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Compensation method for prediction of the adiabatic temperature rise of concrete from semi-adiabatic device

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ABSTRACT

Semi-adiabatic devices have been used for prediction of adiabatic temperature rise by compensating heat loss. Compensation of heat loss is only related to the maximum temperature rise. It does not consider the change of the reaction rate of hydration due to the different curing temperature of concrete in the semi-adiabatic device, even though the reaction rate is more important in terms of the prediction of the material properties of concrete. Therefore, an additional compensation method regarding the reaction rate of hydration is suggested to predict the adiabatic temperature rise from the semi-adiabatic device. The suggested method is verified by comparing the experimental results, and it improves the prediction by about 16 percent compared to the conventional method which only includes heat loss compensation. This research are very useful in construction fields where semi-adiabatic devices are often used instead of adiabatic calorimeter for economical reason.

1. INTRODUCTION

The temperature rise due to the hydration is one of the important characteristics of concrete. Temperature rise affects the mechanical properties of concrete and causes thermal stress and cracks (Springenschmid, 1998). Adiabatic calorimeter is widely used to acquire the adiabatic temperature rise of concrete, but it is expensive and inconvenient in terms of mobility. Semi-adiabatic calorimeter is often used instead of adiabatic calorimeter, but the test results from semi-adiabatic calorimeter should be compensated to acquire the adiabatic temperature rise. Most of the compensation methods have focused on the heat loss compensation (Ng, et al., 2008) (Livesey, et al., 1991). In this paper, one more compensation, reaction rate compensation, is suggested to increase the accuracy of the prediction of adiabatic temperature rise.

Reaction rate of hydration is related with the temperature because hydration is one of the chemical reactions. Concrete in semi-adiabatic calorimeter is under lower temperature condition than adiabatic calorimeter, and the reaction rate is consequently

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slower. The difference cannot be considered by the heat loss compensation. Therefore, a new compensation method is suggested in order to consider the difference of reaction rate in semi-adiabatic calorimeter.

2. REACTION RATE COMPENSATION METHOD

In order to determine the adiabatic temperature rise of concrete, the maximum temperature rise and the reaction rate should be identified as shown in Eq.(1) (Japan Concrete Institute, 1986).

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

where T_{adi} = adiabatic temperature rise, ℃
K = maximum adiabatic temperature rise, ℃
α = reaction rate

Maximum adiabatic temperature rise, K, can be identified by compensating heat loss. Reaction rate, α, can be compensated by the definition of equivalent age. Details of the compensation is as follows.

2.1 Heat loss compensation

Temperature change of concrete in adiabatic condition can be calculated by temperature change of concrete in semi-adiabatic condition and the temperature drop due to the heat loss of the device as shown in Eq.(2) (Jin, et al., 2012).

$$\Delta T_{adi}(t) = \Delta T(t) + h_L \int_0^t \big(T_s(t) - T_{air}(t)\big) dt \tag{2}$$

where ΔT_{adi} = change of temperature in adiabatic condition, ℃
ΔT = average change of the specimen temperature, ℃
h_L = heat loss coefficient of the device, $\mathrm{kcal/(m^2h℃)}$
T_s = surface temperature of the specimen, ℃
T_{air} = ambient temperature, ℃

2.2 Reaction rate compensation

According to Tank and Carino(1991), equivalent age is a concept to account for the combined effects of temperature and time on strength development. Therefore, equivalent age can be used to compare the strength development of concrete specimens cured in adiabatic and semi-adiabatic condition. Equivalent age by Arrhenius model is used in this research as shown in Eq.(3) (Hansen & Pedersen, 1977).

$$t_e = \int \exp\left[-\frac{E}{R}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] dt \tag{3}$$

where T = temperature, deg. Kelvin
T_r = reference temperature, deg. Kelvin

E = apparent activation energy
R = gas constant, 8.3144 J/(mole·K).

According to the definition of equivalent age, the age of concrete under semi-adiabatic condition can be converted into the age of concrete under adiabatic condition as shown in Eq.(4).

$$t_a = \frac{t_{esa}}{t_{ea}} \times t_{sa} \tag{4}$$

where t_a = age of concrete under adiabatic condition
t_{sa} = age of concrete under semi-adiabatic condition.
t_{esa} = equivalent age at t_{sa} under the temperature history of semi-adiabatic condition
t_{ea} = equivalent age at t_{sa} under the temperature history of adiabatic condition

Heat loss compensation determines the temperature rise, y-axis of the adiabatic temperature rise curve. Reaction rate compensation determines the slope of the curve by converting the age of concrete, x-axis of the curve. Because the curing temperature histories of adiabatic and semi-adiabatic device are not same, it is reasonable to convert the age of semi-adiabatic device as if the specimen is cured in adiabatic device by using the concept of equivalent age.

3. VERIFICATION OF THE COMPENSATION METHOD

The suggested compensation method can be verified by comparing the experimental result from the adiabatic calorimeter. Concrete calorimeter of Japanese company called MARUI is used for the adiabatic test. Normal strength and high strength concrete are used as shown in Table 1.

Table 1. The mixture proportions for the verification of the device

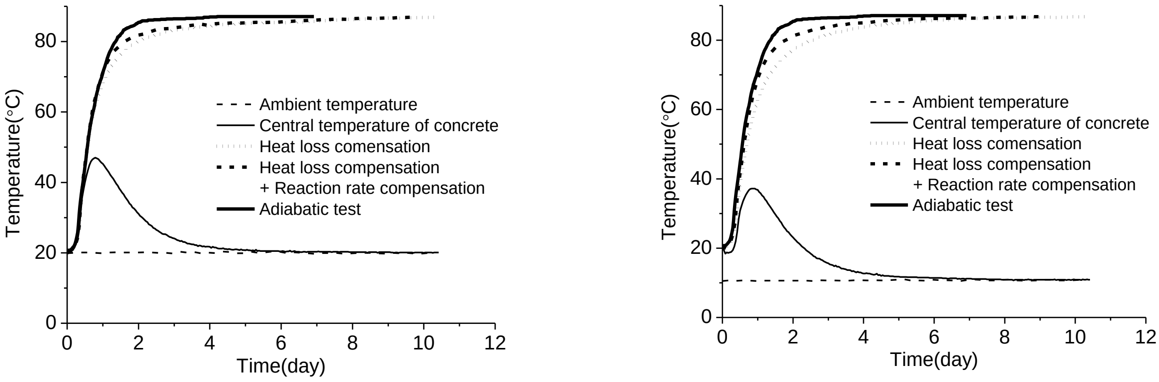
w/c	S/a (%)	Unit weight ($\mathrm{kg/m^3}$)				
		W	C	S	G	A (%)
0.3	40.7	170	566	639	933	1.0
0.5	44.7	182	364	761	943	0.6

For the semi-adiabatic test, the same concretes in Table 1 are used and the initial ambient temperatures are set as 10℃ and 20℃. The heat loss coefficient h_L in Eq.(2) of the device is around $0.8\mathrm{kcal/(m^2h℃)}$ estimated beforehand by the test using the water.

Fig. 1 shows the adiabatic temperature by the calorimeter and predicted temperature rise by the semi-adiabatic device. Prediction by heat loss and reaction rate compensation is more similar to the adiabatic temperature rise compared to the prediction by only heat loss compensation. This is quantitatively presented in Table 2. Parameters, the maximum temperature rise K and reaction rate α in Eq.(1), obtained by regression analysis of each prediction are summarized in Table 2. In case of the maximum temperature rise K, the accuracy of prediction does not increase much but the accuracy of the reaction rate α increases about 2 to 30 percent more after the reaction rate compensation.

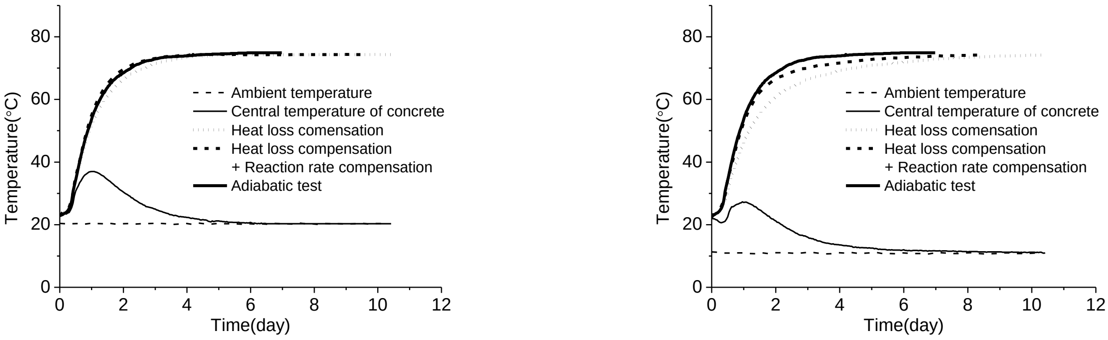
Table 8. The maximum adiabatic temperature K and the reaction rate α of each compensation result

w/c	T_{air}(℃)	Compensation	K	K/K_{adi}	α	α/α_{adi}
0.3	Adiabatic test		67.40	1	1.52	1
	20	Heat loss	65.78	0.976	1.33	0.875
		Heat loss + Reaction rate	65.94	0.978	1.52	1
	10	Heat loss	65.56	0.973	1.07	0.704
		Heat loss + Reaction rate	65.80	0.976	1.39	0.914
0.5	Adiabatic test		52.64	1	1.05	1
	20	Heat loss	51.88	0.986	0.95	0.905
		Heat loss + Reaction rate	52.01	0.988	1.13	1.076
	10	Heat loss	50.82	0.965	0.70	0.667
		Heat loss + Reaction rate	51.01	0.970	1.02	0.971



(a) w/c=0.3, T_{air}= 20℃ (b) w/c=0.3, T_{air}= 10℃

Fig. 1 Comparison of the predicted adiabatic temperature rise with the experimental one



(c) w/c=0.5, T_{air}= 20℃ (d) w/c=0.5, T_{air}= 10℃

Fig. 1 Comparison of the predicted adiabatic temperature rise with the experimental one (continued)

4. CONCLUSIONS

In this research, reaction rate compensation is suggested to increase the accuracy of the prediction of adiabatic temperature rise by semi-adiabatic test. It is basically correction of the age of concrete as if concrete is tested under the adiabatic condition. This compensation gives more similar prediction as verified through the comparison of the actual adiabatic test. A new method including the reaction rate compensation increases the accuracy of prediction by about 16 percent. It is a remarkable achievement and it can help semi-adiabatic devices substitute the adiabatic devices.

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