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Investigation of Shape Stability Indicators of Knitted Fabrics

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ABSTRACT. The influence of the quantity and location in the structure of plush knitted fabric of a lycra thread on its technological parameters and physical-mechanical properties is investigated. Nonlinear regression dependences of the shape stability parameters of knitwear on the amount of lycra and the structure of knitwear are established. On the basis of the analysis performed, to increase the form stability of knitwearit is recommended to use 2.4% lycra filament in the production of plush knitted fabrics, and to knit plain courses in plush knitted fabric with rapport through one.

KEYWORDS: Form stability, the structure of plush knitwear, lycra thread, technological parameters, physical and mechanical properties, regression dependencies.

I.INTRODUCTION

In order to improve the form stability of knitwear, synthetic threads are often used in its knitting. Knitwear made from synthetic yarn have good form stability. However, its hygienic properties are significantly worse than those of natural yarn types. Special requirements for textile materials, conditioned by specific climatic conditions, make the high hygienic properties of cotton irreplaceable, and lightness and beauty contribute to the constant demand for products from it. Clothing made from synthetic yarn is not suitable for children's range, for people suffering from allergies or skin diseases. Also, clothes made from synthetic yarn do not meet consumer requirements for use in hot climates. Even in mixed yarn, the share of synthetic fibers is at least 15%, and most often it reaches 50%.

In order to increase the dimensional stability of knitted fabric, keeping it hygienic properties, research opportunities to use a cotton yarn with a Lycra thread.It is known that lycra thread has unsurpassed elastic properties. The advantage of using of lycra yarn, that the Lycra yarn is very thin and its content in the knitwear does not exceed 5%. Furthermore, when used together with a Lycra yarn cotton yarn due to the structural features of Lycra thread as it rolls in cotton yarn and the finished web is not peeking at the web surface. This means that the synthetic lycra thread will not come into contact with the body when it is worn.

II. REVIEW OF THE KNOWN WORKS

Indian scientists at the National Institute of Technology conducted research on the effect of lycra yarns and full relaxation finishes on elongation at maximum load, immediate and slow elastic recovery, residual deformation and elasticity of the cotton weave web with elastomeric lycra yarns [1]. It has been established that for such a web an immediate elastic recovery, a degree of stretching and elasticity is higher, and a slow elastic recovery and a permanent deformation is lower than for a cotton cloth.

Studies of the physical properties and form-stability of single knitwear from mixed cotton-elastomer yarns are devoted to [2-4]. All samples of single knitwear were obtained on a circular knitting machine. The results of the tests showed that the horizontal density of the obtained samples does not change significantly, and the density along the horizontal and web density change markedly.

A study of the physico-mechanical properties of medical compression hoses developed from latex and elastomeric polyurethane filaments was carried out in [5]. It is established that the properties of elastomeric polyurethane filament surpass in a number of parameters the properties of sleeves made of latex yarn.

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III. NEW WAY OF MATERIAL CONSUMPTION REDUCING

Studies have shown that when the lycra thread is included in the structure of knitwear, its density increases [6-8]. To obtain lightweight plush knitwear, produced from cotton yarn together with lycra thread, it is suggested to include rows of smooth surface in the structure of plush knitwear.
In order to investigate the influence of a lycra string and determine its rational amount of space in the rapport of lightweight knitwear, “Uztex Chirchik” JV on a singlecircular knitting machine Pailung (Taiwan) developed 4 versions of experimental samples of plush knitwear of a lightweight structure. The structure of plush knitted fabrics on the basis of the smooth surface is facilitated by alternating the plush series and a number of smooth surfaces. The raw material used was cotton yarn with a linear density of 20 tex and a lycra yarn with a linear density of 7.8 tex.
The samples of plush knitwear are worked out under the same technical conditions and differ from each other by the percentage and location of the laying of the lycra thread in the rapport of the weave.

IV. EXPEREMENT RESULT AND DISCUSSING

For establishing the dependences of the parameters of the form stability of knitwear on the amount of lycra and the structure of knitwearwill composethe nonlinear regression equation. From a qualitative analysis of the experimental data it follows that an increase in the amount of lycra in knitwear results in an intensive increase in the value of its form stability indexes, which indicates the use of nonlinear regression to establish their dependence on the amount of Lycra. We denote the indices of reversible deformation by (y1), extensibility (y2), and shrinkage (y3) in length and width (in percent). The equation of regression, depending on the percentage of Lycra (in percent) for them, we represent in the form of parabolas

$$y_{1d} = a_{10} + a_{11}x + a_{12}x^2,\ y_{1ш} = b_{10} + b_{11}x + b_{12}x^2, \quad (1)$$

$$y_{2d} = a_{20} + a_{21}x + a_{22}x^2,\ y_{2ш} = b_{20} + b_{21}x + b_{22}x^2, \quad (2)$$

$$y_{3d} = a_{30} + a_{31}x + a_{32}x^2,\ y_{3ш} = b_{30} + b_{31}x + b_{32}x^2, \quad (3)$$

Constant coefficients in the dependencies (1)-(3) a_{ij} and b_{ij} $(i = 0.1,2,\ \ j = 1,2,3)$ we find, applying the method of least squares

$$S_{id} = \sum_{k=1}^{n}(a_{i0} + a_{i1}x_k + a_{i2}x_k^2 - \bar{y}_{idk})^2 \to \min\ ,\ S_{iш} = \sum_{k=1}^{n}(b_{i0} + b_{i1}x_k + b_{i2}x_k^2 - \bar{y}_{idk})^2 \to \min$$

where $\bar{y}_{idk}$ и $\bar{y}_{iшл}$ - The experimental values at the Lycra points of reversible deformation along the length and width ($\bar{y}_{1dk}, \vec{y}_{1шк}$), extensibility ($\bar{y}_{2dk}, \vec{y}_{2шк}$) and shrinkage ($\bar{y}_{3dk}, \vec{y}_{3шк}$). Equating the partial derivatives $\frac{\partial S_{id}}{\partial a_{ik}}$, $\frac{\partial S_{iш}}{\partial b_{ik}}$ to zero we obtain the following system of equations

$$a_{i0}n + a_{i1}\sum_{k=1}^{n}x_k + a_{i2}\sum_{k=1}^{n}x_k^2 = \sum_{k=1}^{n}\bar{y}_{idk} \quad (4)$$

$$a_{i0}\sum_{k=1}^{n}x_k + a_{i1}\sum_{k=1}^{n}x_k^2 + a_{12}\sum_{k=1}^{n}x_k^3 = \sum_{k=1}^{n}x_k\bar{y}_{idk} \quad (5)$$

$$a_{i0}\sum_{k=1}^{n}x_k^2 + a_{i1}\sum_{k=1}^{n}x_k^3 + a_{12}\sum_{k=1}^{n}x_k^4 = \sum_{k=1}^{n}x_k^2\bar{y}_{idk}\ (i = 1,2,3) \quad (6)$$

$$b_{i0}n + b_{i1}\sum_{k=1}^{n}x_k + b_{i2}\sum_{k=1}^{n}x_k^2 = \sum_{k=1}^{n}\bar{y}_{iшк} \quad (7)$$

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$$b_{i0}\sum_{k=1}^{n} x_k + b_{i1}\sum_{k=1}^{n} x_k^2 + b_{12}\sum_{k=1}^{n} x_k^3 = \sum_{k=1}^{n} x_k \bar{y}_{iшk} \qquad (8)$$

$$b_{i0}\sum_{k=1}^{n} x_k^2 + b_{i1}\sum_{k=1}^{n} x_k^3 + b_{12}\sum_{k=1}^{n} x_k^4 = \sum_{k=1}^{n} x_k^2 \bar{y}_{iшш}\ (i = 1.2,3) \qquad (9)$$

With nonlinear regression, random variables $s_R^2 = Q_R/(m-1)$ и $s^2 = Q_e/(n-m)$ have a law χ^2 distribution with $m-1$ and $n-m$ degrees of freedom, respectively, where $Q_R = \sum_{k=1}^{n}(y(x_i)-\bar{y})^2$, $Q_e = \sum_{k=1}^{n}(y(x_i)-\bar{y}_i)^2$, where statistics $s_R^2 / s_e^2 = F$ has a distribution with the same degrees of freedom. Therefore, the regression equation is meaningful at the level α if the criterion

$$F > F_{\alpha,k_1,k_2} \text{ где } k_1 = m-1,\ k_2 = n-m$$

Here is *m* the number of parameters in the regression equation and has a close connection $R = \sqrt{1 - Q_e/Q}$.
Values of the quantities are given in Table 1.

Table 1.

Variants	x	У1		У2		У3	
	Laycra content, %	Reversibledeformation, %		Extensibilityat 6 N, %		Shrinkage, %	
		Y1 by wale	Y1 by course	Y2 by wale	Y2 by course	Y3 by wale	Y3 by course
0	0	68	62	21	28	13,3	-7,3
1	0,9	73	70	29	30	8	-1,6
2	1,2	73	71	32	35	8	0,8
3	1,6	75	73	34	36	8	1,5
4	1,9	77	74	34,6	36	8,2	2,4
5	2,2	78	76	36	36,8	8,2	3,8
6	2,6	82	76,8	37,4	38	8,6	4,2
7	2,87	83	81	38,6	39,3	9,3	4,9
8	3,15	83,6	81,3	40	42	9,41	5,6
9	3,3	84	82,6	43	44,8	10,2	5,68
10	4,8	84,1	82	45,4	47,2	11,7	5,8

1. The equation of regression (approximation) for the length of reversible deformation has $z := 66.72516 + 7.26352\,x - .713893\,x^2$

Fisher-Snedekor criterion is equal For the statistics we have = 75. Since that regression equation is significant with a tight connection of 0.9744

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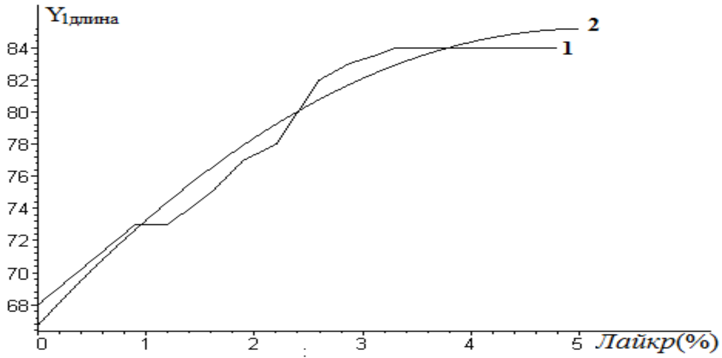

Fig.1. Graphs of the expert (curve 1) and approximating (curve 2) curves for the reverse deformation along the length of the Lycra quantity in%

2. The equation of regression (approximation) for the y1 along the course of reversible deformation will be $z1 := 61.794 + 8.861\,x - .9341\,x^2$

Statistics $s_R^2 / s_e^2 = F$ matters $F := 118.4951558$. Since $F > F_c$ that regression equation is significant with a tight connection $R = .9835373137$

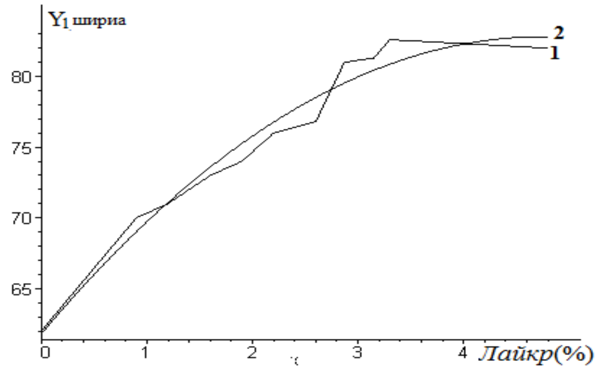

Fig. 2. Graphs of the experimental (curve 1) and approximating (curve 2) curves for the reverse deformation in width from the amount of Lycra in%

3. The equation for extensibility Y2 along the wale will $z1 := 21.83416 + 8.16626\,x - .6852441\,x^2$

Statistics $s_R^2 / s_e^2 = F$ matters $F := 193.1191645$. Since $F > F_c$ that regression equation is significant with a tight connection $R = .9898018520$

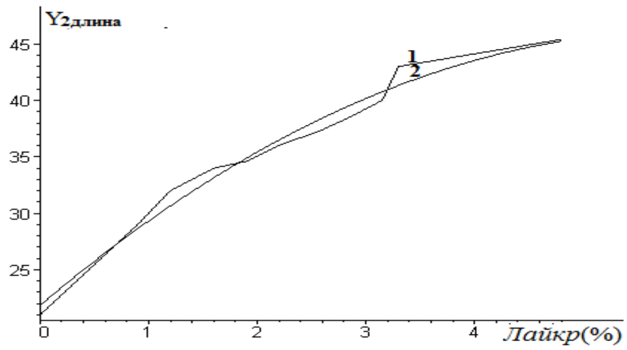

Fig. 3. Graphs of the experimental (curve 1) and approximating (curve 2) curves for length extensibility versus lycra in%

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4. The equation for extensibility y2 along the course will $z1 := 27.602565 + 4.89178\,x - .145261923\,x^2$

Statistics $s_R^2 / s_e^2 = F$ matters $F := 65.10385305$ Since $F > F_c$ that regression equation is significant with a tight connection $R = .9706266571$

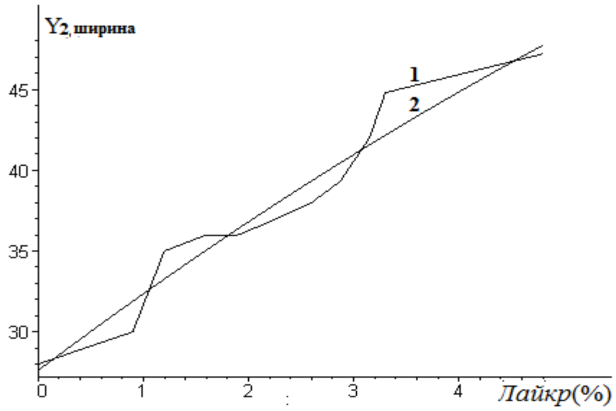

Fig.4. Graphs of the expert (curve 1) and approximating (curve 2) curves for width extensibility versus lycra in%

Analysis of the experimental data and their approximation showed that the theoretical and experimental data have a correlation coefficient R greater than 0.97, which indicates the reproducibility of the experiment and obtaining established dependencies of the properties of knitwear on the amount of lycra yarn in the structure.
Next step in this investigation is Statistical analysis of the change in shape stability depending on the amount of lycra and the structure of plush knitwear.
A full factorial is an experiment in which all sorts of combinations (sets) of factor levels are realized. If"k" factors vary at two levels, the number of all possible sets – $N_2=2^k$. If "k" factors vary on three levels, then $N_3=3^k$.
Let's compose the regression equation for the form stability indicators R, (%).
First, we draw up a two-level ($k = 2$), two-factor experiment, where the first factor is the amount of lycra in knitwear with coding, the second is the number of rows of smooth surface in rapport, with the encoding X_2, with two parallel experiments
To determine the regression equation, we formulate a two-factor experiment matrix at two levels ($k = 2$) for each function by response. Let us consider the case of two experiments in each variant with the number of the set $N_2 = N = 4$, suppose $m = 2$ and add their values in Table 2.

Table 2.
Investigation of the influence of the amount of lycra and plain courses in the repeat of plush knitwear on its form-stability

	X1	X2	У1		У2		У3	
Variants	Laycra content, %	Plain courses content, %	Reversibledeformation, %		Extensibilityat 6 N, %		Shrinkage, %	
			by wale	by course	by wale	by wale	by course	by wale
1	0	50	78	77	29,7	55	12	8
2	2,2	50	82	87	45,2	57,3	9,6	4
3	2,6	67	84	88	43,6	61,5	10	5,3
4	3,4	75	87	90	45	54,8	10,5	5,8
5	4,2	75	87,6	91	46	55	11,2	6,4

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6	5,1	75	89	91	48	56	12,1	7,8

Separately, we will perform statistical processing of the experimental results for each response in the following sequence:

1. Testing the reproducibility of parallel experiments

Willcheck the reproducibility of parallel experiments with the same number m and homogeneity S_u^2 of their dispersion, which characterizes the scattering of the m experimental results.

$$S_u^2 = \frac{\sum_{p=1}^{m}(y_{up} - y_u)^2}{m-1}, \quad m = 2,\ u = 1..N,\ N = 4$$

$y_u = \frac{1}{m}\sum_{p=1}^{m} y_{up}$ - average of all experiments for each option

Results of calculation of values S_u^2 we add to the table 2

Statistics($S^2_{u(\max)}$ - the maximum value of the variance in the variants)

$$G = \frac{S^2_{u(\max)}}{\sum_{u=1}^{N} S_u^2} \qquad (3.10)$$

we check by Cochran's criterion G_{α,k_1,k_2} - the value of which is determined from the reference material table, α - significance level ($0 < \alpha < 1$), $k_1 = N$, $k_2 = m-1$- number of degrees of freedom. In the case under consideration $\alpha = 0.05$,$m = 2$, $N = 4$, $G_{\alpha,k_1,k_2} = G_{0.05,4,1} = 0.91$, $G = 0.474$

If the inequality $G < G_{\alpha,k_1,k_2}$, then the variance homogeneity from the variants m parallel experiments are not refuted, in the case under consideration this inequality is satisfied, and then the variance of reproducibility can be calculated as the average of the variants, i.e.

$$S_y^2 = \frac{1}{N}\sum_{u=1}^{N} S_u^2 = 2.37$$

Further, this variance is used to assess the adequacy of the model.

2. Calculation of regression coefficients

We calculate the regression coefficients from formulas

$$b_0 = \frac{1}{N}\sum_{u=1}^{N} y_u,\ b_i = \frac{1}{N}\sum_{u=1}^{N} X_{iu} y_u,\ b_{ij} = \frac{1}{N}\sum_{u=1}^{N} X_{iu} X_{ju} y_u,\ b_{ijk} = \frac{1}{N}\sum_{u=1}^{N} X_{iu} X_{ju} X_{ku} y_u,$$

$$b_{ijkl} = \frac{1}{N}\sum_{u=1}^{N} X_{iu} X_{ju} X_{ku} X_{lu} y_u$$

Using tabular data, we determine the coefficients and write the regression equation

$$y := 83.70000000 + 5.45000000\ X1 + .05000000\ X2 + .80000000\ X1\ X2$$

3. Evaluation of the importance of regression coefficients

We estimate the significance of the regression coefficients by the Student's test.

First we consider the same confidence interval for all regression coefficients by the formula $\Delta b = t_{\alpha,k}\frac{S_y}{\sqrt{N}}$

(3.11)

$t_{\alpha,k}$ - Student's test, α - significance level, $k = N(m-1)$ - number of degrees of freedom.

If the regression coefficients exceed the confidence intervals in modulus, then they are considered significant,

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i.e.

$$|b_0| \geq \Delta b, |b_i| \geq \Delta b, |b_{ij}| \geq \Delta b, |b_{ijk}| \geq \Delta b \qquad (3.12)$$

In the case under consideration $t_{0.05,4} = 2.78$, $\Delta b = t_{\alpha,k} \dfrac{S_y}{\sqrt{N}} = .2.145$. Comparing the regression coefficients from inequalities (9), we determine the significant coefficients

$b0 := 83.70000000$, $b1 := 5.45000000$

write the approximate regression equation $\hat{y} = 83.7 + 5.45X_1$

4. Evaluation of the adequacy of the model according to the criteria

We estimate the adequacy (the discrepancy between the actual and the calculated models) if there are no insignificant coefficients in the regression equation.

If we accept the regression equation in the form (8), then the variance of the experiments will be identically zero. In this case, all $N = 2^k$ the regression coefficients were calculated from the values, therefore, in this case, there is no degree of freedom to verify the adequacy of the model. The condition of adequacy is fulfilled completely. In this case, the experiment plan is called saturated. If one does not take into account any insignificant coefficients in the regression equation (8), then a degree of freedom appears, and then the adequacy of the model should be checked. The adequacy check consists in comparing the experimental values of the output parameter with the calculated values for different levels of input factors and determining their relative discrepancy by the formula (in percent)

$$R_u = 100\left|\frac{y_u - \hat{y}_u}{y_u}\right| \ (u = 1,2,3,4)$$

The results of the calculation are entered in Table 2. It can be seen from the table data that the greatest value of the discrepancy is about 1%

To check the adequacy of the model using the Fisher criterion, we find the residual variance by formula $S_{oc}^2 = \dfrac{\sum_{u=1}^{N}(\bar{y}_u - y_u)^2}{N-k-1} = \dfrac{\sum_{u=1}^{4}(\hat{y}_u - y_u)^2}{1} = 2,57$ $\hat{y}_u$ - The estimated value of the indicator in u - version, y_u - actual value of the indicator, k - number of factors

Consider statistics

$$F = \frac{S_{oc}^2}{S_y^2} = 1.084$$

and check the Fisher criterion F_{α,k_1,k_2} according to tabular data, here α - level of significance, believing $k_1 = N - k - 1 = 1$, $k_2 = N(m-1) = 4$, from the table we find $F_{\alpha,k_1,k_2} = 7.71$. Since inequality $F < F_{\alpha,k_1,k_2}$ then the hypothesis of adequacy is satisfied.

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Table 2.
The results of statistical processing of the experimental data for reversible deformation along the length

№ Опыта	Уровни переменных		Обратимая деформация %					
			Отклики (длина)					
	X_1	X_2	y_{i1}	y_{i2}	y_u	S_u^2	$\hat{y}_u$	$R_0(\%)$
1	-	-	78	80	79	2	78.25	0.95
2	+	-	89	87.6	88.3	0.98	89.15	0.96
3	-	+	79	76	77.5	4.5	78.25	0.97
4	+	+	91	89	90	2	89.15	0.94
уравнение регрессии $\hat{y} = 83.7 + 5.45X_1$								

Similarly, with the help of computer processing, we perform calculations and test by criteria the experimental data of the remaining components of the form stability of plush knitwear: reversible deformation along the width, elongation at 6N, and shrinkage along the length and width. The obtained data are given in the form of tables.

V. CONCLUSION

The results of the theoretical study showed that the obtained dependencies meet the criteria of Fisher, Student and Cochren. And also found that the presence of a lycra thread in the structure of knitwear affects its form stability is greater than the presence of elements with low extensibility. At the same time, it should be noted that the amount of Lycra in the structure influences the share of reversible deformation, and the presence of low-stretch elements is a less significant factor; The factor of extensibility is influenced by both factors: both the amount of Lycra and the presence of low-stretch elements; However, both factors influence the shrinkage index insignificantly. This is due to the fact that the greatest influence on the shrinkage of the web renders the kind of raw materials used, and all the investigated samples are made from the same raw material.
On the basis of the analysis performed, it is recommended to use 2.4% lycra filament in the production of plush knitted fabrics to increase the form stability, and to tie the rows of smooth surface with rapport in one row.

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