VALIDATION TEST OF THE HOT BALL METHOD FOR SETTING OF THE CEMENT PASTE

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Abstract

The paper deals with the theory and the construction of the hot ball sensor. The sensor in a form of a small ball generates heat and simultaneously measures the temperature response. The thermal conductivity is to be determined from the measured signal. The thermal conductivity is a function of moisture and hardening of the tested mixture. The sensor has been applied for monitoring of the setting of cement paste.

Key words: transient methods, hot ball method, concrete setting, cement paste

1 Introduction

Recently a new class of dynamic methods – transient methods for measuring thermophysical properties started to be used in research and industry [xx]. Methodologies were developed that, depending on the experimental configuration, allow determining one (thermal conductivity or thermal effusivity) or three thermophysical parameters (specific heat, thermal diffusivity and thermal conductivity) within a single measurement [1]. Starting with construction of rather complicated laboratory apparatuses [2, 3, 4, 5], a new class of instruments have been developed that is based on transient methods [5, 6, 7].

Improvements in methodology of the transient methods and use of modern electronic elements allow construction of portable instruments and the monitoring systems that significantly simplified operation. While portable instruments allow realization of the measurements in field (laboratory instruments, production lines, quality testing, etc.) the monitoring systems are aimed for longtime monitoring of the thermophysical property changes due to environmental exposition or operational loads (moisture, drying, setting, solidification, degradation due to temperature cycling, etc.).

Construction of such devices evoked a look for suitable sensors that give information on thermophysical properties of the tested object. Up to now a principle of the hot wire (Needle probe [5]), hot strip (hot bridge [3]), hot disc (Gustafsson probe [4]) and plane heat source [1] are most often used. Recently, it was published a principle of hot ball sensor in two components configuration. i.e. the heat source and the thermometer are fixed apart each other [9].

The present paper deals with the hot ball sensor in a single component configuration i.e. when heat source and the thermometer are unified in a single component. A steady state measuring regime has been utilized for measuring thermal conductivity. Working relation and experimental setup are discussed in detail.

Application of the hot ball for monitoring of the setting of cement paste is presented. The thermal conductivity is a function of moisture and the rigidity of the tested object.

2 Hot Ball Sensor

Model of the Hot Ball Sensor is shown in Fig. 1. The model represents an infinitive medium in which an empty sphere having the radius *r* is placed. A constant heat *q* starts to be delivered

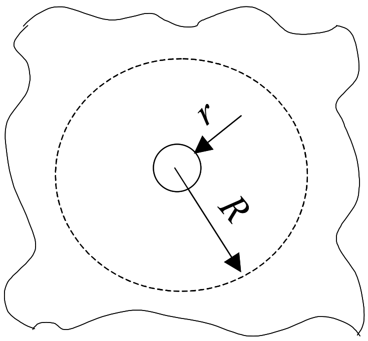

Fig. 1.: Model of the Hot Ball Sensor

through sphere surface into the medium in time $t \geq 0$. Then the temperature at the sphere surface is characterized by a function

$$T(t) = \frac{q}{4\pi\lambda r^2}\left\{\sqrt{\frac{at}{\pi}}\left(1 - e^{-\frac{r^2}{at}}\right) + r.erfc\left(\frac{r}{\sqrt{at}}\right)\right\} \tag{1}$$

where erfc(x) is error function defined by $erfc(x) = \frac{2}{\pi}\int_0^x \left(-\zeta^2\right) d\zeta$

r is radius of the sphere, and λ and *a* are thermal conductivity and thermal diffusivity of the material. Function (1) for long time approximation gives a working relation of the measuring method based on the hot ball sensor

$$\lambda = \frac{q}{4\pi r T_m\left(t \to \infty\right)} \tag{2}$$

where T_m is maximal temperature that is reached in long time limit (see Fig. 2 right). The heat *q* is generated during measuring time t_o. The heat penetrates material volume of the radius *R* (see Fig. 1). Then the calculated value of the thermal conductivity using relation (2) corresponds to this material volume. The heat ball sensor is shown in Fig. 2. The sensor consists of a heating element and of a thermistor. Both elements are fixed in a ball by epoxy resin. Diameter of the ball is around 3 mm. The penetration depth (material volume that is penetrated by heat) is in the range of 20 – 30 mm (Fig. 1).

Working relation (2) includes radius of the hot ball sensor that can't be precisely measured because of irregularities in sphere shape. Therefore a calibration has to be performed prior using of the hot ball sensor. Instruments RT 1.02 and RTB 1.01

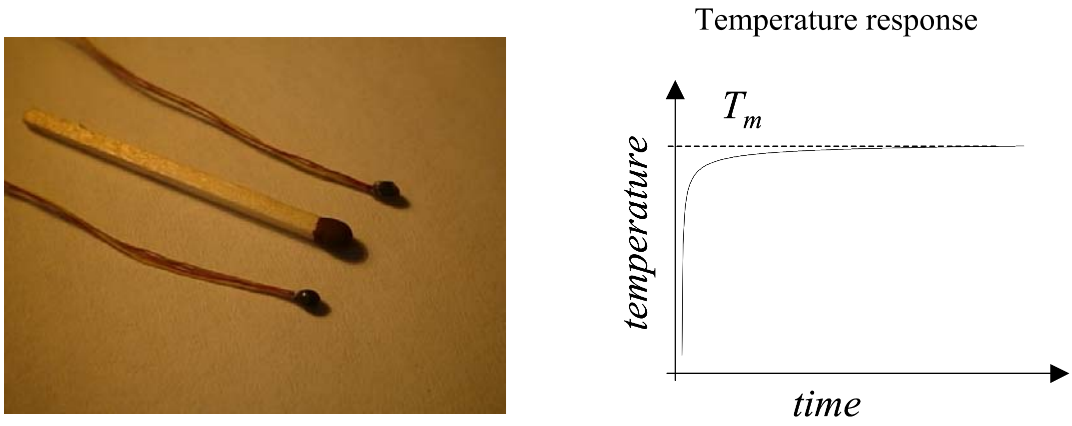

Fig. 2.: The hot ball sensor (left) for measuring thermal conductivity and the corresponding temperature response (right).

(Transient M S, s.r.o.[8]) that are based on the pulse transient method can be used for calibration. However, the measurement sensitivity of the hot ball to any structural change is high. Therefore the hot ball can be used for monitoring the variations of the thermal conductivity without knowing its absolute value.

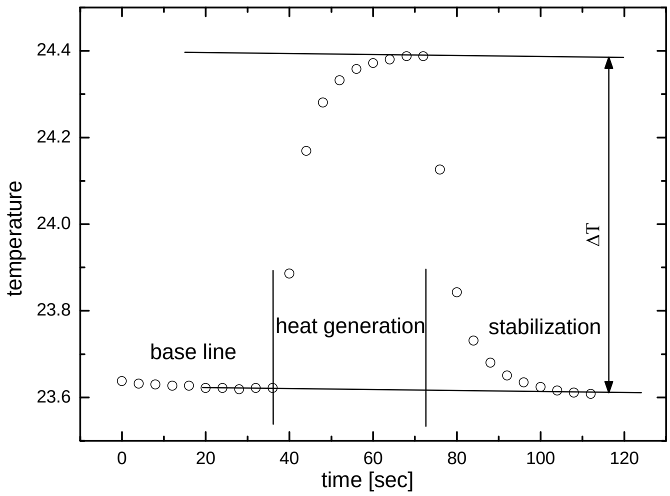

Fig. 3.: Signal of the hot ball sensor measured by monitoring system RTM.

The monitoring is performed using measuring cycle. Measuring cycle using the hot ball method is shown in Fig. 3. The cycle consists of three periods, determination of the base line, measuring period that includes the heat generation and the measuring of the temperature response and, finally, the stabilization period. The cycle represents data obtained on dry marble where heat power of the hot ball of 8 mW during 30 sec was applied.

2 Experiment

The cement paste has been prepared in a standard way, i.e. a mixture of the cement powder of HOLCIM production (Portland cement CEM I 42.5 R) was mixed with the distilled water in ratio 1:40. A steel tube in length of 50 mm and in diameter of 30 mm

Fig. 4.: Experimental arrangement for measuring setting point by RTM 1.01

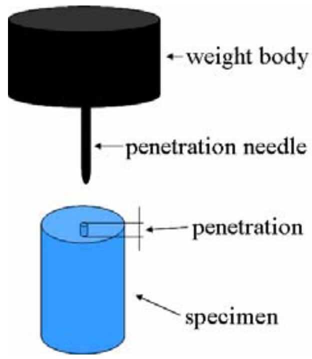

Fig. 5.: Principle of the stiffening test according STN EN 196-3

was filled with mixture. The hot ball sensor was fixed in the centre of the tube and the monitoring instrument RTM 1.01 (Transient M S s.r.o.[8]) was connected with the sensor and the setting was measured as a function of time. The set up is shown in Fig. 4.

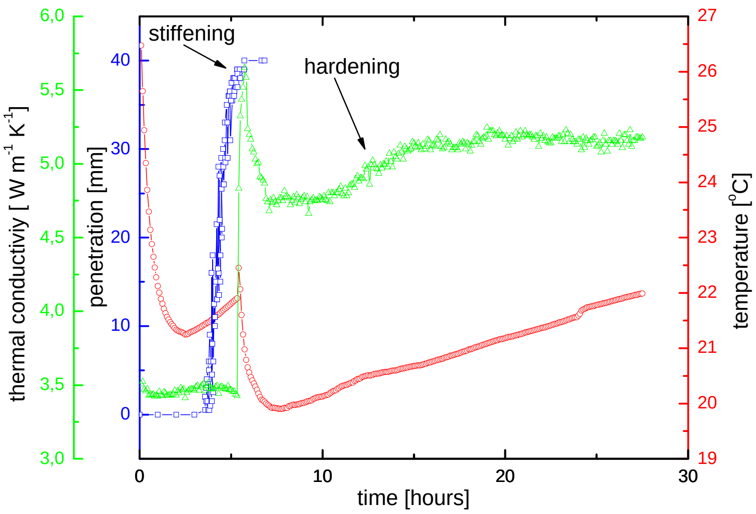

Fig. 6.: Thermal conductivity, penetration and the temperature as a function of time during the setting of the cement paste.

The RTM 1.01 was pre-programmed to perform measurements with repetition of 10 minutes. The experiment was performed in standard condition i.e. at 25°C and 30% humidity of the surroundings. The heat power of the hot ball of 8 mW during 30 sec was used for measuring. Then the working relation in a form

$$\lambda = \frac{214q}{\Delta T}$$

was used for calculation of the thermal conductivity.

A test according STN EN 196-3 standard has been performed in a parallel way. The EN 196-3 standard is dealing with the determination of the setting point by measuring the depth of the needle penetration into the fresh cement paste (Fig. 5). Again the specimen test was prepared in a form like for the hot ball experiment. The measurement was repeated every 10 minutes. To shorten the time interval between two subsequent experiment three independent specimens were used that were consecutively under test within 10 minutes. The experimental point was obtained every 3.3 minutes.

Experimental data are shown in Fig. 6.

5 Conclusion

The hot ball sensor has been validated for identification of the setting process of the cement paste due to intercomparison with the test according the STN EN 196-3 standard. The result shown in Fig. 6 clearly indicates that sensor in connection with the RTM 1.01 instrument can be utilize in situ for testing of the cement setting. A clear stifftening and hardening process can be recognized on the Fig. 6. These results indicate that appropriate version of such instrument can be used in civil engineering in construction works.

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