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INFLUENCE OF POLYMER AGGREGATE REINFORCEMENT ON THE DYNAMICS OF THREE-LAYER CYLINDRICAL STRUCTURE OF ELLIPTICAL CROSS-SECTION

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The dynamic behavior of a three-layer cylindrical structure of normal elliptical cross-section with a discrete polymer filler under internal non-stationary loading was investigated. A finite element model of the structure was created and calculations of normal deflections U_3 and normal stresses σ_{22} of its bearing layers were performed using a software and calculation complex *Fimap with NX Nastran*. The values of deflections and stresses of the specified layers in the absence and presence of reinforcement of the polymer aggregate structure at the ratio of elasticity of the material of bearing layers and aggregate are given $E_{1,2}/E_f$=500.

Keywords: three-layer cylindrical shell, elliptical section, polymer aggregate, finite element model, impulse load, bearing layer.

Introduction. Design and technological solutions of modern machines, mechanisms, building and other structures often use elements and parts of thin-walled layered shells.This reduces the metal consumption and weight of structures and allows, due to the use of their increased resistance to dynamic influences, to ensure the reliability of structures and guarantee their durability. Therefore, it is of particular importance to determine these factors and assess the degree of their influence on the dynamics of layered structures [1].

In layered shells, one of such factors may be the reinforcement of their polymer filler with metal stiffening ribs. To determine the nature and significance of this factor's influence, was studied the dynamics of a three-layer cylindrical shell of normal elliptical cross-section with the absence and presence of reinforcement of its polymer filler with metal ribs (Fig. 1).

The expediency of using such a structure design is due, first of all, to the established zone of maximum influence on the dynamics of this structure under internal impulse load. Such zone, as investigated in [2], is the vertical S_1 cross-section of the structure wall.

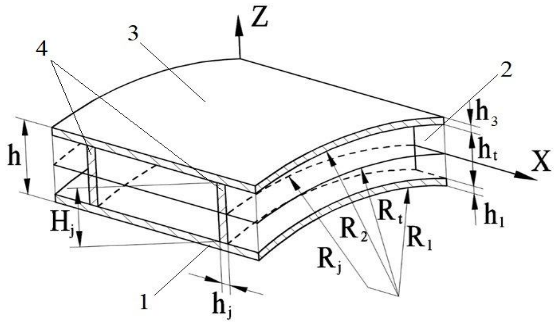


Fig. 1. Fragment of the construction of a three-layer cylindrical shell with a polymer filler reinforced with stiffeners: 1 - inner layer; 2 - polymer aggregate; 3 - outer layer; 4 - reinforcing ribs

Statement of the problem. The dynamics of the bearing layers of a three-layer cylindrical shell of elliptical cross-section was studied with the following parameters: the bearing layers (inner and outer) of both structures h_1 = h_2 = 0,001 m and made of material with the same physical and mechanical properties. The modulus of elasticity of the material of the bearing layers and reinforcing ribs of the aggregate E_1 = E_3 = 7*10^{10}Pa, its density ρ_1 = ρ_3 = 2,7*10^3kg/m^3, Poisson's ratio μ_1 = μ_3 = 0.3, density of the aggregate ρ_t = 25 kg/m^3. The total wall thickness of the cylindrical structure is h=0,010m, and other parameters have the following values:

$$L = 0,40 \text{ m}, \ \frac{L}{h_1} = 0,4; \ \frac{b}{h_1} = 0,1, \ \frac{a}{b} = 1,10; \quad F_j = H_j \cdot h_j = 6,4 \cdot 10^{-5} \text{m}^2,$$

reinforcing ribs of the structure (parallels) are located at the following points:

$$x_j = [16 + 17(k-1)]\Delta x, \quad k = \overline{1,5}, \quad \Delta x = L/100,$$

where k - is the number of reinforcing ribs taken in the calculations.

The dynamic behavior of both structures was evaluated by the values of normal deflections of the median surfaces of the bearing layers and their normal stresses.

The distribution of the pulse load $P(t)$ was carried out as shown in Fig. 2 and had a time interval $0 \le t \le 10T$: $A = 10^6$Pa; T=50*10^{-6}s

$$P(t) = A \cdot \sin\frac{\pi t}{T}[\eta(t) - \eta(t-T)], \tag{1}$$

where: $\eta(t)$ – Heaviside function; A – pulse load amplitude; T – duration of load time; t – time interval.

The load parameters were taken accordingly: $A = 10^6 Pa$; T=50*$10^{-6}s$.

It is assumed that the ends of the shells are rigidly fixed:

$$U_1 = U_2 = U_3 = \varphi_1 = \varphi_2 = \varphi_3 = 0.$$

Was used the finite element method of calculations of normal deflections U_3 and normal stresses σ_{22} [6]. And the calculations were performed by the software and calculation complex *Fimap with NX Nastran* algorithm of direct transient dynamic process by analogy with the calculations of other three-layer structures [3-5].

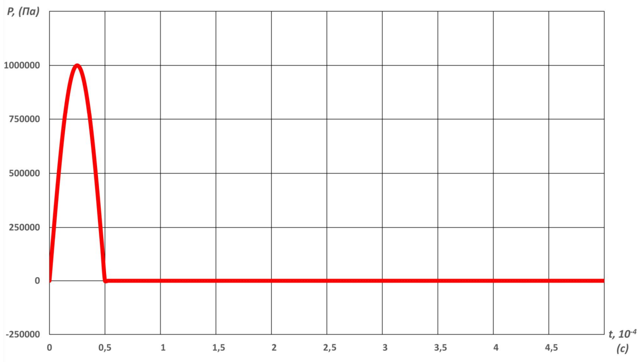


Fig. 2. Distribution of pulse load $P(t)$

In the general formulation, the finite element method involves determining the fieldof displacement vector of an elastic system characterized by minimizing its potential energy, and after its determination, the displacement and stress tensors of this system are calculated [3]. And if the total potential energy of the system has the form:

$$\Pi = E - W , \tag{2}$$

where E – is the potential energy of deformations, W – is the potential of external loads

Then after splitting the whole field into separate elements the potential energy of the system changes accordingly:

$$\Pi = \sum_{e=1}^{E} \left(E^{(e)} - W^{(e)} \right) = \sum_{e=1}^{E} \pi^{(e)}. \tag{3}$$

Global stiffness matrix $[K]$ and the global column vector $\{F\}$ in the matrix equation:

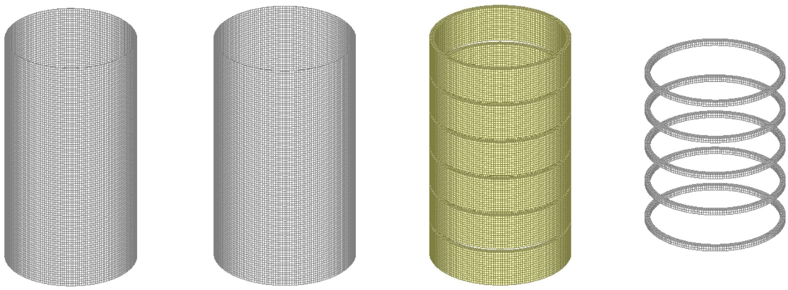
$$[K]\{U\} = \{F\} \tag{4}$$

correspond to the ratio:

$$[K] = \sum_{e=1}^{E} \left[k^{(e)} \right], \ \{F\} = -\sum_{e=1}^{E} \left\{ f^{(e)} \right\}. \tag{5}$$

Minimization of the total potential energy of the system, as a result of the influence of force, heat or other factors provides a solution to the problem.

Even though this method is quite universal and effective, its use requires considerable professional skills, and in some cases - even an intuitive sense of the situation. To determine the values of normal deflections and stresses, was created a finite element model of the structure (Fig. 3). When creating it, was used a three-dimensional volumetric finite element of *Solid* type, which by the aspect ratio,taper and warping, internal angles and other indicators met the quality assurance requirements of the finite element mesh of the Nastran complex [7]. The finite element model of the three-layer cylindrical shell had 120000 finite elements and 141400 nodes.



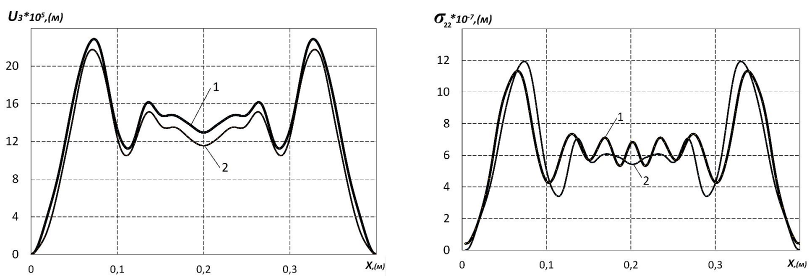
(a) (b) (c) (d)

Fig. 3. Finite element model of a three-layer cylindrical shell of normal elliptical section: (a) internal load-bearing cladding; (b) same outer cladding; (c) polymer aggregate; (d) reinforcing ribs

In determining the effect of reinforcement of polymer aggregate on the dynamics of the structure, were investigated its variants including the presence and absence of reinforcement of polymer aggregate with metal ribs. In both cases, deflections and stresses in the median surfaces of the bearing layers were calculated in the section S_1 in the region: $D = \{0 \le S_1 \le L\}$.

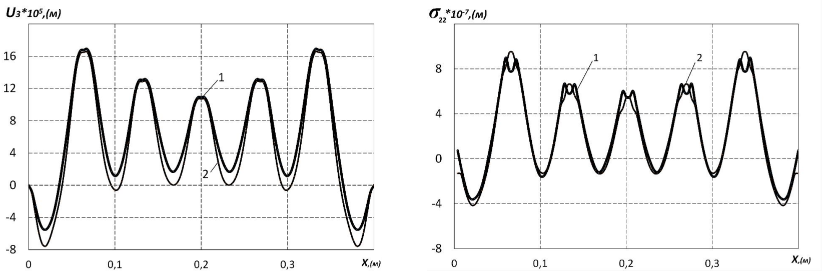
Results and their analysis

The results (Fig. 4 (a), 5 (a)) show that the normal deflections of both bearing layers have almost the same values, and their maximum values are reached: in the first case at t=8.65T, and in the second - at t=8.7T, and the maximum deflections of these layers in the absence of aggregate reinforcement (Fig. 4 (a)) are almost 35% higher than their value in its presence (Fig. 5 (a)).



(a) (b)

Fig. 4. Maximum values of normal deflections (a) and stresses (b) of bearing layers of cylindrical three-layer structure without aggregate reinforcement (section $S1$): 1- inner layer; 2- outer layer



(a) (b)

Fig. 5. Maximum values of normal deflections (a) and stresses (b) of bearing layers of cylindrical three-layer structure with aggregate reinforcement (section *S1*):
1 - inner layer; 2 - outer layer

A similar nature of the influence of reinforcement is shown by changes in the values of normal stresses of the median surfaces of the bearing layers of structures (Fig. 4 (b) and Fig. 5 (b)).

The variant of the structure design in which the polymer aggregate was completely absent was also researched. In this case (Fig. 6), the main impact of the dynamic load was taken by the inner layer of the structure. The difference between the values of maximum deflections of the inner and outer layer wassignifican.

Thus, these results indicate a significant influence of the factor of reinforcement of polymer aggregate on the dynamics of the entire structure.

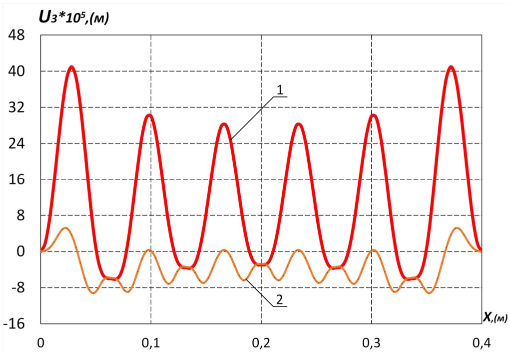


Fig. 6. Maximum values of normal deflections of a cylindrical three-layer structure with ribs without aggregate (section *S*1): 1 - inner layer; 2 - outer layer

Conclusion

Reinforcement of polymer aggregate with metal stiffening ribs significantly affects the dynamic behavior of the three-layer cylindrical structure. The presence of this factor synchronized the stress-strain layer of the bearing layers of the structure, reduced the values of normal deflections and stresses of the bearing layers of the cylindrical three-layer structure. The effectiveness of reinforcement of polymer aggregate is confirmed by other materials [3-5], which indicates the feasibility of the practical use of such a constructive measure.

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ВПЛИВ АРМУВАННЯ ПОЛІМЕРНОГО ЗАПОВНЮВАЧА НА ДИНАМІКУ ТРИШАРОВОЇ ЦИЛІНДРИЧНОЇ СТРУКТУРИ ЕЛІПТИЧНОГО ПЕРЕТИНУ

Досліджена динамічна поведінка тришарової циліндричної структури нормального еліптичного перетину з дискретним полімерним заповнювачем при внутрішньому нестаціонарному навантаженні. Створена скінченно-елементна модель структури і виконані розрахунки нормальних прогинів U_3 і нормальних напружень σ_{22} її несучих шарів програмно-розрахунковим комплексом*FimapwithNXNastran*. Приведені величини прогинів і напружень указаних шарів при відсутності і наявності армування полімерного заповнювача структури при співвідношенні пружності матеріалу несучих шарів і заповнювача $E_{1,2}/E_t$=500.

Армування полімерного заповнювача металевими ребрами жорсткості значно впливає на динамічну поведінку тришарової циліндричної структури. Наявність цього фактора синхронизувала напружено-деформований шар несучих шарів структури, зменшило величини нормальних прогинів і напружень несучих шарів циліндричної тришарової структури. Ефективність армування полімерного заповнювача підтверджують і інші матеріали, що свідчить про доцільність практичного використання такого конструктивного заходу.

Ключові слова: тришарова циліндрична оболонка, полімерний заповнювач, скінченно-елементна модель, еліптичний перетин, імпульсне навантаження, несучий шар.

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Fig. 6. Refs. 7.

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