



Utilization of municipal solid waste incineration bottom ash in autoclaved aerated concrete

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HIGHLIGHTS

- Properties and microstructure of AAC containing bottom ash was investigated.
- The replacement by bottom ash had a positive effect on forming of tobermorite.
- Crumbled foiled tobermorite and grass-like C-S-H structure formed at high level.

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ABSTRACT

The objective of this study was to assess the feasibility of application of municipal solid waste incineration (MSWI) bottom ash as a substitute of quartz sand for the preparation of autoclaved aerated concrete (AAC). Influence of substitution mass ratio and fineness of MSWI bottom ash on the physical-mechanical properties and microstructure of AAC was investigated. Leaching toxicity was also determined to ensure the environmental safety of AAC with MSWI bottom ash. The results demonstrated that the incorporation of MSWI bottom ash can reduce the gas-foaming time, compressive strength, density and thermal conductivity. Moreover, compressive strength and density of AAC increase with the increasing of fineness of MSWI bottom ash. The reactive silica in the bottom ash strongly affected the formation of tobermorite. The needle-like tobermorite in the control sample was transformed into plate-like tobermorite with the increase of bottom ash up to 40% and the crumbled foiled tobermorite and grass-like C-S-H structure formed in ACC with 100% bottom ash. It is also evident that heavy metal concentrations in the leachates of AAC and autoclaved water are far lower than recommended in the GB5085.3-2007.

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1. Introduction

Autoclaved aerated concrete (AAC) is widely used in building construction due to its low density, low thermal conductivity, low shrinkage and high heat resistance [1,2], which can be used for floors, trench fills, roof insulation [3,4] and other insulating purposes, as well as to make masonry units [5]. Generally, the commercialized AAC is a calcium-silicate autoclaving porous material, which is usually produced with cement and lime as calcareous materials, with quartz-rich sand or fly ash as siliceous materials, and small quantities of aluminum powder as pore-forming agent. To extend the range of raw materials and lower the cost of production, the feasibility of preparing AAC from industrial wastes have

been proposed, such as fly ash [6], air-cooled slag [7], coal bottom ash [8], efflorescence sand [9], copper tailings [10] and carbide slag [11], etc.

Incineration is one of the most effective methods of dealing with municipal solid waste (MSW), with the advantages of reducing, stabilizing, detoxifying and recycling solid wastes [12]. As a consequence two main solid by-products (MSWI bottom ash and fly ash) are produced after the incineration process. Accounting for nearly 80% by mass, MSWI bottom ash is the most significant by-product, which represents 25–30% in mass and 10% in volume of incinerated waste [13,14]. MSWI bottom ash contains much less leachable heavy metals and highly toxic organic substances, such as dioxins, as compared to incineration fly ash [15]. The chloride content in MSWI bottom ash is also much less than that in fly ash [16]. All these make MSWI bottom ash a potential waste for recycling and utilization for civil engineering applications [17].

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Several researchers have also used MSWI bottom ash to replace part of Portland cement or aluminum powder in autoclaved aerated concrete [18,19]. In addition, MSWI bottom ash is mainly composed of amorphous silica (usually more than 50 by wt%), alumina, iron oxide and calcium oxide. It also can be used as a silica source in the production of AAC.

The overall aim of the present study was to evaluate the feasibility of using MSWI bottom ash to replace quartz sand in production of AAC. Influence of addition and fineness of MSWI bottom ash on the physical-mechanical properties of AAC was investigated. Meanwhile, the leaching toxicity test was also conducted on the AAC containing bottom ash to evaluate the environmental safety. The results can provide the basis of recycling utilization of MSWI bottom ash.

2. Experimental

2.1. Materials

MSWI bottom ash used in this study was obtained from the Jiangxia MSW Incineration Plant in Wuhan, China. A pre-treatment of bottom ash was carried out to separate the ferrous and non-ferrous elements in the factory. The bottom ash as received come from the waste incineration platform is mainly irregular shape in irregular shape with the middle size of 18 mm. MSWI bottom ash was dried and ball-milled into fine powder for different grinding time. Mechanical grinding of the bottom ash has been used to reduce particle size and increase chemical activity in the hydrothermal process.

Cement and quicklime were used as calcareous materials. Cement (P.O. 42.5) was purchased from Huaxin Cement Co., Ltd. Quicklime and quartz sand were obtained from Shenzhen Building Material, Wuhan. The calcium sulfate dehydrate (gypsum, analytically pure) was supplied by Sinopharm Chemical Reagent Co., Ltd. Al powder, as the gas producing agent, shows a water coating surface of 5417 cm²/g and 86% active Al content. The chemical compositions measured by means of XRF for the cement, quicklime, quartz sand and bottom ash were shown in Table 1.

2.2. Sample preparation

The mixture proportion of each sample was shown in Table 2. The content of cement, gypsum, Al powder and water to dry materials ratio (W/R) for each mixture was kept constant. The dry mixture was prepared by mixing cement, quicklime, gypsum and quartz sand with mass ratio of 8:27:3:62. The amount of aluminum

Table 1
Chemical composition of the raw materials (wt%).

Oxide	Cement	Quartz sand	Bottom ash	Quicklime
SiO ₂	23.15	95.68	64.09	2.29
Al ₂ O ₃	6.15	1.55	8.36	1.43
Fe ₂ O ₃	2.88	1.28	2.61	0.71
CaO	58.44	0.31	10.46	72.37
MgO	2.32	0.17	1.17	1.75
Na ₂ O	–	0.12	5.24	–
K ₂ O	0.61	0.84	1.38	0.12
P ₂ O ₅	–	–	1.04	–
SO ₃	2.26	0.02	0.98	0.23
Cl	–	0.03	0.1	0.01
LOI	4.19	–	4.66	21

Table 2
Mix proportion of each sample (wt%).^{*}

Sample	Calcareous		Siliceous		Gypsum	Al powder	W/R
	Cement	Quicklime	Quartz sand	Bottom ash			
Control	8	27	62	0	3	0.14	0.58
G2-BA20	8	27	49.6	12.4	3	0.14	0.58
G2-BA40	8	27	37.2	24.8	3	0.14	0.58
G2-BA60	8	27	24.8	37.2	3	0.14	0.58
G2-BA80	8	27	12.4	49.6	3	0.14	0.58
G2-BA100	8	27	0	62	3	0.14	0.58
G3-BA40	8	27	37.2	24.8	3	0.14	0.58
G4-BA40	8	27	37.2	24.8	3	0.14	0.58

^{*} Sample G2 was grinded for 20 min. G3 and G4 were grinded for 30 min, 40 min.

powder and water was 0.14% and 58% by weight of dry mixture. The bottom ash was used at 0%, 20%, 40%, 60%, 80% and 100% replacement by weight of quartz sand to prepare AAC samples containing bottom ash. In the following text, the AAC samples containing bottom ash were symbolized as G2-BA20, G2-BA40, G2-BA60, G2-BA80 and G2-BA100, respectively. Furthermore, to evaluate the influence of fineness of bottom ash on the properties of AAC, the replacement level of quartz sand by bottom ash was kept constant as 40%. The AAC samples containing bottom ash with different fineness were symbolized as G2-BA40, G3-BA40 and G4-BA40.

A high-speed shear mixer was employed to prepare the samples using the following mixing procedures:

- Conduct sonication on the aluminum powder in deionized water using a horn sonicator (VCX 500 W) for 60 s to ensure that the aluminum powder is well dispersed. In order to accelerate the digestion of quicklime and the early delivery rate of aluminum powder, the water used in the experiment need to be heated to 50 °C.
- Mix the cement, quicklime, quartz sand, bottom ash, gypsum and warm water at slow speed (2000 rpm) for 120 s in the mixer. Afterwards, add the Al powder solution slowly into the slurry within 15 s. Switch the mixing speed to high speed (4000 rpm) and mix for 120 s.
- Stop the mixer and quickly scrape out all the slurry and pour into the mould of 100 × 100 × 100 mm³. Put the mould into humidity chamber at 45 °C and 40 RH% for 24 h to promote gas generation from foaming agent. After that, cut the swollen part to flat and demold to get the green body.
- Put the green body into an industrial autoclave for hydrothermal reaction at 190 °C and 1.5 MPa for 10 h to obtain the final autoclaved aerated concrete samples.

2.3. Methods

Particle size distribution of MSWI bottom ash was measured by a particle size analyzer (Malvern Mastersizer 2000). The chemical composition of the raw materials was measured by sequential X-ray fluorescence spectrometer (XRF, PANalytical, B.V Axios advanced).

The gas-foaming rate was recorded by the change volume value every 2 min of 100 mL fresh paste in a 250 mL measuring until the value had no change. The bulk density and compressive strength of the AAC samples were determined according to the Chinese standard GB/T 11969-2008 [20]. Thermal conductivity of AAC samples was determined by a QTM-500 quick thermal conductivity meter according to Chinese standard GB/T 10297-1998 [21]. Five samples were carried out in each performance test.

Mineralogical phase composition of bottom ash and autoclaved aerated concrete samples was analyzed by X-ray powder diffraction (XRD, Bruker D8) from 5° to 70° with the scan speed 2° per minute. Morphology evaluation of bottom ash and hydration production of AAC samples was characterized by field emission scanning electron microscopy (FESEM, JSM-2100F). A differential scanning calorimetry and thermogravimetric (NETZSCH STA449F3) was employed to study the hydration products in the AAC samples with a heating rate of 10 °C/min from room temperature to 1000 °C.

Leaching toxicity of heavy metals in MSWI bottom ash and AAC samples was determined according to Chinese standard HJ/T 299-2007 [22]. The concentration of heavy metals was characterized by inductively coupled plasma atomic emission spectrometry (ICP-AES, Perkin Elmer Optima 4300DV).

3. Results and discussion

3.1. Characterization of MSWI bottom ash

Fig. 1 shows the XRD pattern of MSWI bottom ash. It can be seen that the main crystal phases are quartz (SiO₂), calcite (CaCO₃)

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