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STRENGTH AND DEFORMABILITY OF TWO-LAYER COMBINED METAL-COMPOSITE PLATES AND SHELLS WITH CONSIDERATION OF TEMPERATURE LOADS

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Abstract

The paper studies the strength and deformability of combined two-layer slabs (plates) and shells. The influence of shrinkage and temperature loads on the stress-strain state of two-layer plates and shells is investigated. The influence of the adhesive joint flexibility of two-layer combined plates and shells on the stress-strain state is taken into account.

Keywords. Two-layer slab (plate), shell, reinforcing composite layer, shear modulus, shear function, tangential stress, displacement, temperature load, shrinkage of the composite layer.

Introduction

When calculating the strength of combined structures, consideration of the influence of the adhesive layer is particularly necessary when the structure is subjected to temperature effects or when there is a risk of loss of strength and stability of the adhesive and load-bearing layers from tangential loads.

In the case of such combined plates and shells, the resulting transverse shears can significantly change the deformed state. Failure to take into account the physical heterogeneity of the layers and transverse shear at low values of shear modulus leads to significant qualitative errors. It is especially important to be able to correctly evaluate the stress-strain state (SSS) and stability of this kind of structures [3,4]taking into account interlayer shears. These issues are the focus of the research carried out in this paper.

Methods:

A combined plate and shell consisting of two layers bonded by a pliable thin adhesive joint under the action of external loads is considered. The coordinate system is taken according to Fig. 1. The stress-strain state of the combined plate and shell will be determined under the following assumptions:

1)the thicknesses of orthotropic layers are constant and the shell works only in the elastic stage;

2) the thickness of the bearing layer is much greater than the reinforcing layer (h>δ);

3)tangential stresses $\tau_{\alpha\gamma}$, $\tau_{\beta\gamma}$or their corresponding deformations $e_{\alpha\gamma}$, $e_{\beta\gamma}$ along the shell thickness change according to a given law [2,4];

4) Displacement normal to the mid-surface of the shell is independent of the coordinate Ɣ [5,7];

5) there is no pressure between the layers (δ=0).

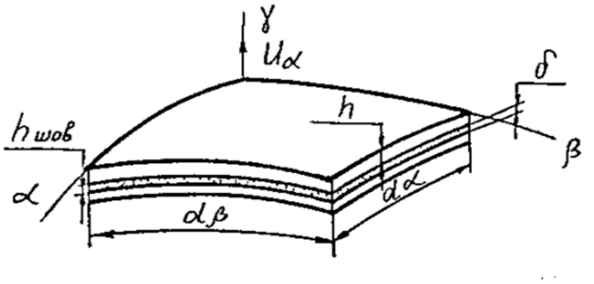

Fig.1 Combined double-layer shell

The tangential stresses have the following analytical expressions:

(a) in the bearing (first) layer

$$\tau_{\alpha\gamma,(\beta\gamma)}=\tau_{1,(2)}(\alpha,\beta)\left(\frac{1}{2}+\frac{\gamma}{h}\right); \qquad (1)$$

b) in the reinforcement layer

$$\tau_{\alpha\gamma,(\beta\gamma)}=\tau_{1,(2)}(\alpha,\beta)\left(\frac{1}{2}+\frac{\gamma_1}{\delta_n}\right); \qquad (2)$$

Taking into account the accepted hypotheses, we have:

$$e_\gamma = 0;\ U_\gamma = \omega(\alpha,\beta); \qquad (3)$$

The shear deformations of the bearing layer can be written in the form:

.
$$e_{\alpha\gamma} = 0,5\left(\frac{h^2}{4}-\gamma^2\right)\Phi_1(\alpha,\beta) + \left(0.5-\frac{\gamma}{h}\right)\frac{\tau_1(\alpha,\beta)}{G_{13}^{(1)}},$$

$$e_{\beta\gamma} = 0,5\left(\frac{h^2}{4}-\gamma^2\right)\Phi_2(\alpha,\beta) + \left(0.5-\frac{\gamma}{h}\right)\frac{\tau_2(\alpha,\beta)}{G_{23}^{(1)}}, \qquad (4)$$

Shear deformations of the reinforcement layer

$$e_{\alpha\gamma}^{(2)} = \left(\frac{1}{2}+\frac{\gamma_1}{\delta}\right)\frac{1}{G_{13}^{(2)}}\tau_1(\alpha,\beta)$$

$$e_{\beta\gamma}^{(2)} = \left(\frac{1}{2}+\frac{\gamma_1}{\delta}\right)\frac{1}{G_{23}^{(2)}}\tau_2(\alpha,\beta) \qquad (5)$$

In the stronger load-bearing layer we assume the presence of shear, arising due to the action of the shear force and defined by the functions:

$\Phi_1(\alpha,\beta), \Phi_2(\alpha,\beta)$.

Here h, δ-thicknesses of bearing and reinforcing layers;

$\Phi_i = \Phi_i(\alpha,\beta)$-arbitrary desired shift functions;

$\tau_i = \tau_i(\alpha,\beta)$- are the required tangential stresses;

$G_{ik}^{(1)}, G_{ik}^{(2)}$- shear moduli of the first and second layers (i=1,2; K=3).

The coordinates γ have the following limits of variation: for the first layer - - -

$$-\frac{h}{2} \le \gamma \le +\frac{h}{2};\ \text{для второго}\ -\frac{\delta}{2} \le \gamma_1 \le +\frac{\delta}{2}.$$

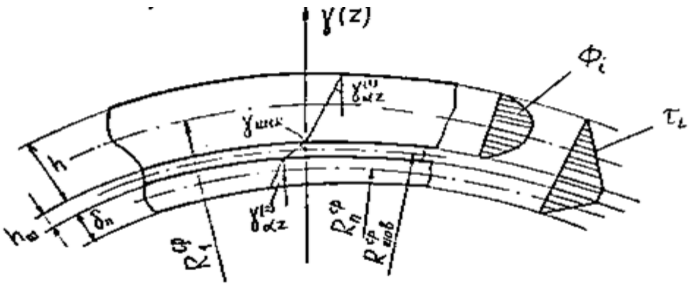

Fig.2 Distributions of functions Φ_i, τ_i by thickness of the shell

In this paper, the problem of thermoelasticity of two-layered plates and shells is solved using the refined theory of S.A. Ambartsumian. [1,2] The hypotheses accepted in [1] are valid for solving this problem. The construction of the refined theory in the paper is based on energy considerations [1,6].

Thermal effects have a significant influence on the behaviour of the structural material. When heated in composite structures, the stresses in the bonding and fibreglass layers change significantly. Temperature strongly affects all mechanical properties of combined laminated plates and shells.

It is considered that the heat flow acts in the transverse direction. From the solution of the heat conduction problem, the temperature distribution in the layers is obtained as follows: in the first layer $T_1 = T_1^0 + \theta_1\gamma$ in the second layer $T_2 = T_2^0 + \theta_Z\gamma_1$

In this case. $-\frac{h}{2} \le \gamma \le +\frac{h}{2};$

θ_1, θ_Z – Temperature gradients in the layers;

T_1^0, T_2^0 – Temperatures of the median planes of the layers.

Taking as usual for full deformations:

$$\varepsilon_{пол} = \varepsilon^{y} + \varepsilon_{T}, \tag{6}$$

Где: ε^{y} – elastic deformations of the system,

ε^{T} – deformation of layers from temperature loads.

To obtain the basic equations of equilibrium of combined two-layer elastic shells with pliable joints, we will use the variational principle of Lagrange, which opens a natural way to reduce the three-dimensional problem of continuum mechanics to one-dimensional and two-dimensional problems. It should be noted that the principle under consideration simultaneously allows us to obtain the corresponding natural boundary conditions for each selected unknown, and also serves as a basis for various approximate methods, including the solution of combined orthotropic plates and shells with interlayer shears.

Total energy expression

$$U = \frac{1}{2}\iiint(\sigma_{\alpha}^{(i)}\varepsilon_{\alpha}^{(i)} + \sigma_{\beta}^{(i)}\varepsilon_{\beta}^{(i)} + \tau_{\alpha\beta}^{(i)}\varepsilon_{\alpha\beta}^{(i)} + \tau_{\alpha\gamma}^{(i)}\varepsilon_{\alpha\gamma}^{(i)} + \tau_{\beta\gamma}^{(i)}\varepsilon_{\beta\gamma}^{(i)})dv +$$

$$+\frac{1}{2}\iint(\tau_1^{ш}\varepsilon_{ш13} + \tau_2^{ш}\varepsilon_{ш23} - 2qW)ds \tag{7}$$

Integrating over the thickness (from -h/2 to +h/2 and for the second layer - $\delta_n/2$ to + $\delta_n/2$), we obtain an expression containing the unknown functions and their derivatives

$$U = \ 1/2 \iint \left(U_F \left(\frac{\partial^2 W}{\partial \alpha^2}, \frac{\partial^2 W}{\partial \beta^2}, \frac{\partial^2 W}{\partial \alpha \partial \beta}, \frac{\partial U_0}{\partial \alpha}, \frac{\partial U_0}{\partial \beta}, \frac{\partial \Phi_1}{\partial \alpha}, \frac{\partial \Phi_1}{\partial \beta}, \frac{\partial \Phi_2}{\partial \alpha}, \frac{\partial \Phi_2}{\partial \beta}, \frac{\partial \tau_1}{\partial \alpha}, \frac{\partial \tau_1}{\partial \beta}, \frac{\partial \tau_2}{\partial \alpha}, \frac{\partial \tau_2}{\partial \beta}, \frac{\partial W}{\partial \alpha}, \frac{\partial W}{\partial \beta}, U_0, V_0, \Phi_1, \Phi_2, \tau_1, \tau_2, W\right) d\alpha, d\beta \right. \qquad (8)$$

According to the variational principle of Lagrange, the potential energy of an elastic system in the equilibrium position takes a stationary value. The integrals of the first sum in the right part of the formula after integration over the thickness are taken over the area of the medial surface Ω, the other integrals over the contour S.

Summary

To analyse the influence of the ductility of the adhesive layer on the VAT, we take a two-layer cylindrical shell taking into account transverse shear and the ductility of the adhesive layer. The calculation is carried out with the following parameters.

$$E_I^{(1)} = E_2^{(1)} = 2.02 \cdot 10^5 : \mu_{12}^{(1)} = \mu_{21}^{(1)} = 0{,}285; E_I^{(2)} = 0{,}471.10^5 \text{ Мпа}$$

$E_I^{(2)} = 0{,}49.10^5$ Мпа, $\mu_{12}^{(2)} = \mu_{21}^{(2)} - 0{,}385$, $R_M = 10.50$ см,

$R_n = 10.35$ см: $h_n = 2.04\ MM$, $\delta_M = 0.96 MM$.

$G_{12}^1 = G_{13}^1 = G_{23}^1 = 7{,}87 \cdot 10^4$ Мпа; $G_{12}^2 = 5.5 \cdot 10^3$Мпа, $G_{13}^2 = 4{,}2 \cdot 10^3$ Мпа, $G_{23}^2 = 0{,}35 \cdot 10^3$ Мпа.

Where τ_1- tangential stress of the first load-bearing layer,

W - deflection, U_0-displacements of the medial surface of the bearing layer

If we take into account non-uniform heating ($T_{\text{нар}} = 20^0\text{C}, T_{\text{вн}} = 200^0\text{C}$), the increase of $G_{шk}$ by 100 times (at α=l/6) from $G_{шik} = 5.10^2$MPa to5.10^4MPa leads to the following results

a) reduction of deflection by 6.4%;

b) reduction of U_0 by 2.9%;

c) decrease of τ_1 by 23%;

d) increase of $ф_1$ by 35%;

$U_0, \tau_1, ф_1$ and deflection W along the axis α

For small shear stiffnesses, increasing the thickness of the bonding joint has a significant effect on the deformability of the shell. For example, increasing $h_ш$ from $1 \cdot 10^{-3}$ to $5 \cdot 10^{-2}$ cm (at α=l/2) leads to a 3.4% increase in W and a 6.9% increase in U_0.

It should be noted that the smaller the shear modulus, the greater the influence of joint pliability on the deformability of laminated combined cylindrical shells.

Numerical examples have shown that shear modulus and joint thickness have a great influence on the strength and deformability of combined two-layer cylindrical shells if the shear modulus of the bonding layer is much smaller than the shear modulus of the layers.

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