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Self-cementitious property of steel slag powder blended with gypsum

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HIGHLIGHTS

- The self-cementitious property of steel slag with 5 wt% gypsum was revealed.
- The hydration and hardening properties of steel slag-gypsum and cement are compared.
- The hydration products of steel slag-gypsum are different from pure steel slag.
- The hydration degree or strength with ages conforms to a functional relationship.

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ABSTRACT

In order to reveal the self-cementitious property of steel slag, the hydration and hardening characteristics of steel slag powder blended with 5 wt% gypsum were investigated from hydration heat, non-evaporable water (W_n) and $Ca(OH)_2$ contents, hydration products, strength and so on. The results show that the hydration process of steel slag-gypsum also has two exothermic peaks, which is similar to cement, but it has a longer early hydration period and lower hydration exothermic rate. The second exothermic peak value of steel slag-gypsum is only about one eighth of that of cement. The hydration products of steel slag-gypsum mainly contain amorphous C-S-H gels, rod-like ettringite and a small amount of $Ca(OH)_2$, while almost no ettringite is generated in hydration products of pure steel slag. Compared with pure steel slag paste, steel slag-gypsum paste has a more hydration products and more compact structure. The relationships of W_n contents or $Ca(OH)_2$ contents with ages for steel slag-gypsum paste show a good exponential relationship, while both the paste and mortar strengths of steel slag-gypsum with logarithm of ages conform to the linear relationship. In addition, the W_n content and strength of steel slag-gypsum paste can be obviously improved by the simulated cement pore solution at 28 days and 90 days.

1. Introduction

Steel slag is a kind of industrial solid waste generated in the steelmaking process [1,2], the amount of which produced is huge annually, but its utilization is very low [3,4]. Currently, most of steel slag is in abandoned state, causing some problems such as environmental pollution, occupation of land and waste of resources [5,6]. In China, close to 100 million tons of steel slag is discharged every year, the cumulative storage amount of which has reached >1.2 billion tons, about less than 30% steel slag can be utilized in some low added value fields, such as aggregates for concrete or asphalt mix, fillers for foundation engineering and so on [3,7–12]. Therefore, it is necessary to improve the comprehensive utilization of steel slag, in particular the use of high added value fields.

A lot of researches indicate that the chemical and mineral compositions of steel slag are similar to Portland cement clinker, containing large amounts of cementitious minerals, such as C_2S, C_3S and C_4AF, so it has a great potential for using in the cement and concrete industry [13–16]. However, as the undesirable volume stability of steel slag, for a long time, the application of steel slag as supplementary cementitious materials (called mineral admixture) for cement or concrete production is limited [17,18]. In china, 70% steel slag is the converter steel slag, with the upgrading of steel slag treatment technology (especially, heat-stewed treatment technology has been widely used) in recent years, the factors (such as f-CaO and f-MgO) caused by undesirable stability of steel slag are greatly controlled, which provide favorable conditions for subsequently processing and application of steel slag [19,20]. Therefore, the converter steel slag, which is treated by heat-stewed method, will be well used as mineral admixture of cement and concrete.

Different from other mineral admixtures such as fly ash, granulated blast furnace slag and so on, steel slag has self-hydration and

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hardening properties (i.e. cementitious property) [5,21–23], which is important for utilization of steel slag as mineral admixture of cement or concrete and raw materials of other low-strength cementitious materials such as backfill materials, brick and wall mortar, but the self-hydration and hardening properties of steel slag is rarely concerned. In order to reveal the self-cementitious property of the heat-stewed converter steel slag, the Portland cement is taken as a reference in this study, as Portland cement generally contains 5 wt% gypsum, so 5 wt% gypsum is also added in steel slag, forming a composite system of steel slag and gypsum. In this paper, the hydration and hardening characteristics of steel slag-gypsum system and Portland cement system under same hydration environment are compared and discussed from hydration process, hydration products, hydration degree and hardened strength and so on.

2. Experimental

2.1. Raw materials

Steel slag used is the heat-stewed converter steel slag, which was provided from Laiwu steel company of Shandong province in China. Need to explain, the principle of heat-stewed process is that the molten steel slag is sprinkle water to generate uneven stress and hydrolysis of f-CaO, resulting in an expansion pulverization of steel slag. The chemical compositions of steel slag are shown in Table 1 and its mineral phases, which were determined by XRD analysis, using a D6000 diffractometer (Cu Ka, 40 kV, 40 mA), are given in Fig. 1. It is evident that C_2S, C_3S and RO phases are the main mineral of steel slag. Steel slag powder was prepared by grinding in a Φ500 mm × 500 mm laboratory ball mill (see Fig. 2). The specific surface area of steel slag powder is 427 m^2/kg. The particle size distribution, which was measured by a laser particle size analyzer, is presented in Fig. 3. Steel slag-gypsum composite powder was obtained by mixing 95 wt% steel slag powder and 5 wt% gypsum powder.

Portland cement used was also prepared by grinding according to the ratio of 95 wt% clinker and 5 wt% gypsum. Its specific surface area is 402 m^2/kg and particle size distribution is given in Fig. 3. The chemical composition of Portland cement clinker is shown in Table 1.

The gypsum used is the natural dehydrate gypsum, which contain 18.65 wt% crystal water and 42.11 wt% SO_3.

2.2. Experimental methods

The hydration heat evolution rate and cumulative hydration heat of steel slag-gypsum paste and cement paste were measured with an isothermal calorimeter (TAM Air from TA instruments). TAM Air has eight parallel twin-chamber measuring channels: one chamber containing the sample, another containing the reference. The tests were performed at 25 °C, within 72 h, conforming to the Chinese National Standard GB/T12959-2008.

Pastes were prepared for the determination of non-evaporable water content, $Ca(OH)_2$ content and morphologies of hydration products. Two pastes were prepared: steel slag-gypsum paste and cement paste. The water-to-binder ratio of the two pastes is 0.35. When the paste specimens were cured at temperature about 20 ± 1 °C and >95% relative humidity to testing ages, the middle portions of specimens were obtained, broken and soaked in absolute ethanol to stop hydration.

The non-evaporable water content of paste was determined as the difference in mass between the sample heated at 105 °C and 1000 °C normalized by the mass after heating at 105 °C, and correcting for the loss on ignition of the unhydrated sample [24,25]. The $Ca(OH)_2$ content of paste was determined by the thermogravimetry differential thermal analysis (TG-DTA), as follows: the weight loss at 400–550 °C in TG curves, which correspond to endothermic peak of $Ca(OH)_2$ at 400–550 °C in DTA curves, is the weight of water decomposed by $Ca(OH)_2$, then the $Ca(OH)_2$ content is calculated according to the following equation [26]:

$$W_{CH} = W_{LOSS} \times \frac{M_{CH}}{M_W} \times 100\% \qquad (1)$$

where, W_{CH} is the $Ca(OH)_2$ content, W_{Loss} is the weight loss of $Ca(OH)_2$ in TG curves, and M_{CH} and M_W is the relative molecular weight of $Ca(OH)_2$ and water, respectively.

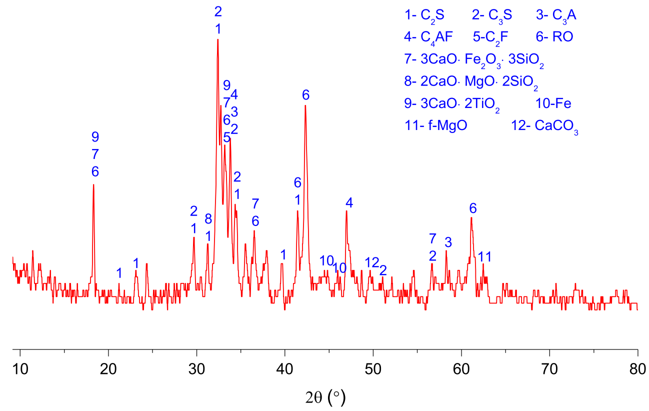

Fig. 1. XRD pattern of steel slag.

Fig. 2. Preparation of of steel slag powder.

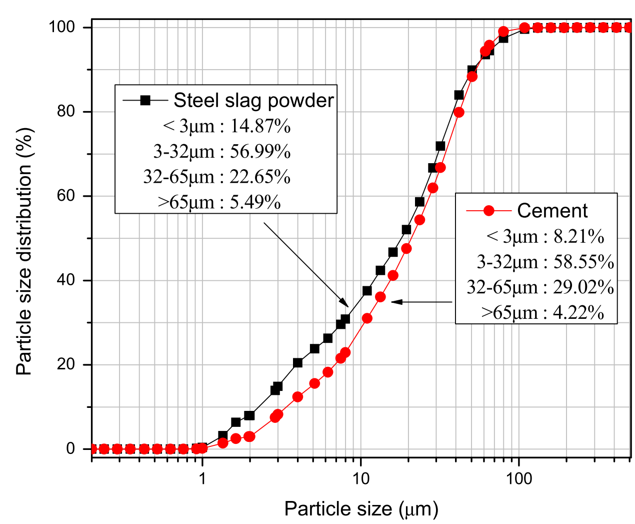

Fig. 3. Particle size distributions of steel slag powder and cement.

Table 1
Chemical compositions of steel slag and cement clinker (wt%).

Materials types	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	P_2O_5	LOI
Steel slag	46.28	16.75	2.29	22.17	5.49	0.03	–	0.25	2.54	0.94
Clinker	64.29	21.60	5.18	3.39	2.31	0.87	0.25	1.35	0.14	0.43