Секція 5
Актуальні питання сучасного матеріалознавства

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INVESTIGATION OF DEFORMATION PROCESSES IN MULTILAYERED SHELLS UNDER COMPRESSION

Purpose. *The aim of the work is to study the processes of changes in the geometric dimensions of multi-layered tissue shells under compression in thickness.*

Scientific novelty. *Scientific novelty is the determination of the magnitude of the total deformation of multi-layered tissue shells, depending on the compression force and the number of loading cycles according to the developed technique.*

Practical value. *The practical value of the work is the determination of factors that determine the operational properties of textile composites based on multi-layer fabric shells. The results of the studies made it possible at the initial design stage to determine the parameters of technological processes for manufacturing multi-layer fabric shells of the required thickness and bulk density.*

Keywords: *Sewing product; Tissue membranes; textile products.*

Objectives. The goal of the research is to improve the design methods of multi-layer reinforced fabric shells for fiberglass products. operational properties of products from reinforced plastics are their bulk density, shape stability and geometrical dimensions. As a criterion for assessing the change in the geometric dimensions of multilayer shells, the magnitude of the compressive strain over the thickness was chosen. Regulation of the geometric dimensions and bulk density depends largely on the technological processes of manufacturing multi-layer fabric sheath and assembly of the product itself. The most affordable way to create reinforced structures is a method of flashing laminated materials using sewing equipment. [1; 2;8]

As a criterion for evaluating changes in the geometric dimensions of the shell, the magnitude of the compression deformation over the thickness was chosen, when creating a reinforcing cage, it is necessary to ensure the required thickness at a certain value of bulk density. The object of the study is a multilayer shell of fiberglass T\S8\3 KTO ST 6-11-216-76 with a surface density of 250 g / m^2.

Methodology. In order to determine the magnitude of the total deformation of multi-layered tissue shells, as well as the values of bulk density depending on the compressive force, a research method was developed.

Tests to determine the change in thickness during compression were carried out according to the developed method on the installation BPMHS, designed to determine the rigidity of plastics for bending. In order to approximate the conditions of the experiment to the actual conditions of production of multilayer reinforced shells, the plant was upgraded: a removable compressive ID was manufactured, having a flat working surface in the form of a presser foot of a universal machine and completely repeating its geometrical dimensions; instead of two supports for placing the samples when testing materials for bending, when testing for compression, one support was used in the form of a horizontal plane simulating the sewing machine platform.

For multilayer shells, the pressure range at which the studies were carried out was chosen taking into account the loads that the multilayer shell experiences under the action of the working bodies of the technological equipment used for the firmware. According to the results of the research carried out on the working equipment, it has been established that the pressing force of the stitched multi-layer shell to the rail varies during the machine's operation cycle and depends on the mass of the pressure device links brought to the stem of the foot, the spring of the foot and the compliance of the stitching details. Based on these data, samples of multilayer shells were tested at pressures of 100, 300, 600, 900, 1200 KPa.

The studies were carried out in static conditions. When static compression tests were carried out for 5 mm., Followed by a 5-minute rest. The duration of the tests was chosen based on the results of the reconnaissance experiment, which showed, in particular, that after a 5-minute load action, the fallout (relaxation) of the effort almost ends and its further change is no more than 1-5% of the initial effort in the sample.

After resting, each specimen was re-loaded with subsequent rest. The number of cycles is determined experimentally and is equal to three, which corresponds to the maximum number of passes of the sewing machine foot at a single point for any method and firmware pattern.

Research results. At the first stage of work, the number of layers was calculated, at which during technological processing the shell thickness reaches 4.9 ± 0.1 mm with a bulk density of 1 ± 0.2 g / cm^3.

Conventional bulk density of the multilayer shell can be calculated by the formula:

$$\gamma = \frac{Mn}{h} \qquad (1)$$

Where M- is the surface density of the shell layer, g \ cm^2

n -is the number of layers, pieces;

h- is the shell thickness, sm.

It was found that the required parameters can be achieved using a multilayer shell of 18, 19, 20, 21, 22 layers [5].

In order to determine the required number of measurements that ensure the reliability of the results, for a given load, various samples of a multilayer shell were investigated. As static results show, to obtain a guaranteed relative error of the arithmetic mean, not exceeding 5%, it is enough to conduct 6 measurements

Since, under the conditions of manufacturing multilayer shells, the change in thickness depends mainly on the actual load, it is necessary to establish the mathematical dependence of the thickness on the compressive load for all cases[4].

Let H1 be the thickness of the shell; H is the thickness at pressure P. Then, when the pressure changes by ΔP, the thickness changes by ΔH.

Assuming these dependencies are non-linear, we get the equation:

$$\Delta H = K\Delta P\left(H_1 - H\right)^{\beta} \quad (2)$$

resulting in $\Delta P \to 0$ a differential equation:

$$dH = K(H_1 - H)^{\beta}\, dp \quad (3)$$

where K and β are some proportionality coefficients determined by the material. Solving this equation, we get:

$$\int \frac{dH}{(H_1 - H)^{\beta}} = K\int dp \Rightarrow (H_1 - H)^{1-\beta} = KP + C \Rightarrow H = H_1 + (KP + C)^{\frac{1}{1-\beta}} \quad (4)$$

These considerations lead us to the following type of dependence of H on P:

$$H = C + BP \quad (5)$$

where A, B, C are some real numbers.

Taking into account the properties of the material, the values of Ho and Hpr are random, therefore, it is not possible to accurately determine the parameters A, B, C from equation (4).

In this regard, the following task was set. The values of A, B, C were found using the least squares method, i.e. minimized value

$$L = \sum_{i=0}^{m}\left(\overline{H_i} - BP^{A} - C\right)^2 / \sigma_i^2 \to \min \quad (6)$$

where $\overline{H}_i$ - the average value of the thickness H at pressure $P = P_i$

$$H_i = \frac{1}{5}\sum_{j=1}^{5} H_{ij}$$

where Hij is the value of H at the pressure Pi in the j dimension,

$$\sigma^2 = \frac{1}{4}\sum_{i=1}^{5}\left(H_{ij} - \overline{H}_i\right)^2$$ - standard deviation.

Model (6) is non-linear and is a rather complicated task [6.7]; to solve it, a modification of the "PRGBL 10" program was used. The estimates of parameters $\hat{A}, \hat{B}, \hat{C}$ were obtained. 95% confidence intervals for A, B, C are:

$$A : \hat{A} \pm \sigma_A t_{95\%} = \hat{A} \pm 3{,}18\sigma_A$$

$$B : \hat{B} \pm 3{,}18\sigma_B, \qquad C : \hat{C} \pm 3{,}18\sigma_C,$$

Where σ_A, σ_B, σ_C, - the estimates of the asymptotic standard deviations were found as well as the values of K_{AC}, K_{AB}, K_{BC} using the coefficients of the matrix inverse to the matrix determined by the second partial derivative:

$$\frac{\partial^2 L}{\partial A^2}; \frac{\partial^2 L}{\partial B^2}; \frac{\partial^2 L}{\partial C^2}; \frac{\partial^2 L}{\partial A \partial B}; \frac{\partial^2 L}{\partial A \partial C}; \frac{\partial^2 L}{\partial B \partial C}$$

and an estimate for the variance of σ^2.

$$S^2 = \frac{\sum_{i=1}^{m}\left(\overline{H}_i - \hat{B} P^{\hat{A}} - \hat{C}\right)}{m-3}$$

$T_{95\%}$ = 3.18 - is selected from the tables of the Student according to the number of degrees of freedom (m-3) = 3.

The standard $\overline{H}(p) = \hat{B} P^{\hat{A}} + \hat{C}$ deviation for was as follows:

$$\sigma^2_{\hat{H}}(p) = \sigma^2\left(\hat{B}\,P^{\hat{A}} + \hat{C} - BP^A - C\right) =$$
$$= \sigma^2 - \left(\hat{C} - C + \left(\hat{B} - B\right)P^{\hat{A}} + BP^{\hat{A}}\left(1 - P^{\left(A - \hat{A}\right)}\right)\right) \tag{7}$$

Further, since the 95% confidence interval is small enough, the last term can be neglected and thus

$$\sigma^2_{\hat{H}}(P) = \sigma^2_B P^{\hat{A}2} + 2K_{BC}P^{\hat{A}} \tag{8}$$

This value is used to determine the average thickness of the product at pressure P. For example, the added 95% confidence interval for the average value H at pressure P would be

$$\hat{H}(P) \pm 3{,}18\sigma_{\hat{H}}(P) = \left(\hat{H}(P) - 3{,}18\sigma_{\hat{H}}(P)\hat{H}(P) + 3{,}18\sigma_{\hat{H}}(P)\right)$$

To check the adequacy of the model, the statistic [8] was used,

$$F_0 = M_{SA} / M_{SW} \tag{9}$$

Where: $M_{SA} = \sum_{i=1}^{m}\left(\hat{H}_i - \hat{H}(P_i)\right)^2 / (m-2)$, $M_{SW} = \sum_{i=1}^{m}\sum_{j=1}^{\sigma}\left(\hat{H}_i - \hat{H}_i\right)^2 / 5$ mean squares of variation relative to regression and within groups.

If: $F_0 < F_{0,95}(m-3{,}5)$, That is the null hypothesis, but the “model is adequate” is accepted at a significance level of 0.05. Values $F_{0,95}(v_1, v_2)$ are from Fisher tables [3].

Based on these dependencies, the test results were processed by methods of mathematical statistics. The error of experience did not exceed 5%, which testifies to a sufficiently good reproducibility of the tests and confirms the high accuracy of the installation used.

Data processing allowed us to obtain a graphical dependence (Fig.1) of the thickness of the multilayer shell on pressure and the regression equation for all the samples studied.

The excess of the tabular value of the Fisher criterion over the calculated one allows to conclude that the obtained regression equations are adequate.

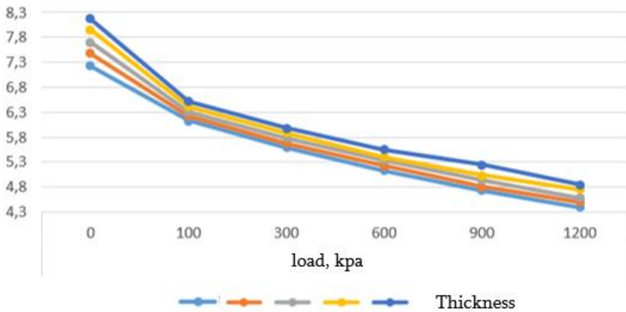

Fig. 1. Dependence of sample thickness on compressive load after three cycles of compression

The analysis of the curves of the dependence of the thickness of the samples on the pressure value indicates their identity. In the initial period of application of the load, a significant deformation of the shell occurs, and then with increasing load, the deformation gradually fades out. Those. the presence of two sections is characteristic: the first is the load causing a significant decrease in the thickness of the material; the second is a decrease in thickness is negligible.

Since in practice it is necessary to obtain a multilayer shell with specified thickness values, at a certain value of bulk density, the tolerances of which should not exceed ± 0.1 mm and ± 0.02 g/cm3, respectively, based on the results obtained (Fig.1) recommended values of compressive load on the package were determined to obtain the required parameters in the manufacturing process (Table 1). And in table 2 the values of bulk density of the studied samples are presented depending on the values of compressive load.

Table 1. The recommended value of compressive load (kPa) to obtain the required shell thickness

Required thickness, mm	The load (kPa) with the number of layers				
	18	19	20	21	22
4,9±0,1	660 ÷ 831	755 ÷ 956	840 ÷ 1058	957 ÷ 1204	1159 ÷ 1467

Table 2. The values of bulk density (g / cm3) shells, depending on the compressive load

Required bulk density, g/cm^3	Bulk density value at compressive load, kPa				
	660 ÷831	755÷956	840÷1058	957÷1204	1159÷1467
1±0,02	0,9-0,94				
1±0,02		0,95-0,99			
1±0,02			1-1,04		
1±0,02				1,05-1,09	
1±0,02					1,1-1,14

Conclusion. As a result of the conducted studies and processing of the results it was established that when designing multilayer shells of glass fabric of grade T\S8\3 KTO ST 6-11-216-76 with a thickness of 4.9 ± 0.1 mm and with a bulk density of 1 ± 0.02 g / cm3, it is recommended to use shells consisting of 20 layers, with a compressive load of 840-1058 kPa.

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