УДК 69.01

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EXPERIMENTAL INVESTIGATION OF WALL AND ROOF SANDWICH PANELS OF THE "ALUTERM" SERIES

The results of an experimental investigation of wall and roof sandwich panels with mineral fibre insulation core are presented in this paper. Features of the stress-strain state of sandwich wall and roof panels made by various enterprises in Ukraine are covered. An analysis of the deformation and failure of the investigated constructions is given.

Keywords: *Sandwich panels, mineral fibre insulation core, lamella, hydraulic test method, stress-strain state (SSS).*

1. Introduction

The problems of the construction industry inextricably linked with the reduction of material, labor and energy resources for the construction and exploitation of buildings and structures are the cause of the constant search for new design solutions and for improvement of existing ones. Particularly on purpose achieving a substantial reduction of the weight of buildings and structures, while maintaining high strength and stiffness characteristics, it is expedient to implement in construction practices use of lightweight external protections in the form of sandwich panels with a high prefabrication level.

The efficiency of constructions based on thin faced materials and nonflammable lightweight cores is defined by their low weight, canonicity of manufacturing process, easy and quick assembling and high exploitation reliability. Buildings, constructed with the use of light wall and roof coverings, are already widely applied in building practices around the world so that in a certain degree determines the relevance of their use. Nevertheless, the experience of designing and exploitation of the discussed structures has outlined a number of issues that may provide the improvement of the construction itself. Primarily, it relates to the development of calculation and rationalization methods of these systems, as well as experimental verification of new solutions and methods of their calculating. Moreover, in the research of sandwich panels with a metal face the priority is to study the behavior of the panels with the core of hard flammable foams and oriented mineral wool. Certain questions have been halfway considered in the works of native and foreign researchers [1,2]. They have shown that the applied core substantially determines the stiffness of the entire panel. Based on the known results of theoretical and experimental studies we can also argue that the polystyrene foam core (especially an extrusion one) provides minimal compression in the supporting sections of the panel. It was also revealed that spreading of strength and deformation properties of mineral wool is incredibly high and it is the reason for a more detailed experimental investigation of the behavior of the mineral core in the sandwich panel.

Mentioned above, together with other unresolved problems, was an occasion to conduct a series of full-scale experimental studies of roof and wall panels with mineral fibre insulation core. The studies were conducted at the O.M. Beketov National University of Urban Economy in Kharkiv. Considering the high budget of the ongoing studies only three specimens of the panels were provided for the tests: two wall panels and a roof one. The length of each panel was equal to 7,2 m (Fig .1,2).

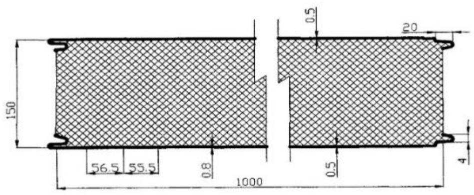


Fig. 1. The geometrical dimensions of the wall panel of the "AluTerm" series (cross section) submitted for testing.

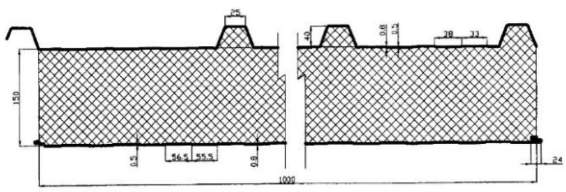


Fig. 2. The geometrical dimensions of the roof panel of the "AluTerm" series (cross-section) submitted for testing.

2. Design features of the investigated object

Three-layer wall and roof panels are composed of two steel faces (inner and outer) with a thickness of 0.5 mm each between which the insulating layer of mineral wool is located. These layers are interconnected with the help of a bicomponent polyurethane adhesive. Metal faces may have the form of shaped, corrugated or flat painted steel sheets. The longitudinal edges of the panels are designed as elements of the lock connection which ensures tightness of joint between panels. Each face has a protective anti-corrosion layer of color covering made of polyester which is placed on the surface of the hot rolled output sheet. Modular panel's width - 1000mm, length - 7200mm. General view of the studied sandwich panels is presented on Fig. 3,4.

Fig. 3. General view of the specimens submitted for testing (wall panel).

Fig. 4. General view of the specimens submitted for testing (roof panel).

3. The procedure of tests

Tests of sandwich panels are made under the action of the transitional and extended uniformly distributed loadings in accordance with the method of hydraulic testing of slabs and membranes based on DSTU B V.2-6-7-95 [3, 4]. Furthermore, during the preparation of the test program account was taken of the instructions which define four types of limited states of considered constructions of sandwich panels [5]:

- on the shear resistance of the insulation;
- by wrinkling (an axial compression of the metal faces);
- on the resistance of the compression at the support ;
- on the ultimate deflection.

The investigated panels were tested according to the following schemes:

- Three-span scheme, with a span of 2.4 meters (Fig. 9);
- Two-span scheme, with a span of 3.6 meters (Fig. 10);
- One-span scheme, with a span of - 7.2 m (Fig. 11).

Special metal structures (jacks) with a height of 1 m, width of 1.2 m and with a width of the bearing part of 100mm were used as the supports (Fig. 5). Loading was applied through degrees by means of filling the tank with water. The size of each degree of loading was determined stepwise and was taken in the range of 0.1-1.0 kN/m2 depending on the nature of the deformation of the panel.

In order to establish the range of elastic resistance of the panel, after each stage of loading, unloading took place (draining the tank). Thus, the nature of the loading was low cycle that simulates actual work of the construction.

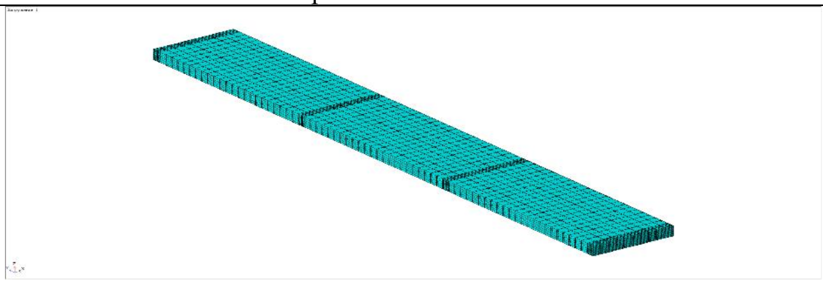
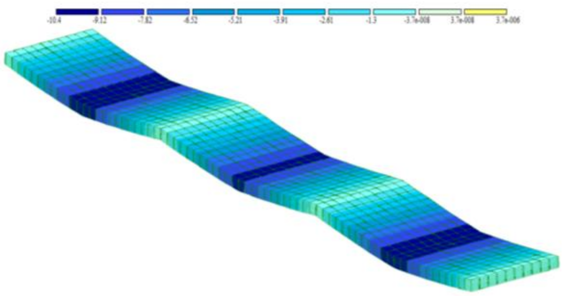
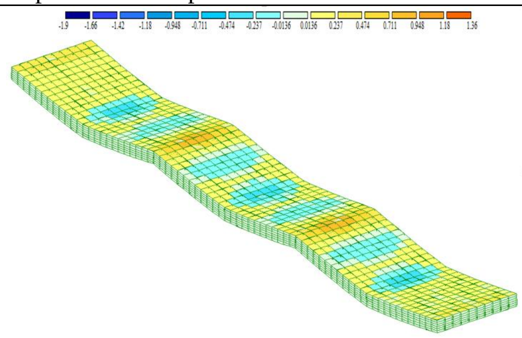
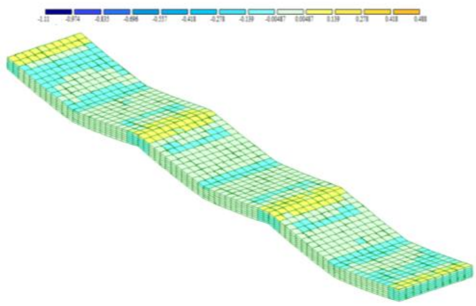
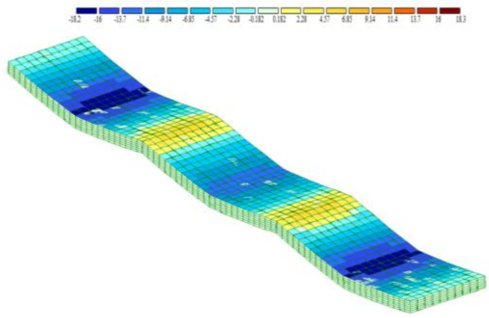
In addition to the tests described above, conditional wind loading was examined. In real conditions, the panel is placed in an upright position so the dead weight of the panel (q_{dw}. = 0.251 kN/m2) was considered as an additional component to the payload.

Fig. 5. Supports – special metal structures (jacks).

4. Theoretical modeling

The simulation (structure - load) and the calculation of the considered sandwich panels with the help of a PC program "Lira- CAD" [6,7] based on the finite element method was produced before the tests in this paper. The object of the study was wall and roof sandwich panels with steel faces and a mineral fibre insulation core presented in a full-scale experiment. All of the accepted geometric dimensions of the model and its physical and mechanical properties corresponded to the actual attributes of the studied panels. The main results of the calculation are given in Table 1. The analysis of the field components of the stress- strain state (SSS) shows their complete qualitative agreement with the representation of the deformation behavior of the considered structures.

Table 1. Main results of calculation of sandwich panels in “Lira-CAD”.

<table>
<tr><td colspan="2">
Finite element model of the three-span sandwich panel</td></tr>
<tr><td>
Displacement contour plots in Z direction, mm</td><td>
Nz tension contour plots, MPa</td></tr>
<tr><td>
Ny tension contour plots, MPa</td><td>
Nx tension contour plots, MPa</td></tr>
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Following information is considered as addition to the Table 1:

- the maximum normal stress along the panel:

• in the face: compression stress - 17.2 MPa , tensile stress - 17.4 MPa;

• in the insulation: compression - -0.01 MPa , tensile: - 0.01 MPa;

- the maximum stress across the panel:

• in the face: compression - -0.31 MPa , tensile - 0.39 MPa;

• in the insulation: compression - 0,013 MPa , tensile - 0.013 MPa;

- normal stress of the compression (along z axis):

• in the face: compression - 0.2 MPa , tensile - 0.02 MPa;

• in the insulation: compression - 0.02 MPa , tensile - 0.003 MPa;

- deflection - 10.4 mm.

5. Principal definitions

The objective of the study was to establish experimentally the character of deformation (including the failure phase) of wall and roof sandwich panels of the “AluTerm” series with mineral wool insulation and to determine their bearing capacity (TU U V.2.6-28.1-32564237-001:2007).

The object of the study was wall and roof sandwich panel of the “AluTerm” series (TU U V.2.6-28.1-32564237-001 : 2007) with “Izovat 110” mineral wool insulation (density 110 kg/m3). Thickness of each panel was 150mm and length was 7.2m.

The subject of the study was the deformation and destruction character of the object of the study under the action of uniformly distributed transitional and extended loadings.

6. Loading system

The method of research based on hydrostatic loading when the load is measured by the weight of water and its value is adjusted by the height of water column was tested [8,9]. The functional scheme of the method is shown on Fig 6.

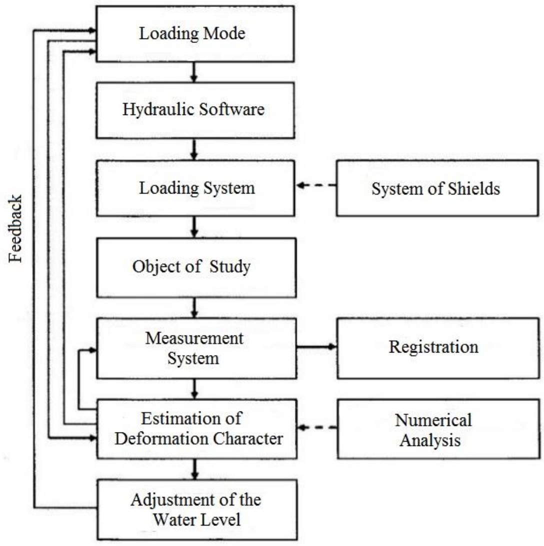


Fig. 6. Functional diagram of the hydraulic test method.

According to the selected program of the experiment the monotonically increasing, active, cyclic mode of loading with following discharge was set (stair-step mode, to estinate the bearing capacity and deformability, in accordance with applicable regulations). The level of loading was determined by the height of the water column in the tank. The required level of loading was provided by a system of supplying and discharging water in and out of the tank. For registering the measured displacements, special sensors were hooked up to the object of the study. They also established the characteristics of the stress - strain state of the object of study. The sensors were connected to the measuring system SIIT-3, which provides for measurements of the signals and converts the result into a digital form.

This load-measuring system functions according to the specificity predetermined by the fact that during the deformation of the object the water level changes, which leads to a change of the value and, possibly, of the nature of the load (tracking loading). Each step of the loading is corrected by the obtained measurements. Thus, as a result of the growing of the displacements over time, the level of loading is constantly changing (because of the previously mentioned tracking nature of loading). Therefore, due to the specialties of such tests the level of water was controlled and corrected not only at each step of the loading, but also during the whole time of the experiment (Fig. 8,9).

The basis for the designated investigations was a device for full-scale tests of slabs and membranes under the action of vertical transitional and extended loads (fig. 7) [10]. This setup includes the investigated structure which is mounted on the supports; shields which create a reservoir and are installed on a circuit area of loading; a waterproof membrane inside of the tank; inlet and outlet sockets. This setup is simple and cheap and it is easy to fit it with the system of measurement.

Fig. 7. Setup for a full-scale tests.

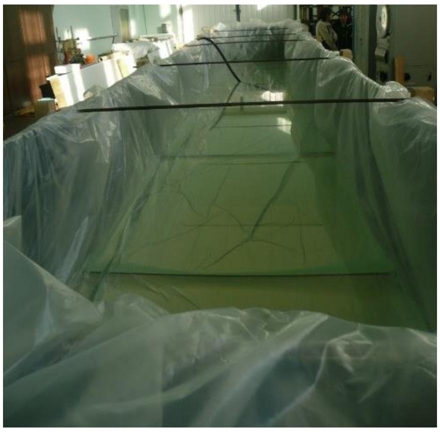


Fig. 8. The specimen under the loading.

Fig. 9. The determination of the height of water column.

7. Measurement system

As indicated above, the three specimens provided for investigation were tested on three-span, two-span and one-span schemes. The deformation parameters were measured by the electronic and mechanical devices. Schemes of arrangement of measuring devices are shown on Fig. 10-12.

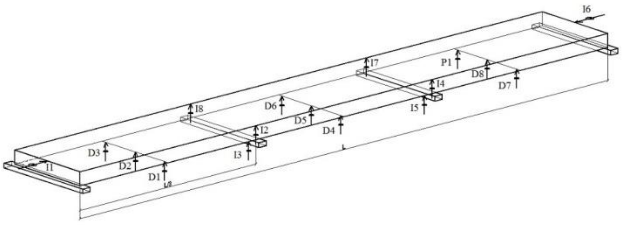


Fig. 10. Schematic arrangement of the devices on a three-span panel.

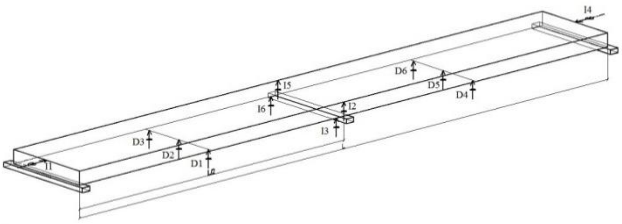


Fig. 11. Scheme of arrangement of the devices on a two-span panel.

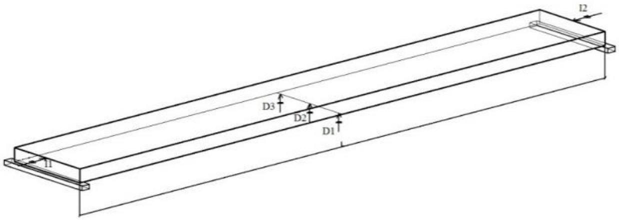


Fig. 12. Scheme of arrangement of the devices on a one-span panel.

The measurement system is represented by the following elements:

- D1 ... D8 - Inductive sensors 100 DPI (Fig. 13) interacting with electronic strain gauge measuring system SIIT - 3 (Fig. 15);
- I1 ... I8 – dial indicators ICH10 with a division scale of 0.01 mm (Fig.14);
- P1 - deflectometer 6PAO with divisions of 0.01 mm (Fig. 15).

Electrical inductive sensors PDI -100 and deflectometer 6PAO measured deflection at the center of the span. Indicators ICH10 were installed in the places of maximum value of the lateral force in order to evaluate the compression of mineral wool and at the ends of the panel to control displacement of the upper and lower faces relative to the insulation core.

Fig. 13. PDI -100 sensors.

Fig. 14. Dial indicator ICH -10.

Fig. 15. Deflectometer 6PAO.

Fig. 16. Strain gauge measuring system SIIT -3.

8. The investigation of sandwich panels of the "AluTerm" series under the action of transitional and extended uniformly distributed loadings

Specimens of wall (2 pc.) and of roof panels (1 pc.) were tested under the action of transitional and extended uniformly distributed loadings in accordance with the test program described above. The results of the experimental study of wall and roof panels are demonstrated by the following plots (Table 2-5).

Table 2. Plots of the relation between deflection and loading for wall panels (three-span scheme).

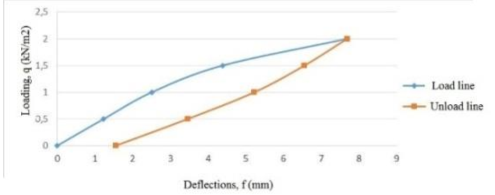
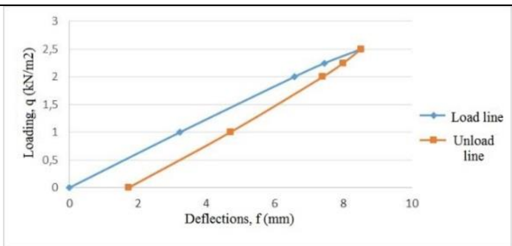
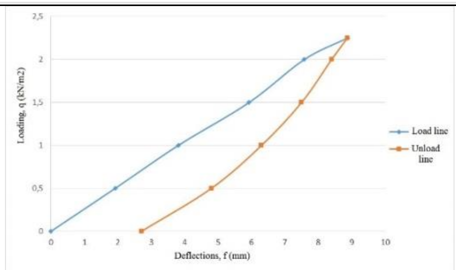
№	Plot	Characteristics
1		Maximum temporary load was 200kN/m2, time of loading - 30min. The maximum value of the deflections in the extreme span (sensors D1 ... D3) was 71 % of its assumed value. 20 hours after the removal of the load the residual deflection was 20.3% of its maximum value.
2		Maximum temporary load was 250kN/m2, time of loading - 20 hours. The maximum value of the deflections in the extreme span (sensors D1 ... D3) was 71 % of its assumed value. 24 hours after the removal of the load the residual deflection was 20.3% of its maximum value.
3		Maximum temporary load was 225kN/m2, time of loading - 20 hours. The maximum value of the deflections in the extreme span (sensors D7 ... D8) was 71 % of its assumed value. 20 hours after the removal of the load the residual deflection was 30.5 % of its maximum value.

Table 3. Plots of the relation between deflection and load for the roof panel (three-span scheme)

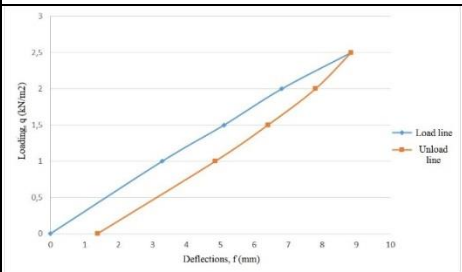
№	Plot	Characteristics
1		Maximum temporary load was 250kN/m2, time of loading - 20 hours. The maximum value of the deflections in the extreme span (sensors D7 ... D8) was 73.8 % of its assumed value. 72 hours after the removal of the load the residual deflection was 15.7% of its maximum value.

Table 4. Plots of the relation between deflection and load for wall panel (two-span scheme)

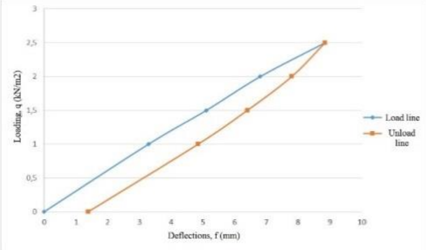
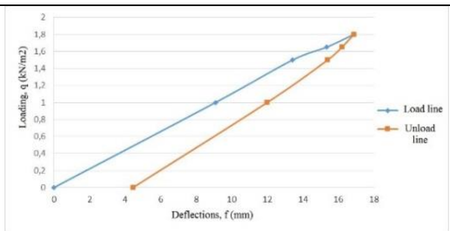
№	Plot	Characteristics
1		Maximum temporary load was 175kN/m2, time of loading - 30min The maximum value of the deflections in the extreme span (sensors D7 ... D8) at the moment of the applying of the load of 175kN / m2 was 87.2% of its assumed value. 20 hours after the removal of the load the residual deflection was 29.9% of its maximum value.

Table 5. Plots of the relation between deflection and load for roof panel (two-span scheme)

№	Plot	Characteristics
1		Maximum temporary load was 180kN/m2, time of loading - 21 hours. The maximum value of the deflections in the extreme span (sensors D4 ... D6) was 96.1% of its assumed value. 20 hours after the removal of the load the residual deflection was 29.9% of its maximum value.

Mentioned earlier the modeling of wind loading experienced by wall panels was produced as follows:

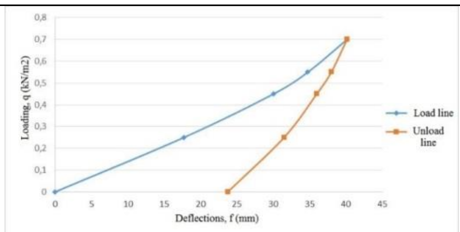
- Panels are installed on the seven supports arranged with a step of 1.2m that basically allowed it to exclude its vertical displacement;
- Taking into account the symmetry of the bearing relative to the center of the panel, intermediate supports were cleaned consistently. According to the testimony of the device inclusion of gravitational loading was recorded;
- Finally, the panel presented a beam element with a span of 7.2m relying only on the extreme supports. Vertical displacements of the panel, in a sense, reflected the loading of its own weight.

This loading simulated 1st step. The hydraulic load of 0.45 kN/m2 was added at the second step. Testimony of the gauges are summarized in Table 6.

Table 6. Testimony of gauges during the wind loading

Temporary loading, кN/m^2	Δt	Testimony of DPI D1-D8 (mm).		
		D-1	D-2	D-3
$q_{dw.}$=0,251	0	16,51	17,72	16,74
	15 min	18,75	19,03	18,81
	30 min	17,75	18,1	17,77
	1 hour	18,64	19	18,52
	1,5 hour	18,75	19,09	18,65
	2 hours	18,88	19,23	18,81
	3 hours	18,99	19,31	18,93
	24 hours	19,26	19,32	19,17
$q_{dw.}$ + 20	0	30,02	30,05	29,94
$q_{dw.}$ + 30	0	35,02	34,77	34,92
$q_{dw.}$ + 45	0	40,5	40,16	40,66
$q_{dw.}$	0	25,08	25,01	24,98
	30 min	23,95	23,76	23,81

Table 7. Plots of the relation between deflection and current loading for wall panel (wind loading).

№	Plot	Characteristics
1		The total load was 0.7 kN/m2. The maximum value of deflection has accounted 84.7% of the acssumed value (L / 150 = 48mm). Reflecting the real conditions, after the application of the total load its forbearing over time was not held.

The output from the normal exploitation state of the panel occurred on the fourth type of the limited states, i.e. on the ultimate deflection. The other types of the limited states were not fixed. Furthermore, the analysis of the failure behavior of the panels revealed that the weakest link in the investigated constructions was the insulation core that has entailed the need of the additional research for determination its physical and mechanical characteristics.

9. Determination of strength and deformation characteristics of the mineral wool used in the tested panels

The objective of the study was to establish experimentally strength and deformation characteristics of "Izovat" mineral wool insulation under transitional loading.

The object of the study was the "Izovat" mineral wool insulation presented in the form of 9 cubes cut from sandwich panels of the "AluTerm" series (TU U V.2.6-28.1-32564237-001 : 2007).

The subject of the study was the deformation and failure behavior of the insulation under the action of uniformly distributed transitional loadings.

Normative support: tests were conducted in accordance with [11].

9.1. Determination of density

Specimens cut from the lamellas of insulation were set for tests (Fig. 17).

The dimensions of each specimen were 100x150x500mm.

Number of specimens - 5pcs.

Fig. 17. Lamellas of insulation from which the specimens were cut

Selected specimens were measured and weighed with following calculations of their volume and weight in kilograms per cubic meter. The arithmetic mean value of density obtained from parallel tests was considered as ultimate result.

9.2.Detemination of deformation modulus

In order to determine the deformation modulus of the 1st kind (E) of the tested material the additional investigations of specimens with construction of the "stress – strain" diagram were conducted on the basis of the laboratory of building constructions of Kharkiv National Automobile and Highway University. Specimens cut from the lamellas of insulation were used for tests. The dimensions of each specimen were 100x100x100mm. Number of specimens - 9 pcs.

Loading of the specimens was carried out via R-5 press. The specimens were placed between the jaws of press (Fig. 18) with the orientation along the fibers of mineral wool. Measurement of deformation parameters was produced via electronic sensor.

On the first steps of loading (0.001-0.003 kN / cm2) visible deformations were not observed. At the following steps of loading the testimony of the sensor were recorded at the moment of their stabilization.

On the basis of the test results of nine specimens the averaged "stress - strain" diagram was constructed (Fig. 19).

Fig. 18. The specimen placed between the jaws of the press

The kind of diagram predetermined the opportunity of approximation of each of its two sections with pieces of straight line. In particular, on the first area (1):

$$\sigma = E_{red} \cdot \varepsilon \, ; \; E_{red} = \frac{1}{(n-1)} \sum_{i=2}^{n} \frac{\sigma_i}{\varepsilon_i} \qquad (1)$$

wherein n – is the number of measuring points; σ_i, ε_i - stress and strain in the i - th point (Fig. 19).

On the second area (2):

$$\sigma = \frac{\sigma_B - \sigma_A}{\varepsilon_B - \varepsilon_A} \varepsilon \qquad (2)$$

wherein σ_A, ε_A - tension at A and B points; σ_B, ε_B - deformation at A and B points.

Built diagram was the basis for determination the actual strength and deformation characteristics of the tested material (Table 8).

The characteristic feature of this diagram is its bilinear nature (diagram for material with quasihardening). This circumstance allowed to determine in a very easy way the approximate values of:

- Modulus of deformation of the 1st kind via formula (3):

$$E = E_{red} \quad (3)$$

- Tensile strength (4):

$$\sigma = \sigma_A^* \quad (4)$$

wherein σ_A^* - the tension at the A point of the approximated diagram.

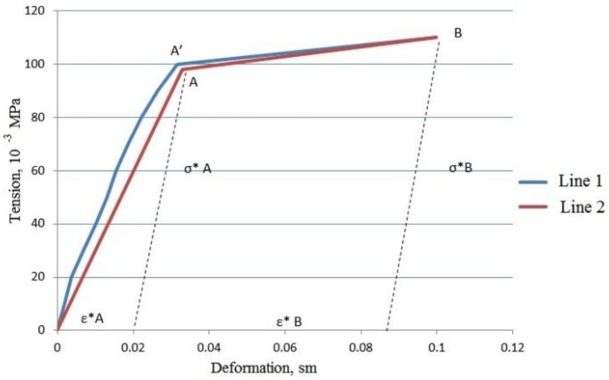


Fig. 19. The "stress - strain" diagram: 1- actual dependency (OA'B); 2- theoretical dependency (BAO)

Table 8. Actual strength and deformation characteristics of the tested material

Parameter	Specifications for calculating MPa	Specifications for calculating, MPa
Compressive Strength	0.105	
Modulus of the deformation of the 1st kind	3.1	11.6
Shear modulus	1.07	4
Shear strength	0,052	

The coefficient of the transverse strain was taken equal $\nu = 0{,}45$. As a consequence, the modulus of deformation of the 2nd kind - G, assumed to be G = 0.345E, and shear strength - $\tau_u = 0.5\sigma_u$, wherein τ_u, σ_u are the ultimate characteristics.

These tests allowed to define the behavior of the insulation material under the loading and to determine its strength and deformation characteristics. Up to 0,009 kN/cm2 tension material has worked linearly and elastically. Installed modulus of deformations of the 2nd kind (shear modulus) is 3.74 times lower than recommended in [4]. The latter explains the increasing deformability of the tested panels.

It was also observed the orthotropic nature of the structure of mineral wool. This fact leads to a well-defined orientation of the lamellas in the process of manufacturing of the panels.

10. General conclusions

1. Adopted theoretical isotropy of the insulation core and construction in general is confirmed by the established results of measured deformations and displacements of the specimens in the form of cubes. Nevertheless, it is noticed that the orientation of the fibers of insulation has a fundamental importance. In this connection, the hypothesis of conditional isotropy has an integral character.

2. Hypothesis of the nondeformable cross sections of the panel in its plane, within acceptable limits, was confirmed experimentally (the difference between measured deflections on opposite edges of the panel does not exceed 15 %).

3. There is a strong influence of the characteristics of the insulation to the characteristics of deformation of the structure. This conclusion determines the necessity of a more careful selection of the element before running it in production.

4. The difference between the values of deflections under the action of a uniformly distributed loadings of 250 kN/m2 based on the actual values of physical and mechanical characteristics and recommended in [10], as well as the actual characteristics, fully substantiate the previous conclusion.

5. The obtained values of bearing capacity within the real values of the physical and mechanical characteristics on the criterion of a maximum deflection (L/200), should be supplemented (at the detailed design) with the verification by the previously mentioned three limited states and taking into account the effect of temperature (if it's necessary).

6. On the basis of the topology of the panels and mineral wool insulation the finite element models were created. This allowed adequately evaluate the behavior of these structures.

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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ СТІНОВИХ ТА ПОКРІВЕЛЬНИХ СЕНДВІЧ-ПАНЕЛЕЙ СЕРІЇ «АЛЮТЕРМ»

В.С. Шмуклер, О.І. Лугченко, О.О. Петрова

В статті приведено результати експериментальних натурних досліджень стінових та покрівельних сандвіч-панелей з мінераловатним середнім шаром. Визначені особливості напружено-деформованого стану тришарових стінових та покрівельних панелей, що виготовляються підприємствами України. Надано аналіз деформування та руйнування досліджуваної конструкції.

Ключові слова: сандвіч-панель, мінераловатний заповнювач, ламель, гідравлічний метод досліджень, напружено-деформований стан (НДС).

ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ СТЕНОВЫХ И КРОВЕЛЬНИХ СЭНДВИЧ-ПАНЕЛЕЙ СЕРИИ «АЛЮТЕРМ»

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В статье приведены результаты экспериментальных натурных исследований стеновых и кровельных сэндвич-панелей с минераловатным средним слоем. Обозначены особенности напряженно-деформированного состояния трехслойных стеновых и кровельных панелей, производимых предприятиями Украины. Дан анализ деформирования и разрушения исследуемой конструкции.

Ключевые слова: сэндвич-панель, минераловатный заполнитель, ламель, гидравлический метод испытаний, напряженно-деформированное состояние.