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# Hydration heat of slag or fly ash in the composite binder at different temperatures

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ABSTRACT

The hydration heat evolution rate and cumulative hydration heat of composite binder containing slag, fly ash or quartz powder and the reaction degrees of slag, fly ash and cement were determined to investigate the hydration heat of slag or fly ash in the composite binder at 25 °C, 45 °C and 60 °C.

Results show that a certain amount of hydration heat of slag is observed at 25 °C, but the amount of hydration heat of fly ash is very small at 25 °C. Elevated temperature promotes the hydration of composite binder and increases the reaction degrees of slag and fly ash. Much more amount of hydration heat of slag or fly ash is determined at elevated temperature. The elevated temperature has greater promoting effect on the reaction of slag than fly ash. There is a good linear relationship between the reaction degree of slag (or fly ash) and the hydration heat of slag (or fly ash). The total hydration heats of per gram of slag and per gram of fly ash are 530 J and 285 J, respectively. The result is acceptable due to the slight deviation between the calculated value and experimental value of cumulative hydration heat of composite binder.

## 1. Introduction

The role of mineral admixture in the blended cement and concrete has been investigated widely in the recent years due to the benefit of reducing carbon dioxide emission [1,2] and improving the performance of concrete [3–5] as well as lowering the cost of construction [6]. The most of mineral admixtures are considered as by products or industrial solid wastes. Ground granulated blast furnace slag and fly ash are the mainly used mineral admixtures due to their pozzolanic characteristics. Slag and fly ash can react with portlandite to produce additional C-S-H gel, whose structure is similar to the C-S-H gel generated by cement hydration. Thus, the reaction of slag or fly ash makes great contribution to the properties development of concrete. Furthermore, the exothermic hydration process of cement and the low thermal conductivity of concrete lead to high temperature in the core of concrete [7]. The high temperature affects the hydration process of binder. The sensitivity of slag or fly ash to temperature is different from that of cement due to their different activities. So the hydration process and reaction mechanism of slag and fly ash are also different from those of cement. To deep understand the hydration mechanism of mineral admixture, study on the hydration heat of slag or fly ash in the composite binder is needed.

Many researchers have studied the influences of mineral admixture on the hydration of composite binder. Merzouki et al. [8] found that addition of slag accelerated the hydration process at the very first hours and reduced the hydration heat after curing 140 h. Cetin et al. [9] pointed out that the peak value of heat evolution was clearly affected by particle size of blended cement containing slag. 0–10 μm particles accounted for 5–10% of total hydration heat in the first 0.5 h. The hydration heat evolution rate did not obviously influence by particle size above 30 μm. Tan et al. [10] reported that the coarse slag particles had higher content of CaO but relatively lower content of $Al_2O_3$, MgO and $SiO_2$, which resulted in higher reactivity and higher increasing rate of hydrating layer thickness of slag particle. Ogirigbo et al. [11] found that the higher temperature increased the hydration degree of slag and had greater influence on the reactivity of slags than the difference in chemical compositions. The elevated temperature also can enhance pozzolanic reaction of fly ash [12]. Tkaczewska [13] noted that finer fly ash particles had higher depolymerization degree of $SiO_4$ units in glass that increased pozzolanic reactivity. The hydration heat of a unit weight of slag derived from the adiabatic heat rise in the first day was 460 J $g^{-1}$ in the literature [14]. Wang et al. [15] reported that the hydration heat of per gram of slag was only 16.7% higher than that of fly ash due to the higher hydraulic activity of slag. Isothermal calorimetric test results showed that there was a third peak on the hydration heat curve of composite binder containing slag, which was induced by

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the reaction of slag [7,16]. However, the third peak was insignificant on the curve of composite binder containing fly ash [17].

On the basis of current literatures, the effects of slag and fly ash on the hydration of binder have been investigated widely. But the hydration heats of slag or fly ash in composite binder at different temperatures are rarely studied. This is due to the fact that the reaction of slag or fly ash is much more complex in composite binder. The hydration of slag or fly ash depends on many factors, such as the alkalinity and composition of pore solution, the size and glass structure of slag, the water-to-binder ratio, et al. Separation of the reaction of slag from the hydration of composite binder is much difficult. To deep understand the exothermic behavior and reaction mechanism of slag or fly ash in composite binder, the hydration heat evolution rate and cumulative hydration heat of composite binder containing slag, fly ash or quartz powder were investigated in this paper. The reaction degrees of slag, fly ash and cement were determined. According to the relationship between the reaction degree of mineral admixture and the hydration heat of mineral admixture, the hydration heat of per gram of slag or fly ash was calculated. Compared the calculated value of hydration heat of composite binder with the experimental value of hydration heat of composite binder, the accuracy of the hydration heat of per gram of slag or fly ash is verified.

## 2. Experimental

### 2.1. Raw materials

P.I 42.5 Portland cement, S95 ground granulated blast furnace slag and Class I fly ash conforming to Chinese National Standards GB175-2007, GB/T18046-2008 and GB/T1596-2005, respectively, were used in this study. The chemical compositions of cement, slag and fly ash were given in the literature [7]. The quartz powders with two different finenesses, Quartz powder (a) and Quartz powder (b), were used as reference materials. The quartz powder contains 99.9% $SiO_2$ and it does not show pozzolanic activity at 60 °C. The particle size distributions of slag, fly ash and quartz powder are shown in Fig. 1. The particle size distributions of Quartz powder (a) and Quartz powder (b) are similar to those of slag and fly ash, respectively. The mix proportions of pastes are shown in Table 1.

### 2.2. Test methods

The hydration heat evolution rate and cumulative hydration heat of composite binder were measured by TAM air isothermal calorimeter at 25 °C, 45 °C and 60 °C within 72 h. The pastes were prepared according to Table 1. The water was put into the glass bottle, and then the weighed binder was put into the bottle. After stirring quickly, the bottle was sealed and put into the chamber. The hydration heat evolution rate and cumulative hydration heat of composite binder can be measured continually as a function of time.

The reaction degrees of slag, fly ash and cement were determined by BSE image analysis. The samples SL30, SL70, FA35 and FA65 were prepared according to Table 1. The pastes were put into plastic centrifuge tubes with volume of 10 ml and then sealed. The pastes were divided into three groups, which were cured at 25 °C, 45 °C and 60 °C, respectively. At the age of 3 days, the same fragments of hardened pastes were cut and soaked in the anhydrous ethanol to cease further hydration. The preparation of sample and the observation of BSE image as well as the calculation of reaction degree were described in detail in the literature [18].

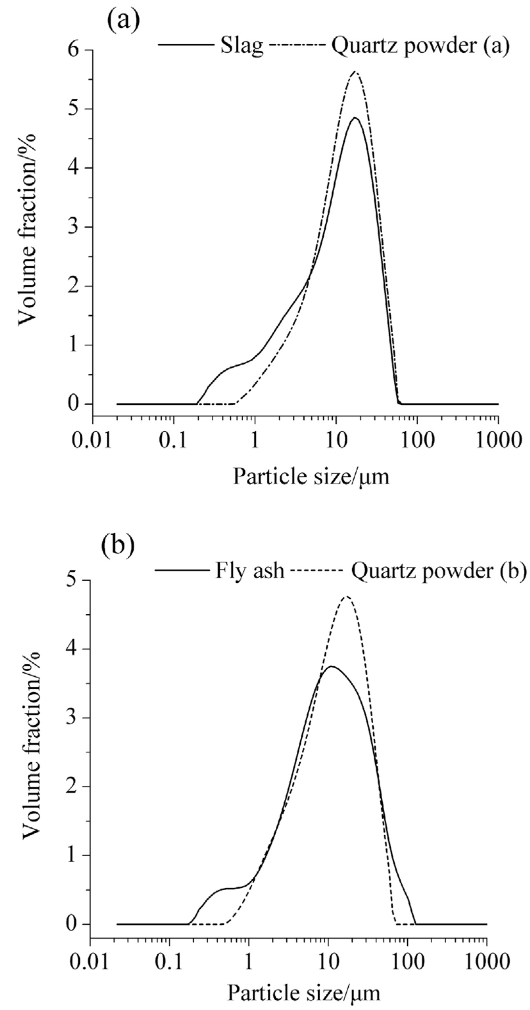


**Fig. 1.** Particle size distributions of slag, fly ash and quartz powder. (a) Slag and quartz powder (a), (b) Fly ash and quartz powder (b).

**Table 1**
Mix proportions of pastes.

| Sample | w/b ratio | Mass fraction/% | | | | |
|---|---|---|---|---|---|---|
| | | Cement | Slag | Fly ash | Quartz power (a) | Quartz powder (b) |
| Cem | 0.4 | 100 | 0 | 0 | 0 | 0 |
| SL30 | | 70 | 30 | 0 | 0 | 0 |
| SL70 | | 30 | 70 | 0 | 0 | 0 |
| FA35 | | 65 | 0 | 35 | 0 | 0 |
| FA65 | | 35 | 0 | 65 | 0 | 0 |
| Q(a)30 | | 70 | 0 | 0 | 30 | 0 |
| Q(a)70 | | 30 | 0 | 0 | 70 | 0 |
| Q(b)35 | | 65 | 0 | 0 | 0 | 35 |
| Q(b)65 | | 35 | 0 | 0 | 0 | 65 |

## 3. Results and discussion

### 3.1. Hydration heat characteristics of composite binder at different temperatures

The hydration heat of composite binder containing slag or quartz powder at 25 °C, 45 °C and 60 °C are shown in Fig. 2, Fig. 3 and Fig. 4,