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The research influence of strained-deformed state of two-layers axially symmetrical cylindrical clad layers on their physic-mechanical properties

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ABSTRACT: The paper considers a combined two-layer axisymmetric cylindrical shell made of composite layers differing in thickness and physical and mechanical properties, and also investigates the influence of the stress-strain state of such shells on their strength and stability.

KEY WORDS:two layers axially symmetrical combined cylindrical clad layer, uniformly-distributive loading, system of differential equations, deforming of clad layer, motion of medial surface, function of displacement, shearing tension, sagging, cyclic motion, simple and particulate decisions of characteristic equation**.**

I. INTRODUCTION

One of the insufficiently studied areas of great applied importance is the study of the strength and stability of shells made of composite and combined materials. Combined two-layer casings can be divided into two main groups:

1) constructions consisting of isotropic and anisotropic layers.
2) constructions, both layers of which are anisotropic.

Individual problems of the statics of two-layer plates and shells, which are based on the application of the Kirchhoff – Love hypotheses, are considered in [2,3,4,5]. In these works, the stability and strength of two-layer cylindrical shells under axisymmetric deformations under the action of internal pressure were investigated, as well as some problems of plate bending.

In work [1] S. A. Ambartsumyan proposed two variants of refinement of the theory of two-layer shells. The first option corresponds to the deflection according to the classical theory, and the second one represents the correction associated with taking into account the shifts in each layer. The author notes that the accuracy of the constructed theories depends both on the geometric parameters of the structures under consideration and on other physical and mechanical characteristics of the layers.

Thus, in the scientific literature devoted to the stress-strain state (SSS), strength, and stability of two-layer combined shells, a significant amount of research has been accumulated on determining the SSS of certain types of shells: spherical, conical, cylindrical and others. Such structures include various containers, aircraft and deep-sea vehicles, apparatus of the chemical industry, building structures and many others.

In connection with the emergence of new structural composite materials, in recent years, two-layer shells have been widely used, which are characterized by a significant difference between the elastic constants of the materials of the layers. An urgent problem is the calculation of structures taking into account various individual factors, such as taking into account the physical nonlinearity of the material, taking into account the transverse shear, the effect of the adhesive layer on the strength and stability of the shells. Neglecting these factors can lead to unacceptable errors.

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II. METHODS OF RESEARCH

This paper considers a combined two-layer axisymmitric cylindrical shell made of composite layers differing in thickness and physical and mechanical properties (Fig. 1)

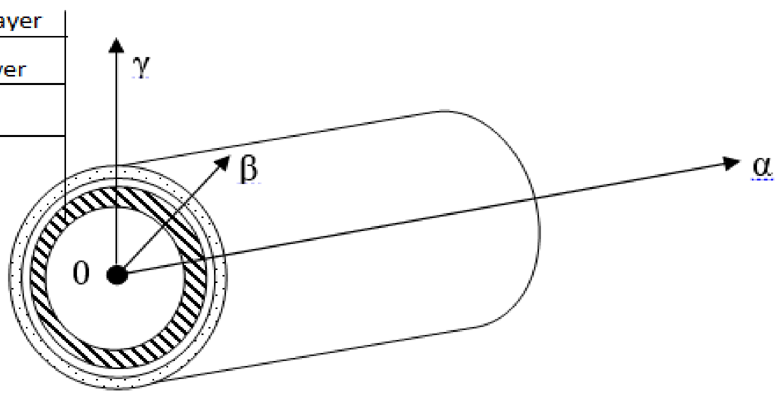

Fig. 1. Two-layer axisymmetric combined cylindrical shell.

It is assumed that:
a) a uniformly distributed load acts on the shell, normal to the middle surface and smoothly changing along the generatrix;
b) the considered two-layer combined shell consists of a carrier (1), and reinforcing and adhesive layers (3 and 2), (see Figure 1). Wherein:
c) the thickness of the bearing, reinforcing and adhesive layers, constant;
d) the thickness of the bearing layer is much greater than that of the reinforcing layer (h> b).
The calculation of the structure for strength and stability, taking into account the above factors, will be carried out using a system of differential equations for the deformation of the shell relative to the unknowns U_0,$\Phi_{1,2}$, $\tau_{1,2}$, W, υ0, (U_0-displacement of the middle surface; $\Phi_{1,2}$-shear functions, $\tau_{1,2}$-shear stresses, W-deflection, υ0-annular displacement).
Bearing in mind that for cylindrical shells the surface shape coefficients: $A_1 = 1$, B = R, $R_2 = A_2 = r$ (β) and $R_1 = \infty$, we write the tensile (compression) and shear deformations in the form:

$$E_{\alpha}^{[i]} = \frac{\partial U^{(i)}}{\partial \alpha}$$

$$E_{\beta} = \frac{1}{R^{(i)}}\frac{\partial \vartheta^{(i)}}{\partial \beta} + \frac{W}{R^{(i)}} \qquad (1)$$

$$E_{\alpha\beta} = \frac{1}{R^{(i)}}\frac{\partial U^{(i)}}{\partial \beta} + \frac{\partial \vartheta^{(i)}}{\partial \alpha}$$

The coordinate system is taken as shown in Figure 1.
The stresses in the layers are determined by the known relations:

$$\sigma_{\alpha}^{(i)} = B_{11}^{(i)} E_{\alpha}^{(i)} + B_{12} E_{\beta}^{(i)}$$

$$\sigma_{\beta}^{(i)} = B_{22}^{(i)} E_{\beta}^{(i)} + B_{12}^{(i)} E_{\alpha}^{(i)} \qquad (2)$$

$$\tau_{\alpha\beta} = G^{(i)} E_{\alpha\beta}$$

where σ -are the voltages between the layers, G- are the shear moduli of the layers.

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We write axial displacements in the bearing layer of a two-layer cylindrical shell in the form:

$$U = U_0 - \gamma \frac{\partial W}{\partial \alpha} + (\frac{\gamma h^2}{8} - \frac{\gamma^3}{6})\Phi_1 + (1 - \frac{\gamma}{h})\frac{\gamma}{2G_{\beta 13}}\tau_1 \quad (3)$$

Movements in the circular direction

$$\vartheta = (1 + \frac{\gamma}{R_M})\vartheta_0 - \frac{\gamma}{R_M}\frac{\partial W}{\partial \beta} + \left[\frac{\gamma h^2}{8}(1 + \frac{\gamma}{2R_M}) - \frac{\gamma}{6}(1 + \frac{\gamma}{4R_M})\right]\Phi_2 + \\ + \left[\frac{\gamma}{2G_{M23}}(1 + \frac{\gamma}{2R_M}) - \frac{\gamma^2}{2hG_{M23}}(1 + \frac{\gamma}{3R_M})\right]\tau_2 \quad (4)$$

The expression for the total energy can be obtained on the basis of the Lagrange variational principle. According to this principle, the potential energy of an elastic system in an equilibrium position takes on a stationary value. It consists of the potential energy of elastic deformation of the layers, the glue line and the work of the external load. Taking into account the expression for the total energy, we obtain in the form of a double integral functional:

$$\text{U}(\varepsilon) = \frac{1}{2}\iint U_F(\frac{\partial U_0}{\partial \alpha}, \frac{\partial U_0}{\partial \beta}, \frac{\partial \vartheta_0}{\partial \alpha}, \frac{\partial \vartheta_0}{\partial \beta}, \frac{\partial \Phi_0}{\partial \alpha}, \frac{\partial \Phi_0}{\partial \beta}, \\ \frac{\partial \Phi_2}{\partial \alpha}, \frac{\partial \Phi_2}{\partial \beta}, \frac{\partial \tau_1}{\partial \alpha}, \frac{\partial \tau_1}{\partial \beta}, \frac{\partial \tau_2}{\partial \alpha}, \frac{\partial \tau_2}{\partial \beta}, \frac{\partial^2 W}{\partial \alpha^2}, \frac{\partial^2 W}{\partial \beta^2}, \frac{\partial^2 W}{\partial \alpha \partial \beta}, \\ \frac{\partial W}{\partial \alpha}, \frac{\partial W}{\partial \beta}, U_0, \vartheta_0, \Phi_1, \Phi_2 \tau_1, \tau_2, W)ds \quad (5)$$

Since for the considered axisymmetric two-layer shell, only axisymmetric loads act, then we read that 0, Φ_2, τ_2 are absent. Then the system of differential equations for the deformation of the shell will be solved with respect to the unknowns U_0, Φ_1, τ_1, W.

General solutions of the system will consist of homogeneous and private solutions

$$W(\alpha) = W_n{}^{first.}(\alpha) + W_n{}^{part} \\ U_0(\alpha) = U_n{}^{first.}(\alpha) + U_n{}^{part} \\ \Phi_1(\alpha) = \Phi_n{}^{first.}(\alpha) + \Phi_n{}^{part} \\ \tau_1(\alpha) = \tau_n{}^{first.}(\alpha) + \tau_n{}^{part} \quad (6)$$

The solution of the system of differential equations of equilibrium, taking into account the boundary conditions, will be sought in the form of Euler's substitution:

$$U_i = \sum a_i e^{Sin\alpha}$$

In our case, the general solution, taking into account multiple roots, takes the form:

$$W^{first.} = \sum_{i=1}^{n} e^{Sin\alpha}(W_i Cosq_i\alpha + W_{i+1} Sinq_i\alpha), \\ U_0{}^{first.} = \sum_{i=1}^{n} e^{Sin\alpha} W_i (a_i Cosq_i\alpha + a_{i+1} Sinq_i\alpha), \\ \Phi_1{}^{first.} = \sum_{i=1}^{n} e^{Sin\alpha} W_i (b_i Cosq_i\alpha + b_{i+1} Sinq_i\alpha), \\ \tau_1{}^{first.} = \sum_{i=1}^{n} e^{Sin\alpha} W_i (c_i Cosq_i\alpha + c_{i+1} Sinq_i\alpha), \quad (7)$$

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Where a_i, b_i, c_i - are constant integrations depending on the boundary conditions; -roots of the characteristic equation of the system.
After substitution and transformations, you can get a characteristic equation of the form:

$$x^4 + ax^3 + bx^2 + cx + d = 0 \qquad (8)$$

For the general case, the roots of this equation can be:
a) complex conjugate

$$S_{1,2,3,4} = \pm P_1 \pm q_i$$

$$S_{5,6,7,8} = \pm P_2 \pm iq_i$$

b) when, as a special case, four roots can be real $\pm P_2, \pm P_3$

and four roots – complex $S_{1,2,3,4} = \pm P_1 \pm q_i$;

$$S_{5,6} = \pm P_2;\ S_{7,8} = \pm P_3$$

Then, based on the system of differential equations for the deformation of the shell, taking these cases into account, we obtain a system of algebraic equations for ai; bi; ci
This system of equations includes the following cases:
a) the real roots of the characteristic equation take positive values;
b) the real part of the roots of the equation takes negative values.
Numerical calculations have shown that the shear modulus and the seam thickness have a significant effect on the strength and deformability of the combined two-layer cylindrical shells if the shear modulus of the adhesive layer is significantly less than the shear modulus of the layers. If the first layer consists of a composite material, then the effect of transverse shear on the stress-strain state of the combined cylindrical shells will be greater.
The calculation results for a two-layer shell with a fiberglass reinforcing layer are shown in the form of a graph (see Figure 2), changes in stresses in layers and a seam, as well as functions of shear and deflections.

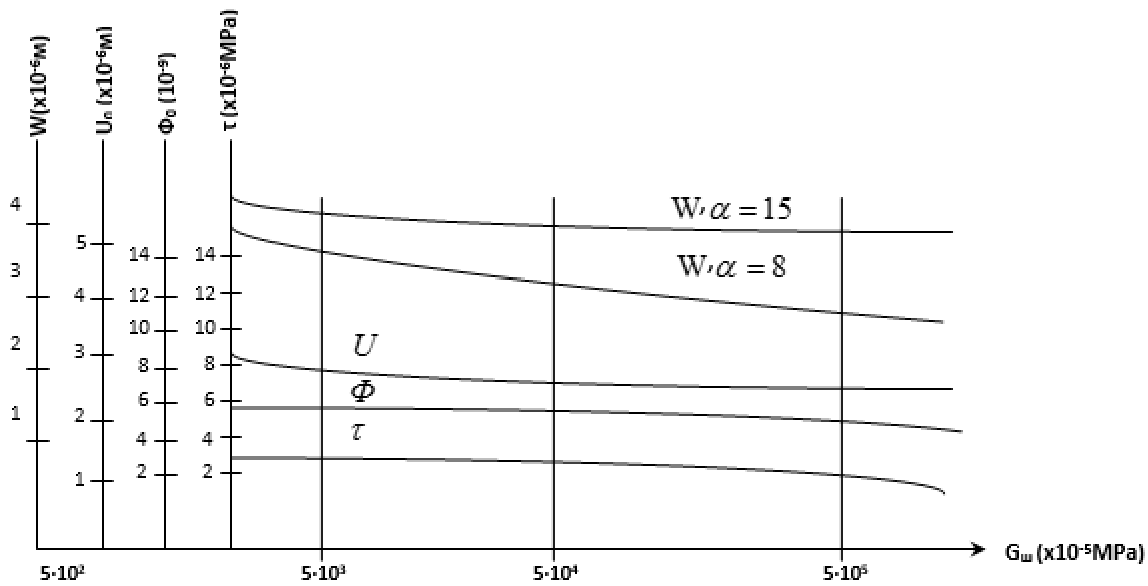

Fig. 2 Change in physical and mechanical characteristics with a change in the shear modulus of the seam.

From the obtained dependences it can be seen that the lower the value of the shear modulus of the weld in comparison with the layer ($G_ш < G_{layer}$), the greater the effect of weld compliance on the stress-strain state of two-layer cylindrical shells.

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III. CONCLUSION

The conducted research and numerical calculations allow us to draw the following conclusions:

The conducted research and numerical calculations allow us to draw the following conclusions:

1) when calculating two-layer orthotropic axisymmetric combined cylindrical shells with low shear stiffnesses, it is necessary to take into account transverse shears and compliance of the glue seam;

2) the effect of the adhesive layer affects significantly more at low shear characteristics

$$\left(\frac{\boldsymbol{h_m}}{\boldsymbol{G_{ш}}} > 5 * \mathbf{10^{-4}}\frac{sm}{Pa}\right)$$

3) with an increase in the thickness of the layer $(h, б, h^{-1}ш)$ *of two-layer cylindrical shells, the influence of the adherence of the adhesive seam on the stress-strain state decreases;*

4) at large values of the shear modulus of the seam $\boldsymbol{G_{mik}} > 500MPa(\boldsymbol{at}\frac{\boldsymbol{h_m}}{\boldsymbol{G_{ш}}} < 5 * \mathbf{10^{-4}}\frac{\boldsymbol{m}}{\boldsymbol{Pa}})$

its influence on the stress-strain state of glass-fiber-reinforced plastic cylindrical shells can be ignored.

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