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Feasibility study on utilization of municipal solid waste incineration bottom ash as aerating agent for the production of autoclaved aerated concrete

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ABSTRACT

Instead of pre-treating IBA to remove or to immobilize metallic aluminum, this paper proposes to utilize IBA as aerating agent to replace costly aluminum powder and as silica source to partially replace silica flour/fly ash in the production of autoclaved aerated concrete (AAC). IBA-AACs with density ranging from 600 to 800 kg/m^3 were successfully synthesized by using IBA as aerating agent. For a given density, the compressive strength of IBA-AAC is higher than that of AAC due to the formation of more uniform pore structure with smaller pore size in IBA-AAC. The free drying shrinkage of IBA-AAC decreases with increasing IBA content. This may be attributed to the porosity of IBA-AAC increases while the strength and stiffness of IBA-AAC decreases with increasing IBA content. As a result, the moisture loss due to drying is faster and the resistance to volume change is reduced in IBA-AAC with higher IBA content.

1. Introduction

Aerated concrete is a lightweight material in which a uniform cellular structure of air voids distributed throughout a matrix of cement paste of mortar. With extremely low density (500 kg/m^3) and thermal conductivity (0.1 W/m-K), aerated concrete is an ideal material for thermal insulation and sound-proofing [1,2]. Aerated concrete can be used for floors, trench fills, roof insulation [3,4] and other insulating purposes, as well as to make masonry units [5]. The introduction of gas in aerated concrete is achieved usually by the use of finely divided aluminum powder. The aluminum reacts with the soluble alkalis in the cement/lime slurry to generate small bubbles of hydrogen [6]. To improve the mechanical strength of aerated concrete, autoclaving that is high-pressure steam curing is generally used. Typical mix proportion of such autoclaved aerated concrete (AAC) can be found in Table 1. Pozzolans [7], microsilica sand, silica flour, and other silica sources such as zeolite [8] is used to modify the hydration sequence and prevents the formation of α-C_2SH during autoclaving [9].

Municipal solid waste incineration bottom ash (IBA) is the ash residual after incineration of municipal solid waste. About 80% of the ash generated from the solid waste incineration is IBA [10]. IBA contains much less leachable heavy metals and highly toxic organic substances, such as dioxins, as compared to incineration fly ash (IFA) [11]. The chloride content in IBA is also much less than that in IFA [12]. All these make IBA a potential waste for recycling and utilization for civil engineering applications. Several studies have been carried out to evaluate the potential use of IBA for civil engineering applications [12,13]. Current state-of-the-art reuses IBA for road construction, embankment, pavement, aggregate and filler for concrete. Some major drawbacks, however, hinder the wide application and acceptance of IBA and are summarized below.

- IBA may be used to replace the materials in the base course and sub-base for road construction [14–17]. The main concern of this type of application is leaching of heavy metals into soil and underground water which can lead to serious environmental problem. Yet, long-term leaching mechanisms are still matter of research [18].
- It has been reported that the use of IBA as concrete aggregates can lead to expansion and cracking of concrete due to the reaction between metallic aluminum in IBA and cement [19–21].

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- Although pre-treatment, such as vitrifying, may address some of the issues, the high cost/energy associated with those processes make them unattractive for practical application [18].

IBA is rich in calcium oxide, silicon oxide, and aluminum oxide and can be used as raw material for cement production [22,23]. In addition, IBA contains a noticeable amount of metallic aluminum due to the increasing growth of incineration of household waste [12]. Unlike ferrous metal which can be easily extracted, the recovery efficiency of non-ferrous metal is relatively low. Traditional eddy current separation method shows an average recovery efficiency of 30% of the aluminum fed into the furnace of the incineration plant [13]. However, it was reported the recovery ratio for fine IBA particles (5–12 mm) is nearly zero [18].

As can be seen in Table 1, aluminum powder represents 10% of the total material cost of AAC. Instead of pre-treating IBA to remove or to immobilize metallic aluminum, this paper proposes to utilize IBA as aerating agent to replace costly aluminum powder and as a silica source to partially replace silica flour/fly ash in the production of AAC. In the following sections, a feasibility study was carried out to evaluate the potential use of IBA as aerating agent and as silica source for the production of AAC. Results on hydrogen generation from IBA in cement-based system were reported. Several IBA-AACs were synthesized along with control samples produced by using pure aluminum powder as conventional aerating agent. The physical and the mechanical properties of the resulting IBA-AACs were experimentally determined and the microstructure of IBA-AACs was studied.

2. Experimental program

2.1. Hydrogen generation from IBA

To understand hydrogen generation from incineration bottom ash (IBA) in autoclaved aerated concrete (AAC) system, tests were carried out to evaluate the effects of particle size on the hydrogen generation from IBA. Table 2 summarizes the hydrogen generation tests. Aluminum powder was tested as the control. Saturated calcium hydroxide solution was used as alkaline source to investigate hydrogen generation of metallic aluminum in cement-based system.

Table 1
Typical mix proportion and cost structure of AAC incorporating aluminum powder as aerating agent.

Material	Mix proportion (kg/m^3)	Unit price ($/ton)	Cost ($/m^3)	Cost ratio (%)
Cement	49	123	6.0	26
Silica flour/coal fly ash	490	11	5.4	25
Lime	133	65	8.6	38
Gypsum	28	16	0.4	2
Aluminum powder	0.46	4,200	1.9	9
		Total	22.3	100

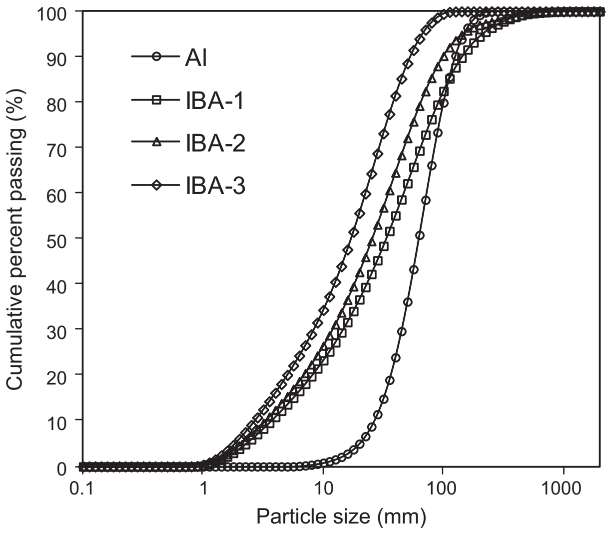

Fig. 1. Gradation curves of aluminum powder (average particle size of 70.4 μm) and three IBAs (average particle size of 61.2 μm, 46.1 μm, 23.2 μm, respectively).

Table 3
Chemical composition (by mass) of IBA and coal fly ash.

Major oxides content (%)	IBA	Coal fly ash
SiO_2	32.75	50.30
CaO	29.06	2.70
Fe_2O_3	10.02	10.60
Al_2O_3	8.57	23.20
P_2O_5	4.77	0.28
SO_3	3.01	1.90
Na_2O	2.87	0.54
MgO	1.75	0.63
TiO_2	1.57	1.27
K_2O	1.24	1.13
Loss on ignition	6.60	7.09

2.1.1. Raw materials

IBA was collected from Keppel Seghers Tuas Waste-to-Energy incineration plant, Singapore. IBA granular was grinded into three sizes and the average particle sizes of the resulting IBA powder are 61.2 μm (IBA-1), 46.1 μm (IBA-2), and 23.2 μm (IBA-3), respectively. Laboratory grade aluminum powder with 99.7% in purity with an average particle size of 70.4 μm was used as the control study. Fig. 1 shows the gradation curves of aluminum powder and three IBAs.

Table 3 provides the chemical composition of IBA through X-ray fluorescence (XRF) analysis. As can be seen, the major oxides are CaO, Al_2O_3, SiO_2, and Fe_2O_3 in IBA. Fig. 2 shows the XRD pattern of IBA. It was found the main crystalline compounds in IBA are quartz and calcium carbonates. The humps in between $2\theta = 20$–40 degree indicates IBA consist of some amorphous phases. These make IBA a potential supplementary cementitious material.

Table 2
Tests on hydrogenation generation from IBA (aluminum powder as control).

Test no.	Type of powder	Particle size	Alkaline solution				$V_{H_2(1\ atm,\ 23\ C)}$ per gram of powder at 3 h (mL/g)
		(μm)	Type	Concen. (mol/L)	pH	Temp. (°C)	
1	Al	70.4	$Ca(OH)_2$	0.0016	11.5	60	582.64
2	IBA-1	61.2	$Ca(OH)_2$	0.0016	11.5	60	0.97
3	IBA-2	46.1	$Ca(OH)_2$	0.0016	11.5	60	1.95
4	IBA-3	23.2	$Ca(OH)_2$	0.0016	11.5	60	5.84