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INFLUENCES IN THERMAL CONDUCTIVITY EVALUATION USING THE THERMAL PROBE METHOD; SOME PRACTICAL ASPECTS

BY

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Abstract. The thermal probe is a device used for measuring the thermal conductivity of materials in the food industry, plastics industry, geotechnical engineering and studies of soft soils and rocks. The method also started being utilized in the field of construction materials with particularities that take into account their composition and the state they are in.

Key words: thermal probe; thermal conductivity; evaluation.

1. Introduction

The thermal probe method is a direct and cheap one, developed for the study of soft soils and rocks thermal conductivity. The thermal probe is a device that includes a linear thermal source and a temperature sensor. The probe is constantly releasing heat in the environment in which it has been introduced and its thermal conductivity is established by the thermal probe’s increasing temperature during a period of heating and measurements. The rise in

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temperature of the thermal probe is inversely proportional to the surrounding material's thermal conductivity.

For the soils study and for the thermal insulator materials, the probes are designed so that the length/diameter ratio is highest (Brandon & Mitchell, 1989; De Vries & Peck, 1958), the probe's diameter is lowest so that it allows the approximation with a linear thermal source.

The eq. of thermal conduction (Kömle *et al*., 2011; Blackford & Harries, 1985; Carslaw & Jaeger, 1959) for a linear thermal source can be easily solved for obtaining the temperature distribution around the probe as a time function. Assuming there is a good thermal contact between the thermal probe and the researched construction material the solution for the heat eq. in cylindrical symmetry also represents the relationship between the thermal probe's temperature and the thermal conduction of the material. The thermal probe method can also be applied for determining the thermo-physical properties of construction materials with the same structure and marking as the soft soils and rocks, meaning it can be applied in studies of thermal behavior of mortars and concrete. For measuring the efficiency of dense and high granularity construction materials is used a high mechanical rigidity probe with a diameter of $d > 2.5$ mm. During the data analysis it is required to take into account the effects induced by the size of the thermal probe on the contact thermal resistance and on the thermal field disturbance around the probe.

2. Determining Thermal Conductivity

If the thermal probe is assimilated with a linear thermal source that meets the condition

$$\frac{L}{d} > 25, \tag{1}$$

where: L is the physical length of the thermal probe; d – outward diameter of the metal body of the probe, then the preponderant radial heat flow condition is met.

If a good thermal contact is made while inserting the thermal probe into the construction material then the thermal conductivity of the construction material sample is obtained with relation

$$\lambda_{\text{app}} = \frac{q_1}{4\pi} \cdot \frac{\ln\left(t / t_0\right)}{T - T_0}, \tag{2}$$

where: λ_{app} is the apparent thermal conductivity of the sample; q_1 – linear uniform heat flow generated by the probe's linear thermal source; t_0, t – the starting and, respectively, the finishing times of the heat generated towards the sample; T, T_0 – the initial and, respectively, the final temperature of the thermal probe; $S = (T - T_0) / \ln (t / t_0)$ – slope of the linear portion of the temperature varia-tion with ln t chart.

Since the S slope depends on the period of time needed to heat the sample material, the errors of the thermal conductivity value because of the thermal probe big diameter and because of a contact thermal resistance, also depend on time. These errors decrease once the time period for monitoring the thermal probe increases, even if the probe has a wider diameter (d = 6 mm), becoming acceptable after a sufficient amount of time (from experience the time has to be > 900 s).

In the case of AAC (type GBNT) measured with two thermal points measured probes, different only by the positioning of thermocouples inside probe, the family of curves obtained is showned in Fig. 1.

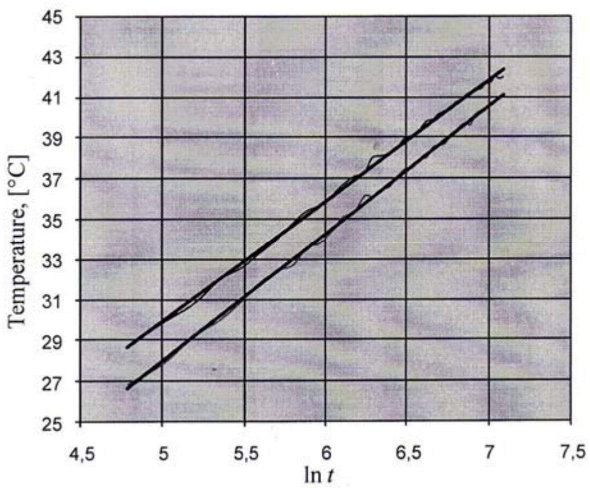

Fig. 1 – Temperature variation curves in different areas of thermal probe.

Processing the experimental data using the curves of the two curves led to obtaining the following values for the apparent thermal conductivity of the AAC sample

$$\lambda_{\text{app1}} = 0.183 \text{ W/m.K} \text{ and } \lambda_{\text{app2}} = 0.175 \text{ W/m.K}. \quad (3)$$

This shows the similar behavior of the environment that surrounds the linear thermal source , inside and on the outer surface of the thermal probe.

By calibrating the thermal probe using standard materials with known thermal conductivity, the errors connected to the physical size are eliminated, errors which affect the variation curve of temperature with ln t.

The thermal probe used in thermal conductivity measurements of construction material samples was calibrated using jellified water (ASTM Standard D5334-08; Hanson *et al.*, 2004). Using the experimental data presented in the Fig. 2. the calibration factor for the probe is obtained, namely

$$C = \frac{\lambda_{\mathrm{meas}}}{\lambda_{\mathrm{tab}}}, \tag{4}$$

where: C is the probe calibration factor; λ_{tab} – thermal conductivity of a standard material; λ_{meas} – thermal conductivity measured with the thermal probe**.**

For the composite construction materials such as mortars and concrete with high granularity, the contact thermal resistance between the probe and the material is high because of surfaces roughness. The contact resistance of grainy construction materials is also high, affecting the accuracy of their apparent thermal conductivity, λ_{app}. To decrease these errors, the method of filling the hollow spaces between the probe and the material with silicone paste is used (ASTM Standard D5334-08; Goodhew & Griffiths, 2005). Using this type of silicone paste, with a good thermal conductivity, has allowed, for grainy materials (quartz sand), the obtaining of a thermal resistivity value (q = 1/λ) comparable with the one obtained by using the stationary method of determination (s. Table 1).

Table 1
Thermal Contact Influence for Granular Materials

Material	Bulk density kg/m^3	Steady-state thermal conductivity W/m.K	Thermal conductivity W/m.K	Thermal conductivity for thermal sonde+thermal grease, [W/m.K]
Quartz sand	1.40	0.23	0.149	0.18
Dry sand	1.25...1.45	0.30	0.21	0.26

The non-uniformities of the thermo-physical properties of the hardened cement paste of aggregate nature of large scale (7…70 mm), or of metal reinforcements, can cause disturbances in the radial heat flow if they are placed at a critical distance from a thermal probe (see Fig. 2).

The disturbance of the thermal field and the disturbance of the thermal probe's temperature variation curve shape as a $\ln t$ type function occurs

(Hanson *et al*., 2004) if the thermal probe is placed at an R distance which can be calculated using the relation

$$\exp\left(-\frac{R^2}{4\alpha t}\right) \le 0.02, \tag{5}$$

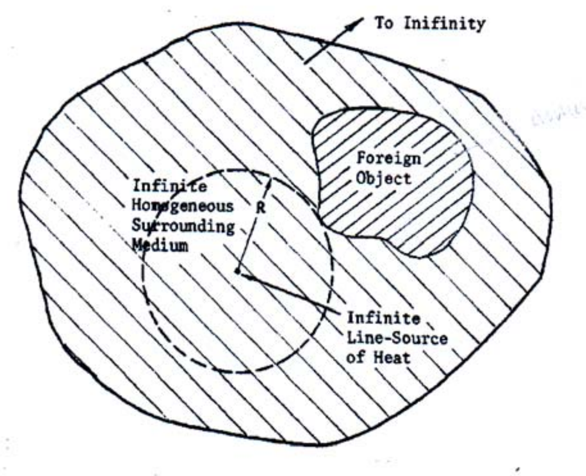

Fig. 2 – Probe non-uniformity interaction pattern.

where: R is the distance between probe and non-uniformity; α – thermal diffusivity of the investigated sample (presumed); t – time needed for heating the sample and for measurements (max. 1,200 s).

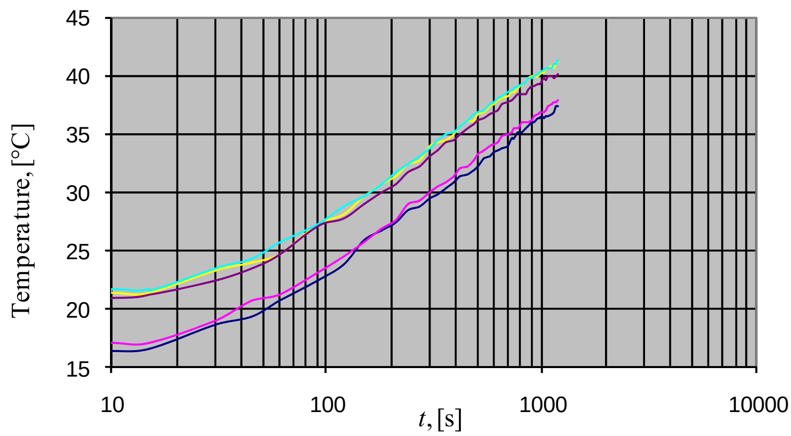

Fig. 3 – Family of probe's temperature variation curves for a probe – metal reinforcement shaping.

Simulating the presence of powerful non-uniform thermo-physical areas in a construction material, that is homogenous in terms of apparent thermal conductivity (*i.e.* AAC), by using high thermal conductivity iron reinforcements, the variations of the probe's temperature were obtained *vs*. the natural logarithm of time (see Fig. 3).

The analyse of the data presented in Fig. 3, and calculated value for λ_{app} shows that when the metallic inclusions (reinforcements, clips) are placed at an 8 mm distance from the thermal probe, even for higher times such as 1,200 s needed for the increase of measurements accuracy, the thermal conductivity measurements are approximately the same.

3. Conclusions

To increase the accuracy of the thermal probe method are necessary

a) higher heating periods of time and measurement are required to minimize the errors due to the geometrical size of the probe (larger diameter);

b) clear delimitation of the linear area, with the constant *S* slope, from the temperature variation *vs*. $\ln t$.

For the construction material samples that are suspected to be inhomogeneous it is necessary to perform at least five measurements in different positions to minimize the disturbances of the thermal field around the thermal probe.

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INFLUENȚE ÎN ESTIMAREA CONDUCTIVITĂȚII TERMICE FOLOSIND METODA SONDEI TERMICE; UNELE ASPECTE PRACTICE

(Rezumat)

Metoda sondei termice se foloseşte cu bune rezultate in măsurarea rapidă a conductivității termice a materialelor în industria alimentara, a vopselelor şi maselor plastice, precum şi în geotehnică. Metoda a început să fie folosită şi în domeniul măsurării conductivității termice a materialelor pentru construcții. În estimarea proprietăților termofizice ale materialelor de construcții este necesar să se țină seama de starea de neomogenitate a acestora.