Construction and Building Materials 164 (2018) 525–534

Contents lists available at ScienceDirect

Construction and Building Materials

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

Modification and enhancement of mechanical properties of dehydrated cement paste using ground granulated blast-furnace slag

Linglei Zhang [a,b,c], Yongsheng Ji [a,b,c,*], Guodong Huang [a,c], Jun Li [a,c], Yijie Hu [a,c]

[a] State Key Laboratory for Geomechanics and Deep Underground Engineering, China University of Mining and Technology, Xuzhou, Jiangsu 221008, China
[b] Jiangsu Collaborative Innovation Center for Building Energy Saving and Construct Technology, Xuzhou, Jiangsu 221116, China
[c] School of Mechanics & Civil Engineering, China University of Mining and Technology, Xuzhou, Jiangsu 221008, China

HIGHLIGHTS

- Basic reason of poor properties of dehydrated cement paste is lower particle hardness.
- Problems occur when DCP is grinded are solved by micro-ball milling effect of slag.
- Slag could provide micro-aggregate framework supports for the cementitious system.
- DCRCM with excellent mechanical properties are prepared.

ARTICLE INFO

Article history:
Received 17 February 2017
Received in revised form 24 December 2017
Accepted 28 December 2017
Available online 5 January 2018

Keywords:
Particle hardness
Micro-aggregate effect
Micro-ball mill effect
Dehydrated cement paste
Composite reactivated cementitious material

ABSTRACT

The grinding process and mechanical properties of dehydrated cement paste (DCP) were modified using ground granulated blast furnace slag (hereinafter as slag) according to the micro-ball mill effect and micro-aggregate effect. In order to investigate the effect of slag contents on the properties of DCP composite reactivated cementitious materials (DCRCM), hydration heat evolution and mechanical properties were analyzed, results of which indicated the extremely low particle hardness as the reason for the poor grinding effect and mechanical properties of DCP. The micro-ball mill effect of slag could solve the problems, such as sticking of particles to the boll and wall as well as occurrence of micro-agglomeration when only DCP was grinded. Slag could provide a micro-aggregate framework support for the DCRCM cementitious system, and composite reactivated cementitious materials with excellent mechanical properties were prepared.

1. Introduction

As an effective solution to recycle waste concrete, recycled aggregate concrete technology plays a significant role in environment protection and energy conservation [1–6]. The crushing of waste concrete can produce a certain amount of fine powders with particle size less than 0.15 mm, whose main ingredient is hardened cement paste (HCP) featured by its highest economic cost and greatest environmental burden in concrete. Thus, effective utilization of HCP through cementitious property regeneration is critical in the waste concrete research [7–9].

It has been demonstrated that HCP, which transforms into dehydrated cement paste (DCP) when exposed to high temperature (600–800 °C) for hours, can recover hydration capacity [10–13]. However, the particle size of HCP separated from the waste concrete is biased coarse. Therefore, grinding of HCP particles is necessary in order to satisfy the requirement concerning the thickness of cement particles. DCP particles are vulnerable to stick to the boll and mill and form micro-agglomeration in the grinding process, consequently resulting in lower grinding efficiency and coarser size of DCP particles than those of cement particles. In this context, cementitious properties of DCP are limited. Therefore, it is necessary and crucial to enhance the grinding efficiency and particle size refinement of DCP.

Even if DCP is grinded into ultrafine powders, there are still some inevitable problems when DCP is used as a cementitious material, such as short setting time, requirement for large quantities of water, and low strength [14]. Specifically, the low strength significantly hinders the wide application of DCP. Therefore, it is critical to modify its mechanical properties so as to ensure its efficient utilization. Free CaO, as one of the main components of DCP,

* Corresponding author at: State Key Laboratory for Geomechanics and Deep Underground Engineering, China University of Mining and Technology, Xuzhou, Jiangsu 221008, China.
E-mail address: jiyongsheng@cumt.edu.cn (Y. Ji).

https://doi.org/10.1016/j.conbuildmat.2017.12.232
0950-0618/

can react with water intensely, providing abundant $Ca(OH)_2$ for the pozzolanic reaction of supplementary cementitious materials. The use of DCP and silica fume as composite cementitious materials is favored by better mechanical properties compared with the exclusive use of DCP, but also disfavored due to much more required water amount [15]. It is found that a large dosage of fly ash and slag activated by DCP can improve the fluidity of the composite cementitious material, but also leads to poor cementitious capacity and low mechanical properties [16]. Therefore, despite modifications to the materials, the DCP cementitious system is of relatively low strength due to the low particle hardness of DCP particles with loose and porous structure, thereby resulting in coarse particles even after grinding. Thus, its cementitious capacity cannot be fully exploited. Furthermore, effective support could not form in the cementitious system, resulting in poor mechanical properties. Only by overcoming the adverse effects of low particle hardness can the problems of DCP cementitious materials be solved completely. Slag with high particle hardness is often used as a micro-milling medium of other cementitious materials, such as cement and red mud, to improve the fineness of such materials, or as a micro aggregate to improve the strength of the cementitious system.

In this study, the grinding process and mechanical properties of DCP were modified with slag through making use of the micro-ball milling effect and micro-aggregate effect. Based on the analysis of heat hydration, and mechanical properties, the intrinsic mechanism of hydration and the hardening characteristics of DCP-composite cementitious materials were revealed. Meanwhile, the DCP-composite cementitious material with excellent properties was prepared. This study aimed to provide a theoretical basis for the effective utilization of DCP.

2. Materials and experimental methodology

2.1. Materials

Ordinary Portland cement (OPC) CEM I42.5 N and ground granulated blast-furnace slag were provided by China United Cement Co., Ltd. Their physical properties and chemical compositions are presented in Tables 1 and 2, and their particle size distributions are shown in Fig. 1.

The waste concrete was derived from an old concrete structure in the local city. The old concrete structure was built for more than 30 years, and the strength of parent concrete measured by coring was about 38.3 MPa.

2.2. Preparation of DCRCM

2.2.1. Preparation of DCP

The crushing and segregating of waste concrete generated recycled coarse aggregate, recycled fine aggregate, and HCP. HCP was placed in a muffle furnace and calcined at 600 °C for 3 h, and then taken out immediately and cooled to room temperature. Thus, DCP was prepared, and its chemical composition is shown in Table 1. The particle size of DCP was biased coarse, which means further grinding was necessary to ensure excellent cementing performance.

Table 1
Physical properties of OPC and slag.

Properties	OPC	Slag
Specific gravity (kg/m^3)	3150	2900
Specific surface (m^2/kg)	350	425
Average particle size (μm)	16	15

Table 2
Chemical composition of OPC and slag.

Materials	Cement	Slag	DCP
SiO_2	24.55	36.51	30.26
Al_2O_3	7.77	15.65	6.64
Fe_2O_3	3.62	1.08	2.54
CaO	54.59	32.93	46.47
MgO	2.68	8.02	2.42
Na_2O	0.31	0.81	0.7
K_2O	1.5	1.11	1.63
SO_3	2.24	0.07	2.25
L.O.I	1.2	1.33	4.97

2.2.2. Preparation of DCRCM

With high particle hardness, slag was utilized as the solid dispersant of DCP to overcome problems, such as sticking of particles to the boll and wall of the tank, as well as occurrence of micro-agglomeration when DCP was grinded alone. Slag and DCP were mixed at the mass ratios of 3:1, 2:1, 1:1, 1:2, and 1:3, respectively. Then the mixtures were placed into a planetary ball mill and grinded for 15 min, during which natural gypsum with an amount of 5 wt% of DCP was added as the retarder. Thus, DCRCM was prepared. The ball-to-powder weight ratio was 4:1, and the speed of the ball mill was set as 220 r/min.

2.3. Methodology

2.3.1. Particle size distribution

Particle size distributions of DCRCM and DCP were determined by using a Winner 3003 laser particle size analyzer to investigate the influence of slag mixing amount on the grinding effect of DCRCM. Both DCP and DCRCM were kept in sealing bags before the test.

2.3.2. Particle hardness

Powders (cement clinker, slag, DCP) and epoxy were mixed and molded. Then the molded samples were polished using an automatic variable speed grinder-polisher with sequential grit sizes of 600, 800 and 1200 mesh for two minutes each, or until all scratches from the previous step were removed. Samples were rinsed with ethanol in the intervals between each step to remove previous grinding media. Final polishing was accomplished with 3 and 1 μm diamond aerosol sprays. Then the hardness of the particles in the plane of the polished specimen was measured by Vickers microhardness meter.

2.3.3. Heat of hydration

According to the State Standard of China (GB/T12959-2008), the heat evolution rate and the heat of hydration of cement and DCRCM, were measured by an automatic analyzer in order to investigate the effect of slag mixing amount on the hydration kinetics of DCRCM. All measurements lasted for 72 h.

All samples were mixed with a water-to-binder ratio of 0.5 and a binder-to-sand ratio of 1:3 separately. Each sample contained 450 g DCRCM, 1350 g standard sand (ISO) and 225 g water (with superplasticizer and borax). Mixed water and DBCM was gently added into the mixer over 30 s at a low speed, then the standard sand was gently added into the mixer, and the mixing was kept for 30 s at a low speed. Subsequently, the mixing was implemented for 60 s at a high speed. The mixer was quickly taken down after mixing, and the mortar was mixed with a spoon several times. Then, two mortar samples with the masses of (800 ± 1) g were weighted by electronic balance, and packed into the measuring container respectively.