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IMPACT OF ELASTICITY OF POLYMER FILLER OF THREE-LAYER CYLINDRICAL STRUCTURE OF ELLIPTICAL SECTION ON ITS BEHAVIOR UNDER INTERNAL IMPULSE LOADING

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The impact of the elasticity of the polymer filler of a three-layer cylindrical structure of normal elliptical cross-section on its stress-strain state under internal impulsive loading was studied. Determined values and distribution of normal deflections and stresses in sections S_1 and S_2. The finite-element method of calculating the stress-strain state (SSS) of such a structure by the software-calculation complex *Fimap with NX Nastran* was applied. Conclusions were made regarding the sufficient expediency of considering the elasticity of the filler when optimizing the design of such structures.

Key words: three-layer cylindrical shell, polymer filler, finite element model, elliptical cross section, impulsive axisymmetric load, finite element method.

Introduction. Expanding the specificity and increasing the volume of use of layered shells in various fields of technology requires early effective engineering solutions that guarantee reliability and ensure the economy of such structures.

In this regard, a need to take into account the geometric shape of the structure, physical and mechanical properties of its material, dynamic and other influences on it arises. That is, a comprehensive approach is needed.

A test attempt, in this situation, to increase the reliability of the layered structure by increasing the elasticity of its polymer filler. The implementation of the given task ensures the determination and distribution of indicators of the stress-deformed layered structure, which determine its dynamic behavior, the selection and justification of the design features and the shape of the structure under study to ensure the objectivity of such information [1-4].

Problem statement. The stress-strain state of the inner and outer working layers of the cylindrical shell of a normal elliptical cross-section (Fig. 1) is determined when the ratio of the semi-axes of the elliptical cross-section is a/b= 1,10.

The total thickness of the shell is h=10 mm (h_1=h_2=1 mm). The modulus of elasticity of the material of the layers E_1 = E_3 = 70 GPa, and that of the polymer filler is E_t = 0,14 GPa. Other indicators have the following values $\mu_1 = \mu_3 = 0{,}3$, $\rho_1 = \rho_3 = 2{,}7{*}10^3$ kg/m^3, ρ_t=25 kg/m^3.

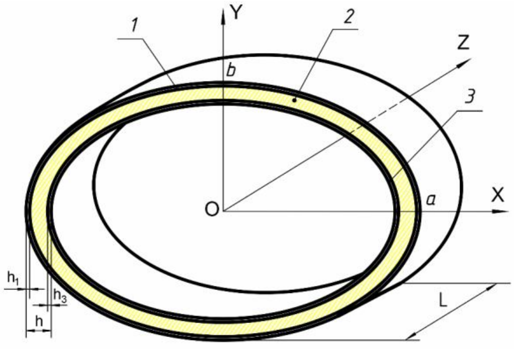


Fig. 1. Construction of a three-layer cylindrical shell structure:
1 – inner layer; 2 – polymer filler; 3 – outer layer

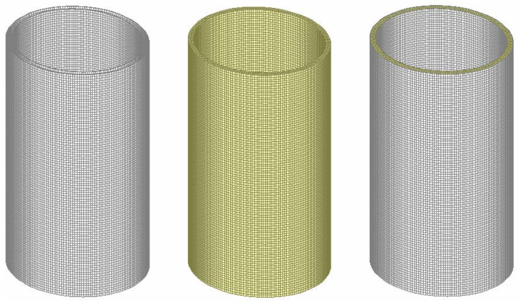
The shell uses a polymer filler that is significantly inferior to the elasticity of the material of its supporting layers. The ratios $E_{1,3}/E_t$ =500 are considered; $E_{1,3}$ /E_t =50, where $E_{1,3}$ is the modulus of elasticity of the materials of the inner and outer layers, and E_t is the filler. The values of normal deflections and normal stresses of the bearing layers of the shell are determined.

The impulse load distribution $P_3(s_1,s_2,t)$ is carried out in the following form:

$$P_3(s_1,s_2,t) = A * \sin\frac{\pi t}{T}[\eta(t)-\eta(t-T)], \tag{1}$$

where: A – the amplitude of the impulsive load; T – duration of load time; t – time interval. Their following parameters are accepted: $A = 10^6$ Pa; $T = 50\cdot10^{-6}$ s.

The finite element method is used in the research [5]. Calculations of the indicators of the stress-strain state of the studied structures are carried out by the software and calculation complex *Fimap with NX Nastran* by the direct transient dynamic process algorithm. The specially created finite element model (Fig. 2) had 120000 finite elements and 141400 nodes. It uses a three-dimensional volumetric finite element of the *Solid* type, which in terms of the degree of elongation, narrowing, curvature, internal angles and other indicators meets the requirements for ensuring the quality of the finite element mesh [6].



(a) (b) (c)

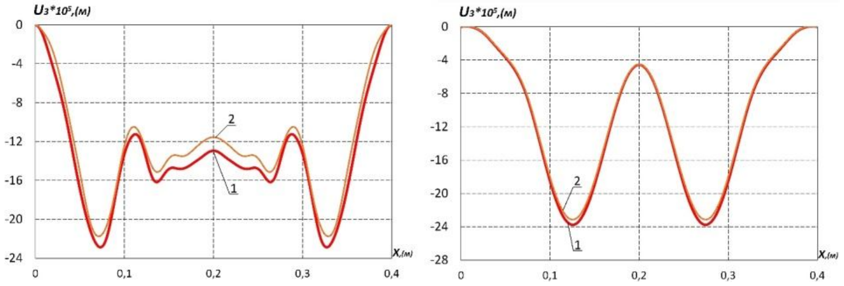
Fig. 2. Finite-element model of a three-layer cylindrical shell of elliptical cross-section:
(a) – inner and outer load-bearing sheathings; (b) – polymer filler; (c)- three-layer shell

It is assumed that the edges of the shell are tightly clamped, that is, at $S_1 = 0$ and $S_1 = L$: $U_1 = U_2 = U_3 = \varphi_1 = \varphi_2 = \varphi_3 = 0$. Calculations of deflections and stresses of the middle surface of the layers are carried out in the range of $D = \{0 \le S_1 \le L, 0 \le S_2 \le A*\pi/2\}$ and in the time interval $0 \le t \le 10T$.

The obtained results of numerical calculations are shown in Fig. 3 – 6. When the ratio of the modulus of elasticity of the material of the working layers is $E_{1,3}$ and the polymer filler E_t, with the value of $E_{1,3}/E_t = 500$, the normal deflections U_3 have more absolute values in the cross-section S_1 of the structure compared to the cross-section $S_2 = A \cdot \pi/2$.

In cross-section S_1, their values reached a maximum at t=8,65T, and in cross-section S_2 – at t=9,85T. In the examined sections, the deflection of the inner layer turned out to be slightly larger, which is especially visible in Fig. 3 and 4. Thus, the absolute value of the maximum deflections in the S_1 section exceeded its value in the S_2 section by almost 6,67%.

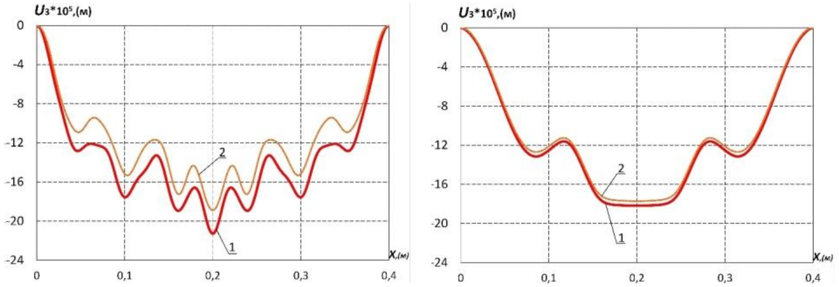
With an increase in the elasticity of the polymer filler ($E_{1,3}/E_t = 50$), the absolute value of the deflections was reduced in both cross-sections of the structure. In the S_1 section, its value decreased by almost 4,58%, and the peak values shifted towards the middle of the length of the structure. The deflections of both working layers became almost completely the same. In cross-section S_2, the reduction of the maximum deflection reached 17,1%, and its maximum value was distributed on the section 0,1L inside the length of the structure.



(а) (б)

Fig. 3. Normal deflections of working layers of cylindrical shells in cross-section S_1:
(а) – $E_{1,3}/E_t$ =500 at t=8,65T; (б) – $E_{1,3}/E_t$ =50 at t=8,4T

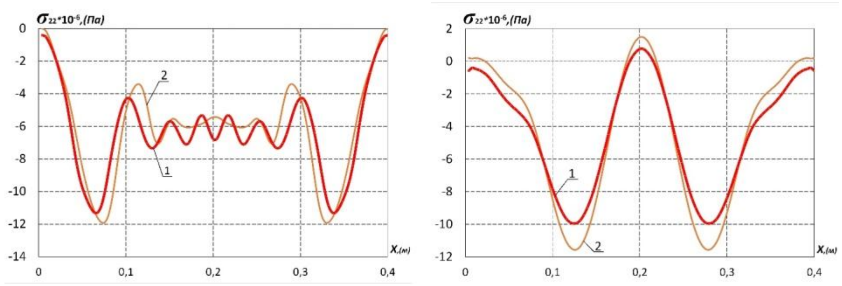
In a similar way the normal stresses of the working layers of the structure react to the change in the modulus of elasticity of the polymer filler. Thus, in the S_1 section at $E_{1,3}/E_t$=500, the maximum value of the normal stress of the outer layer of the shell exceeded the similar value at $E_{1,3}/E_t$=50 by 3,0%. And in the section S_2 at $E_{1,3}/E_t$=500, the maximum value of the normal stress of the inner layer of the shell exceeded by almost 24,6% the similar value at the ratio $E_{1,3}/E_t$=50.



(а) (б)

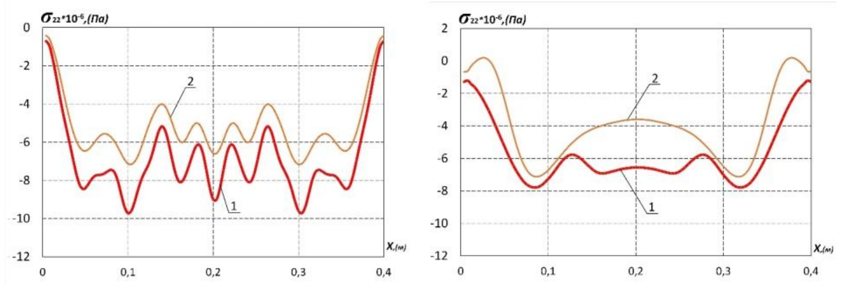
Fig. 4. Normal deflections of working layers of cylindrical shells in cross-section S_2:
(а) – $E_{1,3}/E_t$ =500 at t=9,85T; (б) – $E_{1,3}/E_t$ =50 at t=3,55T

Therefore, the increase in the modulus of elasticity of the polymer filler strengthened the layered structure, reduced the heterogeneous character of the SSS of its working layers, and caused the redistribution of the stress-strain state in its individual elements. The obtained results indicate the expediency of using this factor in a complex system for ensuring the reliability of layered shells.



(а) (б)

Fig. 5. Normal stresses of the working layers of cylindrical shells in the cross section and S_1:
(а) – $E_{1,3}/E_t$ =500 at t=8,65T; (б) – $E_{1,3}/E_t$ =50 at t=8,4T



(а) (б)

Fig. 6. Normal stresses of working layers of cylindrical shells in cross-section S_2:
(а) – $E_{1,3}/E_t$ =500 at t=9,85T; (б) – $E_{1,3}/E_t$ =50 at t=3,55T

Conclusion. Increasing the elasticity of the polymer filler increases the strength and monolithicity of the layered structure. The use of this method ensures efficiency and is appropriate when the ratio of elasticity of the materials of the layers and filler is $E_{1,3} / E_t \leq 50$.

REFERENCES

1. *Timoshenko S.P., Woinowsky-Krieger S.* Theory of Plates and Shells. Second Edition. New York etc.: McGraw-Hill Book Company INC, 1959. 636 p.
2. *Lugovoi P.Z., Gaidaichuk V.V., SkosarenkoYu.V., Kotenko K.E.* Stress–Strain State of Three-Layer Cylindrical Shells with Reinforced Light Core Under Nonstationary Loading "International Applied Mechanics", 2021, 57(4), P. 395–404.
3. *Gaidaichuk V.V., Kotenko K.E.* Stress-strain state of a three-layer cylindrical shell under internal axisymmetric pulse load с Strength of Materials and Theory of Structures. – 2020. – Issue. 105. – P. – 145-151.
4. *Meish V.F., Meish Y.A.* Dyinamichna povedinka tsyilindryichnyih obolonok nekrugovogo pererizy pri nestationarnyih navantazhennyah (Dynamic behavior of cylindrical shells of non-circular cross-section under non-stationary loads). Dopov. Nats. akad. naukUkr. 2021. № 5. P. 33—38.
5. *Segerlind L.* Primeneniemetodakonechnyihelementov (Application of the finite element method). M.: Mir, 1979- 392 p.
6. *Rychkov S.P.* Modelirovanie konstruktsiy v srede Femap with NX Nastran (Structural modeling in Femap with NX Nastran). - M.: DMK Press, 2016.-784 p.

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ВПЛИВ ПРУЖНОСТІ ПОЛІМЕРНОГО ЗАПОВНЮВАЧА ТРИШАРОВОЇ ЦИЛІНДРИЧНОЇ СТРУКТУРИ ЕЛІПТИЧНОГО ПЕРЕТИНУ НА ЇЇ ПОВЕДІНКУ ПРИ ВНУТРІШНЬОМУ ІМПУЛЬСНОМУ НАВАНТАЖЕННІ

Досліджено вплив пружності полімерного заповнювача тришарової циліндричної структури нормального еліптичного перетину на її напружено-деформований стан при внутрішньому імпульсному навантаженні. Визначені величини і розподіл нормальних прогинів U_3 і напружень σ_{22} в перерізах S_1 і S_2. Застосовано скінченно-елементний метод розрахунку показників напружено-деформованого стану таких структур програмно-розрахунковим комплексом Fimap with NX Nastran. Зроблено висновки відносно доцільності врахування пружності заповнювача при оптимізації конструкцій таких структур.

Збільшення пружності полімерного заповнювача збільшує міцність і монолітність шаруватої структури. Використання такого прийому забезпечує ефективність і являється доцільним при співвідношенні модулів пружності матеріалів шарів і заповнювача $E_{1,3} / E_t \leq 50$.

Ключові слова: тришарова циліндрична оболонка, полімерний заповнювач, скінченно-елементна модель, еліптична форма перетину, імпульсне осесиметричне навантаження, скінченно-елементний метод.

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Increasing the elasticity of the polymer filler increases the strength and monolithicity of the layered structure. The use of this method ensures efficiency and is appropriate when the ratio of elasticity of the materials of the layers and filler is $E_{1.3}/E_t \leq 50$.

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Fig. 6. Ref. 6.

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