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Preliminary investigation on the pozzolanic activity of superfine steel slag

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HIGHLIGHTS

- Superfine steel slag with different particle sizes were prepared.
- The chemical and mineral compositions of the steel slag were analyzed.
- The activity index of superfine steel slag is much higher than ordinary steel slag.
- Too much superfine steel slag is disadvantage to the strength of cement mortar.
- The cement paste with superfine steel slag has much more hydration products.

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ABSTRACT

In this research, superfine steel slag with different particle sizes were prepared by a superheated steam powdered jet mill, then the pozzolanic activity of the superfine steel slag was investigated. The results show that the content of f-CaO decreases when the particle size of steel slag is decreased. The requirement of normal consistency for water, setting time, and soundness of the cement paste with the superfine steel slag all remain within the acceptable ranges of the national standard. A decrease in the particle size of superfine steel slag can accelerate the hydration reaction of blended cement and results in higher mortar strength. The activity index of superfine steel slag (D_{50} = 2.52 μm) can reach up to 95.0% which is much higher than that of ordinary steel slag powder (D_{50} = 13.3 μm). For blended cement with 10% weight ratio of superfine steel slag (D_{50} = 5.10 μm) as a replacement, cement mortar exhibits higher compressive strength at 28 days than that of pure cement mortar. While the strength of cement mortar is gradually decreased when the replacement weight ratio of superfine steel slag is above 10%. Microstructure analysis confirms that there are more hydration products yielded in cement paste with superfine steel slag than that of ordinary steel slag powder, which is consistent with the result of mechanical experiments.

1. Introduction

Steel slag is one kind of industrial residue in the steelmaking process. The discharge weight ratio of steel slag is approximately 15% of steel output. At present, there are several billion tons of steel slag discharged in China, but the utilization ratio is only about 20%. Large amounts of steel slag not only pollute the environment but also occupy a large area of land.

Steel slag contains a certain amount of cementitious minerals, such as C_3S, C_2S, C_4AF and C_2F [1]. Thus, the utilization of steel slag as a cementing component should be given a priority from technical, economical and environmental considerations [2]. Previous research studies [3–9] indicate that steel slag has great value as a secondary resource. Ahmedzade et al. [3] found that steel slag used as a coarse aggregate could improve the mechanical properties of asphalt mixtures. Moreover, volume resistivity values demonstrated that the electrical conductivity of steel slag mixtures were better than that of lime stone mixtures. Tsakiridis et al. [4] used steel slag as an ingredient to fire cement clinker and conducted experiment studies to analyze its performance. The results showed that there was no negative effect on the cement raw meal calcination process. And steel slag could accelerate the formation of C_2S, C_3S, C_4AF and other minerals in a solid phase reaction. Qasrawi et al. [5] found that the use of steel slag as a fine aggregate in concrete mixtures had a positive effect on both compressive and tensile strength, hence introducing it in concrete would eliminate one of the environmental problems created by the steel industry.

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Nevertheless, there are still some problems with the utilization of steel slag. Firstly, the activity of the cementitious composition in steel slag is much slower than that of Portland cement clinker because of its thermal history [10,11]. Secondly, the high amount of f-MgO and f-CaO content in steel slag leads to an undesirable volume change of steel slag cement [12,13]. In order to solve these problems, we use superfine grinding steel slag as a blending material and explore its pozzolanic activity. Because some researchers have increased pozzolanic activity of other cementitious materials by grinding. Allahverdi et al. [14] found that the increase of grinding time can accelerate the hydration reaction of chemically activated high phosphorous slag content cement and results in higher compressive strength. The studies of Sun Hongfang et al. [15] showed that, for ordinary Portland cement and fly ash mixture, jet mill grinding can accelerate the rate of hydration and strength development. Jaturapitakkul et al. [16] stated that the replacement of Portland cement type I with 15%, 25%, 35% and 50% of ground fly ash (D_{50} = 3.8 μm) can produce high-strength concrete and 25% cement replacement by ground fly ash gives the highest compressive strength.

In this paper, superfine steel slag with different particle sizes are prepared by superheated steam powdered jet mill which is considered an efficient and low-cost machine [17]. The pozzolanic activity of superfine steel slag with different particle size and different replacement weight ratios are investigated. Then the microstructures of cement pastes containing superfine steel slag are analyzed. And they are compared with ordinary steel slag powder.

2. Experimental procedures

2.1. Materials

The steel slag which comes from a basic oxygen furnace was provided by Shanghai Baosteel, and the cement (P.142.5) was procured from China Building Materials Academy.

2.2. Experimental methods

2.2.1. X-ray diffraction analysis

The mineralogical compositions of steel slag were determined by XRD. XRD analysis was conducted using X' Pert PRO-type X-ray diffractometer (PANalytical Corporation, Netherland) with the following conditions: 40 kV, 50 mA, Cu-Kα radiation.

2.2.2. Microstructure analysis

The microstructure of steel slag and cement paste admixed with superfine steel slag were performed on EVO18-type tungsten filament SEM (Zeiss Instrument Corporation, Germany) at 30 kV and Ultra 55-type field emission SEM (Zeiss Instrument Corporation, Germany) at 10 kV and 15 kV.

2.2.3. Particle size analysis

The particle sizes of steel slag were analyzed by LS13320-type laser particle size analyzer (Beckman Coulter, Inc. USA).

2.2.4. Sample preparation and characterization

The SS_1 ordinary steel slag powder was prepared by a jaw crusher, roll crusher and ball grinder, respectively. Superfine steel slag SS_2, SS_3 and SS_4 which taken SS_1 ordinary steel slag as raw materials, were superfine ground by a superheated steam powdered jet mill. The grinding system of the jet mill is illustrated in Fig. 1.

By using the superheated steam generated by a heat recovery boiler, supersonic airflow was produced by a Laval nozzle, which could accelerate raw materials moved by screw feeder. The raw materials were crushed by collision and friction with supersonic airflow. The superfine steel slag which could satisfy the requirement of particle size was collected in a bag filter. The steel slag powder which did not satisfy the requirement of particle size would return to the crushing chamber until the particle size was suitable. In this process, the particle size of superfine steel slag was controlled by the rotation speed of the classifier. In order to ensure this system was operated above dew point of steam, the bag filter and steam pipeline were kept warm and the system was preheated before operation. Superheated steam was taken as a refrigerant in this system. Its crushing strength is much higher than other refrigerants. Hence it is suitable for the superfine grinding process of high hardness materials like steel slag.

2.2.5. Physical and mechanical properties

(1) The pure cement (P.142.5) was respectively replaced by SS_1 ordinary steel slag powder and SS_2, SS_3, SS_4 superfine steel slag at 30% replacement weight ratio. The requirement of normal consistency for water, setting time, and soundness of the blended cements were tested in accordance with Chinese National Standard GB/T1346-2001 Test Method for Water Requirement of Normal Consistency, Setting Time, and Soundness of the Portland Cements, which is generally equal to ISO9597. And they were compared with pure cement (P.142.5).

(2) The strength of cement mortars admixed with ordinary steel slag and superfine steel slag were tested in accordance with Chinese National Standard GB/T17671-1999 Method of Testing Cements: Determination of Strength, which complies with ISO 679. Cement mortar specimens measuring 40 × 40 × 160 mm were prepared by adopting the water-to-binder ratio of 0.50 and the sand-to-binder ratio of 3.0. The specimens were first cured in a curing chamber at 20 °C and 95% relative humidity for 1 day, and then they were cured in water at 20 °C. At the age of 3, 7, and 28 days, the strength of specimens were tested.

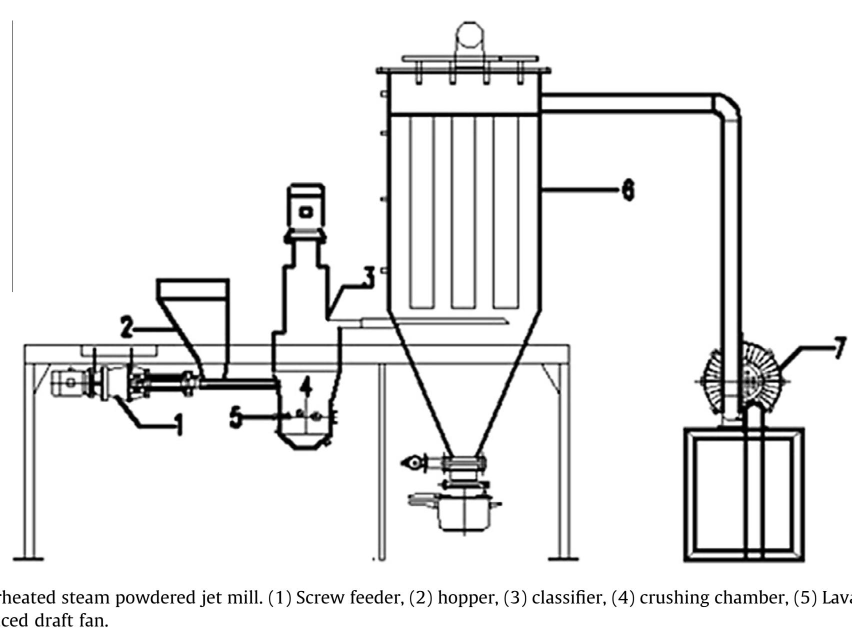

Fig. 1. Grinding system of superheated steam powdered jet mill. (1) Screw feeder, (2) hopper, (3) classifier, (4) crushing chamber, (5) Laval nozzle, (6) bag filter suitable for superheated steam and (7) induced draft fan.