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Autoclaved aerated concrete incorporating waste aluminum dust as foaming agent

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HIGHLIGHTS

- Al dust is used as foaming agent to produce AAC.
- 15.6 g of Al dust generates the same amount of gas as 1 g of Al powder.
- Al dust causes rapid stiffening of paste.
- Al dust-AAC possesses a density of 800 kg/m^3 and a compressive strength of 2.5 MPa.

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ABSTRACT

Aluminum dust is a waste from aluminum dross recycling industry. Instead of treating aluminum dust to remove or to immobilize aluminum metal for landfill disposal, a novel approach of utilizing aluminum dust as foaming agent in replacement of costly aluminum powder for the synthesis of autoclaved aerated concrete (AAC) is proposed. Results show that 15.6 g of aluminum dust is able to generate the same amount of gas as 1 g of aluminum powder and both have comparable gas generation rate. Inclusion of aluminum dust causes rapid stiffening of fresh paste while the use of aluminum powder does not change the yield stress development of AACs. As a result, volume expansion and density of Al dust-AAC remains almost unchanged with increasing dosage of aluminum dust. Al dust-AACs; however, possess smaller voids due to higher yield stress of paste. The use of aluminum dust as foaming agent may not achieve a very low density AAC, but it does not compromise the mechanical properties of the resulting Al dust-AACs, which possess a density of around 800 kg/m^3 and a compressive strength of about 2.5 MPa in this study. Aluminum dust thus can be considered as alternative foaming agent for AAC production.

1. Introduction

Global demand of aluminum increases continuously and annual production of aluminum exceeds 49 million tons worldwide as of 2014 [1]. Aluminum dross is the by-product generated from the aluminum smelting process. More than 5 million tons of aluminum dross is generated globally each year [2]. Aluminum dross is generally categorized into white dross and black dross according to its metal content. White dross has higher recoverable aluminum metal (15–70%) while black dross contains only 12–18% recoverable aluminum metal [3]. It has been reported that aluminum dross may be used for the production of refractory materials [4], Al-alumina composites [5] and aluminate cement [6]. The most common practice in industry; however, is to extract aluminum metal from aluminum dross as shown in Fig. 1. Aluminum dross is first mechanically crushed, followed by a sieving process to separate aluminum metal rich particles (coarse particles) from the residue (aluminum dust) [7]. The aluminum metal rich particles are re-melted and cast into ingot for resale. The aluminum dust; however, has low metallic aluminum content (below 10%) which is not economically attractive for further extraction of aluminum metals, and therefore is often considered as waste and disposed of by landfill.

Aluminum dust generates hydrogen gas when in contact with water, especially in alkaline environment, leading to explosion [8]. Aluminum dust is therefore regarded as hazardous waste and needs to be treated before landfill. Different treatment methods have been proposed and reported in literature. For example, aluminum dust can be treated by aqueous dissolution at 60 °C for 48 h to reduce its reactivity [9]. A combined hydrolysis and heat

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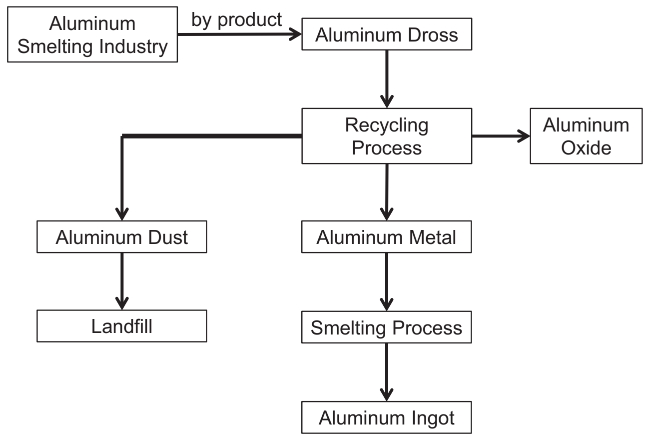

Fig. 1. Flow chart of aluminum dross recycling process.

treatment was applied to covert aluminum dust into an inert material [10]. It has also been shown that aluminum dust can be stabilized with gypsum [11]. Additional cost is therefore associated with the disposal of aluminum dust.

Autoclaved aerated concrete (AAC) is a lightweight building material which can be used to produce blocks, wall panels, floor, and roof panels. With extremely low density (less than 1000 kg/m^3) and thermal conductivity (0.1 W/m-K), AAC is also an ideal material for thermal insulation [12]. The low density of AAC results from the uniform cellular structure of air voids distributed throughout a matrix of cement paste or mortar. The introduction of gas in AAC is achieved usually by the inclusion of finely divided aluminum powder. The aluminum reacts with water in the presence of soluble alkalis in the cement slurry to generate small bubbles of hydrogen. The properties of AAC depend on the aeration kinetics of the foaming agent and the fresh properties of the paste [13]. Proper coordination of the two is the key to produce AAC with optimized physical and mechanical properties [14]. A reference AAC mix according to [15] is shown in Table 1. As can be seen, very small amount of cement is used to reduce the cost. Lime is added to provide additional calcium resource. Furthermore, hydrolysis of lime quickly increases the alkalinity of fresh paste and facilitates gas generation from aluminum powder. Micro silica sand or fly ash is often used as the silica source to modify the hydration sequence so that tobermorite can form during the hydrothermal process, i.e. autoclaving, which increase the strength of AAC. The addition of gypsum (setting time around 30 min) increases the green strength of AAC paste after pre-curing. While only a small dosage of aluminum powder is needed for the production of AAC, it represents about 10% of the total material cost due to the high unit price of aluminum powder.

Instead of treating aluminum dust to remove or to immobilize metallic aluminum for landfill disposal, this study utilizes aluminum dust as foaming agent to replace costly aluminum powder for the synthesis of AAC. Properties and aeration kinetics of aluminum dust was characterized and investigated. The influence of using aluminum dust as foaming agent on the fresh properties of AAC paste and the hardened properties of the resulting Al dust-AACs were documented and discussed.

2. Experimental program

2.1. Raw materials

Type I Portland cement, micro silica sand (SiO_2 with 99% in purity and average particle size of 80 μm), lime (CaO with >90% in purity), gypsum ($CaSO_4{\cdot}2H_2O$ with 99% in purity), and aluminum dust were used to prepare Al dust-AAC samples. Chemical compositions of Type I Portland cement and aluminum dust are summarized in Table 2. Waste aluminum dust was collected from a local factory, which recycles aluminum dross from primary smelters and die-casters, with a production capacity of 1200 tons per month. During the recycling process, aluminum dross (white and black) is first milled and screened. Particles above 1.2 mm are fed into the furnace to produce metal aluminum, which is subsequently cast into ingots. Aluminum dust is collected in cyclones and dust collector systems. To prepare the reference AACs, industrial grade aluminum powder with 99.9% in purity and an average particle size of 45 μm was used.

2.2. Mix design and sample preparation

Table 3 summarizes the mix proportions of Al dust-AACs and the corresponding reference AACs. Three levels of aeration were designed by controlling the dosage of foaming agent in the mix design. Aluminum powder was used to prepare the reference AAC mixes, while the corresponding dosage of aluminum dust (i.e. 15.6 times that of aluminum powder) was used to generate the same amount of gas in the Al dust-AAC mixes. The corresponding dosage was determined by the aeration tests in the following section.

To prepare the fresh paste, silica sand and gypsum were dry-mixed first followed by the addition of two-thirds of water and mixed for one minute. Portland cement was then added into the fresh mixture and mixed for another minute. Lime together with the remaining one-third of water was added into the paste and mixed for another minute. The foaming agent, either aluminum powder or aluminum dust, was added last and mixed under high-speed for 15 s. Immediately after mixing, the fresh paste was poured into cubic molds (50 mm) and placed in an environmental chamber for pre-curing/rising at 60 °C and 98 RH% for 6 h to promote gas generation from foaming agent. After this, specimens were demolded and autoclaved in a high pressure autoclave at 210 °C and 2 MPa for 18 h. After the specimens were taken out from autoclave, excessive material on the casting surface due to aeration and rising of the fresh mixture was removed by saw cutting to ensure a flat surface.

Table 1
A reference mix design of AAC [15] and corresponding material cost.

Material	Mix proportion (kg/m^3)	Unit price (S$/ton)	Cost (S$/m^3)	Cost ratio
Cement	49	152	7.4	26%
Sand	490	14	6.9	25%
Lime	133	80	10.6	38%
Gypsum	28	20	0.6	2%
Aluminum powder	0.46	5200	2.4	9%
		Total	27.9	100%