Study of the thermal and sound insulation properties of ceramic plates with cavities designed for beehives

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***Summary**: The article presents a study of the sound and thermal insulation properties of ceramic plates with cavities, designed for beehives. The plates are obtained by the "casting" method from a water-dispersed colloidal system based on a patent-protected quartz glass-ceramic. They are composed of amorphous SiO_2, mullite and cristobalite. To measure the thermal conductivity, a thermal chamber is constructed with a heater installed in it. Given that the heat flow passing through the three-layer ceramic plate for beehives is constant, the temperature difference between the two opposite sides of the plate at steady state (at constant heat flow) is measured and the thermal conductivity is calculated. A two-chamber method is used to determine the sound insulation capacity of the ceramic plates for beehives. The sound pressure of the sound waves – the incident one and of the wave which has passed through the sample –is measured in the frequency range from 100 to 3150 Hz*

***Keywords:** HOLLOW CERAMIC CONSTRUCTIONS, WATER DISPERSION COLLOIDAL SYSTEMS, THERMAL CONDUCTIVITY, SOUND INSULATION*

1. Introduction

The object of study are ceramic structures with cavities, designed for beehives [1]. They are obtained using the "casting" method from water-dispersed colloidal system based on quartz glass-ceramics and are composed of amorphous SiO_2, mullite and cristobalite. The ceramic structures consist of three layers - two dense outer layers and an intermediate air layer which is formed between them. Of practical importance for providing the necessary heat and sound insulation are the thicknesses of the three layers. The internal structure of the cavities in the ceramic products was studied usingthe computer-tomographic nondestructive method and is presented in [1].

2. Experimental part and discussion

2.1. Determination of the thermal conductivity

The methods for determining the thermal conductivity are divided into two main groups: stationary and non-stationary. The former require experimental conditions in which the temperature gradient does not change with time, while the latter allow determination of thermal conductivity when the temperature of the material varies over time [2-5].

One of the formulations of the problem of determining the thermal properties of materials using stationary methods is based on the passage of heat through flat walls.

The value of the heat flux $\dot{Q}$ passing through n layers of flat walls is the same if there are no heat losses [2,3]

$$\dot{Q}_1 = \dot{Q}_2 = \cdots = \dot{Q}_n = \dot{Q} \tag{1}$$

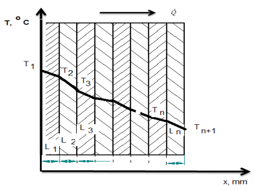


***Fig.1.** Temperature distribution in a flat wall with n layers crossed by a constant heat flux (steady state condition)*

According to Fourier's law of heat conduction, the heat flux passing through the first layer of the wall is [2,3]:

$$\dot{Q}_1 = \frac{\lambda_1}{L_1} \dot{A}(T_1 - T_2), \tag{2}$$

where λ_1 is the coefficient of thermal conductivity, L_1 is the wall thickness, A is the area of the wall perpendicular to the temperature gradient, T_1 and $T_2$are the temperatures on both sides of the layer.

The temperature difference for the first layer is determined by the expression:

$$\mathrm{T}_1 - \mathrm{T}_2 = \frac{L_1}{\lambda_1 A} \dot{Q}_1 \tag{3}$$

Temperature differences for other layers are determined analogously:

$$\mathrm{T}_2 - \mathrm{T}_3 = \frac{L_2}{\lambda_2 A} \dot{Q}_2 \tag{4}$$

....

$$\mathrm{T}_n - \mathrm{T}_{n+1} = \frac{L_n}{\lambda_n A} \dot{Q}_n \tag{5}$$

By summing equations (3) - (5) and taking into account equation (1), we get the following for the value of the heat flux through the multilayer wall:

$$\dot{Q} = \frac{T_1 - T_{n+1}}{\sum_{i=1}^{n} \frac{d_i}{\lambda_i A}} \text{ [W]} \tag{6}$$

The value of the heat flux passing through the first layer can be determined using the dependence (2).

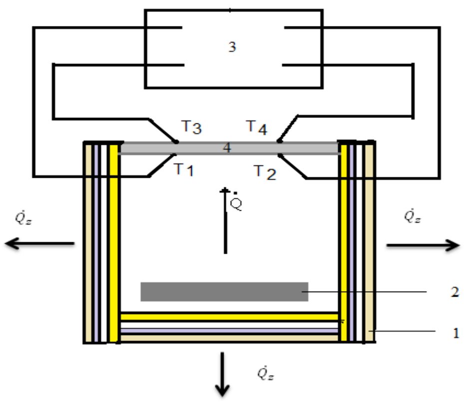


Fig.2. *Experimental setup for measurement of thermal conductivity by guarded hot plate*

In the present paper, the experimental study of the coefficient of thermal conductivity is realized using the method of the guarded hot plate.

For this purpose, a thermal chamber was constructed in the shape of a box measuring 0.43 x 0.40 m, insulated with four layers – a gypsum plasterboard (as an outer layer), a steel layer, an air layer and a heat-insulating fibrous building material type Fibran. The thicknesses of the layers are shown in Table 1.

A heater is installed in the chamber. The heat flux $\dot{Q}$ is equivalent to the electric power of the heater. The tested sample – a ceramic plate for a beehive with dimensions 300 x 360 x 25 mm – is placed in the chamber and is well insulated. A diagram of the experimental setup is shown in Figure 2, where 1 is a thermal chamber, 2 is a heater and 3 is a device for recording the change of temperatures T1, T2, T3, T4 over time (4-channel digital thermometer CENTER 304 type K).

Two thermocouples are located on the heated surface of the plate, and two others – on its upper unheated surface.

Thermocouples 1 and 3 are located at one end of the two opposite surfaces of the plate, and thermocouples 2 and 4 are placed in the middle of the plate on the heated and unheated surfaces correspondingly.

Five experiments were conducted using heaters of different power in which the temperature differences between the two opposite sides of the studied ceramic plate for beehives were measured until a constant temperature difference was established.

2.2. Acoustic studies

The determination of the sound insulation capacity of the ceramic plate for beehives was performed by the method of measuring sound transmission loss using two testing chambers (rooms), between which the test sample is placed [6,7]

On the wall of the first camera,“source room”, is mounted a speaker which creates a sound field, and in its center is installed a microphone that measures the intensity of the created sound field. In the other chamber,“receiving room”, is mounted a microphone that receives the sound signal which has passed through the tested sample. The volume of the chambers is 0.125 m^3. They have thick walls and are lined with sound-absorbing materials. The transmission of sound outside the studied ceramic plate is reduced to a minimum. The operating mode is stationary.

A VK 0829/38 speaker with a frequency band from 80 Hz to16 kHz and emitting sound waves excited by a generator type MS-9160 was used. The microphones in the source camera and the receiving camera were type ECM-999, with a frequency band from 20 Hz to 20kH. The measuring device consisted of a 16-bit computerized real-time measuring system (Sound Level Meter System) VT RTA and a two-channel sound card Focus rite Scarlett 2i2 type ASIO. The measurement software was Multi-Instrument Software 3.8 [8]. The signals and their frequency characteristics were monitored with an oscilloscope. The analysis was performed using third-octave frequency bands.

The sound pressure measurements in both chambers were performed using a sinusoidal signal fed to the loudspeaker at separate fixed frequencies.

The sound insulation coefficient is defined as the difference between the measured sound pressures in the source and receiving chambers:

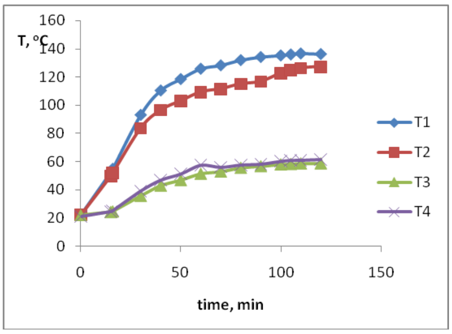
$$R = L_S - L_R \text{ [dB]}, \qquad (7)$$

where L_S and L_R are the sound levels of the incident sound wave and of the one which has passed through the sample respectively.

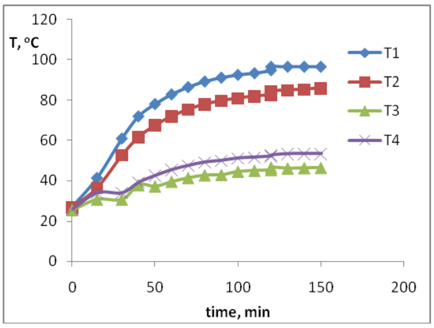
3. Results and Discussion

Determination of thermal conductivity

Figures 3 (a) and (b) show the results of the experimental determination of the thermal conductivity using heaters with power of 150 W (a) and 80 W (b).



a)



b)

Fig.3*. Temperature variation vs time*
a)Heater with power of 150 W; b) Heater with power of 80 W

The thermocouples T_1 and T_2 are located on the heated surface of the ceramic plate, and the thermocouples T_3 and T_4 are located on its unheated surface.

The temperature differences between the heated and unheated surfaces of the samples are $\Delta T_{1,3}=T_1-T_3$ and $\Delta T_{2,4}=T_2-T_4$ and are shown in Table 2. Different temperatures were observed in the middle and at the periphery of the ceramic plate. The coefficient of thermal conductivity is determined by the dependence:

$$\lambda = \frac{d(\dot{Q}-\dot{Q}_z)}{A\Delta T}, \quad (8)$$

where: ΔT is the temperature difference between the two surfaces of the plate, A is the area of the plate perpendicular to the temperature gradient, d is the thickness of the plate, $\dot{Q}$ is the power of the heater, $\dot{Q}_z$ are the heat losses through the walls of the heat chamber and $\dot{Q} - \dot{Q}_z$ is the heat flux that has passed through the studied sample.

Heat losses $\dot{Q}_z$ are estimated using the dependence (6):

$$\dot{Q} = \frac{T_1 - T_{n+1}}{\sum_{i=1}^{n} \frac{d_i}{\lambda_i A}}$$

Reference values of the thermal conductivity coefficients of the insulation layers, shown in Table 1, were used for the calculations.

The surrounding surface of the chamber is 0.25 m^2, and the area of its bottom is 0.1 m^2, the thickness of the sample is d = 0.025m

Table 1. *Thicknesses of the layers*

Insulation of the thermal chamber	1st layer	2nd layer	3th layer	4th layer
	gypsum plaster board	steel	air	Fibran
Layer thickness L, [m]	0.012	0.001	0.008	0.015
λ , W/m.K	0.21	53	0.02	0.03

The resultsof the conducted experiments and the obtained values of the thermal conductivity are given in Table 2.

Table 2. *Results of the conducted experiments and obtained values of the thermal conductivity*

Power of the heater [W]	Heat losses, $\dot{Q}_z$, [W]	$\dot{Q}-\dot{Q}_z$ [W]	$\Delta T_{1,3}$ [K]	$\Delta T_{2,4}$ [K]	$\lambda_{1,3}$, W/m.K	$\lambda_{2,4}$ W/m.K	$\bar{\lambda}$ W/m.K
150	37.0	113.0	77.9	65.3	0.33	0.39	0.36
150	37.0	113.0	70.3	70.3	0.36	0.36	0.36
100	33.4	66.6	63.3	60.5	0.32	0.34	0.33
80	22.4	57.6	50	33	0.34	0.33	0.34
80	22.4	57.6	48	35	0.29	0.34	0.31

The obtained value of the coefficient of thermal conductivity of the ceramic plates for beehives is $\lambda = 0.34 \pm 0.1$ [W / m. K].

This value is comparable to the coefficient of thermal conductivity of thermal insulation bricks made of diatomite. The role of well-formed cavities in the plates is to reduce the thermal conductivity of the hives.

2.3 Acoustic studies

In Fig.4 are shown the averagevalues of the results of the acoustic measurements compared with the measurements of Fibran 20 mm.

The airborne noise insulation index of the ceramic tile, estimated according to EN 717-1 in the frequency range from 100 to 3150 Hz, is Rw = 23 dB. The sound insulation index for Fibran is Rw = 15 dB.

The results of the conducted experiments show that the ceramic cavity plates with cavities, designed for beehives, have good sound insulation and thermal insulation properties.

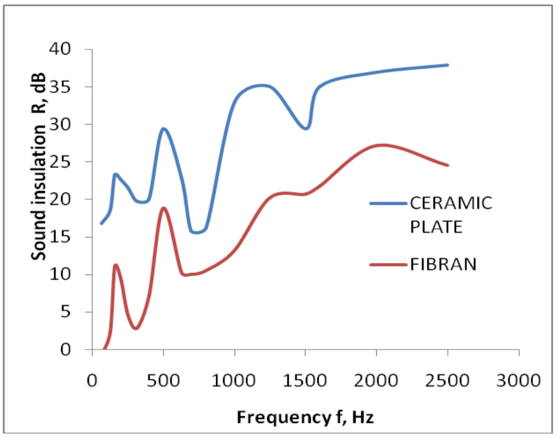


Fig.4. *Sound insulations of a ceramic plate and Fibran*

4. Conclusion

In this way, the presented results correspond to the best thermal insulation materials in practice.

References

1. Lakov L., N. Stoimenov, M. Aleksandrova, Investigation of hollow ceramic structures by contactless computer-tomographic nondestructive method, International scientific journal “industry 4.0”, year VI, issue 1, p.p. 21-24 (2021).
2. Janna W S 2000 *Engineering heat transfer, Second edition*, CRC Press LLC, US.
3. M Flori *et al* Using the heat flow plate method for determining thermal conductivity of building materials, *IOP Conf. Ser.: Mater. Sci. Eng.* **163** 012018, 2017.
4. Yesilata B and Turgut P 2007 A simple dynamic measurement technique for comparing thermal insulation performances of anisotropic building materials, *Energy and Buildings* **39** 1027- 1034.
5. Numan Yüksel, The Review of Some Commonly Used Methods and Techniques to Measure the Thermal Conductivity of Insulation Materials, Chapter 6, Insulation Materials in Context of Sustainability, http://dx.doi.org/10.5772/64157
6. Fahy F., Foundations of Engineering Acoustics , Imprint: Academic Press,2000, eBook ISBN: 9780080506838
7. Христев Ст., Архитектурна акустика, 2014, София (Hristev St. Architectural Acoustics, 2014, Sofia), http://www.stivox.com/akustika/Arhitekturna-akustika-Hristev-022015.pdf
8. www.virtins.com