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Self-hydration characteristics of ground granulated blast-furnace slag (GGBFS) by wet-grinding treatment

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HIGHLIGHTS

- Three GGBFS slurries were prepared by wet-grinding treatment (WGT).
- Self-hydration characteristic was achieved after WGT without chemical activation.
- The reaction of GGBFS was accelerated after long grinding duration.
- Compressive strength was notably increased when prolonging the grinding time.

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ABSTRACT

The aim of this paper is to evaluate the self-hydration characteristic of GGBFS activated by wet-grinding treatment (WGT). Three slag slurries with different fineness were prepared through milling with varying duration (20 min, 40 min and 60 min, abbreviated as S2, S4 and S6, respectively). The reaction kinetics, mechanical properties, hydration products and microstructure of hardened GGBFS pastes were analyzed to assess the effect of WGT on the self-hydration process of GGBFS. The results indicated that self-hydration was achieved after grinding without chemical activation and the rate of self-hydration was improved with the increased grinding duration. The setting times were dramatically shortened and the compressive strength was notably increased when prolonging the grinding time. The hydration process of GGBFS slurry after 20 min milling included incubation period, but the others did not. The electrical resistivity development of samples S2 and S4 decreased during the initial period, followed by setting, acceleration and deceleration stage. However, sample S6 exhibited an absence of the initial stage. The self-hydration products analyses indicated that the main products were calcium silicate hydrate, calcium aluminosilicate hydrate (C-A-S-H), hydrotalcite, akermanite and calcite.

1. Introduction

It is well known that Portland cement (PC) is the most widely used engineering material which plays an important role in the human civilization process. Nevertheless, the cement industry discharges approximately 7% of total carbon dioxide emission and consumes about 6 billion tons of nature resource per year and large amount of energy [1–10]. For this reason, numerous efforts had been done to mitigate the adverse effects of the cement industry. The utilization of industrial by-products (e.g. silica fume and slag) as a supplementary cementing material to reduce the clinker production is one of the effective ways. In fact, these materials not only offer beneficial environmental and economic effect but also provide other advantages such as low hydration heat and excellent durability [11,12].

Ground granulated blast-furnace slag (GGBFS) is mainly consisting of CaO, SiO_2 and Al_2O_3. In recent decades, the use of GGBFS as an alternative binding material (alkali-activated slag, AAS) and partial replacement of cement has increased [13,14]. Nevertheless, the low strength development of cement based materials with GGBFS restricts its utilization in some aspects [15]. The most common techniques to overcome this disadvantage include thermal activation, chemical activation and mechanical activation: Thermal activation refers to curing cement based materials under elevated

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temperature to improve early strength, but this method may adversely affect the later strength and is commonly restricted to precast concrete plants [15]. Chemical activation is accelerating the reactivity of cementitious materials through mixing chemical admixtures with cement based materials [16]. Mechanical activation refers to grinding PC and mineral admixtures to higher specific surface area for the purpose of obtaining desired initial strength, which has been proposed to be an effective technology to improve the reactivity of GGBFS. This approach not only leads to the generation of higher fineness and structural defects accompanied by the surface amorphization, but also optimizes the particle distribution of GGBFS [17]. Therefore, mechanical grinding improves the chemical activation of GGBFS and has been the theme of many researchers [18,19].

Unlike dry-grinding that has been used for traditional cement, wet-grinding disposes solid materials in aqueous condition. Wet-grinding treatment (WGT) leads to mechanical activation and chemical activation on account of chemical transformation as well as improving the reaction ability of supplementary cementing materials. Sobolev et al. [20] investigated the effect of wet-grinding on the performance of cement containing ground cement slurry and showed that wet-grinding benefits the structure formations as well as mechanical strength at early ages.

Many experimental studies have been performed on the performance of GGBFS with different particle sizes as a supplementary cementing material blended with cement. Norrarat et al. [21] studied the contribution of GGBFS with different particle sizes on the hydration kinetics of composite cement (CC). They found that the hydration rate of CC increased with decreasing GGBFS size due to the reaction of GGBFS. Meanwhile, the higher was the cement replacement by GGBF slag, the higher was the slag reaction. Douglas et al. [22] observed that decreasing the GGBFS particle size had a positive effect on the development of mechanical property due to physico-chemical characteristics of GGBFS. Wang et al. [23] also investigated the influence of fineness and particle size distribution of GGBFS on the performance of CC. They found that GGBFS with higher fineness had greater rate of reaction and the fraction of GGBFS less than 5 μm played an important role on hydration. However, the reaction of slag-cement system is a complex process since both reactions are influenced by each other. Thus, some researchers focus on the hydration of slag individually. Song [24] found that the alkalinity of the pore solution plays an important role in slag reaction process, high pH value (normally >11.5) was one of the basic conditions for activating the reactivity of GGBFS. Other researchers also reported that higher alkalinity contribute to better hydration performance of AAS materials [24–27].

The above studies mainly relate to the interactions between GGBFS and cement. Furthermore, many other reports are focused on the influence of water/cement ratio, temperature and GGBFS type on the reaction degree of GGBFS in CC system. However, the hydration of GGBFS without chemical additives is rare. It is well known that GGBFS has hydraulic properties but the hydration rate is slow after mixing with water. In this paper, the effects of wet-grinding on the self-hydration characteristics of GGBFS were investigated. The reaction kinetics of GGBFS were evaluated by isothermal calorimetry and electrical impedance. The microstructure and hydration products of hardened GGBFS pastes were investigated by scanning electron microscopy (SEM), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR) and thermogravimetric analyses (TGA). The results are intended to add valuable knowledge to the field of the hydration of GGBFS.

2. Materials and experiment

2.1. Materials

The main binder material used in this work was GGBFS (China Baowu Steel Group Corporation). The chemical composition of GGBFS was assessed by X-ray fluorescence and listed in Table 1. The major components are Al_2O_3, SiO_2, CaO and MgO with concentration of 12.3%, 36.9%, 38.6% and 7.5%, respectively. The basicity coefficient ($(CaO + MgO)/(Al_2O_3 + SiO_2)$) is 0.94. The X-ray diffraction pattern of GGBFS was shown in Fig. 1. It is revealed that the GGBFS was predominantly amorphous in view of the large diffuse diffraction peak at about 20°–40°.The specific surface area and the mean grain size of adopted GGBFS are 410 m^2/kg and 13.01 μm, respectively.

2.2. Experiments

2.2.1. Grinding

The grinding of GGBFS was carried out in a self-made vertical stirred mill (VSM) and schematic illustration of VSM is shown in Fig. 2. The VSM includes four types of zirconia balls (10 mm: 8 mm: 5 mm: 3 mm = 1:3:6:2). At first, zirconia balls, GGBFS and water were separately weighted (water/GGBFS (w/b) = 1:2, GGBFS/grinding media = 0.5). Then GGBFS was premixed with water in the feed tank, and zirconia balls were put in the VSM. Following that, the slurry was milled for specific durations (20 min, 40 min and 60 min) with VSM motor speed 400 rpm. Finally, the slag paste was obtained by passing through a valve with a fine screen.

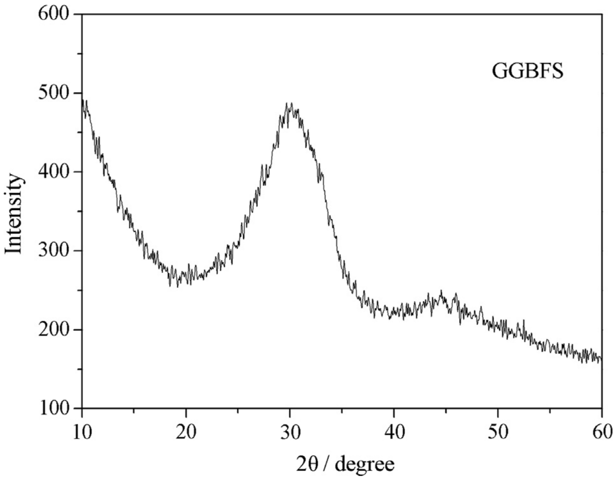

Fig. 1. The XRD pattern of GGBFS.

Table 1
Chemical composition of GGBFS, wt%.

CaO	Fe_2O_3	SiO_2	MgO	MnO	Al_2O_3	TiO_2	SO_3
38.6	0.3	36.9	7.5	0.3	12.3	0.7	2.1