Construction and Building Materials 124 (2016) 999–1006

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effects of temperature and carbonation curing on the mechanical properties of steel slag-cement binding materials

Liu Qian, Liu Jiaxiang *, Qi Liqian

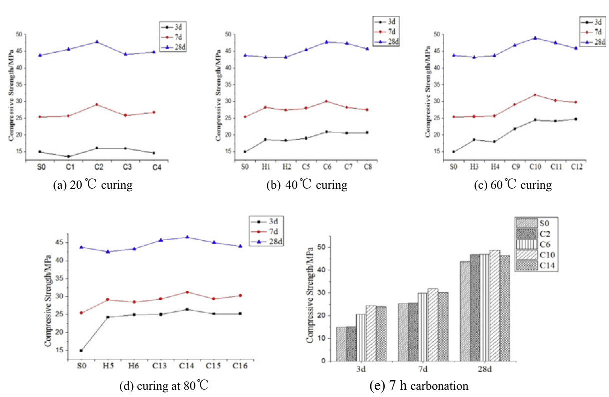
Beijing Key Laboratory of Electrochemical Process and Technology for Materials, The State Key Laboratory of Chemical Resource Engineering, Beijing University of Chemical Technology, Beijing 100029, PR China

HIGHLIGHTS

- Carbonation curing improve the slag cement binding materials' compressive strength.
- Carbonation curing can produced a dense shell layer of $CaCO_3$.
- .The shell of $CaCO_3$prevent the cementitious material dissolution erosion.

GRAPHICAL ABSTRACT

Relationship between curing conditions and the compressive strength of the SS cementitious material.



ARTICLE INFO

Article history:
Received 12 December 2014
Received in revised form 26 August 2016
Accepted 28 August 2016
Available online 2 September 2016

Keywords:
Steel slag
Higher temperature curing
Carbonation curing
Hydration rate
Mechanical properties

ABSTRACT

In this study, 30% of cement was replaced by steel slag to prepare cementitious material, additionally, higher temperature and carbonation curing were investigated to study the effects of curing conditions on the mechanical properties of steel slag-cement binding materials. The hydration degree of the steel slag cementitious material was analysed by XRD and TG-DTG. Characterization of the hydration products and the changes in the cementitious material morphology was investigated using SEM and EDS. The results showed that the best curing condition was 60 °C combined with carbonization for 7 h. The 3 d, 7 d, 28 d flexural compressive strengths were greater compared with that of standard curing. The compressive strength increased by 63.94% at 3 d, 25.55% at 7 d, and 11.79% at 28 d. The cementitious material surface produced a dense shell layer of $CaCO_3$ after carbonation curing, and the particle size of the $CaCO_3$ was 1–8 μm. The dense shell can effectively prevent the occurrence of dissolution erosion of cement-based materials, and the shell can improve the durability of the cementitious material. The fine $CaCO_3$ particles provide nucleation points for the hydration of C_3S, accelerate the hydration of C_3S, and create a micro-aggregate effect, which enhances the compactness of the cementitious material.

1. Introduction

Basic oxygen furnace steel slag (SS) is the by-product of steel production and constitutes 15–20% of steel output [1,2]. In 2013,

* Corresponding author.
E-mail address: ljxpost@263.net (J. Liu).

http://dx.doi.org/10.1016/j.conbuildmat.2016.08.131
0950-0618/

China's crude steel production reached 782 million tons and accounted for 50.84% of the world's steel production, which was the first time that China's output represented the majority of the world's steel production. Production of SS as a by-product has reached more than 100 million tons [1,2]. The large amount of SS storage not only occupies land resources but also pollutes the environment. Therefore, it is imperative to find effective ways to utilize SS. Research shows that SS and Portland cement clinker have similar chemical and mineral compositions and can be used as a cement admixture. However, if the addition amount reaches 30%, the early strength of the concrete decrease drastically [3–5], and there will be other problems, such as poor stability [6–8]. Therefore, the addition of SS is better less than 30%. So far, the excitation mode used to improve the early strength of SS cementitious materials can be divided into three categories: 1. Physical excitation, which refers to the use of physical methods to improve the fineness of the ground slags [9,10], 2. Chemical excitation, which means adding some chemical excitation components to improve the early strength [11–14], 3. Thermodynamic excitation, which rises the temperature of the SS hydration to improve the cement performance.

CO_2 emissions from global fossil fuel combustion increased up to 36 billion tons in 2013 [15]. CO_2 emission reduction has become a popular issue. In this paper, through higher temperature carbonation curing, CO_2 can quickly cure and be permanently stored in the SS. CO_2 can also stimulate the activity of the SS. Through CO_2 curing, the early and late strength of cementitious materials with a large amount of SS increased significantly and achieved the PO 42.5 cement intensity level. This strategy not only solved the problem of low early strength in the cementitious materials with a large volume of SS but also stored gaseous CO_2, which helps alleviate the greenhouse effect. This study aspect is rarely reported. The composition and microstructural changes of SS cementitious materials after high-temperature and carbonation curing was also studied. The hydration process of a SS cementitious material after high-temperature and carbonation curing was revealed.

2. Experimental

2.1. Raw materials

Cement: Portland cement with a strength grade of PI 42.5 that complies with the Chinese National Standard GB 175-2007 was used. The 28 d flexural and compressive strengths were 9.1 MPa and 51 MPa, respectively.

SS: BOF steel was obtained from the Xin Yu Iron and Steel Company of China, this steel was hot stuffy steel slag. The chemical composition of the cement as well as the SS is listed in Table 1.

CO_2 gas: Gas from the Xiang He Rui Long gas factory in Hebei China was used. The purity was 99.9%.

2.2. Experimental methods

2.2.1. Preparation of SS powder

The SS was crushed with a jaw crusher to a particle size less than 5 mm. Grinding was performed with a ball mill to a specific surface area of 450–500 m^2/kg after deironing.

2.2.2. Preparation of paste specimens

To prepare the cementitious material, 30% of the cement was replaced by SS. The water to binder (w/b) ratio of the pastes was 0.5 (mass ratio). The sand to binder ratio of the pastes was 3.0. The mortar size was 40 mm × 40 mm × 160 mm. The pastes were cured in a moist chamber at (20 ± 1) °C with a relative humidity greater than 95%. The moulds were demolished 24 h after curing used to create the mortar specimens.

2.2.3. Higher temperature and carbonation curing for paste specimens

Mortar specimens were prepared at different curing conditions. The mortar specimens cured in standard cement water conservation tanks. The specimen curing conditions are listed in Table 2. The standard water conservation tank was numbered S0. The specimens that were only cured a higher temperature are numbered H1–H6. The specimens cured at different temperatures along with carbonization curing are numbered C1–C16. At 3, 7 and 28 d, the flexural and compressive strengths of the samples were determined according to Chinese National Standards GB/T17671-1999.

3. Results and discussion

3.1. The mineral compositions of XinYu SS

As Fig. 1 shows, the active mineral composition of the Xin Yu SS was the following: C_3S, C_2S, C_3A, C_4AF, etc. This result is the main reason SS has cementitious properties. Additionally, SS contained a greater RO phase (CaO-MgO-FeO-MnO solid solution). This is one of the reasons SS has poor stability.

Table 1
Chemical composition of raw materials wt.%.

Chemical composition	CaO	SiO_2	Fe_2O_3	Al_2O_3	MgO	FeO
Composition of the cement	65.44	21.86	3.47	4.56	2.60	
Xin Yu steel slag	41.35	11.04	12.69	1.35	8.62	12.74
Chinese steel slag average	40–50	10–15	3.14	1–5	12	24

Table 2
Specimen Curing Conditions.

	Temperature /°C	Standard curing	High temperature Curing		Carbonation curing			
Curing time /h		–	7	9	5	7	9	11
	20	S0			C1	C2	C3	C4
	40		H1	H2	C5	C6	C7	C8
	60		H3	H4	C9	C10	C11	C12
	80		H5	H6	C13	C14	C15	C16