceeds the endurance of yarn B. At $E_{s.c}$ = 3.8 % the mode of distribution of yarn A endurance is smaller because the structure of this yarn is more mobile compared to the classical structure. In addition, yarn B has a greater number of technological transitions in its production and, consequently, a greater number of mechanical effects on the fibers and their greater damage. As the value of $E_{s.c}$ increases, the arithmetic mean, mode, and median of the endurance of each type of yarn converge, which is explained by harder test conditions. The figure 1 shows the graphs of endurance under repeated extensions on the device PN-5.

With increasing $E_{s.c}$, there is a decrease in standard deviation, and the coefficient of variation remains significant. With increasing $E_{s.c}$ the excess and right-hand asymmetry of empirical distributions of the endurance of yarn A increases. For yarn B with increasing $E_{s.c}$ asymmetry and excess of empirical distributions of endurance do not have a clear tendency to change.

Since the twisting intensity of the yarn of the two types is almost the same, the change and differences in statistical indicators are explained by the peculiarities of their structure. With a more mobile structure of yarn A increasing $E_{s.c}$, in addition to tiresome wear, there is also some fiber raveling, confirmed by examining the ends of the yarn under a microscope. Due to the greater mobility of the fibers in the structure of yarn A, there is a better distribution of load in its fibers, which provides it with greater endurance at low $E_{s.c}$ compared to the endurance of yarn B.

Table 3 Indicators of woolen yarn endurance under repeated extensions

Endurance distribution statistics	$E_{s.c}$ [%]							
	2.6		3.0		3.2		3.8	
	Yarn A	Yarn B	Yarn A	Yarn B	Yarn A	Yarn B	Yarn A	Yarn B
Arithmetic mean X [cycles]	7409	2336	479	270	206	194	77	40
Standard deviation [cycles]	7180	1976	387	240	191	189	97	21
Asymmetry A	0.9	0.8	1.0	1.1	3.3	0.9	2.4	0.8
Kurtosis E_s	-0.4	-0.6	-0.2	0.3	1.0	-1.0	5.3	0.7
Mode M_0 [cycles]	1983	708	110	58	58	44	41	53
Median M_e [cycles]	4705	1570	375	190	150	90	50	40
Coefficient of variation [%]	97	85	81	89	92	97	123	53

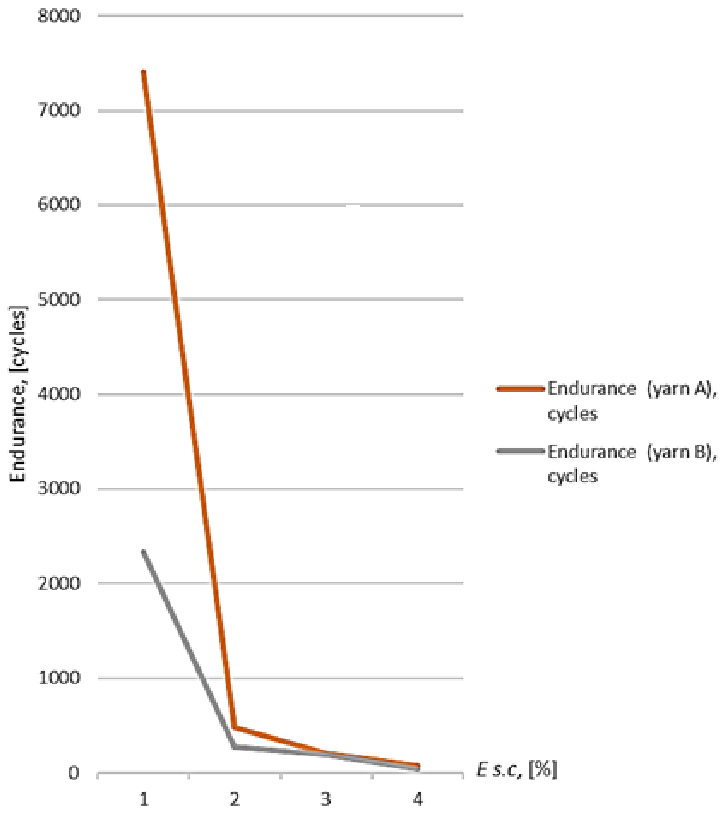

Figure 1 Graphs of yarn endurance under repeated extensions

Table 4 Values of reliability indicators of the yarns with different structures

Given cyclic deformation $E_{s.c}$ [%]	Type of yarn	Failure intensity *X(x)*	Probability of failure-free operation *P(x)*	Operating time to the given probability of failure x_p
2.6	A	4.22×10^{-1}	0.69	580
	B	2.40×10^{-1}	0.38	314
3.0	A	5.02×10^{-3}	0.62	84
	B	2.09×10^{-3}	0.34	34
3.2	A	4.26×10^{-3}	0.44	19
	B	2.90×10^{-3}	0.40	14
3.8	A	3.62×10^{-2}	0.66	9
	B	6.41×10^{-2}	0.58	13

Reliability indicators were also calculated taking into account the correspondence of the distributions to the theoretical law (log-normal) according to the standard method [12].

From the results given in Table 4, it is seen that the failure rate of yarn B is greater, except for the value at $E_{s.c}$ = 3.8 %, because the endurance of yarn B is less compared to yarn A (see Table 3). At all the values of $E_{s.c.}$, except 3.8 %, the density of failure probabilities of yarn A is higher, which affects the increase in failure rate. In yarn B in comparison with yarn A, fibers have a greater degree of bonding, so at significant values of $E_{s.c.}$ = 3.8 %, they are mostly destroyed but do not unravel, which is typical for yarn A. This is also confirmed when studying the fiber ends in the areas of yarn destruction under a microscope.

The probability of failure-free operation of yarn A is higher for all $E_{s.c}$, which is due to its greater endurance. Yarn B is inferior to yarn A by operating time to a given probability of failure, except $E_{s.c}$ = 3.8 %. This can be explained by the greater standard deviation of the endurance of yarn A compared to this indicator of yarn B at the given value of $E_{s.c}$. As the value of the standard deviation of the endurance of both types of yarns increases, the difference in the indicators of the probability of failure-free operation and operating time to a given probability of failure decreases.

Considering the above, it is possible to predict that the yarn with a more mobile structure will be more reliable at low values of $E_{s.c}$, and with a significant increase in $E_{s.c.}$ fiber raveling and a decrease in its reliability can be observed. In real conditions of weaving production in the manufacture of household fabrics on the loom $E_{s.c.}$ does not exceed 3.0 %. Therefore, yarn A with a more mobile structure also has sufficient endurance and reliability at low values of cyclic deformations and can be used to produce a new range of suiting.

At the fourth stage, to more fully determine the ability of yarns for textile processing, changes in their semi-cycle breakage characteristics depending on the number of cycles of repeated extensions were investigated. A one-factor experiment was performed for this purpose. The number of repeated extensions of yarn (X) on the pulsator PN-5 was taken as a variable parameter, the response was: breaking force (Y_1, cN - centinewton) and relative elongation at the time of yarn breakage (Y_2, % - percent).

Subsequently, the functional dependence of the breaking force (Y_1, cN) and elongation (Y_2, %) on the number of cycles of repeated extensions of both types of yarns was determined.

At the beginning of the tests, the samples of both types of yarns were subjected to the extension of 500 cycles, which was taken as conditional zero. Thus, the fibers in the yarn structure were pre-straightened.

The obtained results were processed using statistical information processing programs. As a result of this processing, adequate (P_d = 0.95) linear one-factor mathematical models of the dependence of tensile strain (Y_A, cN) and relative elongation at the moment of breaking (Y_B, %) of both types of the yarns from 500 to 5000 extension cycles were obtained (2-5):

$$Y_{1A} = 18.9 - 2.2 \cdot 10^{-4} \cdot \mathrm{X}, \quad (2)$$

$$Y_{1B} = 18.4 - 7.6 \cdot 10^{-4} \cdot \mathrm{X}, \quad (3)$$

$$Y_{2A} = 7.4 - 4.5 \cdot 10^{-4} \cdot \mathrm{X}, \quad (4)$$

$$Y_{2B} = 6.1 - 4.6 \cdot 10^{-4} \cdot \mathrm{X}, \quad (5)$$

where Y_{1A} – breaking force of yarn A; Y_{1B} – breaking force of yarn B; Y_{2A} – relative elongation at the time of yarn A breakage; Y_{2B} – relative elongation at the time of yarn B breakage; X – number of extension cycles.

The breaking force of yarn A (Y_{1A}) at 500 cycles of its extension differs slightly from the breaking force of yarn B (Y_{1B}) (P_d = 0.95) when comparing the averages according to Student's *t*-test. Starting with the first 1000 tensile cycles, the strength of yarn A (Y_{1A}) is significantly higher than the strength of yarn B (Y_{1B}). This is explained by the greater mobility of fibers in the structure of yarn A compared to yarn B.

The more mobile structure of yarn A (compared to yarn B) makes it possible to regroup the fibers, and thus redistribute the mechanical load that occurs during repeated extensions at 1000 cycles. In addition, the fibers in yarn B have additional damage, which they receive in the longer technological process of manufacturing this yarn (additional technological transitions of crushing and twisting). The breaking elongation of yarn A (Y_{2A}) is significantly greater (P_d = 0.95) compared to the elongation of yarn B (Y_{2B}) for all variants of tensile cycles. This is also due to the more mobile structure of yarn A.

Thus, the study of changes in the strength of yarns after their repeated extensions more fully reveals the structure of different types of yarns and makes it possible to predict their behavior in textile processing. In addition, it was determined that the correlation dependence of the breaking force on the number of cycles of repeated extensions is not high enough for both types of yarns. Thus, the correlation coefficient for yarn A is 0.51, and for yarn B – 0.49.

4 COMPLEX METHOD OF ASSESING THE ABILITY OF THREADS (YARNS) FOR TEXTILE PROCESSING

A lot of processes of textile production have complex types of mechanical deformations. The use of techniques and devices in the above studies took a lot of material and time. Therefore, further research was related to determining the optimal method for assessing the ability of textile threads and yarns for textile processing, which does not require significant material and time. The features of the method and device are presented in Section 2.

The endurance ratio of one thread K_i is calculated by the following formula (6):

$$K_{\mathrm{i}} = \frac{P_{2\mathrm{i}}}{P_{1\mathrm{i}}} 100, [\%] \quad (6)$$

where i – thread sample number.

The endurance ratio of a production unit K_{un} is calculated by the formula (7):

$$K_{un} = \frac{1}{n}\sum_{i=1}^{n} K_i, [\%] \quad (7)$$

where n – number of samples from a production unit.

The endurance ratio of yarns K, % for the whole batch is determined by the formula (8):

$$K = \frac{1}{m}\sum_{i=1}^{n} K_{un}, [\%] \quad (8)$$

where m – the number of production units from one batch.

The ability of the tested batch of yarns for textile processing is evaluated according to the dependence $K \geq [K_d]$, where K_d is the allowable endurance ratio, which is taken as 50 %.

The study identified that the endurance ratio (K, %) for both types of yarns is quite high (yarn A – 94.9 %, yarn B – 94.3 %), which makes it possible to conclude about the possibility of their normal processing in textile production. This is confirmed by the reduction of breaks of certain types of yarns in weaving.

Thus, this complex method should be used to predict the endurance of yarns and other types of textile threads in their textile processing, as well as for comparative analysis of yarns and threads of different structures.

5 CONCLUSIONS

It is advisable to use S.N. Zhurkov's fluctuation kinetic theory of strength to assess the endurance and wear resistance of textile materials. According to the basic equation of textile material endurance, it has been determined that it has a significant dependence on the structure of the material. Knowledge of the structure of textile threads and yarns is essential for predicting their behavior in processing and operation.

The destruction mechanism of combed (worsted) yarns for weaving purposes_of different structures under different types of extensions has been studied. The dependence of the mechanical characteristics of yarns on the peculiarities of their structure and the presence of their significant thickenings and thinnings at different types of deformation of uniaxial tension has been determined. In the case of single and repeated extensions of yarns of various structures, the nature of their breakage is different and depends on the homogeneity in the structure, order, and degree of fiber bonding.

The log-normal law corresponds to the empirical distributions of yarn endurance of different production methods and structures under repeated extensions according to the criteria λ and χ^2. It has been determined that yarns with a more mobile structure will be more reliable at small amounts of a given cyclic deformation due to better load redistribution between fibers. With a significant increase in cyclic deformation of yarns with a more mobile structure, there may be notable fiber loosening and raveling, which reduces their reliability.

One-factor mathematical models of the breaking force and relative elongation at the moment of breaking different types of yarns depending on the number of cycles of their extensions ranging from 500 to 5,000 cycles have been obtained. Starting with the first 1,000 extension cycles, the strength of yarns with a more mobile structure is significantly greater than the strength of yarns with a less mobile structure. The more mobile structure of the yarn makes it possible to regroup the fibers, and thus redistribute the mechanical loads between the fibers during the first 1,000 extension cycles. Breaking elongation of yarns with a mobile structure is significantly greater for all the variants of extension cycles than of yarns with a more fixed structure.

The practicability of determining the ability of yarns for textile processing to predict their reliability and scope of use by applying a comprehensive test method has been substantiated. This method also fairly accurately simulates the real conditions of textile processing of yarns and can significantly reduce the number and time of tests.

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