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COMPARATIVE ANALYSIS OF THE THERMAL CONDUCTIVITY COEFFICIENTS OF ENVIRONMENTALLY FRIENDLY BUILDING MATERIALS

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Abstract: *The present paper represents a comparative analysis of the experimental results, observed by determination of thermal conductivity coefficient of environmentally friendly building materials made of clay (gray marl), sand and different quantity of straw. The thermal conductivity study was carried out by using of two different methods – method of infinite flat plate with "D-r Bok" stand and modified transient plane source method with thermal conductivity analyzer CTherm TCi. The comparative analysis of the results, obtained from the both apparatus, shows that there is a good repeatability of the thermal conductivity values and this is a reason to confirm the good thermal insulating properties of the tested materials. The experimental research established that the studied materials have thermal properties which could be compared with the thermal properties of common materials as lightweight concrete (k=0,1-0,3W/m.K) and ceramic bricks (k=0,6-1,31W/m.K).*
Keywords: *thermal conductivity, environmentally friendly materials*

INTRODUCTION

During the last few years the very topical theme is the refurbishment of old buildings and building-up of new energy efficiency buildings. Some of the reasons which provoke the humanity to start to think in that direction are the global warming of the Earth and as a result the unfavorable climatic changes. Huge part of natural resources is used for energy production and transmission, and this is always accompanied by loading of ecological system and potential risks for the future.

The main indicators that each advanced product designed for industry, transport and households must meet are price, energy efficiency and environmental friendliness. The energy efficiency is the most important since it determinates the possibilities and terms for payment of the product at its future using and the competitiveness of the manufacturing in which it participate.

The use of alternative building materials whose thermal characteristics are comparable with those of the advanced materials is one of the ways to increase the energy efficiency of buildings. A reason these materials to be environmentally friendly is that most of them come entirely from it, this means that they do not pollute it and could be used repeatedly thought working. Other advantages of the alternative building materials are: work with them is time-consuming and it is not needed special qualification to use them; often they could be extracted directly from the place which will be building up, so the transporting emissions are reduced; thermal characteristics of some alternative building materials show that they are applicable at different temperature ranges because they have very good insulating properties [1-4].

From the foregoing it is clear that the ever-changing conditions and requirements of the regulations impose continues search of new solutions [5-7]. According of various manufacturers of building materials, thermal conductivity coefficient of the offered by them products is in wide ranges [8-12]. Linked to the expected massive influx of the environmentally friendly building materials in the practice, it is necessary to control their declared parameters and especially the thermal conductivity coefficient [12-16].

A comparative analysis of the experimental results of thermal conductivity measurements of environmentally friendly building materials is represented. Two methods of measurements were used to determinate the thermal conductivity coefficient - method of infinite flat plate and modified transient plane source method.

METHODOLOGY OF EXPERIMENTAL STUDIES

The formulated above problem was solved by measurement of the thermal conductivity coefficient of the environmentally friendly building materials made of clay (gray marl), sand and various amount of straw.

Sample preparation

For the research purpose four flat samples were made with composition as follows:

1^{st} sample – clay with sand (1:2) (fig. 1a);
2^{nd} sample – clay with sand (1:2) and 68 g straw (fig. 1b);
3^{rd} sample – clay with sand (1:2) and 102 g straw (fig. 1c);
4^{th} sample – clay with sand (1:2) and 136 g straw (fig. 1d).

Samples were prepared as follows: The clay was dissolved in water, after that the sand was added and the composition was mixed to homogenous mixture. For samples 2, 3 and 4 the defined quantity of straw was added as well. The next steps were: the mixture was cast in wooden mould with length of 0,24m and height of 0,0245 m; the mould was "reversed" on a flat surface and after that removed; the sample was placed to dry at room temperature in ventilated area for 48 hours; the roughness was smoothed with sandpaper to reduce the errors in subsequent measurements.

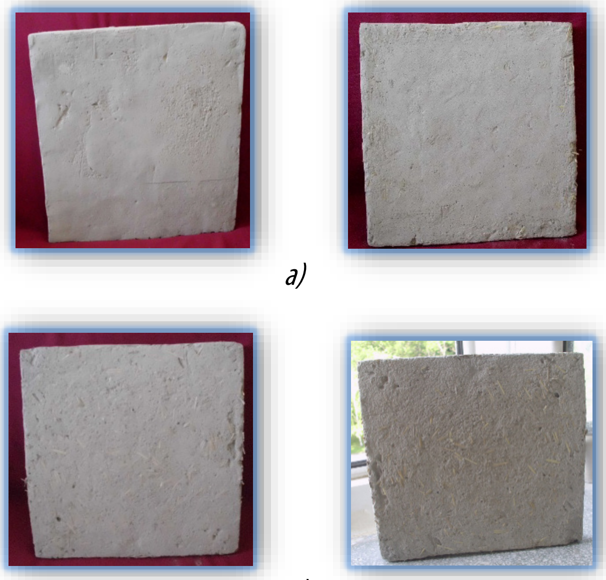

Figure 1. View of the samples: a) sample 1; b) sample 2; c) sample 3; d) sample 4

Method of infinite flat plate

"D-r Bok" stand was used (figure 2 and figure 3). The stand is used to determinate the thermal conductivity coefficient k in the range from 0,029 to 1,98 W/(m.K) (0.025÷1.7 kcal/(m.h.grad)) of natural and synthetic fine-porosity, porosity and fibre materials.

Figure 2 „D-r Bok" stand

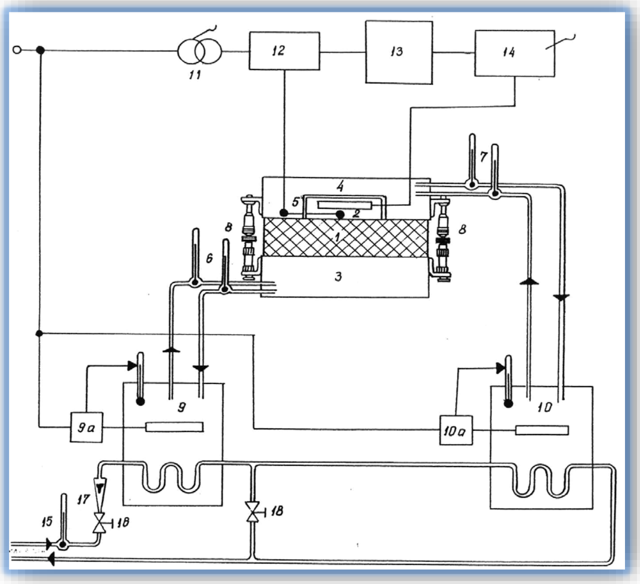

Figure 3 . Principle scheme of "D-r Bok" stand
1. Sample; 2. Hot plate; 3. Cold plate; 4. Protective plate; 5. Temperature sensor; 6. Thermometers on the cold plate; 7. Thermometers on the protective plate; 8. Micrometers; 9. Thermostat for the cold plate; 9a. Thermoregulator to 9; 10. Thermostat for the protective plate; 10a. Thermoregulator to 10; 11. Transformer; 12. Two-position regulator; 13. Electric meter; 14. 12-points potentiometer; 15. Thermometer for cooling water; 16. Valve for cooling water; 17. Rotameter for cooling water; 18. Bypass valve

Principle of stand operation – the sample (1) is put between two flat plates with different temperatures – hot plate (2) and cold plate (3). The hot plate keeps constant temperature by supplying electricity. The temperature of the cold plate is kept constant by heat removal through the water. The hot plate is covered by protective plate (4) with the same temperature and as a result the heat losses to the surrounding space are prevented and the heat flow is directed to the specimen. Thus, at quasi-stationary mode, the supplied electrical power to the hot plate is proportional to the heat flow to the specimen, figure 3.

Modified transient plane source method

A thermal conductivity analyser CTherm TCi was used (figure 4). The apparatus has a wide range of measurement of the thermal conductivity (k=0-220 W/(m.K)) at temperatures from -50 °C to 200 °C. It allows precise measurement with an accuracy of ±1%. The test time is in 5 seconds. Tested material could be in form of solids, fluids, creams or powders.

Figure 4 . Thermal conductivity analyzer CTherm TCi

Principle of analyzer operation – the sensor is placed on the specimen. Current is applied to the heating element of the sensor and the required amount of heat is produced. As a result, the temperature on the boundary surface between the sensor and the specimen is increased. This temperature increasing causes a change in the voltage drop on the sensor. The velocity of increasing the sensor's voltage is used to determinate the thermal properties of the tested materials. Thermal physical properties of the material are inversely proportional of the velocity of increasing the sensor's voltage. Specialized software is used to process the results of the measurements [17].

EXPERIMENTAL RESULTS

On the base of above described experimental procedures for both apparatus 5 experiments on the "D-r Bok" stand and with the thermal analyzer CTherm were carried out. The results are shown below.

According to the references [13-15], thermal conductivity coefficients for clay, sand and straw are as follows: dry to wet clay - $k_{clay} = 0,15 \div 1,8$ W/(m.K) [14]; sand with 10% humidity - $k_{sand} = 0,97$ W/(m.K) [15]; straw no matter direction of the stems - $k_{straw} = 0,048$ W/(m.K) [13]. It was concluded that the thermal conductivity coefficient of the new composite material - object of the present research, will be within the measurement range of the both apparatus.

Experiment № 1

For calibrating the "D-r Bok" stand an experiment with a glass specimen was made. Thermal conductivity coefficient of the glass is known – k_{glass}=1,15W/m.K [14]. The glass probe was with thickness of 0,015 m (figure 5).

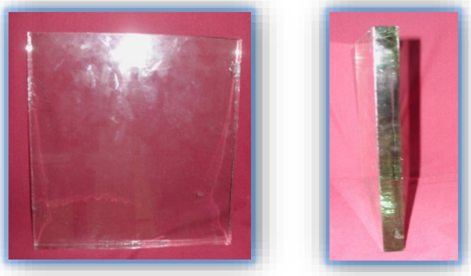

Figure 5. Sample - glass

The specimen was placed between the hot and the cold plates. All contact surfaces were properly cleaned beforehand. By using the micrometers (position 8, figure 3), the thicknesses in the fourth middles of the glass were measured. After that the protective plate (position 4, figure 3) was placed on the plates.

When the stand was in its established mode, it was performed reading of the ambient temperature, the temperature of the cooling water from the water-main, the stand electrometer and the temperatures on the inlet and outlet of the cold and of the protective plates on every 30 min. during period of 2,5 hours. According to the measured values the thermal conductivity coefficient of the glass was calculated. The obtained coefficient of thermal conductivity was k_{glass}= 1,115 W/(m.K).

Experimentally obtained value of the thermal conductivity coefficient of the glass is near to the table one (the difference is in 3%), therefore the stand is in proper working condition and the tests of the specimens made of the environmentally friendly mixtures could start.

Experiment №2

The object of study of the second experiment was a sample of clay and sand (figure 1, sample 1). The test was carried out following the same procedure as it was described in the first experiment. The result was k=0,561 W/(m.K).

Experiment №3

The object of study of the third experiment was a sample of clay, sand and straw (figure 1, sample 2). The test was carried out following the same procedure as it was described in the first experiment. The result was k=0,436 W/(m.K).

Experiment №4

The object of study of the fourth experiment was a sample of clay, sand and straw (figure 1, sample 3). This test was carried out following the same procedure as it was described in the experiment №1. The result was k=0,253 W/(m.K).

Experiment №5

The object of study of the fifth experiment was a sample of clay, sand and straw (figure 1, sample 4). This test was carried out following the same procedure as it was described in the experiment №1. The result was k=0,228 W/(m.K).

On the same specimens were carried out similar tests with thermal conductivity analyzer CTherm TCi.

For experiment №1, the glass specimen with thickness δ_{glass}= 0,015 m was placed on the sensor of the analyzer. It is necessary the sensor and the specimen to be in thermal equilibrium, only then the contact resistance between them is zero. The measurements were made in 20 points and after software processing the results obtained were averaged. The result was k_{glass}=1,18 W/(m.K). Experimentally obtained value of the thermal conductivity coefficient of the glass is near to the table one (difference is in 3%), therefore the analyzer is in proper working condition.

Experiments with numbers 2, 3, 4 and 5 on specimens from 1 to 4 were carried out similar to the first one.

The results obtained from the measurements by both methods were represented in table 1.

***Table 1.** Experimental results obtained from testing of environmentally friendly building materials made from clay, sand and different amount of straw*

Sample №	δ m	ρ kg/m³	k_1 W/(m.K)	k_2 W/(m.K)
1	0,0240	2000	0,562	0,498
2	0,0241	1877	0,436	0,379
3	0,0245	1737	0,254	0,241
4	0,0247	1683	0,228	0,219
glass	0,015	2600	1,115	1,18

Symbols

δ – average value of the specimen thickness, m;

ρ - density, kg/m³; k – thermal conductivity coefficient, W/(m.K);

The analysis of results shows that with increasing the quantity of straw the thermal conductivity decrease. That means that material *with greater quantity of straw has better thermal insulating properties.*

CONCLUSION

On the base of the carried out experiments and obtained results for thermal conductivity coefficient of environmentally friendly building materials made of clay (grey marl), sand and various quantity of straw the following conclusions could be made:

1. The thermal conductivity coefficient of a specimen made of clay and sand is k = 0,562 W/(m.K) when "D-r Bok" stand was used and k = 0,498 W/(m.K) when thermal analyser CTherm TCi was used. The difference in results is caused by the using of totally different methods of measurement but they are comparable and commensurable.

2. Depending on the amount of the added straw to the clay and sand mixture the values of the thermal conductivity coefficient, obtained by "D-r Bok" stand, are: at the lowest amount of straw (68 g) - k=0,436 W/(m.K) and at the highest amount of straw (136 g) - k=0,228 W/(m.K). The same specimens, tested on the thermal conductivity analyzer CTherm, gave the following results: k = 0,379 W/(m.K) and k = 0,219 W/(m.K). The conclusion could be made is that with increasing the quantity of straw thermal conductivity coefficient decrease. That means that the tested materials become better insulating properties.

3. The comparative analysis of the results, obtained from the both apparatus, shows that there is a good repeatability of the thermal conductivity values and this is a reason to confirm the good thermal insulating properties of the tested materials.

The conclusions made above and the experimental study of the thermal conductivity coefficient are the basis for confirmation the possibilities for good application of the tested environmentally friendly building material on places where the advanced thermal insulating materials are not applicable.

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