

Influence of classified steel slag with particle sizes smaller than 20 μm on the properties of cement and concrete



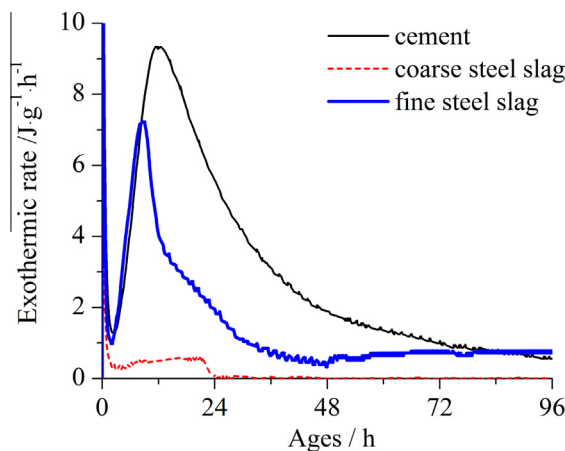
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HIGHLIGHTS

- Fine steel slag (FSS) with particle sizes smaller than 20 μm was prepared.
- FSS shows good cementitious properties.
- The activity of FSS is a little lower than that of cement.
- The 20% FSS replacement has little negative effect on the properties of concrete.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, steel slag was classified into two fractions by an air classifier: fine steel slag (FSS) with particle sizes smaller than 20 μm and coarse steel slag (CSS) with particle sizes larger than 20 μm . The hydration properties of FSS and its effect on the properties of cement and concrete were investigated. The results show that FSS possesses relatively good cementitious properties. Its activity is a little lower than that of Portland cement. Additionally, its hydration degree is slightly lower and its hydration products are relatively fewer compared with cement. FSS has nearly no influence on the porosity of paste and the strength of mortar when its replacement ratio is not more than 20%. The effect of FSS on the strength and drying shrinkage of normal concrete is negligible when its replacement ratio is not more than 20%. FSS affects the chloride permeability of normal concrete very little when its replacement ratio is not more than 30%. Adding FSS in high-strength concrete can decrease its autogenous shrinkage.

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1. Introduction

Steel slag is one of the biggest industrial waste residues in China. Its utilization ratio is rather lower than that of fly ash and

ground granulated blast furnace slag (GGBS). The chemical compositions of steel slag depend on the steel production method and its raw materials, primarily CaO , Fe_2O_3 (FeO), SiO_2 , MgO , and Al_2O_3 [1,2]. Further, its common mineral components consist of C_2S , RO phase (solid solution of CaO , FeO , MgO , and MnO), C_3S , C_4AF , C_2F , free- CaO , olivine and merwinite [3,4]. Steel slag can be treated as a cementitious material due to its silicate calcium minerals.

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However, the hydration activity of steel slag is much lower than that of Portland cement due to its slow cooling process and relatively high content of inert components [4–6].

At present, most of the recycled steel slags are used as aggregates for cement concrete [7–9], asphalt concrete [10–12] and road base material [13]. Because steel slag has certain cementitious properties, it is also a good option to use steel slag as an additive or mineral admixture in cement or concrete production. Tsakiridis et al. [14] added steel slag into the raw meal to produce Portland cement clinker and found that the use of steel slag had little negative influence on the cement with a 10.5% addition. Wang et al. [15] combined steel slag powder and GGBS as a composite mineral admixture in cement based materials and found that steel slag and the composite mineral admixture with high content of steel slag had some negative effects on the late properties and durability of concrete. Liu and Li [16] studied the influence of ground steel slag on the mechanical properties of concrete. The results showed that the early strength of concrete decreased with the increase of steel slag addition and the strength decrease was more obvious when the steel slag addition ratio was over 20%. Additionally, Wang et al. [17] studied the mechanical properties and durability of concrete with steel slag. It was found that increasing the steel slag replacement tended to negatively affect the compressive strength (especially the early strength), permeability and anti-carbonation ability of the concrete. Although such studies have provided valuable contributions to this field, the utilization ratio of steel slag as a substitute for cement is, in general, still very low. Relatively low activity and high content of inert components in steel slag are the main problems restricting its widespread application in the cement and concrete industries.

However, it was reported that raising the fineness of steel slag could improve the activity of its components and accelerate its hydration rate at early ages [16,18,19]. For example, Shi et al. [20] found that increasing the fineness of superfine steel slag could promote the activity of blended cement and bring about a higher strength. Additionally, Feng et al. [21] found that superfine steel slag could be used as mineral admixture in high strength concrete. It has been indicated [22] that small particles in ground steel slag primarily take the form of silicate and aluminate, whereas large particles primarily take the form of inert components such as RO phase, Fe_2O_3 , and C_2F , which make little contribution to the activity of steel slag. Therefore, particle size classification may be worthwhile to pursue to generalize the utilization ratio of steel slag to cement and concrete productions. Steel slag with small particle sizes can be used as a type of mineral admixture, whereas the large steel slag particles may be used as fine aggregates for concrete.

In this paper, steel slag was classified into two fractions with different particle sizes by an air classifier: fine steel slag (FSS) (<20 μm) and coarse steel slag (CSS) (>20 μm). The aim is to examine the hydration properties of FSS and its effect on the properties of cement and concrete. Then, the feasibility of using FSS in cement and concrete industries is analysed.

2. Raw materials and test methods

The cement used was Portland cement with specific surface area of 350 kg/m^3 . Table 1 shows the chemical compositions of the cement. The steel slag used was a type of ground basic oxygen

Table 1
Chemical compositions of the cement/%.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	$\text{Na}_2\text{O}_{\text{eq}}$	f-CaO	Loss
25.10	6.38	4.19	54.87	2.61	2.66	0.56	0.79	2.18

Note: $\text{Na}_2\text{O}_{\text{eq}} = \text{Na}_2\text{O} + 0.658\text{K}_2\text{O}$.

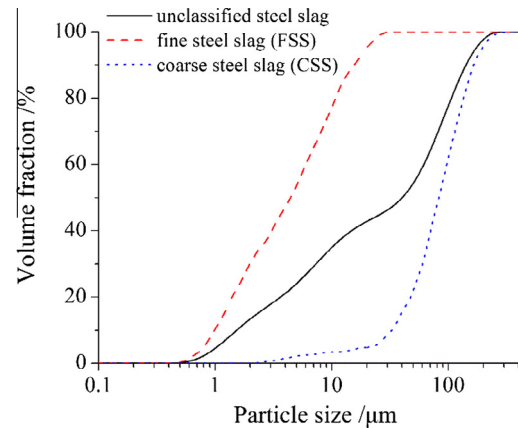


Fig. 1. Particle size distributions of unclassified steel slag, fine steel slag, and coarse steel slag.

furnace steel slag with specific surface area of 429 kg/m^3 . The steel slag was classified into two fractions by an air classifier: fine steel slag (FSS) with particle sizes smaller than $20 \mu\text{m}$ and coarse steel slag (CSS) with particle sizes larger than $20 \mu\text{m}$. Fig. 1 shows the particle size distributions of unclassified steel slag, FSS and CSS. Table 2 provides the chemical compositions of FSS and CSS. The free-CaO contents of FSS and CSS were 1.32% and 0.87%, respectively. It can be seen from Table 2 that the CaO, SiO_2 , and Al_2O_3 contents of FSS were higher than those of CSS, but its Fe_2O_3 , MnO, MgO, and P_2O_5 contents were lower than those of CSS. Fig. 2 shows the XRD patterns of FSS. Fig. 3 shows the morphologies of FSS. It is evident that the FSS particles are irregular.

The sand used for the mortar preparation was ISO reference sand with particle sizes smaller than 2 mm. The fine aggregate used for the concrete preparation was continuous grading sand with the largest size of 5 mm. The coarse aggregate for the concrete preparation was crushed limestone between 5 and 20 mm. The cumulative sieve residues of coarse aggregates after square hole screen with diameters of 4.75 mm, 9.50 mm, 16.0 mm, and 19.0 mm are 0%, 71%, 24%, and 6%, respectively. Superplasticizer of polycarboxylic acid type was used to improve the workability of the concrete.

The water to binder ratio (W/B) of the pastes was 0.4 (mass ratio). The pastes were sealed in plastic tubes immediately after preparation. At testing ages, the hardened pastes were immersed in acetone to prevent further hydration and then dried in a vacuum drying oven before testing. The mineral phases of hydration products was determined by X-ray diffraction (XRD). The $\text{Ca}(\text{OH})_2$ content of hydration products was determined by thermogravimetric analysis (TGA). The morphologies of hardened paste were determined by scanning electron microscope (SEM). The elemental compositions of the C-S-H gel were determined by energy dispersive X-ray spectroscopy (EDS). The pore size distributions were measured by mercury intrusion porosimetry (MIP). The non-evaporable water (w_n) content was performed according to Ref [23]. The hydration heat evolution of cement, FSS and CSS was tested using a TAM-Air isothermal calorimeter at a constant temperature of $25 \text{ }^\circ\text{C}$ according to ASTM C1702 [24]. The water to cement (or steel slag) mass ratio was 0.4.

Mortars were prepared by mixing binder, water, and sand at a mass ratio of 2:1:6 using moulds of $40 \times 40 \times 160 \text{ mm}$. The specimens were cured at a room with temperature of $20 \pm 1 \text{ }^\circ\text{C}$ and relative humidity higher than 95% before demould and then cured under water at $20 \pm 1 \text{ }^\circ\text{C}$. The compressive and bending strengths of the mortars were tested at the ages of 3, 28, 90, and 360 days.

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