Construction and Building Materials 114 (2016) 874–879

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Preparation and application of the cement-free steel slag cementitious material

Xiao-dong Xiang, Jia-chen Xi *, Can-hua Li, Xin-wei Jiang

School of Resource and Environmental Engineering, Wuhan University of Science and Technology, Wuhan 430080, China

HIGHLIGHTS

- A new kind of cement-free steel slag cementitious material is developed.
- The performances of the cementitious material are analyzed.
- A dense structure can be obtained in the adequate hydration reactions.
- The cementitious material can be used in the practical engineering.

ARTICLE INFO

Article history:
Received 27 January 2016
Received in revised form 26 March 2016
Accepted 29 March 2016
Available online 8 April 2016

Keywords:
Steel slag
Cementitious material
Mortar

ABSTRACT

In order to utilize the steel slag effectively, the steel slag, compound agent, fine sand, gravel and admixture are used to prepare cement-free steel slag cementitious material. The compressive strength of the mortar can reach 70 MPa. The performance tests are conducted on the C50 grade of the material. The experimental results indicate that the relative dynamic modulus of elasticity maintains at 66% and the mass loss is 1.1% at 300 cycles, so the frost resistant grade of the material is F300. The average carbonation depth is 0.3 mm, which can be regarded as no carbonized. In addition, the passed charge of the cementitious material slice for 6 h is less than 1000 C. The microstructure of the material taken from the practical engineering project is analyzed by SEM and EPMA. It is shown that the hydration reactions of the steel slag, composite agent and admixture are mutually promoted. The acicular sulphoaluminate hydrate and the villous flocculent calcium silicate sol are intertwined and linked closely with the interface of steel slag and hydrate.

1. Introduction

The steel slag is the by-product of the steel production, which accounts for a proportion of approximately 15% by mass of the steel output [1–3]. In China, about 1 hundred million tons of steel slag have been produced every year [4]. However, the comprehensive utilization ratio of the steel slag is only about 22% in China [5]. The accumulation of steel slag not only occupies large area of land but also leads to the environmental pollution [6–8]. Thus, the recycling utilization of steel slag has become one of the common concerned problems in the resource utilization and environmental protection area [9–13].

The mineral composition of the steel slag is similar to that of the cement [14,15]. The compositions of C_3S, C_2S and C_2F in the steel slag contribute to a certain potential of cementitious property [16–18]. Therefore, the steel slag can be possibly used to prepare steel slag composite cementing material. Some related studies have been carried out on this problem. The performance of blended mortars prepared from granulated blast furnace slag was tested in the previous research [19–21]. A. Srinivasa Reddy [22] demonstrated the feasibility that converter slag could be applied to prepare hydraulic binding materials. E. Anastasiou [23] investigated the feasibility of producing good quality concrete by using fly ash as fine aggregate and steel slag as coarse aggregate. The study [24] on the possibility of adding steel slag in the raw material for the production of Portland cement clinker showed that steel slag did not affect the mineralogical characteristics of the Portland cement clinker and did not negatively affect the quality of the produced cement. A new kind of cementitious material made from steel slag, cement and slag was developed by Wang Qiang [25]. In his work, the influence of the amount of steel slag on the performance of the composite cementitious material was discussed. Also, M.R. Karim [26] reported a new non-cement binder using slag,

* Corresponding author.
E-mail address: 981782952@qq.com (J.-c. Xi).

http://dx.doi.org/10.1016/j.conbuildmat.2016.03.186
0950-0618/

palm oil fuel ash and rice husk ash. The compressive strength of 40.68 MPa and a flexural strength of 6.57 MPa at 28 days of the new non-cement binder mortars were achieved. Du Jun [27] had prepared the 42.5 composite cement. In this composite cement, 30% steel slag, a suitable amount of dihydrate gypsum ($CaSO_4{\cdot}2H_2O$), and silica powder were used. M.M. López [28] carried out an experiment to produce cement mortar by using different size of steel slag in different proportion. The mechanical strength test indicated that the mortar specimens made from the fine steel slag had the strongest ability of resistance to sulfate attack. Li Dongxu [29] discussed the method to prepare high-content blast furnace slag cement and the influence of compound admixtures on the properties of high-content slag cement. Nicola Faraone [30] demonstrated that mortars prepared using a commercial CII/B-LL Portland cement, steelmaking slag, superplasticizer and water with improved compressive strength can be achieved by using slag containing extensive amounts of large particles. Additionally, the investigation of strength development of concretes with blast furnace slag as a partial replacement of Portland cement was carried out, which showed that the strength reduced as the amount of slag increased. Nevertheless, for high binder contents, similar strengths were attained for lower Portland cement contents [31]. However, most of the studies are limited to the method of steel slag partially replacing cement to prepare cementitious materials at present. Few researches concentrate on the problem that using pozzolanic materials as full replacement of cement to prepare high strength cementitious materials.

In this paper, the preparation of the cement-free steel slag cementitious material is discussed. The performances of the mortar specimens are tested to confirm the feasibility of the technology. The cementitious material has been well applied in the practical road construction.

2. Experiment

2.1. Materials

The steel slag that is the tailing after magnetic separation is taken from Wuhan Iron and Steel Group Corporation in China. The main chemical components of the steel slag are CaO, SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, P_2O_5, MnO. The physical and mechanical properties of the steel slag are given in Table 1. The steel slag is directly used without grinding. The particle sizes of the steel slag range from 0 mm to 10 mm.

2.2. Methods

Four kinds of steel slag including hot-spray poured steel slag, hot-stuffing steel slag, Baosteel short-flow (BSSF) steel slag, and wind-quenched steel slag are used to prepare cement-free steel slag cementitious material. Same compound agent consisting of blast furnace slag, gypsum and silicate is added in the preparation. The chemical compositions of the compound agent are equivalent to CEM III and the specific surface area is larger than 350 m^2/kg. To a certain degree, it has gelling property and has a good effect on retarding and stimulating the hydration reaction. The setting time, boiling stability, compressive strength and bending strength after 3 days and 28 days of the mortar specimens are tested.

The four kinds of steel slag mentioned above, compound agent, fine sand, gravel, concrete admixture and water are blended according to the mix proportion, shown in Table 2. The compressive strength tests of every group after 3 days, 7 days, and 28 days are carried out respectively according to the Chinese National Standard GB/T50081-2002.

The C50 strength grade of concrete is used in the following performance trials. The frost resistance test and the carbonization test are conducted according to the Chinese National Standard GB/T50082-2009. The resistance to chloride ion penetration test is carried out in accordance with the ASTM C1202 norm of the United States.

2.3. Equipments

In frost resistance test, the main equipments include MTD-1 fast freeze-thaw of concrete test machine, DT-10W dynamic modulus instrument, and TC 10K counter Scale. JDH-70 carbonating-oven is used in carbonization test. An intelligent instrument of the concrete permeability is applied in resistance to chloride ion penetration test.

3. Results and discussions

3.1. Compressive strength test

The setting time and boiling stability are tested according to the Chinese National Standard GB/T1346-2011. Compressive strength and bending strength after 3 days and 28 days of the mortar specimens are measured based on the Chinese National Standard GB/T50081-2002.

The tests results of the cementitious material prepared from four kinds of steel slag and the same compound agent are shown in Table 3. It is revealed that this cementitious material has the characteristics of normal setting time, qualified boiling stability, high early strength, and excellent bending strength. The strength of mortar specimens can meet the index of 32.5–62.5 grade of Portland cement.

The results of compressive strength test are presented in Table 4. It can be seen that in the 9–12 group, the compressive strength values of cube specimens (150 mm × 150 mm × 150 mm) at 7 d and 28 d are up to 70 MPa, even 93.4 MPa. In these cases, the content of steel slag is as high as 800 kg/m^3 without any fine sand. Therefore, the mixture can be used to prepare C50 and C70 cement-free steel slag cementitious material in accordance with the specific classification of the strength grade of the Chinese National Standard GB175-1999.

3.2. Frost resistance test

In accordance with the Chinese National Standard GB/T50082-2009, quick freezing method is adopted to assess the durability of the material when it is exposed to the extreme temperatures. In each freeze-thaw cycle, the specimen (100 mm × 100 mm × 400 mm) is first immersed in a container that is filled with water up to 5 mm above the upper face of the specimen. Then, the specimen is frozen in the water at −18 °C in the freeze-thaw box. Finally, the specimen is thawed in the water at 5 °C in the freeze-thaw box. The whole time of every freeze-thaw cycle varies from 2 h to 4 h. The relative dynamic modulus of elasticity of the material is collected at the end of 0, 25, 50, 75, 100, 125, 150, 175, 200, 225, 250, 275 and 300 cycles respectively.

The relationship between the number of freeze-thaw cycles and relative dynamic modulus of elasticity can be found in Fig. 1. It turns out that the relative dynamic modulus of elasticity decreases gradually with the increasing of the freeze-thaw times. The relative dynamic modulus of elasticity of the specimen decreases to 91.9% and 81.9% at 100 cycles and 200 cycles respectively. When the

Table 1
Physical and mechanical properties of the steel slag.

Program	Crushing value/%	Water absorption/%	Adhesion level	Angeles abrasion value/%	Polishing value/%	Acicular content/%	Soundness/%
Test results	14.9	2.06	4	10.5	68	4.5	2.6
Requirements	⩽28.0	⩽3.0	⩽4	⩽28	>60	⩽18.0	⩽12.0