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STRENGTH OF ANISOTROPIC NICKEL-MESH COMPOSITE MATERIALS

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The authors studied the characteristics of strength of filtering composite materials reinforced by a two-layer nickel mesh with a coating depending on the cutting-out angle. The anisotropy of the characteristics of strength is shown to be the closest to the Ashkenazy phenomenological strength criterion in the form of a fourth degree polynomial, which describes the ultimate strength vs net cut-out angle limiting curve.

Key words: anisotropy, strength, tension, filters, nickel mesh.

Čvrstoća anizotropnih kompozitnih materijala na temelju nikljevih mreža. Istraživane su karakteristike čvrstoće dvoslojnih filtrirajućih kompozirtnih materijala na temelju nikljovih mreža s pokrićem u ovisnosti od kuta rezanja. Dokazano je, da anzotropija karakteristike čvrstoće je najbliža fenomenološkom kriteriju čvrstoće po Ashkenazy-u u obliku polinoma četvrtog stupnja koji opisuje krivulja granice razvlačenja u ovisnosti kuta rezanja mreže.

Ključne riječi: nikljeva mreža, anizotropija, čvrstoće, filteri

INTRODUCTION

The development of modern engineering involves high requirements for strength of structural materials and the reduction of materials consumption for the structures manufactured from them [1, 2]. One of the widely known ways to increase strength is to impart orderliness to the material structure or to reinforce the material. Reinforced materials are composites in which one of the components (the reinforcing one) has a much higher strength and rigidity than another (the binding one). These materials are structurally anisotropic since a corresponding arrangement of fibers is used in manufacturing them.

The goal of this investigation is to select an optimum expression for the approximation of the diagrams describing the dependence of the mechanical characteristics of nickel meshes on the cutting-out angle.

EXPERIMENTAL RESULTS AND DISCUSSION

The material studied was two-layer sheet compositions obtained by spraying nickel powder twill weave No. 80/720 of grade NP-2 on the nickel mesh. To ensure the required mechanical properties and porosity characteristics, the materials were subjected to various heat treatments according to the regimes presented in the Table [1] together with the experimental procedures and results.

Specimens in the form of a strip of length 100 mm and width 5 mm with the thickness of the mesh with a sprayed layer 0,15 mm were cut out in seven different directions with respect to the weft in 15 degree intervals.

The paper presents the results of investigations performed on materials (No. 2, 3, 4, and 5) that differed only in the temperature of annealing [3].

The problem of strength of anisotropic bodies includes two tasks: determination of the dependence of the characteristics of strength on the orientation of the force with respect to the material symmetry axes and generation of an equation (criterion) that describes strength under the action of complex (bi- and three-axial) stress states [4]. Both tasks are closely related and generally considered as a whole.

Description of the whole curve of the ultimate strength anisotropy by a single equation requires a phenomenological approach whereby the ultimate states of various physical natures are considered jointly, among them the stresses σ_x, σ_y, and τ_{xy} acting along the dangerous symmetry area element of the specimen parallel to the fibers. For anisotropic bodies, uniaxial tension or compression at an angle to the symmetry axis is considered as a particular case of the complex stress state. The most general formulation of the phenomenological strength criterion of anisotropic bodies was proposed by

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A. K. Malmeister [5] and E. M. Wu [6] in the form of polynomials in stress tensor components. Particular forms of this tensor polynomial are two groups of strength criteria. One of them comprises the first and the second degrees of the stress tensor components [7-9], the other only the second and fourth degrees of those components [10, 11].

The use of a simplified Noris' quadratic criterion for plane stress states has received wide acceptance [8, 12]. For the *xy* plane of an orthotropic material (a material with three mutually perpendicular symmetry axes) at τ_{xy} = 0, this criterion corresponds to the surface of strength in the form of an ellipsoid.

The criterion in the form of a fourth degree polynomial [11] is more general than the quadratic one and for the plane stress state in one of the symmetry planes *ik* of an orthotropic material it has the following form:

$$\left(\frac{\sigma_i^2}{\sigma_{ui}}+\frac{\sigma_i^2}{\sigma_{uk}}+\frac{\tau_{ik}^2}{\tau_{uik}}+\sigma_i\sigma_k s_{ik}\right)^2-\sigma_i^2-\sigma_k^2-\sigma_i\sigma_k-\tau_{ik}^2=0 \qquad (1)$$

where σ_i, σ_k, and τ_{ik} are the stresses acting along the symmetry area elements of the material that are perpendicular to the symmetry axes *i* and *k*; σ_{ui}, σ_{uk}, and τ_{uik} are the relative ultimate strengths of the material; the parameter S_{ik} for tension is determined from the formula $s_{ik}=\frac{4}{\sigma_{uik}^{(45)}}-\frac{1}{\sigma_{ui}}-\frac{1}{\sigma_{uk}}-\frac{1}{\tau_{uik}}$, where $\sigma_{uik}^{(45)}$ is the ultimate strength under the action of only normal stresses at an angle of 45° to the axes *i* and *k* in the symmetry plane *ik*.

By setting *i* = *x* and *k* = *y*, we consider the uniaxial tension of specimens variously oriented in the plane *ik*. Let us express the values of the limit stresses as a function of the load application angle $\sigma_i = \sigma_u \cos^2\alpha$; $\sigma_k = \sigma_u \sin^2\alpha$; $\sigma_{ik} = \frac{\sigma_u}{2}\sin 2\alpha$; and $\sigma_u = \sigma_i + \sigma_k$ [11]. Now we can obtain an equation describing the dependence of the ultimate strength σ_u on the fiber inclination angle α in the specimen. For this purpose, let us again express σ_x, σ_y, and τ_{xy} in terms of σ_u and, on substitution into the polynomial strength criterion (1), we obtain

$$\frac{1}{\sigma_u}=\frac{\cos^4\alpha}{\sigma_{ux}}+\frac{\sin^4\alpha}{\sigma_{uy}}+\sin^2\alpha\cos^2\alpha\left(\frac{4}{\sigma_{uxy}}-\frac{1}{\sigma_{ux}}-\frac{1}{\sigma_{uy}}\right). \qquad (2)$$

If we assume $\sigma_{uy} = \sigma_0$, $\sigma_{uy} = \sigma_{90}$, and $\sigma_{uxy}^{(45)} = \sigma_{45}$, formula (2) can be rewritten in the following form:

$$\sigma_u=\frac{\sigma_0}{\cos^4\alpha+b\sin^2 2\alpha+c\sin^4\alpha}, \qquad (3)$$

where $b=\frac{\sigma_0}{\sigma_{45}}-\frac{1+c}{4}$, $c=\frac{\sigma_0}{\sigma_{90}}$.

Formula (3) is referred to as the "tensorial one"; it describes well the whole curve of the ultimate strength variation depending on the fiber inclination angle α.

If the principal stresses σ_1 and σ_2 act in parallel to the symmetry axes of an orthotropic material ($\sigma_y = \sigma_1$, $\sigma_y = \sigma_2$, and $\tau_{xy} = 0$), then for graphic representation, it is sufficient to construct the limiting curve of strength for one octant in the coordinates $\sigma_x - \sigma_y$.

A criterion in the form of a fourth degree polynomial makes it possible to approximate the strength surface in each of the octants of the stress space over the least number of the parameters determined experimentally.

The investigation of the dependences of the anisotropy of the strength characteristics on the cut-out angle with respect to the symmetry axes for composite materials No. 2, 3, 4, and 5 heat-treated under different conditions (see the Table in [3]) has shown that the Ashkenazi phenomenological criterion of strength [4] in the form of a fourth degree polynomial (1) is the closest to the dependences studied. Hence, after some transformations, the ultimate strength as a function of the material cut-out angle is determined from formula (3), where we substitute φ for α. Formula (3) describes well the limiting curve of the ultimate strength variation depending on the material cut-out angle φ for one octant in the coordinates $\sigma_x - \sigma_y$. This is seen from Fig. 1, where the data for composite No. 2 are presented as an example.

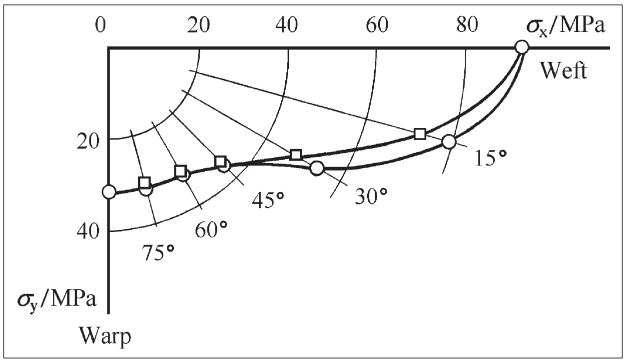

Figure 1. Limiting curves of the ultimate strength variation depending on the cut-out angle φ for composite material No. 2 for one octant in the coordinates $\sigma_x - \sigma_y$. Symbols: □ – according to the calculated data ; ○ – according to the experiment [3].

The test data and the results of strength analysis for materials No. 2, 3, 4, and 5 presented in Table 1 lend support to the validity of the choice of the strength criterion (the deviation of the calculated data from the test results does not exceed 11 %).

CONCLUSION

Thus, using formula (3) and having three characteristics of strength (along the weft, along the warp, and at an angle of 45°), it is possible to determine the characteristics of strength of nickel-mesh composite in different directions with respect to the weft for one octant.

Table 1. **Results of determining σ_u as a function of the cut-out angle φ for composite materials No. 2, 3, 4, and 5 heat-treated in hydrogen and annealed in vacuum obtained in tension and by calculation**

Material number	Data	Ultimate strength (σ_u/MPa) as a function of the cut-out angle (φ/deg.) of the material						
		0 (along the weft)	15	30	45	60	75	90 (along the warp)
2	Experimental	92,6	78,8	53,4	36,0	32,1	32,1	31,5
	Calculated	–	72,3	47,8	36,0	31,9	31,2	–
	Deviations in %	–	8,2	10,4	–	0,8	2,6	–
3	Experimental	85,4	76,5	62,6	44,7	40,3	34,5	35,9
	Calculated	–	74,4	56,5	44,7	38,8	36,5	–
	Deviations in %	–	2,7	9,7	–	3,7	5,7	–
4	Experimental	89,8	81,6	68,4	48,0	44,1	40,0	36,4
	Calculated	–	79,3	61,1	48,0	40,8	37,4	–
	Deviations in %	–	2,8	10,7	–	7,6	6,6	–
5	Experimental	87,9	76,3	60,7	42,5	33,3	31,6	31,3
	Calculated	–	75,6	55,8	42,5	35,5	32,2	–
	Deviations in %	–	0,9	8,1	–	6,5	2,0	–

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Note: The Author N. P. Rudnitsky is responsible for English language in the Article.