BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVIII (LXII), Fasc. 2, 2012
Secţia
CONSTRUCŢII. ARHITECTURĂ

THERMAL CONDUCTIVITY MEASUREMENT OF CONSTRUCTION MATERIALS USING THE THERMAL PROBE METHOD

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Received: March 23, 2012
Accepted for publication: April 30, 2012

Abstract. The thermal probe method is a direct and reliable method of measurement, used for establishing the thermal conductivity of soft soils and rocks. The simplicity of the device used for measurement and the fact that it doesn’t alter the local properties of the material, enables this method to be applied also to the construction materials that have similar composition and behavior as the soft soils and rocks. Using the thermal probe allows measurements of the materials inherent thermo-physical properties in short periods of time.

Key words: thermal probe method; thermal conductivity; construction materials properties; thermal properties.

1. Introduction

The ranges that characterize the construction materials thermo-physical properties are determined currently in the laboratory using the ‘hot plate’ method or the equivalent ‘hot box’ method. The equipment and devices used are measuring the stationary heat flow of the sample that is tested. During the

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period of time needed to acquire the stationary temperature, the humidity level modifies, changing the thermo-physical properties.

Measuring the thermal conductivity of construction materials involves using massive and complex devices and also a longer period of time for measurements (hours).

As an alternative method, in terms of device complexity and shorter period of time for measurements (minutes), the thermal conductive probe method can also be used, for determining the thermal conductivity properties of construction materials regardless of their structure (porous, fibrous or granular). This method allows the direct measurement of thermal conductivity during a transient temperature by measuring the radial heat flow generated by a linear thermal source with a constant intensity. This method has been developed and used mainly in geotechnics (the study of Earth's soils and rocks and of other celestial bodies), in the food industry and in the plastics industry and its theoretical basis is the linear thermal source of thermal conduction in cylindrical symetry model (Kömle *et al*., 2011; de Wilde *et al*., 2007; Carslow & Jaeger, 1959).

2. The Thermal Probe

As a measurement device, the thermal conductive probe is a thermal source because of the axially placed linear thermal source and is also a temperature sensor because inside and centrally located there is a thermocouple. The two components are introduced in a metal tube with a high thermal conductivity, thereby obtaining a device similar to the one represented in Fig. 1.

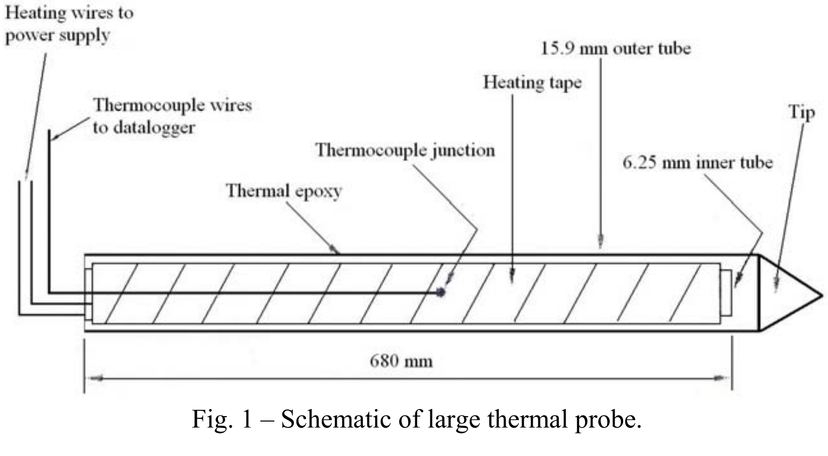

Fig. 1 – Schematic of large thermal probe.

Manufacturing the thermal conductive probe is made by taking into account the restriction (de Vries & Peck, 1958) of geometrical nature:

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

where: L is the thermal probe length; d – probe's diameter.

After placing the probe into the measured sample material, the short period of time needed for measurements has a minimal impact on the sample's humidity level so that the method used for measuring the thermal conductivity shows the real thermal properties of the analysed sample. The constant uniform heat flux generated by the linear thermal source of the probe produces a variation of temperature in a certain point of the sample, after a period of time from the beginning of the heating process namely

$$T - T_0 = \frac{q_l^{'}}{4\pi\lambda}\ln\frac{t}{t_0}\,, \tag{2}$$

where: $q_l^{'}$, [W/m], is the heat flux; λ, [w/m.K] – thermal conductivity of the sample; T, T_0, [ºC] – environment initial and final temperature; t, t_0 [s] – time at which heating period starts and finishes.

The temperature rise is linear to the heating time logarithm and it depends only on the thermal conductivity, λ, of the sample. The linear variation of the temperature is distorted especially at the beginning of the heating period because the thermal probe has a thermal capacity and there is a contact thermal resistance between the probe and the sample. In longer periods of time, the axial heat losses through the ends of the thermal conductive cylindrical probe are also producing nonlinearity in the temperature variation.

When manufacturing a thermal conductive probe, for its geometry the condition (1) is taken into account, so that heat conduction around it is radial. The probe is calibrated (de Wilde *et al.*, 2008; ASTM, 2008) using standard thermal conductivity materials, because it has $d > 2.5$ mm diameter.

3. Experimental Investigation

The experimental device used in laboratory for measuring the thermal conductivity of AAC samples is made from a copper tube with a $d = 6$ mm diameter in which there is placed a thermo-resistive constantan wire (linear thermal source) and a *S*-type thermocouple which is placed centrally. The system is rigidified using epoxy resin with a high thermal conductivity. Temperature monitoring is made by an electronic millivoltmeter or by a hybrid electronic recorder.

After introducing the probe into the construction material sample, there is a waiting period of 15…30 min until the thermal balance between the sample and the thermal conductive probe is acquired. The measurements start by coupling the thermo-resistive wire (the linear thermal source) to an electric generator of 1 A constant current, so that the sample temperature rise is approximately 12º…15ºC after 1,000 s. During the entire heating period the response of the probe's temperature is monitored after which the data is used for processing this experiment reflected in the linear region of the temperature variation chart of the ln *t* function.

Knowing the linear uniform heat flux and the chart slope, the thermal conductivity of the sample is measured using the formula

$$\lambda_{ap} = C\frac{q_l^{'}}{4\pi}\cdot\frac{1}{S} = C\frac{q_l^{'}}{4\pi}\cdot\frac{\Delta(\ln t)}{\Delta T}, \tag{3}$$

where: $q_l^{'} = Ul / L$ is the uniform linear heat flow of probe's linear thermal source; U – DC voltage supply of the wire; I – intensity of power that goes through the wire; L – thermal conductive probe length; $S = \Delta T / \Delta(\ln t)$ – slope of the chart's linear portion; ΔT – probe's temperature variation measured with the probe thermocouple; C – probe calibration factor.

The conductive probe method was used to estimate the apparent thermal conductivity of an AAC –GBNT type sample with the following sizes in dry state: 100 × 240 × 300 mm. Using different values for the uniform linear heat flow ($q_{11}^{'}$ = 2.45 W/m and $q_{12}^{'}$ = 9.56 W/m), the slopes in the linear parts of the probe's temperature variation chart are proportional to the linear heat flow, as is shown in Fig. 2.

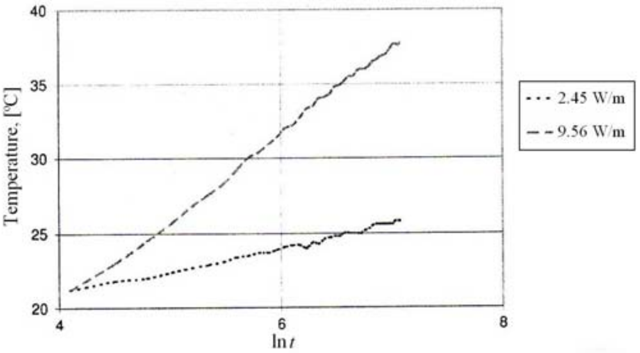

Fig. 2 – Temperature variation in thermal probe: linear part selected for processing the experimental data.

Using relation (3), the calculated thermal conductivity for the two experiments, have the following results:

$$\lambda_{ap1} = 0.185 \text{ W/m.K}, \lambda_{ap2} = 0.182 \text{ W/m.K},$$

results which are close to the ones guaranteed by the material's manufacturer.

When the linear heat source is generating an uniform linear heat flow, the variation curves of the temperature in the thermal conductive probe, are shown in Fig. 3, proving the repeatability characteristics of the experiment's results.

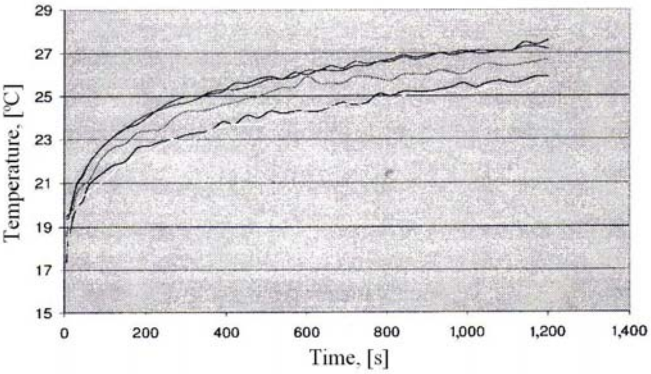

Fig. 3 – Family of temperature variation curves.

The thermal conductive probe method shows how the humidity level affects the apparent thermal conductivity of an AAC sample, when the thermally conductive probe is inserted into the sample, it shows no changes with the humidity level, as results from the Fig. 4.

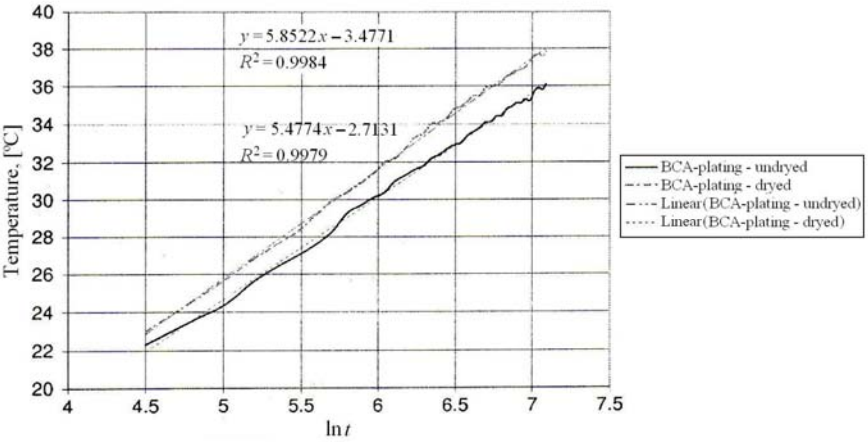

Fig. 4 – Changes in temperature variation curves at different humidity levels.

4. Conclusions

Analysis of the experimental data obtained by using the thermal conductive probe method shows that in certain conditions regarding the measuring time (tens of minutes) this method ensures:

a) a great experimental results repeatability;

b) great experimental results accuracy (in comparison to results given by other laboratory methods);

c) no changes in local humidity.

If we keep in mind that the device used for measurements is simple and economic, that the other additional devices are also cheap and easy to handle and most importantly if we keep in mind that the time needed for the measurements is short and there aren't any changes in the sample's thermophysical properties (as with other methods), the method using the thermal conductive probe can be developed and implemented as customary in laboratories designated for measuring the construction material's thermophysical properties.

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MĂSURAREA CONDUCTIVITĂȚII TERMICE A MATERIALELOR DE CONSTRUCTII UTILIZÂND METODA SONDEI TERMICE

(Rezumat)

Pentru măsurarea rapidă a conductivității termice a materialelor de construcții indiferent de starea lor poate fi folosită metoda sondei termice. Metoda începe să fie dezvoltată şi în acest domeniu fiind preluată din domeniul geotehnicii, al industriei alimentare sau al maselor plastice şi adaptată măsurătorilor de laborator şi chiar măsurătorilor *in situ*. Metoda asigură o bună repetabilitate a rezultatelor experimentale şi foloseşte dispozitive ieftine în comparație cu alte metode de laborator pentru măsurarea conductivităților termice.