



The effect of ultrahigh volume ultrafine blast furnace slag on the properties of cement pastes

Xingyang He^{a,b,*}, Mengyang Ma^a, Ying Su^{a,b}, Meng Lan^a, Zhengqi Zheng^a, Tingwei Wang^a, Bohumír Strnadel^{a,c}, Sanhai Zeng^{a,b}

^aSchool of Civil Engineering and Environmental Sciences, Hubei University of Technology, Wuhan, China

^bHubei Province Building Waterproof Engineering Research Center, Hubei University of Technology, Wuhan, China

^cCentre of Advanced and Innovation Technologies, Faculty of Metallurgy and Materials Engineering, VŠB-Technical University of Ostrava, 708 33 Ostrava-Poruba, Czech Republic

HIGHLIGHTS

- Ultrahigh volume ultrafine BFS are prepared through wet-milling and dry-separation respectively.
- The reaction degree of WS system develop at a faster rate owing to dissolution of ions.
- Mixes containing WS can exhibit compressive strength of 43.9 ± 2.3 MPa after 3d of curing.

ARTICLE INFO

Article history:

Received 8 May 2018

Received in revised form 30 August 2018

Accepted 1 September 2018

Keywords:

Mineral admixture

Wet-milling

Hydration characteristics

Hydration products

ABSTRACT

The dosage of blast furnace slag (BFS) in cement is limited on account of relative low reaction rate and low early strength. Improving the early age activity of BFS is the fundamental solution for high volume BFS cementitious materials. Generally, mechanical activation is one of the main techniques to accelerate the early reaction of mineral admixtures. In this study, wet-milling and dry-separation are respectively used to prepare ultrafine BFS to improve its early reactivity. The early hydration characteristics, mechanical property, hydration products of ultrahigh volume BFS cementitious materials are analyzed to assess the efficiency of ultrafine BFS on the properties of BFS cement paste. The results show that the initial and final setting time both gradually decrease as the dry-separation BFS (GS) dosage increases, while the wet-milling BFS (WS) series present the opposite tendency. The electrical resistivity of WS specimens develops at a faster rate than that of GS specimens. Mixes containing WS, at a maximum dosage of 90%, have higher mechanical property than those with GS, resulting in an enhancement of strength. The hydration products mainly include calcium hydroxide, hydrotalcite, hydrotalcite-like phase, calcium carbonate, strätlingite, C-S-H, C-A-S-H, and akermanite.

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1. Introduction

Cement and concrete, as the widely used engineering materials, offer the potent guarantee for the global infrastructure projects. However, cement industry produces high levels of greenhouse gases that come from raw material calcination [1–3]. Beyond that, cement manufacturing consumes a large amount of energy and resources [4–6]. The demand for cement continues to rise with the rapid growth of the construction industry, which is projected to increase 4 times in the twenty-first century compared with the end of the twentieth century and will present a significant

challenge to environment, resources, and energy. Substituting cement by potential cementitious wastes, such as ??, will reduce CO₂ emissions and resources consumption if the wastes being used would instead have been burned or disposed of without energy and material recovery.

As an industrial by-product, blast furnace slag (BFS) is one of the most widely used supplementary cementitious materials in cement and concrete industry. The main chemical components of BFS are SiO₂, Al₂O₃, and CaO, which are similar to cement. The negative effect of cement industrial can be mitigated through the application of BFS. For example, due to the existence of BFS, the mechanical performance and the durability of concrete can be both improved. [7–10]. Meanwhile, BFS can also remarkably reduce the rate of hydration heat evolution and cumulative heat release of concrete [11].

* Corresponding author at: Hubei Province Building Waterproof Engineering Research Center, Hubei University of Technology, Wuhan, China.

E-mail address: hexycn@163.com (X. He).

The replacement level of BFS in cement, however, was limited on account of relative low hydration rate and early strength. The dosage of BFS is usually 30–60%, rarely reaches 80% [12,13]. The research by Oner et al. indicates that BFS is adverse to the strength development of PC-BFS when BFS dosage exceeds 55% [14]. Cahit et al. [15] reported that the maximum compressive strength of concrete with 80% BFS and 0.5 water/binder ratio was about 29.9MPa. The pozzolanic reaction of BFS is a very slow process even though BFS can react with calcium hydroxide to form calcium silicate hydrate. Therefore, the early strength of slag cement hardened paste mainly comes from the hydration of cement clinker.

Improving the early age activity of BFS is the fundamental solution for high volume BFS cementitious materials to enhance the early stage strength. Bellman [16] showed that overcoming low early stage strength of cement paste is possible if hydration of BFS is better improved. Mechanical activation is one of the main techniques to accelerate the early reactions of BFS [17–19]. Besides, it is more attractive that energy consumption of BFS treatment is much lower than that of cement production. Mechanical activation method not only decreases the particle size but generates surface defect that can improve the reactivity of materials to form compact structure at early age. Wang et al. [20] researched the self-hydration characteristics of BFS by wet-grinding treatment. They found that due to the physicochemical activation the self-hydration characteristic of GGBFS could be achieved after wet-grinding treatment without any chemical admixture. The setting time meets the requirement of national standard GB1346-2001, but the compressive strength of self-hydration pastes is unsatisfied according to some relevant standards. However, it is clear that wet-milling can significantly improve the hydration rate of BFS. Wet-grinding disposes of admixtures in aqueous condition, which extremely differs from the classical or conventional treatment (dry-grinding). Wang et al. [20,21] have verified that wet-grinding significantly improved the activity of cement.

This research aims to explore the effect of ultrafine GGBFS on the properties of cement pastes. The characteristics of cement pastes with wet-grinding BFS and air separation BFS are compared to highlight the main differences between the two grinding methods. Substitution of Portland cement with BFS at ratios as large as 80–95% is performed with the attempt to formulate a more sustainable cementitious material.

2. Materials and experiment

2.1. Materials

The major cementitious materials are BFS provided by EnGro-Baowu Corporation Limited with a basicity coefficient $((\text{CaO} + \text{MgO})/(\text{Al}_2\text{O}_3 + \text{SiO}_2))$ of 0.91 and Portland cement (PC) P.I 42.5 according to Chinese standard GB175-2007 from Lafarge-Huaxin. The chemical composition of BFS and PC determined by X-ray fluorescence is listed in Table 1. Mineralogical analyses of BFS and PC by X-ray diffractometry are shown in Fig. 1 and Fig. 2. Location of the broad diffuse hump peak detected in the pattern ranging from 20° to 40°, representing the main amorphous structure in BFS. Table 2 shows the basic physical properties of PC.

Polycarboxylate superplasticizer (PCE, 40% concentration, RHEOPLUS 420, BASF) is used as a dispersant to disperse BFS during the grinding process.

Table 1
Chemical composition of cement and GGBFS.

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O	Surface area [m ² /kg]
Cement	21.13	4.12	2.98	65.12	1.53	1.26	1.16	0.08	316
GGBFS	37.8	12.8	0.2	38.0	7.7	2.0	–	–	–

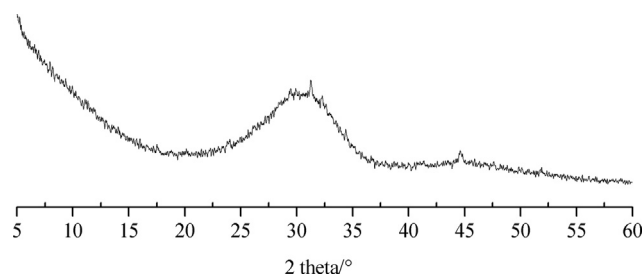


Fig. 1. XRD pattern of BFS.

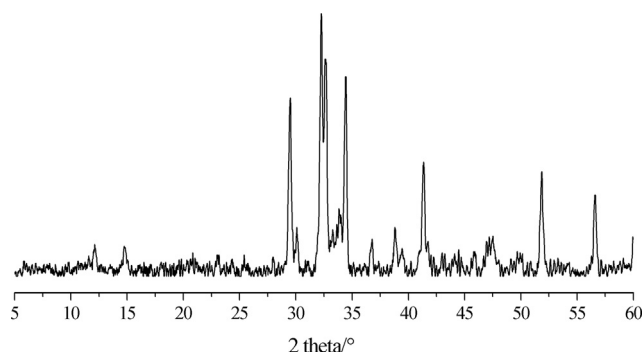


Fig. 2. XRD pattern of PC.

Table 2
The basic physical properties of PC.

Setting time /min		Soundness	Compressive strength /MPa		
Initial	Final		3 d	7 d	28 d
155	230	Qualified	28.2	38.9	45.6

2.2. Experiments

2.2.1. Treatment

Ultrafine BFS is obtained respectively through two methods: one is acquired by cyclone dust collector with airflow 12 m³/min (named GS), the other is obtained by self-made vertical stirred mill as described in the work of Wang and He [20] (named WS, see Fig. 3). It can be seen from Fig. 3 that the morphological characteristics of WS and GS particles are similar. The particle size distribution of WS and GS are performed using Mastersizer 3000, and the results are presented in Fig. 4. It is shown that WS and GS have similar distribution pattern with the maximum size about 10 μm and the minimum size about 1 μm. No agglomeration can be observed according to the scattergram. The average size of WS and GS is 1.9 μm and 1.8 μm, respectively. The chemical composition of slag is measured after the treatment, and the results are shown in Table 3.

2.2.2. Mixture preparation

Six different mixtures are prepared to illustrate the influence of ultrafine BFS (UFBFS) on the reaction kinetics and other related properties of cement paste with ultrahigh volume UFBFS, as shown

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