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Conclusion it is reasonable to say that the cloth placed on the gymnastic girls in various movements is based on a high level of resistance to the strong contrasts against the clothing force to the direction vector force in the human movement.

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MODELING OF STRENGTH RELIABILITY AND TRANSFORMATION OF A KNITTED LOOP AT THE LIMIT STATE OF THE STRUCTURE

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Abstract:

Objective. The aim of research is studying the mechanism of strength reliability and transformation of a knitted loop at the limit state of the structure. Comparative analysis of the transformation of the loop of various knitted fabrics, it is advisable to introduce the concept of the average coefficient of transformation of the loop ψ_{cp} was introduced.

Methods. The model of three-stage stretching of knitwear must be borne in mind that the increment of deformation is carried out due to the elongation of the thread on the scale of the loop structure, which occurs after the curved sections of the loop are straightened and the sliding (displacement) of the contact points between the mating loops is completed.

Results. Thus, the introduced loop transformation coefficient ψ can quantitatively characterize the degree of loop variability in the limit state, when the loop step and the height of the loop column take on the maximum possible values. On the other hand, this coefficient may indirectly reflect the mobility of the loop structure.

Conclusion. For the considered types of stitches (rib, satin stitch, interlock), of course, the highest mobility has plain (ψ_c = 1.456) and the lowest - interlock (0.617), which is explained by the peculiarity of the stitch structure. So, for example, interlock stitch, which is a derivative of an rib, has the largest set of external bonds (“saturation”) among the stitches under consideration, which determines the relatively low mobility of the structure.

Keywords: knitwear, strength reliability, deformability, structure, knitwear deformation mechanism, transformation of the loop, loop transformation coefficient.

Introduction. Unlike weaved fabrics, where the structural elements for geometric models are described by relatively simple geometric constructions, in particular, intersecting straight lines (threads) at right angles, and are relatively constant, knitwear has a more complex geometric structure that is easily deformed under the action of an external load.

It is important to note that changes in the structural parameters of textile materials (knitwear, fabrics), including structural changes in thread, occur not only under the influence of mechanical influences, but also shrinkage and contamination as a result of filtration [1]. A set of structural characteristics, such as specific fill indicators, porosity, supporting surface area, translucency, etc., in most cases, are adjusted with thermophysical properties, contact pressure, and frictional interaction. Assessing changes in the structural parameters of a material is the basis for determining the performance properties and functional suitability (reliability) of products.

As is known, knitted fabrics, in comparison with fabrics, are distinguished by a significant anisotropy of properties, in particular, higher extensibility and low initial modulus of elasticity in the direction of the loop rows than when deformed in the direction of the loop columns. The maximum deformation in the direction of

The absolute elongation Δ*l* of the thread at break is

$$\Delta l = l_p - l, mm$$

where *l* p is the length of the loop thread at break, mm

l - loop length, mm

Relative elongation ε of the thread at break, mm

$$\varepsilon = \frac{\Delta l}{l} \text{ or } \varepsilon = \frac{\Delta l}{l} \cdot 100, \%$$

The strength reliability condition for axial tension of the thread corresponds to the form

$$\sigma_\text{p} = \varepsilon E \leq [\sigma_p], \quad (1)$$

where *E* is the modulus of elasticity of the knitted thread, MPa;

$[\sigma_p]$- allowable normal tensile stress, MPa

When modeling the strength reliability of a knitted thread as a stress $[\sigma_p]$ it is possible to accept the stress at break σ_p, determined experimentally by the standard method on a tensile testing machine. Thus, based on the above, we get

the loop rows and loop columns leads to the limiting state of the loop structure, which is characterized by the transformation of the loop parameters: $A_0 \to A_{max}$, $B_0 \to B_{max}$.

Methods. Considering the model of three-stage stretching of knitwear, it is necessary to keep in mind that the increase in deformation is carried out due to the elongation of the thread on the scale of the loop structure, which occurs after straightening the curved sections of the loop and completing the sliding (displacement) of the contact points between the conjugate loops.

Consider this elongation of a knitted thread under the most unfavorable nature of loading, when the geometric parameters of the loop structure take the highest values (A_{max} and B_{max}) under conditions of uniaxial tension.

$$\sigma_\text{p} = \frac{l_p - l}{l} \cdot E = \left(\frac{l_p}{l} - 1\right) \cdot E \leq [\sigma_p],$$

whence the breaking length of the thread will be

$$l_p = l\left(1 + \frac{\sigma_p}{E}\right) \quad (2)$$

If we substitute the expression for the length of the loop thread into dependence (2), then we finally obtain

$$l_p = 0{,}0357\sqrt{\frac{T}{\gamma}}\sigma\left(1 + \frac{\sigma_p}{E}\right), \quad (3)$$

where 0.0357 $\sqrt{\frac{T}{\gamma}}$, mm is the nominal diameter of the thread; σ is the loop modulus.

Breaking stress σ_p, MPa - relative load, expressing the ratio of the tensile load R_r to the cross-sectional area S of a single sample:

$$\sigma_p = P_p / S, \text{ MPa} \quad (4)$$

It is difficult to calculate the cross-sectional area of a single sample for textile fabrics and therefore, in practice, the breaking stress is determined by the formula [2]

$$\sigma_p = P_0 \gamma, \text{ MPa} \qquad (5)$$

where γ is the density of the substance of threads and yarn, g / cm^3 ;

P_0 - specific breaking load, kN m / kg.

The specific breaking load is used to compare the breaking load of textile fabrics of different weights and is calculated by the formula

$$P_0 = \frac{10^3 P_p}{\rho_s a_p}, \text{ kN m/kg} \qquad (6)$$

where P_p is the absolute breaking load, N;

ρ_s - surface density of the canvas, g/m^2

a_p is the working width of the sample strip, mm.

Results. Using expression (3), one can conduct a detailed analysis of the dependence of the breaking length of the thread on the modulus of the loop, the linear density of the thread, the density of the fiber, and the mechanical properties of the thread. This dependence only in the first approximation gives an estimate of the breaking length, since Hooke's law is of limited use for fibrous materials. Thus, the modulus is most often used for the initial stage of tension at an elongation of the order of 1–2%, when the overwhelming proportion of elongation (up to 95%) is conventionally considered as elastic and therefore is called the “initial modulus of longitudinal elasticity” [3].

Let's calculate the breaking length of the thread in the loop according to dependence (2). To do this, we will first calculate the specific breaking load (6) with the following data: the absolute breaking load P_p for the satin surface (cotton yarn 20 tex x 3) is equal to 239 and 123 N, respectively, along the length and width; for an rib (cotton yarn 20 tex x 3) - 673 and 253 N; for interlock (cotton yarn 20 tex x 3) - 610 and 348 [4]; working width of the sample strip a_p = 50 mm. The modulus of elasticity for cotton carded yarn E = 1350 MPa [3].

Discussion. The assessment of the breaking length of the thread in the loop is given as a first approximation, since the elastic modulus E = 1350 MPa corresponds to the linear density of cotton yarn equal to 25 tex. The obtained values of the breaking length of the thread most likely correspond to the length of the thread without taking into account the elastic-elastic (reversible) deformations manifested at the moment of destruction of the thread during testing.

Table 1

Calculated values of the breaking length of the thread in the loop in accordance with the model of strength reliability of the loop structure

No.	Type of yarn, stitch	Breaking load, N		The surface density of the canvas ρ_s, g/m^2	The density of the substance of the yarn γ, g / cm^3	Specific breaking load P_0, kN m /kg	Breaking stress σ_r, MPa	Breaking length of thread l_p, mm
		By lenght	Width					
1	cotton yarn, rib	673	253	394	1.52	34.2	52.0	4.885
2	cotton yarn, plain	239	123	241	1.52	19.8	30.1	4,809
3	cotton yarn, interlock	610	348	509	1.52	24.0	36.5	5,291

Consideration of the limiting state of the loop structure, which occurs when the loop parameters A$_{max}$, B$_{min}$ and B$_{max}$, A$_{min}$ are combined, makes it possible to quantify the transformation of the loop in relation to the equilibrium state of knitwear. To do this, we introduce the transformation coefficient of the loop along the loop step ψ $_{ш}$:

$$\psi_{\text{ш}} = \frac{A_{max}-A_0}{A_0} = \text{A}_{\varepsilon} \qquad (7)$$

and the coefficient of transformation of the loop along the loop column ψ $_{c}$:

$$\psi_{\text{c}} = \frac{B_{max}-B_0}{B_0} = \text{B}_{\varepsilon} \qquad (8)$$

It should be noted that expressions (4) and (5) are called, respectively, the relative breaking elongation of a knitted loop [5] when stretched along the width and when stretched along the length. However, this interpretation does not seem entirely correct and justified. The fact is that when deformed, for example, along the width of a knitted fabric, even when the loop pitch A max is reached, the samples do not collapse instantly. For sample destruction it is necessary to increase the load, which transforms the loop step: A $_0$ → A$_{max}$. As the load increases, the threads in the loop experience irreversible (plastic) deformations and only after the plasticity reserve is exhausted does the destruction of the thread occur. As a result of plastic deformation, the length of the thread in the loop, naturally, increases and therefore the corresponding values of the loop step and loop column, exceeding A$_{max}$ and B$_{max}$, should be substituted into the formula, which will constitute an updated value of the relative breaking elongation.

We transform the expression (7) taking into account A $_{max}$

$$\psi_{\text{ш}} = \frac{l-3\pi f-A_0}{A_0},$$

where the length of the loop *l* is expressed in terms of the modulus of the loop σ and the conditional diameter of the thread d $_{yc}$, corresponding to the minimum thickness of the thread. Therefore, we obtain the dependence for the transformation coefficient of the loop along the loop step

$$\psi_{\text{ш}} = \frac{\sigma d_{\text{yc}} - 3\pi f - A_0}{A_0} = \frac{d_{\text{yc}}(\sigma - 3\pi)}{A_0} - 1$$

and finally, taking into account the expression for the conditional diameter of the thread d $_{yc}$:

$$\psi_{\text{ш}} = \frac{0{,}0357\sqrt{\frac{T}{\gamma}}\ (\sigma-3\pi)}{A_0} - 1 \qquad (9)$$

Similarly, we obtain the formula for the maximum transformation coefficient of the loop along the loop column

$$\psi_{\text{c}} = \frac{B_{max}-B_0}{B_0} = \frac{\frac{l-3\pi f}{2}-B_0}{B_0} = \frac{l-3\pi f}{2B_0} - 1 = \frac{\sigma d_{\text{yc}}-3\pi f}{2B_0} - 1 = \frac{d_{\text{yc}}(\sigma-3\pi)}{2B_0} - 1\ ;$$

$$\psi_c = \frac{0{,}0357\sqrt{\frac{T}{\gamma}}\ (\sigma-3\pi)}{2B_0} - 1 \qquad (10)$$

in dependences (9) and (10), the nominal thread diameter d$_y$ is taken equal to the minimum thread thickness *f* [6].

For the possibility of a comparative analysis of the transformation of the loop of various knitted fabrics, it is advisable to introduce the concept of the average coefficient of transformation of the loop $\psi_{c\text{p}}$, defined as the arithmetic mean of the coefficients:

$$\psi_{c\text{p}} = \frac{\psi_{\text{ш}}+\psi_{\text{c}}}{2},$$

which, taking into account (8) and (9), takes the form

$$\psi_{\text{cp}} = \frac{0{,}0357\sqrt{\frac{T}{\gamma}}\,(\sigma-3\pi)\left(\frac{1}{\text{A}_0}+\frac{1}{2\text{B}_0}\right)}{2} - 1 \qquad (11)$$

Table 2

Loop transformation ratio values for cotton yarn (20 tex x 3) of various stitches

No.	Type of yarn, stitch	**A max**	**A 0**	**in max**	**At 0**	**ψ ш**	**ψ c**	**ψ cp**
1	cotton yarn, rib	5.188	1.436	1.297	0.999	1.333	0.436	0.885
2	cotton yarn, plain	2,594	1.112	1,297	0.903	2,613	0.298	1.456
3	cotton yarn, interlock	3,042	1,550	1.521	1,197	0.963	0.271	0.617

Conclusion. Thus, the introduced loop transformation coefficient ψ can quantitatively characterize the degree of loop variability in the limiting state, when the loop step and the height of the loop column take the maximum possible values. On the other hand, this coefficient may indirectly reflect the mobility of the loop structure. For the types of stitches under consideration (rib, satin stitch, interlock), of course, the highest mobility has the satin stitch (ψ $_{\text{c}}$ = 1.456) and the lowest – interlock (0.617), which is explained by the peculiarity of the stitch structure. For example, an interlock stitch, which is a derivative of an rib, has the largest set of external connections (“saturation”) among the stitches under consideration, which predetermines the relatively low mobility of the structure.

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