A METHOD OF DETERMINING THE HEAT OF CEMENT HYDRATION

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A method is described by which the heat of cement hydration can be determined with a dynamic calorimeter and the specific power of hydration at any instant of time is obtained as an intermediate result of measurement.

At the Thermophysics Department of the Leningrad Institute of Precision Mechanics and Optics (LITMO) a method has been developed and instruments (dynamic calorimeters) have been designed for measuring the power of all kinds of energy sources. These instruments are widely used in physiology for studying the heat transfer in warm-blooded animals [2]. The method and the instruments can also be used for determining the heat released during the curve of materials with bonding agents and, specifically, for measuring the heat of cement hydration.

Let us consider a certain volume of cement mix in a thin-walled container. As a result of hydration, a certain quantity of heat Q is released from the cement during the experiment. Some of this heat is expended on changing the enthalpy of the mass (Q_1) and some is dissipated into the ambient medium (Q_2). According to the law of energy conservation,

$$Q = Q_1 + Q_2 = C(\bar{t}_\tau - \bar{t}_i) + \int_0^\tau P(\tau)\,d\tau. \tag{1}$$

The $P = P(\tau)$ characteristic can be found with the aid of a dynamic calorimeter, while $t = t(\tau)$ can be determined by means of a thermometer column or a thermocouple.

The test specimen is placed inside the calorimeter vessel. The energy dissipated from the specimen enters the vessel walls, heats them up, and then passes into the calorimeter housing. Consequently, the temperature difference between the vessel and the housing is related to the power P dissipated by the test specimen.

The functional relation between both quantities has been shown in [1, 2] to be

$$P = \frac{1}{mF} \cdot \frac{\Delta t_c}{\Delta\tau} + \frac{t_v - t_h}{F}. \tag{2}$$

We will now describe the procedure for determining the power $P = P(\tau)$. The test curve $\vartheta_s = t_c - t_h$ at t_h = const (Fig. 1) is subdivided into segments which can be considered linear, and for each segment one measures the time interval $\Delta\tau$, the temperature increment $\Delta\vartheta_s$, and the average temperature level $\vartheta_s(\tau)$. The thus obtained parameters $\Delta t_v/\Delta\tau$ and $\vartheta_s(\tau)$, together with coefficients m and F, are inserted into formula (2) and from there one finds the thermal power $P(\tau)$ dissipated from the test specimen at instant of time τ. The values of coefficients m and F are obtained by calibration tests.

Knowing both the thermal flux dissipated from the vessel with cement mix and the mean-over-the-volume temperature of the cement mix during definite time intervals, one can now determine the heat of cement hydration by formula (1).

A series of control tests was performed with this instrumentation and a low-(thermal) inertia heater as the source of thermal flux. The mean-squared error of the thermal flux measurements did not exceed 1.5%.

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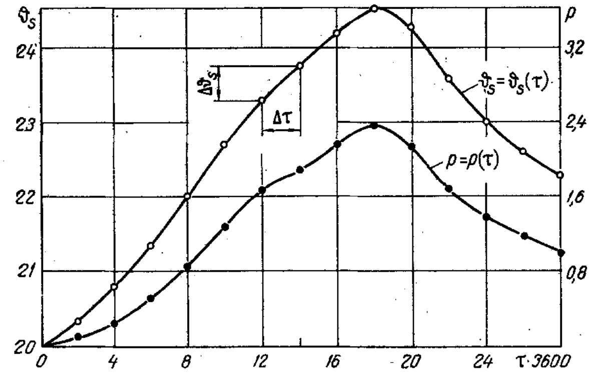

Fig. 1

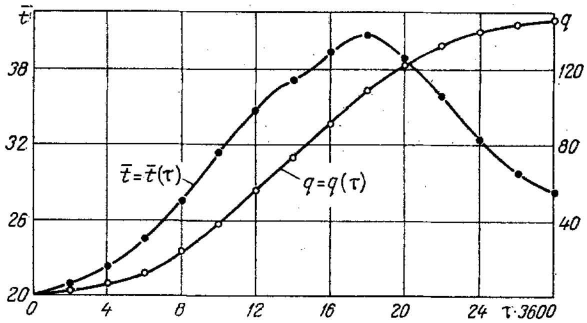

Fig. 2

Fig. 1. Vessel temperature over housing temperature $\vartheta_s(\tau)$, °C and specific thermal power loss $p(\tau)$, W/kg as functions of time τ.

Fig. 2. Cement temperature $\bar{t}(\tau)$, °C and specific heat of hydration $q(\tau)$, kJ/kg as functions of time.

A series of tests was performed to determine the heat of cement hydration. The results of one such test are shown in Fig. 2.

We note that the proposed method involves measuring the time characteristics of temperature $\bar{t}(\tau)$, $t_v(\tau)$, and $t_h(\tau)$, which then at any instant of time yield the thermal power expended on changing the enthalpy of the mass $(C d\bar{t}/d\tau)$ and the thermal power $P(\tau)$ dissipated from the vessel surface.

The sum of these two quantities

$$C\frac{d\bar{t}}{d\tau} + P(\tau) = W(\tau)V. \tag{3}$$

yields the specific power of hydration $W(\tau)$. In order to determine the heat of hydration, it is necessary to integrate Eq. (3) with respect to time from 0 to τ, after which one can switch to Eq. (1).

Temperature fields in hardening concrete are calculated by the equation in [3]:

$$\frac{\partial t}{\partial \tau} = a\nabla^2 t + \frac{W(\tau)V}{C},$$

which contains quantity $W(\tau)$ rather than Q.

Thus, the proposed method makes it possible to determine not only the parameter Q widely used for such measurements but also, as an intermediate result, the parameter W necessary for temperature calculations.

NOTATION

Q	is the quantity of heat released during cement hydration, J;
Q_1	is the quantity of heat expended on changing the enthalpy of the mass, J;
Q_2	is the quantity of heat dissipated into the ambient medium, J;
q	is the specific heat of hydration, kJ/kg;
C	is the heat capacity of vessel with cement mix, J/deg C;
$\bar{t}_i$, $\bar{t}_\tau$	are the mean-over-the-volume mix temperature at the beginning and at the end of a given period respectively, °C;
$P(\tau)$	is the power dissipated into the ambient medium from the vessel with mix at time τ, W;
$p(\tau)$	is the specific thermal power loss in cement, W/kg;
t_v, t_h	are the mean-over-the-surface temperature of the vessel and of the housing respectively, °C;
ϑ_s	is the temperature of vessel above temperature of housing, °C;
m, F	are the coefficients, functions of the housing temperature 1/deg C and deg C/W respectively;
τ	is the time;
V	is the volume occupied by cement, m^3;
W	is the specific power of hydration, W/m^3;
a	is the thermal diffusivity of concrete, m^2/sec.

LITERATURE CITED

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