



Development of a portable device and compensation method for the prediction of the adiabatic temperature rise of concrete



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HIGHLIGHTS

- A portable semi-adiabatic device and new compensation method are developed.
- Adiabatic temperature rise of concrete can be predicted by the semi-adiabatic device and compensation method.
- New compensation method regarding the reaction rate of hydration is suggested.
- New compensation method improves the accuracy of prediction of adiabatic temperature rise.

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ABSTRACT

Semi-adiabatic devices are widely used as a substitute for the adiabatic calorimeter to predict adiabatic temperature rise. The maximum temperature and the reaction rate in the adiabatic temperature rise are important parameters to demonstrate the thermal characteristic and mechanical properties of concrete. However, the existing method for the prediction of the adiabatic temperature rise from semi-adiabatic device only includes heat loss compensation, which is related to the maximum temperature, though the reaction rate is even more important. Therefore, a new compensation method regarding the reaction rate is suggested in this paper. It improves the accuracy of prediction of adiabatic temperature rise.

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1. Introduction

The hydration of cement is an exothermic reaction that releases hydration heat at about 120 cal per gram. This hydration heat causes the temperature to rise in early-age concrete. The temperature rise affects the mechanical properties of concrete such as the compressive strength and generates thermal cracking resulting from the thermal stress. The change of concrete properties such as the development of the strength is directly related to the stability problem, and the thermal cracking causes a durability problem due to the penetration of the hazardous substances as well as aesthetic problems and serviceability problems such as leakage [1–4]. These problems become more important for the mass concrete structures. Therefore, the temperature rise generated by the hydration should be predicted and managed in order to minimize the decrease of strength and thermal cracking of concrete [4].

The temperature rise of concrete can be indirectly predicted by measuring the hydration heat of cement or directly measured by an adiabatic or semi-adiabatic calorimeter [4]. Even though model equations have been suggested to predict the temperature rise as a function of the unit weight of cement [5], the direct measurement through the adiabatic or semi-adiabatic test is preferred to reflect the various conditions such as binder and other unknown factors. The adiabatic test is direct and reliable and is practically the best method to predict the temperature rise of concrete, but the high cost of the test and the immobility of the calorimeter are the barriers to the application of the tests on construction sites. A semi-adiabatic test predicts the temperature rise by compensating the heat loss from the measured temperature in concrete placed in the semi-adiabatic calorimeter, in which some heat exchange to the exterior occurs. The accuracy is lower than that of the adiabatic test, but it is cost-effective and has mobility depending on the size of the device. Therefore, the semi-adiabatic test is widely used as an alternative test of the adiabatic one.

Most of the precedent studies about the semi-adiabatic device and compensation method to predict the temperature rise only

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compensate the heat loss [1,6,7]. However, the heat loss compensation is not sufficient to predict the temperature rise because the reaction rate of concrete under semi-adiabatic condition is different from that of adiabatic condition because of the different curing temperature. The reaction rate is more related to the thermal stress with age and the development of the properties such as strength than the amount of the temperature rise that has been predicted by the heat loss compensation. Therefore, the reaction rate should be corrected when adiabatic temperature rise is predicted from a semi-adiabatic device in order to predict more reliable development of thermal cracking and mechanical properties of concrete.

Ultimately, the final objectives of this study are the development of a portable semi-adiabatic device and the suggestion of a new compensation method for the prediction of a temperature rise of concrete for general construction site. The overall procedure to predict the adiabatic temperature rise from the test result of the semi-adiabatic device is as follows. The fourth step, the compensation of the reaction rate, is the distinction of this paper and the details of each step are explained in the following subsections.

- Step 1. Estimate the heat loss coefficient of the device using water (Subsection 2.2).
- Step 2. Place the concrete in the device and measure the temperature for about 10 days.
- Step 3. Predict the temperature rise by compensating the heat loss from the measured temperature and estimated heat loss coefficient (Subsection 3.2).
- Step 4. Correct the age of concrete in the semi-adiabatic device using the concept of the equivalent age as if the concrete is tested in the adiabatic device (Subsection 3.3).
- Step 5. Predict the final adiabatic temperature rise from the temperature rise in Step 3 and the age in Step 4.

The device and the method are verified by comparing the predicted temperature rise with the experimental result of the adiabatic test. The suggested compensation method enables more reliable prediction of the adiabatic temperature rise and consequent thermal stress as well as the mechanical properties with age.

2. Development of the portable device for the prediction of adiabatic temperature rise

2.1. Design of the device

The shape and dimensions of the semi-adiabatic device are shown in Fig. 1. The device is composed of a vacuum-bottle, high-performance thermal insulation material, and polyethylene plastic case. A datalogger for the temperature measurement and a tablet PC for data processing and display are located at the top of the device. High-performance thermal insulation material is placed between the vacuum-bottle and the external plastic case, and the additional rubber packing is used where the cap and the body of the device meet in order to maintain the adiabatic condition as much as possible. K-type thermocouples are located at three essential points – the center and surface of the specimen and the exterior of the device – for the compensation of the heat loss.

In order to predict the adiabatic temperature rise as simple as possible, it is necessary to assume the heat loss condition as an axially symmetric condition. If the specimen is infinitely long cylinder, heat loss of specimen can be considered as axial symmetry, but there are practical problems to make it. Therefore, the shape of specimen is decided as a cylinder whose diameter and height are 100mm and 200mm, respectively. Also, the shape of device is

designed as a cylinder whose total diameter and the height are 240mm and 370mm. The size of the specimen is the same as the one for the standard strength test; thus, it is easy to replace the test specimen by using existing disposable molds.

2.2. Estimation of the heat loss coefficient of the device

The heat loss coefficient is a critical parameter to predict the adiabatic temperature rise from the semi-adiabatic device. The heat loss in the semi-adiabatic device is the result of complex heat transfer composed of conduction, convection, and radiation. An apparent parameter called the heat loss coefficient is defined to simply explain this complex heat transfer. If the generation of the hydration heat can be ignored, the heat loss coefficient can be estimated from Eq. (1) [8].

$$h_L = \frac{-\Delta T(t)}{\int_0^t (T_s(t) - T_{air}(t)) dt} \quad (1)$$

where h_L is heat loss coefficient, ΔT is average change of the specimen temperature, T_s is surface temperature of the specimen, and T_{air} is ambient temperature.

In other words, the heat loss coefficient can be estimated by using water, which does not generate heat, as well as the concrete whose hydration is almost finished. In this paper, water is used to estimate the heat loss coefficient of the device because it is more convenient for the experiment. As presented in Table 1, 55 °C water is put in the device, and the ambient temperatures are set as 10 and 20 °C, similar to the normal construction field. Estimated heat loss coefficients of four developed devices through the experiments using water are represented in Table 2. The ambient temperature does not affect the heat loss coefficient of the device, as shown in Table 2. This result is consistent with an advanced study [8]. According to the study [8], the heat loss coefficient is unaffected by the ambient humidity and internal temperature as well as the ambient temperature because the thermal insulating ability of the device is sufficient. In this paper, the heat loss coefficients in Table 2 estimated from the experiments are rounded off to 0.8 and used for the compensation of heat loss explained in Subsection 3.1.

3. Prediction of the adiabatic temperature rise considering the reaction rate of concrete

3.1. Necessity of compensation of the reaction rate

The adiabatic temperature rise is generally expressed as Eq. (2). [5]

$$T_{adi} = K(1 - e^{-\alpha(t-t_0)}), \quad (2)$$

where T_{adi} is adiabatic temperature rise, K is maximum adiabatic temperature rise, α is reaction rate, t is age of concrete, and t_0 is starting time of hydration.

The maximum temperature rise, K , and the reaction rate, α , are important parameters that decide the characteristic of the adiabatic temperature rise curve. The heat loss compensation, which is widely used for the semi-adiabatic device, can be regarded as compensation for the maximum adiabatic temperature rise, K . This method does not consider the effect of temperature on the reaction rate of the hydration. Temperature histories in the adiabatic and semi-adiabatic devices are different, and these histories affect the reaction rate of hydration and maturity of concrete. In other words, the maturity of concrete in the semi-adiabatic device does not coincide with that in the adiabatic device at a certain age. Therefore, it is necessary to adjust the age under the semi-adiabatic condition to the age under the adiabatic condition to have the same maturity. The adjustment of age means a change in the abscissa

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