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A COMPREHENSIVE ANALYSIS OF THE PROPERTIES OF COMBINED CONDUCTING THREAD

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The behavior of combined conducting thread of different composition under tensile loads was comparatively analyzed. Recommendations are given on developing a line of articles made of combined conducting thread.

Technology for production of combined conducting thread on a doubler-twister was developed in the Department of Spinning of Natural and Chemical Fibres at Vitebsk Technological University. Copper microwire 0.05 mm in diameter (17 tex linear density) and complex chemical fibre with a linear density of 5 to 29.5 tex was used as the initial raw material. The essence of the technology consists of obtaining a two-component thread with a conducting element twisted with a right twist with 480 tw./m in the first pass of the doubler-twister. In the second stage, the intermediate product formed is twisted in the opposite (left) direction with a complex chemical fibre with twist of 530 tw./m to obtain a stable structure. This method of fabricating a combined conducting thread allows increasing the electrophysical properties of the combined thread by bringing the metal microwire to the surface of the conducting thread.

To determine the indexes characterizing the strength and deformation characteristics of the thread, we performed a comprehensive analysis of the mechanical properties of the combined conducting thread obtained with the indicated technology. "Stress at break—elongation at break" tensile curves were plotted as a result of semicyclic tensile tests for different versions of combined thread. The change in the properties of the complex fibres was analyzed after twisting in the structure of the combined thread.

The tensile curves of polyester complex fibres with a linear density of 29.4 (curve 1) and 5.2 tex (curve 2), copper microwire (curve 3), and combined conducting thread with a linear density of 55 tex (curve 4) made from the indicated complex chemical fibres and the copper microwire are shown in Fig. 1. In analyzing the tensile curves of the complex fibres (curves 1 and 2), the following character of the change in them was found: for thread with a higher linear density, greater force must be applied for breaking it, and the elongation at break is almost the same, 14-15%.

The deformation properties of the thread were assessed with arbitrary indirect indexes — the limit of elasticity, plasticity, and strengthening. According to the method in [1], the deformation properties of the thread were calculated with Eqs. (1)-(3):

$$\sigma_e = \frac{1}{b_0}\varepsilon_b, \tag{1}$$

$$\sigma_{pl} = \frac{\varepsilon_b}{b_0 + b_1\varepsilon_b}, \tag{2}$$

$$\Delta\sigma_{str} = b_2\varepsilon_b^2, \tag{3}$$

where σ_e is the arbitrary limit of elasticity, Pa; σ_{pl} is the arbitrary limit of plasticity, Pa; σ_{str} is the arbitrary limit of strength, Pa; b_0, b_1, b_2 are the parameters of the universal mathematical model determined from an analysis of the tensile curve; ε_b is the relative elongation at break, %. Parameter b_0 in the model characterizes the elastic properties of the thread, parameter b_1 characterizes the plastic properties of the thread, and b_2 characterizes the tensile strength properties of the thread.

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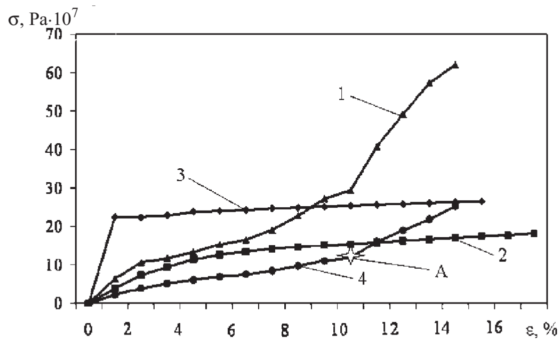

Fig.1

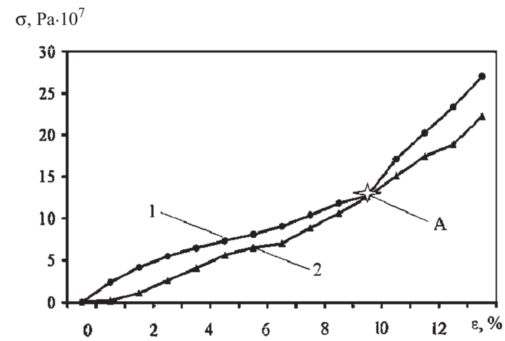

Fig.2

Fig. 1. Tensile curves of complex and combined thread: 1, 2) 29.4 and 5.2 tex polyester complex thread; 3) copper microwire; 4) 55 tex combined conducting thread.

Fig. 2. Tensile curves of combined conducting thread: 1) version 1; 2) version 2.

TABLE 1. Arbitrary Limits of the Deformation Properties of the Thread

Parameter of the mathematical model	Copper microwire	Complex polyester fibre		Combined conducting thread
		5.2 tex	29.4 tex	
b_0	0.00193	0.0101	0.017	0.0618
b_1	0.0037	0.00127	0.000143	0.00081
b_2	0	0	0.0245	0.0115
$\sigma_e \cdot 10^7$, Pa	8264.2	1187	588	258.7
$\Delta\sigma_{str} \cdot 10^7$, Pa	0	0	2.45	2.96
$\sigma_{pl} \cdot 10^7$, Pa	261.6	473.1	542.4	212.44

TABLE 2. Comparative Analysis of the Deformation Properties of Combined Conducting Thread

Deformation properties	Version 1	Version 2
$\sigma_e \cdot 10^7$, Pa	171.67	52.67
$\sigma_{str} \cdot 10^7$, Pa	1.4	2.17
$\sigma_{pl} \cdot 10^7$, Pa	212	143

As the results of the calculation show (Table 1), the highest arbitrary limit of elasticity corresponds to the copper microwire. This is due to the molecular structure of the metal used to fabricate the metallic thread. The microwire has high elastic properties (σ_e), significant slow plastic deformations develop during extension, and there is no strengthening effect ($\Delta\sigma_{str} = 0$).

Polyester complex 5.2 tex fibre has behavior in stretching similar to the microwire, i.e., it is characterized by high plastic properties and the absence of strengthening. Such behavior is characteristic of partially oriented threads: the macromolecules in the structure of the thread are randomly positioned and when tensile loads are applied, they straighten along the axis until they break.

The arbitrary limit of elasticity of the combined conducting thread (Fig. 1, curve 4) is lower than in the initial thread. When the twisted thread is stretched, the complex fibres initially straighten and are oriented along the axis of twisting. Then a strengthening effect arises in the thread, i.e., the molecular structure of the polymer is transformed, and the molecular chains are stretched in the direction of the effect of the load due to plastic deformation (σ_{str}). When the applied load increases, the weakest element in the structure of the combined thread fails, and the stress corresponds to the coordinate of point A on the tensile curve (second point of inflection). Point A corresponds to the limiting tensile stress at which the material begins to fail. The plastic properties of the combined conducting thread decrease. This behavior of the thread is due to its structure: the copper microwire, joined with the polyester complex threads with a different twist, is located on the surface of the twisted thread, so that the plastic properties of the combined conducting thread decrease due to the mutual effect of all of the components. In addition, the strengthening effect of the combined thread is basically a function of the properties of the 29.4 tex complex polyester fibre $\left(\Delta\sigma_{str}^{PE} \approx \Delta\sigma_{str}^{comb}\right)$.

The values of the deformation properties of the combined conducting thread of different raw-material composition obtained for the same manufacturing parameters on a TK2-160-M doubler-twister in two passes (first twist of 480 tw./m, second of 530 tw./m):

– *version 1* — combined polyester conducting thread (consists of a copper microwire 0.05 mm in diameter and 5.2 and 29.4 tex polyester complex fibers);

– *version 2* — combined polyamide conducting thread (consists of a copper microwire 0.05 mm in diameter and 5 and 29.5 tex polyamide complex fibres).

The tensile curves of the two versions of the combined thread are shown in Fig. 2. In analyzing these curves, note that regardless of the raw-material composition, failure of the combined conducting thread begins at the same stress and elongation values (point A: $\sigma = 12.5 \cdot 10^7$ Pa, $\varepsilon = 10.5\%$). The character of the change in the tensile properties of the combined conducting thread is the same, but the combined polyester conducting thread is stronger.

Based on the comprehensive analysis of these data, it is possible to develop a line of articles using combined conducting thread. The composition of the textile material should be selected as a function of its application. In production of fabrics for clothing for gas service workers, it is better to use thread with high elastic properties which do not allow the articles to lose shape during use, that is, the combined polyester conducting thread. For manufacturing technical tapes exposed to heat for medical purposes, it is better to use thread with high strength and plastic properties — combined polyamide conducting thread.

The department is currently investigating the properties of combined conducting thread made by covering a copper microwire with a fibre.

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