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SIMULTANEOUS MEASUREMENT OF THERMAL CONDUCTIVITY OF THE MATERIALS FROM THE LAYERS OF A MULTILAYER CONSTRUCTION SYSTEM

BY

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Abstract. Estimation of thermo-physical characteristics of the exterior stratified walls is based on thermal conductivity measurements on samples of the materials that make up these walls. The methods used for these experimental measurements require the use of dry samples, a different condition that the wall material is in office. Measurement of thermal conductivity of the material composition of an external wall layers can be made *in situ* using a new type of thermo probe. This type of probe is based on linear heat source method for measuring thermal conductivity and measures simultaneously the thermal conductivity in two different points.

Key words: thermal conductivity; two layer wall; simultaneous measurement; thermo-conductive probe.

1. Introduction

The composite walls are a combination of two or more individual materials, different in shape and composition at the macroscopic level, interconnected to meet as a whole. Vertical walls, by their composition, are structural composites composed of layers (homogeneous composites soldered

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between them) of different thicknesses and different mechanical and thermo-physical characteristics. For the inhomogeneous structures of the walls, the thermal resistance depends on the thickness of the layer and on the thermal conductivity components and materials composing them. As a whole, composite wall has an equivalent thermal conductivity

$$\lambda_{\mathrm{eq}} = \frac{\sum_i \delta_i}{\sum_i \frac{\delta_i}{\lambda_i}}, \tag{1}$$

where: δ_i is the thickness of i layer; λ_i – thermal conductivity of the i layer.

2. Thermal Conductivity Measurements

The thermo-physical characteristics of materials in the layers of the walls of buildings are determined on samples taken from these building blocks using common laboratory methods. The Romanian standards (STAS 5912, 1989) indicate as methods for measuring thermal conductivity of building materials the use of stationary thermal methods such as hot plate method or termofluxmetric method.

The linear heat source method can be used as a nondestructive *in situ* measurement method of thermal conductivity of materials (De Wilde *et al.*, 2007; Strâmbu, 2012), also known as the "needle" thermal probe method, given the specificity of construction materials (micro- and macro-structure) from other materials. The thermal conductivity of a material is measured following the temperature response (Carslaw & Jaeger, 1959) from a point in studied material constantly heated by a linear heat source. The response is

$$\Delta T = \frac{q^I}{4\pi\lambda}\ln t + C, \tag{2}$$

where: ΔT is the temperature variation in one point at distance r from linear heat source; q^I – uniform heat flux of the linear heat source; λ – thermal conductivity of the material in which heat generated by the linear source spreads; t – the time the heat source is generating heat; C – a constant that depends on the size of the probe and the thermal contact between the probe and the environment.

The graphical representation of this eq. has a linear portion whose slope (Fig 1) is used in following eq. to determine the thermal conductivity of the material in the “needle” thermal probe is inserted, without having to know other thermo-physical characteristics

$$\lambda_{\text{app}} = \frac{q^I}{4\pi} \cdot \frac{1}{S}, \qquad (3)$$

where: $S = \Delta T/\Delta \ln t$ is the slope in Fig.1; λ_{app} – the apparent thermal conductivity of building material.

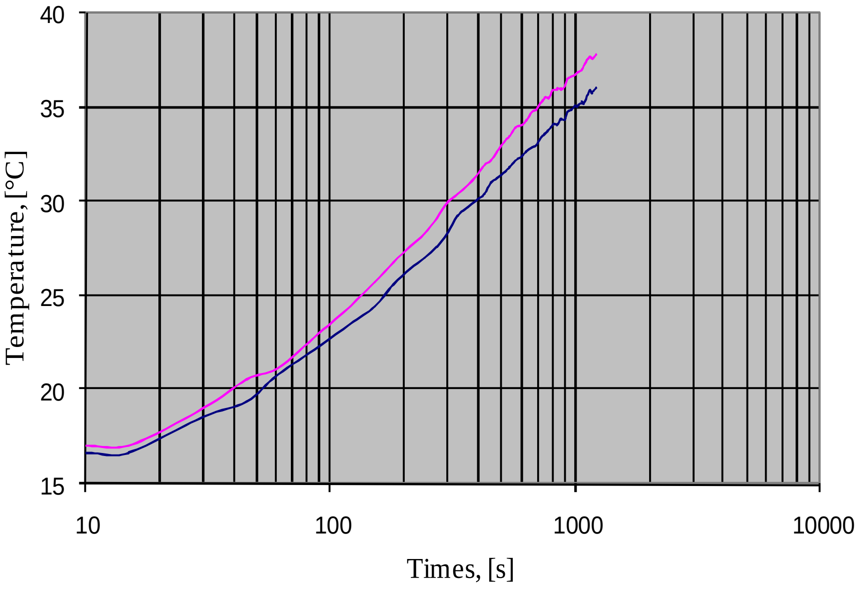

Fig. 1 –Semilog graph of the curve $\Delta T = f(\ln t)$ for a sample of AAC.

Thermal probe is a device comprising a linear heat source and a thermocouple rigidified in a cylindrical metal body. This device is simultaneously a linear heat source (generates a constant linear unitary heat flux, q^I, in the studied environment) and also a sensor that measures the thermal response time, thus allowing the measuring of the thermal conductivity only in planes perpendicular to the probe axis.

3. Simultaneous Measurement of Thermal Conductivity

If an environment is anisotropic in terms of heat conduction through it (it has areas with different thermal conductivities), the anisotropy can be highlighted using a new type of multipoint thermo-conductive probe. The design of this new type of probe is shown schematically in Fig. 2. The multipoint thermal probe consists of a resistive wire used as a linear heat source and two S-type thermocouples placed asymmetrically with respect to the middle of the device. Simultaneous measurement of thermal conductivity in two points in an environment that receives a uniform constant linear heat flux is based on the fact that the linear heat source method provides thermal conductivity representative values only in planes perpendicular to the probe in the temperature measurement points.

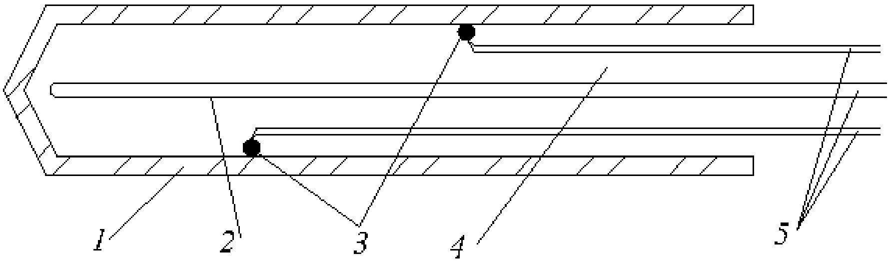

Fig. 2 – Schematic realization of a multi-point thermoconductive probe (*1* – thermal probe body; *2* – line thermal source; *3* – thermocouples; *4* – epoxy resin; *5* – electrical connection).

If a calibration is made using materials with known thermal conductivity, the thermal conductivity of the materials studied is given by relation

$$\lambda_{\text{app}} = C_i \frac{q^I}{4\pi} \cdot \frac{1}{S}, \tag{4}$$

where: C_i is a calibration factor corresponding to the two points of measuring of thermal conductivity and is obtained compared with known values of thermal conductivity.

4. Experimental Investigation

To record the way the multipoint thermo-probe reveals different values of thermal conductivity, we simulate a two layer building structure consisting of AAC and EPS, (building materials for thermal insulation; their thermal conductivity differs by one order of magnitude), as shown in Fig. 3.

Using eq. (4), the slope of the linear portion of the graph $\Delta T = f(\ln t)$, used in the analysis, is presented in Fig. 4.

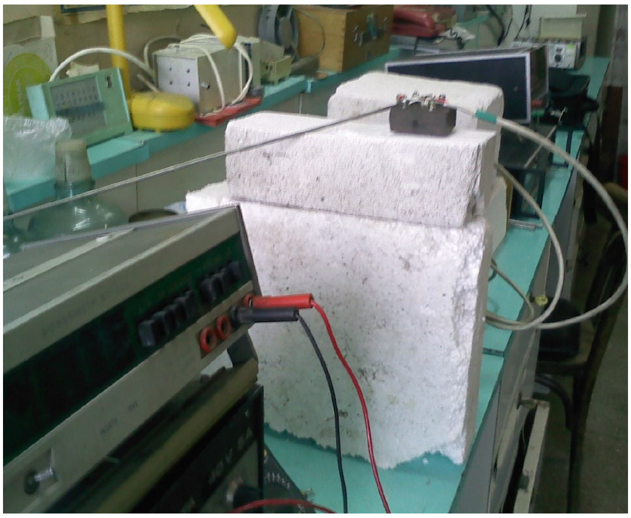

Fig. 3 – Two layer structure model (top layer AAC, bottom layer EPS).

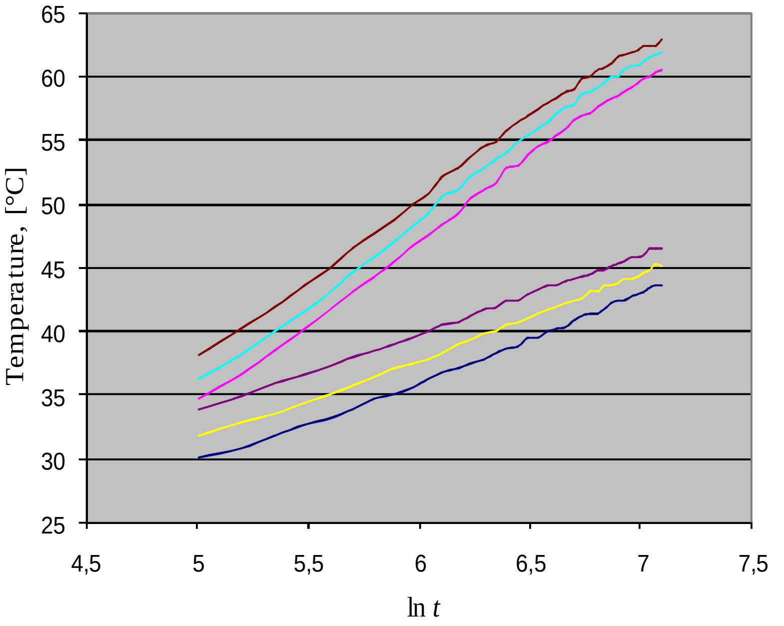

Fig. 4 – Linear portion of the graphics used to simultaneously measure the thermal conductivity of the investigated environment in two points; top curves – EPS, bottom curves – AAC.

Simultaneously measured values for the thermal conductivity, λ_{app} , of the materials that compose the two layer laboratory model, are presented for comparison with tabulated thermal conductivities (Table 1).

Table 1

Thermal Conductivity Simultaneous Measured

Material	$\lambda_{\mathrm{AAC}}^{\mathrm{calc}}$, [W/Mk]	$\lambda_{\mathrm{EPS}}^{\mathrm{calc}}$, [W/Mk]	$\lambda_{\mathrm{AAC}}^{\mathrm{tab}}$, [W/Mk]	$\lambda_{\mathrm{EPS}}^{\mathrm{tab}}$, [W/Mk]
AAC	0.11	–	0.1	–
EPS	–	0.051	–	0.045

Comparing the values of thermal conductivities simultaneously measured with the calculated results in the tables it results an acceptable relative error (good accuracy of the measurements).

5. Conclusions

Analysing the experimental data obtained using the probe for simultaneous measurement of thermal conductivity in two different layers of the two layer system we observe

a) a good repeatability of measurements, which indicates a good measurement accuracy;

b) the measuring device notifies the anisotropy in thermal behavior of the investigated environment and reveals thermal conductivity values which differ from each other by one order of magnitude.

The experimental results suggest that the new type of device for simultaneous measurement of thermal conductivity in two points in an environment can be used for measurement of thermal conductivity in large composite sandwich panel type used for exterior walls.

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MĂSURAREA SIMULTANĂ A CONDUCTIVITĂȚII TERMICE A MATERIALELOR DIN STRATURILE UNUI SISTEM CONSTRUCTIV MULTISTRAT

(Rezumat)

Estimarea caracteristicilor termofizice la pereții exteriori stratificați se face în baza măsurătorilor de conductivitate termică a eşantioanelor de materiale extrase din aceştia. Măsurătorile de laborator se realizează pe eşantioane de materiale uscate, deci în condiții diferite de cele pe care materialul le are când lucrează în elementul de construcție (conductivitatea termică a materialelor de construcție depinde de gradul de umiditate). Folosind un nou tip de sondă termoconductivă cu două puncte de măsurare se poate măsura simultan conductivitatea termică a materialelor de construcție din două straturi succesive din compunerea unui element de construcție stratificat.