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DETERMINATION OF MECHANICAL CHARACTERISTICS OF AIRCRAFT WING PANELS

ВИЗНАЧЕННЯ МЕХАНІЧНИХ ХАРАКТЕРИСТИК ПАНЕЛІ КРИЛА ЛІТАКА

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Abstract. *The paper presents the method of calculating the mechanical characteristics of multilayer composite panels. The optimal sequence of laying out monolayers was selected. The mechanical behavior of the composition is determined by the ratio of the properties of the reinforcing elements and the matrix, as well as the strength of the connection between them. Among the most important requirements for the designs of modern aircraft, we can mention the minimum weight, the maximum stiffness and strength of the nodes, the maximum service life of the structures in operational conditions, and high reliability. With the help of the developed methodology, the elastic properties of the composite material with different angles of laying layers were determined. Calculations of the mechanical characteristics of carbon-plastic panels made of carbon tape and carbon fabric are given.*

Key words: *Composite materials, monolayer, carbon tape, carbon fabric*

Introduction.

A variety of fibers and matrix materials, as well as reinforcement schemes, used in the creation of composite structures, which allows us to purposefully adjust the strength, stiffness, level of operating temperatures and other properties by selecting the composition, changing the ratio of components and the microstructure of the composite [1-3,7]. High-modulus carbon fibers are used for the manufacture of aircraft parts. Polymeric carbon plastics are characterized by low density, high modulus of elasticity, low thermal and electrical conductivity, low frictional wear and high damping capacity.

Problem setting and problem solving

For a plane stress state when the axes are rotated by an angle φ^o (Fig. 2), the dependence of the acting stresses in the coordinate systems of the monolayer and the package of monolayers has the form

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} c^2 & s^2 & -2 \cdot s \cdot c \\ s^2 & c^2 & 2 \cdot s \cdot c \\ s \cdot c & -s \cdot c & c^2 - s^2 \end{bmatrix} \cdot \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix},$$

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} c^2 & s^2 & 2 \cdot s \cdot c \\ s^2 & c^2 & -2 \cdot s \cdot c \\ -s \cdot c & s \cdot c & c^2 - s^2 \end{bmatrix} \cdot \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix},$$

where

$c = \cos \varphi^o$; $s = \sin \varphi^o$; σ_1, σ_2, τ_{12} are the stresses acting in the monolayer,

σ_x, σ_y, τ_{xy} are the stresses acting in the monolayer packets.

Each individual layer (monolayer) consists of unidirectional fibers that determine the direction of the layer, and a matrix that provides normal and transverse stiffness of the layer. Such a monolayer is orthotropic because it has two mutual axes of symmetry. Its characteristic feature is that normal stresses acting along the axes of orthotropy do not cause shear deformations, and tangential stresses - elongations. Hooke's law describing the stress-strain relationship for a unidirectional monolayer in a flat stress-strain state has the form:

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} C_{11}^0 & C_{12}^0 & 0 \\ C_{12}^0 & C_{22}^0 & 0 \\ 0 & 0 & C_{66}^0 \end{bmatrix} \cdot \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix},$$

where

σ_1, σ_2, τ_{12} are the stresses acting in the monolayer;

ε_1, ε_2, γ_{12} are the monolayer deformations;

C_{kl}^0 are the coefficients of the stiffness matrix of the monolayer, which are determined as:

$$C_{11}^0 = \frac{E_1}{1 - \mu_{12} \cdot \mu_{21}}; \qquad C_{12}^0 = \frac{E_1 \cdot \mu_{21}}{1 - \mu_{12} \cdot \mu_{21}} = \frac{E_2 \cdot \mu_{12}}{1 - \mu_{12} \cdot \mu_{21}};$$

$$C_{22}^0 = \frac{E_2}{1 - \mu_{12} \cdot \mu_{21}}; \qquad C_{66}^0 = G_{12},$$

where

E1, E2 are the longitudinal and transverse modulus of elasticity of the monolayer;

G12 is the monolayer shear modulus;

μ_{12} is the Poisson's main ratio;

μ_{21} is the second-order Poisson's ratio, which is determined from Maxwell's relation:

$$\mu_{12} \cdot E_2 = \mu_{21} \cdot E_1.$$

If the loading of the monolayer does not occur along the orientation axis, then it is in the state of layer-by-layer loading as part of the composite package. Then Hooke's law takes shape:

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} C_{11}^{\varphi} & C_{12}^{\varphi} & C_{16}^{\varphi} \\ C_{13}^{\varphi} & C_{22}^{\varphi} & C_{26}^{\varphi} \\ C_{16}^{\varphi} & C_{26}^{\varphi} & C_{66}^{\varphi} \end{bmatrix} \cdot \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix},$$

where the coefficients of the stiffness matrix of the monolayer rotated by an angle φ^o

$$C_{11}^{\varphi} = V_1 + V_2 \cdot \cos 2\varphi + V_3 \cdot \cos 4\varphi ;$$
$$C_{12}^{\varphi} = V_1 - 2 \cdot V_4 - V_3 \cdot \cos 4\varphi ;$$
$$C_{16}^{\varphi} = 0.5 \cdot V_2 \cdot \sin 2\varphi + V_3 \cdot \sin 4\varphi ;$$
$$C_{22}^{\varphi} = V_1 - V_2 \cdot \cos 2\varphi + V_3 \cdot \cos 4\varphi ;$$
$$C_{26}^{\varphi} = 0.5 \cdot V_2 \cdot \sin 2\varphi - V_3 \cdot \sin 4\varphi ;$$
$$C_{66}^{\varphi} = V_4 - V_3 \cdot \cos 4\varphi .$$

Here, the independent coefficientsV_1, V_2, V_3 and V_4 are determined:

$$V_1 = \left(3 \cdot C_{11}^0 + 2 \cdot C_{12}^0 + 3 \cdot C_{22}^0 + 4 \cdot C_{66}^0\right)/8 ;$$
$$V_2 = \left(C_{11}^0 - C_{22}^0\right)/2 ;$$
$$V_3 = \left(C_{11}^0 - 2 \cdot C_{12}^0 + C_{22}^0 - 4 \cdot C_{66}^0\right)/8 ;$$
$$V_4 = \left(C_{11}^0 - 2 \cdot C_{12}^0 + C_{22}^0 + 4 \cdot C_{66}^0\right)/8 .$$

Coefficients V_1 and V_4 characterize the average stiffness of the monolayer under tension and shear, and coefficients V_2 and V_3 characterize the degree of anisotropy of the material. Thus, the behavior of a monolayer in a flat stress-strain state is characterized by four independent elastic constants: E_1, E2, G_{12},μ_{12} for reinforcement angles 0° i 90°; V_1, V_2, V_3, V_4 for reinforcement angles φ^o

Monolayer stiffness matrix coefficients

$$C_{11}^0 = \frac{E_1}{1-\mu_{12}\cdot\mu_{21}} = \frac{65000}{1-0.07\cdot 0.06785} = 65310\ (\text{Ì Pà})$$
$$C_{12}^0 = \frac{E_1\cdot\mu_{21}}{1-\mu_{12}\cdot\mu_{21}} = \mu_{21}\cdot C_{11}^o = 0.06785\cdot 65310 = 4431\ (\text{Ì Pà})$$
$$C_{22}^0 = \frac{E_2}{1-\mu_{12}\cdot\mu_{21}} = \frac{63000}{1-0.07\cdot 0.06785} = 63301\ (\text{Ì Pà})$$
$$C_{66}^0 = G_{12} = 6500\ \text{Ì Pà}$$

independent coefficients are

$$V_1 = \left(3\cdot C_{11}^0 + 2\cdot C_{12}^0 + 3\cdot C_{22}^0 + 4\cdot C_{66}^0\right)/8 =$$
$$= \left(3\cdot 65310 + 2\cdot 4431 + 3\cdot 63301 + 4\cdot 6500\right)/8 = 52587\ (\text{Ì Pà})$$
$$V_2 = \left(C_{11}^0 - C_{22}^0\right)/2 = (65310 - 63301)/2 = 1005\ (\text{Ì Pà})$$
$$V_3 = \left(C_{11}^0 - 2\cdot C_{12}^0 + C_{22}^0 - 4\cdot C_{66}^0\right)/8 =$$
$$= \left(65310 - 2\cdot 4431 + 63301 - 4\cdot 6500\right)/8 = 11719\ (\text{Ì Pà})$$
$$V_4 = \left(C_{11}^0 - 2\cdot C_{12}^0 + C_{22}^0 + 4\cdot C_{66}^0\right)/8 =$$
$$= \left(65310 - 2\cdot 4431 + 63301 + 4\cdot 6500\right)/8 = 18219\ (\text{Ì Pà})$$

Coefficients of the stiffness matrix of a monolayer rotated at an angle φ° = 45°

$$C_{11}^{45} = V_1 + V_2 \cdot \cos(2 \cdot 45°) + V_3 \cdot \cos(4 \cdot 45°) =$$
$$= 52587 + 1005 \cdot \cos(2 \cdot 45°) + 11719 \cdot \cos(4 \cdot 45°) = 40868 \ (\text{Ì Pà})$$
$$C_{12}^{45} = V_1 - 2 \cdot V_4 - V_3 \cdot \cos(4 \cdot 45°) =$$
$$= 52587 - 2 \cdot 18219 - 11719 \cdot \cos(4 \cdot 45°) = 27868 \ (\text{Ì Pà})$$
$$C_{16}^{45} = 0.5 \cdot V_2 \cdot \sin(2 \cdot 45°) + V_3 \cdot \sin(4 \cdot 45°) =$$
$$= 0.5 \cdot 1005 \cdot \sin(2 \cdot 45°) + 11719 \cdot \sin(4 \cdot 45°) = 502 \ (\text{Ì Pà})$$
$$C_{22}^{45} = V_1 - V_2 \cdot \cos(2 \cdot 45°) + V_3 \cdot \cos(4 \cdot 45°) =$$
$$= 52587 - 1005 \cdot \cos(2 \cdot 45°) + 11719 \cdot \cos(4 \cdot 45°) = 40868 \ (\text{Ì Pà})$$
$$C_{26}^{45} = 0.5 \cdot V_2 \cdot \sin(2 \cdot 45°) - V_3 \cdot \sin(4 \cdot 45°) =$$
$$= 0.5 \cdot 1005 \cdot \sin(2 \cdot 45°) - 11719 \cdot \sin(4 \cdot 45°) = 502 \ (\text{Ì Pà})$$
$$C_{66}^{45} = V_4 - V_3 \cdot \cos(4 \cdot 45°) = 18219 - 11719 \cdot \cos(4 \cdot 45°) = 29937 \ (\text{Ì Pà})$$

Elastic characteristics of a monolayer turned at an angle φ° = 45°

$$E_x = \frac{\Delta C}{C_{22}^{45} \cdot C_{66}^{45} - (C_{26}^{45})^2} = \frac{2.67445 \cdot 10^{13}}{40868 \cdot 29937\text{-}502^2} = 21864 \ (\text{Ì Pà})$$
$$E_y = \frac{\Delta C}{C_{11}^{45} \cdot C_{66}^{45} - \left(C_{16}^{45}\right)^2} = \frac{2.67445 \cdot 10^{13}}{40868 \cdot 29937\text{-}502^2} = 21864 \ (\text{Ì Pà})$$
$$G_{xy} = \frac{\Delta C}{C_{11}^{45} \cdot C_{22}^{45} - (C_{12}^{45})^2} = \frac{2.67445 \cdot 10^{13}}{40868 \cdot 40868\text{-}27868^2} = 29930 \ (\text{Ì Pà})$$
$$\mu_{xy} = \frac{C_{12}^{45} \cdot C_{66}^{45} - C_{16}^{45} \cdot C_{26}^{45}}{C_{22}^{45} \cdot C_{66}^{45} - (C_{26}^{45})^2} = \frac{27868 \cdot 29937 - 502 \cdot 502}{40868 \cdot 29937 - 502^2} = 0.68$$

Similarly, the elastic characteristics of a monolayer rotated at other angles φ° are determined. The values of the modulus of elasticity and shear depending on the angle φ° in the polar coordinate system are presented in Fig. 1, and Poisson's ratio in Fig. 2.

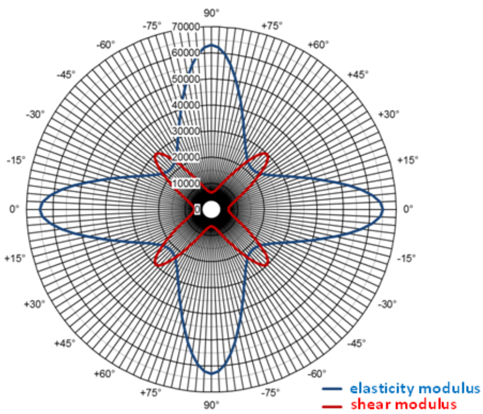

Fig. 1. The modulus of elasticity E and shear G for carbon fiber depending on the angle φ° in the polar coordinate system

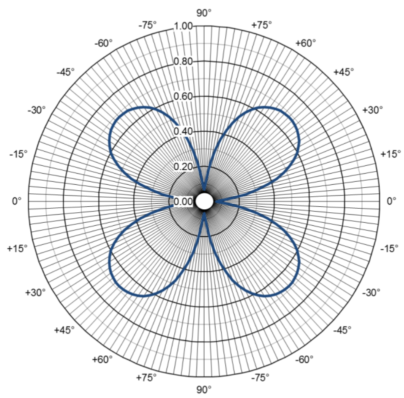

Fig. 2. Poisson's ratio for carbon fiber depending on the angle φ° in the polar coordinate system

Conclusion

This approach allows to determine the location of possible destruction of the structure, and to optimize the geometry, which should increase the life of the bellows compensator.

The paper presents the method of calculating the mechanical characteristics of multilayer composite panels. The optimal sequence of laying out monolayers was selected. With the help of the developed methodology, the elastic properties of the composite material with different angles of laying layers were determined. Calculations of the mechanical characteristics of carbon fiber panels made of carbon tape and carbon fabric are given, and a comparison of composites made of carbon tape and carbon fabric is made.

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