OBTAINING A REGRESSION MATHEMATICAL MODEL OF THE BREAKING STRENGTH AND MULTI-CYCLE ELONGATION DEFORMATION RESISTANCE OF NATURAL SILK YARNS

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Abstract

This article studies the breaking strength and resistance to multi-cycle tensile deformation of natural silk warp yarns. In the course of the research, the influence of the main technological factors on the properties of the yarn was analyzed based on the multi-factor experimental design method. A regression mathematical model was developed and optimal parameters were determined. Based on the results, opportunities for improving the process of preparing silk yarns for weaving were indicated.

Keywords

natural silk, warp yarn, breaking strength, tensile deformation, regression model, optimization.

INTRODUCTION

During the production of products from textile yarns and the use of finished products, they are subjected to multi-cycle tensile deformation. When weaving fabrics, warp yarns undergo several thousand cycles of tensile deformation on the loom. In turn, finished products obtained from the fabric undergo various cycles of deformation during use. As a result, complex changes occur in the structure of the yarns [1].

It is known that in crepe fabrics, right- and left-twisted crepe yarns are used simultaneously. Usually, the warp yarns are woven in pairs in the direction of the warp, 2 right-twisted yarns, 2 left-twisted yarns. In crepe fabrics, raw silk yarns are used as warp. In recent years, in order to increase the productivity of the warping process, improve the physical and mechanical properties of warp yarns, create the possibility of using warp tracking on the loom, and increase the quality of the fabric and the productivity of the loom, new types of crepe fabrics and technologies for their production have been created, consisting of low-twisted cooked yarns as warp yarns. In this regard, it is of great importance to study the resistance of low-twisted natural silk yarns prepared for weaving to multi-cycle tensile deformation [2-3].

It is known that the multi-cycle deformation forces acting on materials are numerically much less than the strength of the material. However, as a result of these forces acting repeatedly for a long time, complex changes in the structure of the materials are formed and destroyed [5].

Therefore, the selection of natural silk yarns for weaving is an important factor in the technological process.

METHODS

Optimization is carried out using multi-factorial experimental design, that is, a FFE 23 experiment is conducted. Here, 2 is the number of levels; 3 is the number of factors; the number of trials is 23=8.

1. Factors influencing the implementation of the optimization process and the resulting parameters are selected.

Incoming parameters that require optimization by value:

X1- Number of turns, (turns/meter).

X2- Number of paired threads, (pcs).

X3- Number of turns in the first and second mating, (turns/meter).

As a result of the experiment, the following yarn parameters were adopted as output factors:

Y1– Resistance to multi-cycle tensile deformation of yarns (cycle, period)

Y2 – Yarn breaking strength (sN) values were obtained.

The variation limits of the factors were determined and are included in the table below.

Table 1

Table of factor levels in natural value

Varied factors	Average level	Lower level	High level	Variation range
Number of turns,**(**bur/meter**)**	300	0	600	300
Number of paired threads,(one).	3	2	4	1
The number of twists in the first and second mating,**(**bur/meter**)**.	100	0	200	100

2. In order to simplify the processing of research results, we calculate the encoded values of the factors from their natural values using the following formula.

$$x_i = \frac{X_i - X_{ai}}{I_i} \qquad (1)$$

Where: - the coded value of the factor;X_i

X_{ai}-the natural value of the th factor;

I_i- range of variation.

The results of the coding are presented in Table 2.

Thus, after encoding the incoming factors, all higher levels are denoted by +1 or simply (+), and lower levels are denoted by –1 or simply (–).

Table 2

Factor coding results

No.	Varied factors	Low-level coding	High-level coding
1	Number of turns, (TPM)	$x_1 = \frac{0-300}{300} = -1$	$x_1 = \frac{600-300}{300} = 1$
2	Number of paired threads,(one).	$x_2 = \frac{2-3}{1} = -1$	$x_2 = \frac{4-3}{1} = 1$
3	The number of twists in the first and d mating, (TPM)	$x_3 = \frac{0-100}{100} = -1$	$x_3 = \frac{200-100}{100} = 1$

The experiments are carried out with the values of the input parameters set strictly in the sequence given in column 4. The results obtained are recorded in column 5. The order of column 4 is based on a random table, the purpose of which is to conduct the tests in this order and eliminate the influence of random factors on the process under study.

Table 3

Table summarizing the results of the experiments

No	Factors				Interrelated factors				Y_1 value of	Y_2 value of	Serial variance	Serial variance
					x_2	x_3	x_3	x_2x_3			$^2(Y_1)$	$^2(Y_2)$
1	+	-	-	-	+	+	+	-	6336	121.32	744	14.22
2	+	+	-	-	-	-	+	+	8270	113.5	636	31.5
3	+	-	+	-	-	+	-	+	8991	256.32	1051	33.45
4	+	+	+	-	+	-	-	-	23285	281.11	2048	12.1
5	+	-	-	+	+	-	-	+	6737	126.03	802	21.16
6	+	+	-	+	-	+	-	-	15440	249.6	1630	19.34
7	+	-	+	+	-	-	+	-	10237	286.46	906	14.79
8	+	+	+	+	+	+	+	+	35997	266.78	4091	9.94

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3. A test matrix is created and the experimental results are processed.

The planning matrix, which incorporates the research results, is presented in the table above.

The arithmetic mean value of the optimization parameters for each test consisting of repetitions according to the experimental results is calculated using the following formula (2).

$$\bar{Y} = \frac{\sum_{i=1}^{N} Y_i}{m} \qquad (2)$$

$$\bar{Y}_{1i} = \frac{115293}{8} = 14411{,}6 \qquad \bar{Y}_{2i} = \frac{1701{,}12}{8} = 212{,}64 \qquad (3)$$

S2(Y1) =11908, S2(Y2) =156.6

4. Homogeneity of variance is determined using the Cochrane criterion.

$$G_x = \frac{S^2\{Y\}_{max}}{\sum S^2\{Y\}} \qquad (4)$$

Here: - the estimated value of the Cochrane criterion; G_x

$S^2\{Y\}_{max}$- Maximum variance of the first test;

$\sum S^2\{Y\}$- all linear dispersions;

$$G_x\{Y_1\} = \frac{S^2\{Y_1\}_{max}}{\sum S^2\{Y_1\}} = \frac{4091}{11908} = 0{,}344$$

$$G_x\{Y_2\} = \frac{S^2\{Y_2\}_{max}}{\sum S^2\{Y_2\}} = \frac{33{,}45}{156{,}6} = 0{,}214$$

To determine the recovery of the experiment, we compare the calculated value of the Cochrane criterion with the table.

In this case, for TOT 23 and PD=0.95

$$G_x\{Y_1\} = 0{,}344 < G_{\text{jad}} = 0{,}5137$$

$$G_x\{Y_2\} = 0{,}214 < G_{\text{jad}} = 0{,}5137$$

If so, we can proceed to calculating the regression coefficients. $G_x\{Y\} < G_{jad}$

$$Y_R = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{123}x_1x_2x_3$$

The coefficients in the equation are .

$$b_0 = \frac{1}{N}\sum Y \qquad (5)$$

Here: i – test order; j – order of factors

$$b_i = \frac{1}{N}\sum x_i\bar{Y} \qquad (6)$$

$$b_{ij} = \frac{1}{N}\sum x_i x_j\bar{Y} \qquad (7)$$

For our example, it looks like this:

Y1-Calculation of the coefficients in the equation for the resistance of yarns to multi-cycle tensile deformation is presented in Appendix 6.

$$Y_1 = 14411{,}6 + 6336{,}4x_1 + 5215{,}9x_2 + 2691{,}1x_3 + 3677{,}1x_1x_2 + 02279{,}4x_1x_3 + 798{,}4x_2x_3 + 587{,}1x_1x_2x_3$$

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Y2- Calculation of the coefficients in the equation for the breaking strength of the threads is given in Appendix 7.

$$Y_2 = 212{,}6 + 15.1x_1 + 60x_2 + 19{,}6x_3 - 13{,}8x_1x_2 + 10{,}9x_1x_3 - 15{,}6x_2x_3 - 22x_1x_2x_3$$

The significance of the regression coefficients is determined using the Student's t-test calculation criterion tR:

$$t_R\{b_i\} = \frac{|b_i|}{S\{b_i\}} \quad (8)$$

$$S\{b_i\} = \frac{S^2\{Y\}}{N} \quad (9)$$

Here: S2{Y} is the serial variance. It is determined using the following formula.

$$S^2\{Y\} = \frac{1}{m} S^2\{\overline{Y}\} \quad (10)$$

Here: m is the number of test repetitions.

$S^2\{\overline{Y}\}$- recovery dispersion. It is determined using the following formula.

$$S_m^2\{Y\} = \frac{1}{N} S^2\{Y_i\} \quad (11)$$

Here: N is the number of tests; $S^2(Y_i)$- sum of serial variances.

We calculate the recovery dispersion values of the coefficients in the equation for the resistance of yarns to multi-cycle tensile deformation.

$$S^2(b_0) = \frac{1}{8} 11908 = 1488{,}5 \qquad S^2(b_{ij}) = \frac{186{,}06}{8} = 23{,}258$$

$$S^2(b_i) = \frac{1}{8} 1488{,}5 = 186{,}06 \qquad S(b_{ii}) = \sqrt{23{,}258} = 4{,}82$$

We calculate the coefficients in the equation for the breaking strength of the threads to determine the recovery variance values.

$$S^2(b_0) = \frac{1}{8} 156{,}5 = 19{,}6 \qquad S^2(b_{ij}) = \frac{2{,}45}{8} = 0{,}306$$

$$S^2(b_i) = \frac{1}{8} 19{,}6 = 2{,}45 \qquad S(b_{ii}) = \sqrt{0{,}306} = 0{,}55$$

We determine the estimated values of the Student's test for the calculated coefficients:

Estimated values of Student's test for Y1:

$$t_1(b_0) = \frac{|14411{,}6|}{1488{,}5} = 9{,}68 \qquad t_1(b_{12}) = \frac{|3677{,}1|}{23{,}258} = 187{,}6$$

$$t_1(b_1) = \frac{|6336{,}4|}{186{,}06} = 34{,}05 \qquad t_1(b_{13}) = \frac{|2279{,}4|}{23{,}258} = 98$$

$$t_1(b_2) = \frac{|5215{,}9|}{186{,}06} = 28{,}03 \qquad t_1(b_{23}) = \frac{|7{,}984|}{23{,}258} = 0{,}34$$

$$t_1(b_3) = \frac{|2691{,}1|}{186{,}06} = 14{,}5 \qquad t_1(b_{123}) = \frac{|587{,}1|}{4{,}82} = 121{,}8$$

Estimated values of Student's t-test for Y2:

$$t_2(b_0) = \frac{|212,6|}{19,6} = 10,84 \qquad t_2(b_{12}) = \frac{|-13,8|}{0,31} = 44,51$$

$$t_2(b_1) = \frac{|15,1|}{2,43} = 6,21 \qquad t_2(b_{13}) = \frac{|10,9|}{0,31} = 35,2$$

$$t_2(b_2) = \frac{|60,0|}{2,43} = 24,7 \qquad t_2(b_{23}) = \frac{|-15,6|}{0,31} = 50,3$$

$$t_2(b_3) = \frac{|19,6|}{2,43} = 8,06 \qquad t_2(b_{123}) = \frac{|-0,22|}{0,55} = 0,4$$

The calculated value of the Student criterion is compared with the tabulated value of this criterion taken from Appendix 3 of the textbook "Fundamentals of Modeling Technological Processes in the Textile Industry" [4].

$f_2 = (m-1)N = 16$;where m=3, N=8 $t_{жад}[P = 0,95; f_2 = 16] = 2,12$

If there are regression coefficients, it is significant. $t_R > t_{table}$

Thus, the coefficients in our equation for the resistance of yarns to multi-cycle tensile deformation became significant, and the coefficients in our equation for the breaking strength of yarns became significant. The regression equation, after discarding the insignificant coefficients, takes the following form:$Y_1 b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{123}$ $Y_2 b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}$

$$\mathrm{Y}_1 = 14411{,}6 + 6336{,}4\mathrm{x}_1 + 5215{,}9\mathrm{x}_2 + 2691{,}1\mathrm{x}_3 + 3677{,}1\mathrm{x}_1\mathrm{x}_2 + 2279{,}4\mathrm{x}_1\mathrm{x}_3 + 587{,}1\mathrm{x}_1\mathrm{x}_2\mathrm{x}_3$$

$$Y_2 = 212{,}6 + 15.1x_1 + 60x_2 + 19{,}6x_3 - 13{,}8\mathrm{x}_1\mathrm{x}_2 + 10{,}9x_1x_3 - 15{,}6x_2x_3$$

It should be remembered that if all regression coefficients are significant, the model is considered inadequate. The model can be tested even if only one coefficient is not significant.

RESULTS AND DISCUSSION

The resulting equation is checked for adequacy. The check is carried out using the Fisher criterion. The calculated value of the Fisher criterion is determined as follows.

$$F_R = \frac{S^2_{adeq}\{Y\}}{S^2\{Y\}} N - M > \qquad (12)$$

Here: - adequate dispersion;$S^2_{adeq}\{Y\}$

$S^2\{Y\}$- linear variance

$S^2(Y_1) = 11908 \quad S^2(Y_2) = 156,6$

$$S^2_{adeq}\{Y\} = \frac{m}{\mathrm{N-M}} \sum (Y_i - Y_{Ri}) \qquad (13)$$

Here M is the number of significant regression coefficients (M=7; 7), N is the total number of tests (N=8), and m is the number of replicate tests (m=3).

The calculated value of the factor being optimized is determined by substituting the coded values (–1 and +1) from columns 2 and 3 of the table. The values are taken row by row, not column by column. The calculation for the formula is as follows:

Y1- We calculate the resistance of yarns to multi-cycle tensile deformation by substituting their encoded values into the equation (Appendix 8):

$$Y_1 = 14411{,}6 + 6336{,}4x_1 + 5215{,}9x_2 + 2691{,}1x_3 + 3677{,}1x_1x_2 + 2279{,}4x_1x_3 + 587{,}1x_1x_2x_3$$

Y2- Calculate the breaking strength of the yarns by substituting their coded values into the equation (9- in the application):

We determine the adequacy variance using formula:

Y1- Resistance to multi-cycle elongation deformation of yarns

Calculating the Adequacy Variance by:

$$S^2_{ад}\{Y_1\} = \frac{3}{8-7}186{,}06 = 558{,}18$$

$$F_{RY1} = \frac{558{,}18}{11908} = 0{,}05$$

Y2- Calculation of Adequacy Variance by Yarn Breaking Strength:

$$S^2_{ад}\{Y_2\} = \frac{3}{8-7}2{,}45 = 7{,}35$$

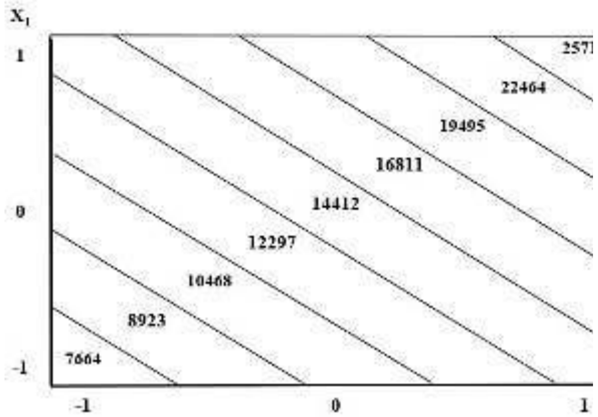
$$F_{RY2} = \frac{7{,}35}{156{,}6} = 0{,}047$$

The tabular value of this criterion is taken from Appendix 4 of the textbook "Fundamentals of Modeling Technological Processes in the Textile Industry" and for our example is equal to the following.

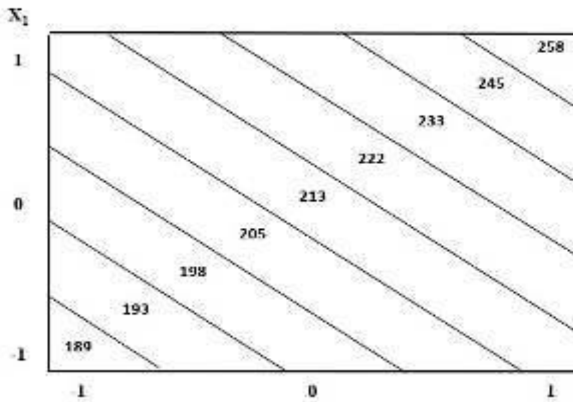
$$F_{table} = [P = 0{,}95; f_1 = N(m-1) = 16; f_2 = N - M = 1] = 4{,}49$$

If so, the model is considered adequate. In the case under study, this means that the process is stationary and the model adequacy has been determined. $F_m < F_{table} F_{m1} < F_{table} (0{,}05 < 4{,}49; \quad 0{,}047 < 4{,}49)$

The analysis was conducted according to a coded model of factor values. The value of the regression coefficients describes the contribution of the corresponding factor to the resulting parameter value.



0 (-1) 300 (0) 600 (1)



2 (-1) 3 (0) 4 (1)

Figure 1. Dependence of the multi-cycle tensile deformation resistance of natural silk yarns on the number of twists in the first (X1) and second (X3) addition-twisting.

Figure 2. Dependence of the breaking strength of natural silk threads on the number of twists in the first (X1) and second (X3) addition- twisting.

CONCLUSION

Based on the theoretical and experimental research, an improved technology and rational parameters for the process of preparing natural silk yarns for weaving were developed, as a result of which the number of rings during the spinning process was reduced by 26%, and the productivity of the spinning machine was increased 4.18 timesincreased, raw material waste decreased by 24.9%. According to the results of the studyto produce a resource-saving improved technology for preparing natural silk threads for weavingThe annual economic efficiency from the introduction of the system is 213.06 million soums. An adequate regression mathematical model of the multi-cycle tensile deformation resistance of natural silk yarns with low twist was obtained, and rational parameters were based on it.

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