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THEORETICAL DETERMINATION OF THE STRENGTH OF COMBINED CONDUCTING YARN OF HIGH LINEAR DENSITY FOR CARPETING

E. G. Zamostotskii, P. A. Kostin, and A. G. Kogan

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The strength of combined conducting yarn of high linear density for carpeting was theoretically determined. Software for determining the basic physicomechanical characteristics of the combined conducting yarn is reported. The difference between the calculated and real characteristics does not exceed 5%, so that this calculation can be recommended for determining the strength of combined conducting yarns.

The Department of Spinning of Natural and Chemical Fibres (SNCF) at VSTU developed new technology for manufacturing combined conducting yarn of high linear density on a modernized TK-176-2 double twister in the conditions of Vitebsk Carpet Co. The yarn consists of four components (one three-component yarn of the composition wool + Capron + Nitron with linear density of $T = 160$ tex and copper microwire with $T = 18$ tex) twisted together on a double twister.

The specific features of spinning of the combined conducting yarn on a TK-176-2 double twister required a theoretical study of its properties.

One feature of the combined conducting yarn (CCY) obtained on the TK-176-2 double twister is its structure, which determines its physicomechanical, electrophysical, and performance properties. The composition (in %) of the combined conducting yarn with a linear density of 500 tex (160·3 + 18 tex) is presented below:

Wool fibre	53.4
Polyacrylonitrile fibre	37
Polyamide fibre	6
Copper microwire	3.6

The diameter of the combined conducting yarn is determined with the equation [2]

$$D_{\text{comb.y}} = 0.04 \cdot \sqrt{\frac{T_{\text{comp.1}}}{\gamma_{\text{comp.1}}} + \frac{T_{\text{microw}}}{\gamma_{\text{microw}}} + \frac{T_{\text{comp.2}}}{\gamma_{\text{comp.2}}} + \frac{T_{\text{comp.3}}}{\gamma_{\text{comp.3}}}}, \tag{1}$$

where $D_{\text{comb.y}}$ is the diameter of the combined conducting yarn, mm; $T_{\text{comp.1}}$, $T_{\text{comp.2}}$, $T_{\text{comp.3}}$ are the linear density of the three components, tex; $T_{\text{microw.}}$ is the linear density of the copper microwire, tex; $\gamma_{\text{comp.1}}$, $\gamma_{\text{comp.2}}$, $\gamma_{\text{comp.3}}$ are the average density of the three components, g/cm^3; γ_{microw} is the average density of the copper microwire, g/cm^3.

A new theoretical dependence was obtained in experiments on calculating the breaking load for determining the breaking load of the combined conducting yarn.

The diagram of the position of the axial lines and their angles for all components with respect to the axis of the CCY is shown in Fig. 1, where the following notation is used: $Q_{\text{c.p.}}$ is the loading force; $O_{\text{comp.1}}$, $O_{\text{comp.2}}$, $O_{\text{comp.3}}$ are the axial lines of the three components; O_{microw} is the axial line of the copper microwire in the CCY; β is the angle of the axial line of the copper microwire with respect to the axis of the CCY, rad; α, ω, γ are the angles of the axial lines of the corresponding components with respect to the axis of the CCY, rad; A is the twisting point of all components of the CCY. Here $\angle\alpha = \angle\gamma = 39°$, $\angle\beta = \angle\omega = 28.7°$.

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Vitebsk State Technological University, Republic of Belarus. Translated from *Khimicheskie Volokna*, No. 6, pp. 34-37, November-December, 2010.

TABLE 1. Dependence of the Forces of the Fibres on the Constant Deformation Rate

Yarn	Tension, cN, for different elongations at break, %								
	9.4	10.1	10.3	10.4	10.7	11.0	12.0	12.1	12.6
Wool-chemical twisted 480 tex	2140	2305	2225	2000	2026	2078	2145	2662	2204.3
single 160 tex	43.1	43.5	44.3	45	45.3	45.3	45.3	45.3	45.3
Copper microwire	43.1	43.5	44.3	45	45.3	45.3	45.3	45.3	45.3
500 tex CCY	2190	2306	2256	2100	2030	2081	2160	2669	2204.3

TABLE 2. Comparison of Theoretically Calculated and Real Indexes of 500 tex Combined Conducting Yarn

Parameter	Value		Difference, T
	calculated	measured	
Diameter, mm	1.289	1.337	3.6
Absolute breaking load, cN	2257.4	2204.3	2.4

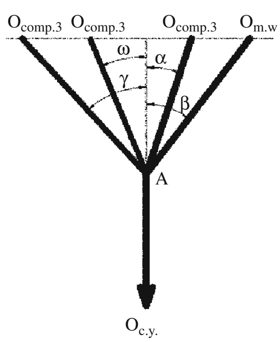

Fig. 1.

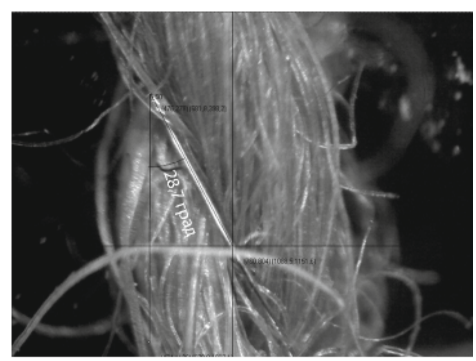

Fig. 2.

Fig. 1. Diagram of the position of the axial lines and their angles for all components of CCY.

Fig. 2. Experimental determination of angle β under the microscope.

The combined conducting yarn with a linear density of 500 tex is used in carpeting with an antistatic effect. One of the requirements for such carpets is the absence of any break in the metal constituent, so that the limiting state (absolute breaking load) of the combined conducting yarn is determined with the equation

$$Q_{\text{c.y.}} = Q_{\text{microw}} \left(q_{\text{comp.1}} \cdot \frac{\cos^2\beta \cdot \cos\alpha}{\cos^2\gamma} + q_{\text{comp.2}} \cdot \frac{\cos^2\beta \cdot \cos\gamma}{\cos^2\alpha} + q_{\text{comp.3}} \cdot \frac{\cos^2\beta \cdot \cos\omega}{\cos^2\alpha \cdot \cos^2\gamma} + \cos\beta \right), \tag{2}$$

where q_{comp1}, q_{comp2}, q_{comp3} are ratios of the rigidity of the three components to the rigidity of the copper microwire; Q_{microw} is the breaking load of the copper microwire, cN.

Components $q_{\text{comp1}} = q_{\text{comp2}} = q_{\text{comp3}} = q_{\text{s.y}}$, so that Eq. (2) becomes:

$$Q_{\text{c.y.}} = Q_{\text{microw}} \left[q_{\text{s.y.}} \cdot \left(\frac{\cos^2\beta \cdot \cos\alpha}{\cos^2\gamma} + \frac{\cos^2\beta \cdot \cos\gamma}{\cos^2\alpha} + \frac{\cos^2\beta \cdot \cos\omega}{\cos^2\alpha \cdot \cos^2\gamma} \right) + \cos\beta \right], \tag{3}$$

where $q_{\text{s.y.}}$ is the ratio of the rigidity of the single three-component yarn to the rigidity of the copper microwire.

We find the rigidity of the fibres with Table 1, which reports the experimental values of the forces that arise in the fibres in deformation on a tensile-testing machine in conditions of a constant deformation rate. The experiment was conducted in the Department of SNCF using an automated RM-3 complex.

Initial data | Result | Diagram of position of components | Print

Parameter	Value	Unit of measurement	Explanation
Tm.w	18	tex	linear density of conducting wire
Ym.w	8.92	g/cm^3	average linear density of substance of conducting wire
Km.w	0.1	tw./mm	primary twist of conducting wire
Qm w	45.3	cN	breaking load of conducting wire
Em w	0.145		elongation at break of conducting wire
Em w *Fm w	312.414	cN	rigidity of conducting wire
Knm w	1.1	Coef.	pileup coefficient
β	28.7	deg	helix angle of copper microwire with respect to axis of yarn
β	0.501	rad	helix angle of copper microwire with respect to axis of yarn
Tcomp.3	160	tex	linear density of third component
Ycomp.3	1.205	g/cm^3	average density of substance of third component
Kcomp.3	0.1	tw/mm	twist of third component
Qcomp.3	165	cN	breaking load of third component
Ecomp.3	0.039		elongation at break of third component
Ecomp.3*Fcomp.3	4230.769	cN	rigidity of third component
Kcomp.3	1.002	coeff.	pileup coefficient of third componen
Dc.y	1.289	mm	diameter of CCY
Rc.y	0.644	mm	radius of CCY
α	0.68	rad	helix angle of first component with respect to vertical of CCY
α	38,961	deg	helix angle of first component with respect to vertical of CCY
γ	0.68	rad	helix angle of axis of second component with respect to vertical of CCY
γ	38.961	deg	helix angle of axis of second component with respect to vertical of CCY
ω	0.68	rad	helix angle of axis of third component with respect to vertical of CCY
ω	38.967	deg	helix angle of axis of third component with respect to vertical of CCY
qcomp.1	13.542		ratio of rigidity of first component to conducting wire
qcomp.2	13.542		ratio of rigidity of second component to conducting wire
qcomp.3	13.542		ratio of rigidity of third component to conducting wire
Qc.y	2257.426	cN	theoretical breaking load of CCY

Fig. 3. Appearance of the page with the results of calculating some physicomechanical indexes of CCY.

Let us calculate the rigidity of the fibres [1]:

$$E_{\text{s.y.}} F_{\text{s.y.}} = \frac{P_{\text{s.y.}}}{\varepsilon_{\text{s.y.}}}, \tag{4}$$

$$E_{\text{microw}} F_{\text{microw}} = \frac{P_{\text{microw}}}{\varepsilon_{\text{microw}}}. \tag{5}$$

Then the rigidity ratio is

$$q_{\text{s.y.}} = \frac{E_{\text{s.y.}} F_{\text{s.y.}}}{E_{\text{microw}} F_{\text{microw}}}, \tag{6}$$

where E_{microw} is the modulus of elasticity of the copper microwire, MPa; $F_{\text{s.y.}}$ is the area of the cross section of the single yarn, mm^2; F_{microw} is the area of the cross section of the copper microwire, mm^2; $P_{\text{s.y.}}$ is the tension of the single yarn, cN; P_{microw} is the tension of the copper microwire, cN; $A_{\text{s.y.}}$ is the modulus of elasticity of the single yarn, MPa; $E_{\text{s.(p)}}$, $F_{\text{s.(p)}}$ is the tensile rigidity, MPa·mm^2; $\varepsilon_{\text{microw}}$ is the deformation of the axial line of the copper microwire, %.

The calculated strength of the 500 tex combined conducting yarn, determined with Eq. (3), is equal to

$$Q = 45.3\left[13.542\left(\frac{\cos^2 0.5\cdot\cos 0.68}{\cos^2 0.68}+\frac{\cos^2 0.5\cdot\cos 0.68}{\cos^2 0.68}+\frac{\cos^2 0.5\cdot\cos 0.68}{\cos^2 0.68\cdot\cos^2 0.68}\right)+\cos 0.5\right]=2257.4 \qquad (7)$$

Then the helix angle of the microwire is determined experimentally (Fig. 2), angle $\beta = 28.7° = 0.5$ rad.

The experimental value of the breaking load of the combined conducting yarn, equal to 2204.5 cN (see Table 1), almost coincides with the calculated value – the relative difference is 2.4%.

The theoretically calculated and real indexes of 500 tex CCY are compared in Table 2.

The difference between the calculated and experimental indexes does not exceed 5%; as a consequence, the theoretical curves can be used for calculating the linear density and absolute breaking load of combined (wool + Capron + Nitron) conducting yarn.

The calculations of the breaking load, rigidity, ratio of the rigidity of each component to the rigidity of the copper microwire, diameter of the CCY, and other characteristics were checked and confirmed by software (Fig. 3).

Since the difference between the computed and actual characteristics does not exceed 5%, the software and the theoretical curves can be recommended for determining the strength of the combined conducting yarn of high linear density**.**

REFERENCES

1. V. P. Shcherbakov, *Applied Mechanics of Fibres* [in Russian], MSTU, Moscow (2001).
2. A. G. Kogan, *Production of Combined Yarn and Fibres* [in Russian], Legkaya i Pishchevaya Pro-st', Moscow (1981), p. 143.