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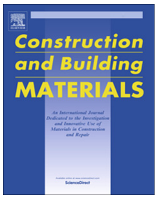

Use of slaked lime and Portland cement to improve the resistance of MSWI bottom ash-GBFS geopolymer concrete against carbonation

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HIGHLIGHTS

- BA has a decreased resistance against carbonation compared to CC.
- Both $Ca(OH)_2$ and Portland cement enhance the resistance against BA carbonation.
- Portland cement provides better carbonation resistance of BA than $Ca(OH)_2$.

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ABSTRACT

This study investigated the resistance of municipal solid waste incinerator bottom ash geopolymer concrete (BA), $Ca(OH)_2$-modified BA, and Portland cement-modified BA against carbonation using the accelerated carbonation test. The resistance enhancing effects and resistance enhancing mechanism of $Ca(OH)_2$ and Portland cement against carbonation of BA were studied via periodic monitoring of carbonation depth and microscopic analysis of carbonation products. The results show that BA has a decreased resistance against carbonation compared to cement concrete; $Ca(OH)_2$ and Portland cement can both enhance the resistance against BA carbonation. Larger contents will lead to larger enhancements. The enhancing effect of Portland cement on the carbonation resistance of BA exceeds that of $Ca(OH)_2$. The main reason for this is the polymerization of the initial stage of hydration consuming part of the $Ca(OH)_2$, which lowers the effective $Ca(OH)_2$ content.

1. Introduction

Geopolymer materials are a new type of inorganic nonmetallic material developed during recent years. Compared to conventional Portland cement material, geopolymer material does not only have high strength, high temperature resistance, resistance against acids, alkali, and salts, low permeability, and other advantages, but also does not require high temperature calcination or sintering processes to complete polymerization at room temperature [1–3]. Compared to Portland cement, geopolymer materials have a lower energy consumption, cause almost no pollution, and require no consumption of limestone resources; therefore, this is an environmentally friendly green building material [4]. However, with further research on geopolymer materials, researchers have shown that geopolymer concrete has a much weaker resistance against carbonation than cement concrete, causing severe concern [5]. As the atmospheric carbon dioxide enters into reinforced concrete via diffusion, it constantly dissolves pore liquid and causes a reduction of the pH value of pore liquids. The lower pH value will damage the protective film of the rebar, resulting in accelerated corrosion of the rebar and thus a reduction in bearing capacity. Therefore, resistance against carbonation is closely related to the durability of reinforced concrete.

Some studies have investigated the carbonation of granulated blast furnace slag (GBFS) geopolymer concrete and other related geopolymer materials [6–11]. The results of these studies indicate that geopolymeric concrete possesses a higher carbonation rate than Portland cement concrete while having the same compressive strength; however, the carbonization mechanism between both materials differs [8,11–13]. The higher carbonation rate of geopolymer materials results in a performance degradation, which leads to an important decrease in compressive strength. These results are consistent to those reported by Palacios et al. [8] and Bernal

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et al. [14]. Thus, further study of the carbonization mechanism of geopolymer materials and the proposed methods for the improvement of the carbonation resistance performance became a research focus both in China and internationally.

Compared to geopolymer materials, cement concrete (CC) has good carbonation resistance since cement constantly hydrolyzes and produces $Ca(OH)_2$, the dissolution of which eases the pH reduction of the pore solution, which results in an enhanced resistance against carbonation [15,16]. Therefore, with respect to the anti-carbonation mechanism of CC, the incorporation of an appropriate amount of cement and slaked lime in the preparation of geopolymer materials may enhance its resistance against carbonation.

This study assesses the effect of accelerated carbonation on concrete matrices produced by MSWI bottom ash, and its improvement effect on the carbonation resistance performance of Portland cement and slaked lime. Changes in carbonation depth of BA are observed in regular time, and the carbonation products are evaluated using Fourier Transform infrared spectroscopy (FT-IR) and X-ray diffraction, respectively.

2. Experimental material and method

2.1. Materials

(1) MSWI bottom ash

The MSWI bottom ash used in this experiment was supplied from GCL-Poly (Xuzhou) Renewable Energy Power Generation Co., Ltd. The municipal solid waste was first separated via magnetic separation and then calcined at 800 °C. The bottom ash was washed at the recycle station and its chemical composition is shown in Table 1. In this experiment, the bottom ash required grinding into fine powder with a surface area and specific gravity of 400 m^2/kg and 2.47, respectively. The particles were mainly spherical with a median particle size of 47 μm and 28% was retained on a 45 μm sieve.

(2) Granulated blast furnace slag (GBFS) and slaked lime

The GBFS used in the experiment is S95 granulated blast furnace slag powder, which conforms to the Chinese standard GB/T 18046-2008 [17]. The surface area and specific gravity of GBFS are 416 m^2/kg and 2.89 and 35% was retained on a 45 μm sieve. Its chemical composition is also shown in Table 1. Industrial grade slaked lime was adopted and the chemical composition is shown in Table 2. The purity of it is 95%, the specific gravity is 2.24, and the surface area is 400 m^2/kg.

(3) Activator

For alkali activated solutions, sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) were used with 9.65% Na_2O, 25.22% SiO_2, and 65.13% H_2O. The sodium silicate solution has a modulus of 2.7 and a Baume of 37°Bé. NaOH dosage and water are listed in Table 3, and a 1953 ml 4.8 M NaOH solution was prepared to obtain each set of concrete. The solution was left for 24 h before use.

(4) Others

The Portland cement used for the experiment is the P·O 42.5 type, which conforms to the Chinese standard GB 175-2007 [18]. Commercially available limestone with a maximum size of 30 mm and a specific gravity of 2.67 in saturated surface dry conditions was used as coarse aggregate. For the fine aggregate, river sand with specific gravity of 2.56 and fineness modulus of 2.8 was used. Tap water was used for the test.

2.2. Methods

2.2.1. Mix proportion of concrete

BA and CC were prepared with reference to the GB/T50107-2010 [19] "Standard for evaluation of concrete compressive strength – ISO". Since the pure MSWI bottom ash is less active and has a lower strength, to improve its mechanical properties, the MSWI bottom ash was calcinated at 700 °C and mixed with GBFS [20–22]. Table 2 shows the mix proportion of CC and BA geopolymer concrete. The groups from L-1 to L-2 represent CC and BA, which compares the carbonation resistance between both types of concrete. The groups from L-3 to L-5 represent the BA mixed with slaked lime, which was used to examine the impact of slaked lime on the resulting carbonation resistance. The groups of L-6 and L-8 represent the BA mixed with Portland cement, which was used to examine the impact of Portland cement on carbonation resistance.

2.2.2. Casting concrete specimens

The CC and BA specimens were mixed in a 20 ± 2 °C controlled room. Before preparing BA, it is necessary to mix the bottom ash with NaOH solution to form slurry and to age this slurry for 4 h as a defoaming pre-treatment, which can eliminate the effect of foaming and expansion on the performance of geopolymers when bottom ash meets alkali. The procedure of BA preparation was started by mixing the slurry, GBFS, slaked lime, and Portland cement for 1 min; then, sand and sodium silicate solution were added and the mixture was stirred for 30 s; finally, coarse aggregates were added and stirred for 1 min. The procedure of CC was started by mixing Portland cement, sand, and water for 1 min; then, coarse aggregates were added

Table 1
Chemical composition of raw material (%).

Raw material	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	Zn, Pb, Ba, Sr, Cu	Loss
GBFS	31.35	34.65	18.65	0.57	9.31	–	–	–	0.7
Cement	26.55	62.9	7.77	3.62	2.68	1.5	0.31	–	3.2
MSWI bottom ash	43.82	24.44	14.18	6.18	3.26	2.52	2.24	0.61	1.62

Table 2
Chemical composition of slaked lime (%).

Raw material	$Ca(OH)_2$	CaO	$CaCO_3$	Fe_2O_3	MgO	Others	Loss
Slaked lime	95.12	1.44	2.48	0.15	0.26	0.11	–

Table 3
Mix proportion of the concrete kg/m^3.

	Cement	MSWI bottom ash	GBFS	Slaked lime	Water	Water glass	NaOH	Sand	Gravel
C-1	330	0	0	0	165	0	0	651	1056
C-2	0	198	132	0	92.4	88	17.6	651	1056
C-3	0	165	132	33	92.4	88	17.6	651	1056
C-4	0	132	132	66	92.4	88	17.6	651	1056
C-5	0	99	132	99	92.4	88	17.6	651	1056
C-6	33	158	132	7	92.4	88	17.6	651	1056
C-7	66	125	132	7	92.4	88	17.6	651	1056
C-8	99	92	132	7	92.4	88	17.6	651	1056