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Crystallization behavior of blast furnace slag modified by adding iron ore tailing

Qian-qian Ren[1,2], Yu-zhu Zhang[1,3,*], Yue Long[3], Shao-sheng Chen[3], Zong-shu Zou[1], Jie Li[3], Chen-guang Xu[3]

[1] School of Metallurgy, Northeastern University, Shenyang 110819, Liaoning, China

[2] State Key Laboratory of Advanced Steel Processes and Products, Central Iron and Steel Research Institute, Beijing 100081, China

[3] College of Metallurgy and Energy, North China University of Science and Technology, Tangshan 063009, Hebei, China

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ABSTRACT

Blast furnace (BF) slag is a by-product of the ironmaking process and could be utilized to manufacture slag fiber by adding iron ore tailing. The crystallization behavior of the modified BF slag is significant to the fibrosis process. To investigate the influence of basicity on the crystallization behavior, BF slag was modified by adding iron ore tailing at room temperature and melted at 1500 ℃. FactSage simulation, X-ray diffraction, scanning electron microscopy backscattered electron imaging coupled to an energy dispersive spectrometer, and hot thermocouple technique analysis were performed to explore the crystallization behavior of the modified BF slag during the cooling process. It was found that the initial crystallization temperature increased with the increase in basicity. Melilite, anorthite, clinopyroxene, and wollastonite could be generated during the cooling process as basicity ranged from 0.7 to 0.9. Spinel could be found as one of the phases; however, wollastonite disappeared under a basicity of 1.0. The initial crystallization temperature was controlled by the crystallization of melilite during the cooling process when the basicity of the modified BF slag ranged from 0.7 to 1.0. Moreover, the cooling rate could also influence the crystallization of the modified BF slag.

1. Introduction

Blast furnace (BF) slag is a by-product of the ironmaking process, with approximately 240 Mt generated annually in China[1-4]. Valorization of BF slag is beneficial not only for the economy but also for an environmentally friendly steel factory. Currently, most BF slag has been used for cement manufacture, civil engineering materials, glass ceramics, roadbed materials, and concrete admixtures[5-8]. BF slag is discharged at temperatures ranging from 1450 to 1650 ℃ and contains a large amount of latent heat. The latent heat could not be adequately used by the recycling methods mentioned above[9-11]. Slag fiber is one of the inorganic fibers that has the highest potential owing to its low cost and simple production process. Attempts have been made to obtain this material with molten BF slag, which is an effective approach to utilize both BF slag and its latent heat[12-15]. Long et al.[14] investigated the influence of the acidity coefficient of modified BF slag on the physical and chemical properties of slag fiber. It was found that the diameter of the slag fiber was exponentially increased with the increase in the acidity coefficient. The reasonable acidity coefficient of modified BF slag used in the slag fiber manufacture process was between 1.0 and 1.4. According to Zhang et al.[12], slag fiber was utilized to produce slag wool board, which is an effective approach for BF slag recycling.

The key point of this utilization is that the crystallization behavior of the BF slag should be reasonably controlled to generate more amorphous phases. The crystallization behavior of BF slag is significantly affected by its mineralogical composition. The major phases of BF slag are melilite and merwinite[16-18]. The initial crystallization temperature of these phases would influence the fibrosis process of molten BF slag. Mendybaev et al.[19] studied the crystallization temperatures of melilite for three melt compositions and found a simple relationship among the melt composition, crystallization tem-

* Corresponding author. Prof., Ph.D.
E-mail address: *zyz@ncst.edu.cn* (*Y. Z. Zhang*).

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perature, and composition of the primary crystallized melilite. According to the XRD analysis of Gan et al.[18], gehlenite and akermanite existed in crystalline BF slag. The crystallization of gehlenite is thermodynamically more stable than that of akermanite and should occur earlier. The precipitation of gehlenite is significant to the crystallization of BF slag. Consequently, the initial crystallization temperature controlling mineral is significant to the fibrosis process of molten BF slag.

BF slag, which is primarily composed of CaO, SiO_2, MgO, and Al_2O_3, has a basicity ranging from 1.0 to 1.2[20]. The basicity of BF slag is significant to the fluid ability and mineralogical compositions, which impact the crystallization behavior of the molten BF slag. BF slag could be modified by adding iron tailings, fly ash, and other wastes to control its basicity[21-23]. Esfahani and Barati[24] studied the influence of slag composition on the crystallization of synthetic CaO-SiO_2-Al_2O_3-MgO slags. They showed that both crystallization temperature and slag basicity affected the size and growth of the crystals. For slags with low basicity, the crystalline phases were translucent and nucleation was limited, leading to the growth of only a few large crystals. Yang et al.[25] studied the effect of the ratio of CaO to SiO_2 on the crystallization kinetics of glass-ceramics prepared from copper slag. The results indicated that the activation energies of crystallization increased with the increase in the ratio of CaO to SiO_2 up to 0.38, and a decrease in the activation energies was observed as the ratio of CaO to SiO_2 ranged from 0.38 to 0.42. Mousavi et al.[26] studied the effect of basicity on the template free crystallization of zeolite rho via a hydrothermal synthesis and showed that increasing basicity increased the nucleation and decreased the crystals size. However, few investigations can be found on the influence of basicity on the crystallization behavior of BF slag that has been modified by a mixture of iron ore tailing.

This paper aims at performing a further investigation on the influence of basicity on the crystallization behavior of modified BF slag. FactSage simulation was carried out to investigate the influence of basicity on the initial crystallization temperature of the modified BF slag during the cooling process. Based on the FactSage simulation, the initial crystallization temperature controlling phase under different basicities was determined. To verify the validity of the FactSage simulation and further confirm the crystallization behavior of the modified BF slag, X-ray diffraction (XRD), scanning electron microscopy backscattered electron imaging (SEM-BSE) coupled to an energy dispersive spectrometer (EDS), and the hot thermocouple technique (HTT) were performed.

2. Materials and Methods

2.1. Materials

The BF slag and iron ore tailings used in this work were obtained from a steel plant and a mining area in China, respectively. The chemical compositions of the BF slag and iron ore tailings were determined by chemical analysis (YBT 140-1998) and are shown in Table 1. As presented in Table 1, the BF slag is rich in CaO, which originates from the addition of lime as flux during the melting process. The CaO content is followed by SiO_2 content, with a weight percentage of 33.53%. BF slag waste has a binary basicity of 1.08, which is inappropriate to manufacture slag fiber[27]. Iron ore tailing is also a waste product, which contains a higher content of SiO_2 and a lower content of CaO. The weight percentage of SiO_2 could reach 67.78%; therefore, iron ore tailing is a good basicity modifier for BF slag.

Table 1

Chemical compositions of blast furnace slag and iron ore tailings (wt. %)

Component	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	TiO_2	K_2O	Na_2O	MnO	S	P
Blast furnace slag	33.53	36.25	8.64	15.82	1.57	1.38	0.54	0.32	0.17	0.84	0.012
Iron ore tailing	67.78	2.50	2.58	13.50	6.56	0.28	3.90	2.21	0.098	0.048	0.046

2.2. Modified BF slag

Considering the requirement of viscosity in the slag fiber manufacture process, the reasonable basicity R of modified BF slag is generally in the range from 0.7 to 1.0[28,29]. The BF slag used in this work was modified using iron ore tailing. The mass ratios between BF slag and iron ore tailing and the major chemical compositions of the modified BF slag are shown in Table 2.

Table 2

Main chemical compositions of modified blast furnace slag

Basicity	Mass ratio/wt. %		Content of component/wt. %			
	BF slag	Iron ore tailing	SiO_2	CaO	MgO	Al_2O_3
0.7	77.9	22.1	41.11	28.78	7.30	15.31
0.8	84.6	15.4	38.81	31.05	7.71	15.46
0.9	90.6	9.4	36.75	33.08	8.07	15.60
1.0	96.0	4.0	34.90	34.90	8.40	15.73