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Pre-treatment of municipal solid waste incineration (MSWI) bottom ash for utilisation in cement mortar

Nabajyoti Saikia [a,b,*], Gilles Mertens [c], Koenraad Van Balen [d], Jan Elsen [c], Tom Van Gerven [b], Carlo Vandecasteele [b]

[a] School of Basic Sciences, Kaziranga University, Koraikhowa, Jorhat 785006, India
[b] Department of Chemical Engineering, Katholieke Universiteit Leuven, W de Croylaan 46, 3001 Leuven, Belgium
[c] Applied Geology & Mineralogy Research Group, Department of Geology, Katholieke Universiteit Leuven, Celestijnenlaan 200E, 3001 Heverlee, Belgium
[d] Department of Civil Engineering, Katholieke Universiteit Leuven, W de Croylaan 46, 3001 Heverlee, Belgium

HIGHLIGHTS

- Two methods were applied to improve the qualities of two types of municipal solid waste incineration ash samples.
- Treated ash samples were used as partial replacement of fine aggregate in cement mortar preparation.
- The adopted methods considerably improved their properties for using as fine aggregate by removing harmful components.
- The leaching of investigated toxic elements from the cement mortar containing ash samples met the specifications.

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ABSTRACT

The removal of elemental aluminium, sulphate and harmful organics from two types of MSWI ash samples, the sand sized (0.1–2 mm) fraction of MSWI bottom ash from a grate furnace (SF), and boiler and fly ash from a fluidized bed incinerator (BFA), were done to use as fine aggregates in preparation of cement mortar. Results indicate that the chemical treatment by 0.25 M Na_2CO_3 solution can dissolve the Al and the sulphate bearing minerals from the BFA and therefore enhance its quality to use as a fine aggregate in cement mortar preparation. On the other hand, heat treatment at about 675 °C before Na_2CO_3 treatment is necessary to improve the quality of SF for using as a fine aggregate. The compressive strengths of mortars improve significantly due to the partial replacement of sand by heat and Na_2CO_3 treated ash samples. The proposed treatment methods slightly change the toxic element leaching behaviours of the ash samples. The concentrations of toxic elements in the leachates generated from the treated ash samples as well as the leachates generated from the mortars containing these ash samples are well within the regulatory limits.

1. Introduction

The generation of municipal solid waste (MSW) is increasing rapidly due to recent world-wide rapid urban expansion. These wastes create several environmental problems and therefore the management and treatment of MSW are very important tasks for sustainable growth of our society [1]. Landfilling in suitable places and recycling as construction materials are the major disposal techniques of these wastes. Now-a-days, a large portion of MSW are recycled and reused after various types of treatment and separation processes. Therefore, before recycling or disposal, treatment methods such as chemical (e.g. phosphate treatment), biological (e.g. composting) and thermal methods (e.g. incineration) are normally applied to remove undesirable components from MSW [1].

Currently, huge amounts of MSW are incinerated all over the world to reduce the volumes of waste as well as for various recycling purposes of these wastes. Usually, MSW incineration generates three types of solid residues: bottom ash, fly ash and air-pollution control residues [1–3]. The key management options of these wastes are the land filling or recycling. Normally, municipal solid waste incineration (MSWI) ash is toxic in nature because of the presence of various toxic inorganic and organic components such as heavy metals and dioxins. These ash also contain high

* Corresponding author at: School of Basic Sciences, Kaziranga University, Koraikhowa, Jorhat 785006, India.
E-mail address: saikianj@gmail.com (N. Saikia).

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amount of various soluble salts such as chlorides and sulphates. Therefore, prior treatment before their landfilling and recycling is necessary [1,4–8]. Now-a-days, several techniques such as cement based solidification/stabilization, melting, stabilization using some chemical compounds and extractions of toxic components using some reagents are applied to treat various types of MSWI ash [9].

The fly ash and bottom ash, generated from MSW incineration can also be used in cement and concrete productions as the bulk chemical compositions of these wastes are similar to the compositions of various raw materials used in cement and concrete productions. In fact, several studies were undertaken on the utilisations of different types of MSW incineration ash in cement and concrete productions. MSWI fly ash can be used as a raw material in various types of cement clinker productions [10–14]. The granular portion of concrete (fine and coarse aggregates) can be replaced by the bottom ash [15,16]. Ground bottom ash can be used as a pozzolanic additive into cement [17,18]. The MSWI bottom ash can also be used in some other civil engineering applications such as in road construction or as a road base material [19,20].

In view of the recycling of MSWI ash as pozzolanic additives in cement or granular replacement in concrete, cement based products (mortar or concrete) containing these ash must meet the technical and environmental requirements such as sufficient strength, and durability performances as well as the leaching limits of toxic elements from the product [21]. Therefore, prior treatment of MSWI ash is often necessary to decrease the concentrations or mobilities of hazardous components [1,4,8,13,22,23].

In a previous study, it was shown that the sand sized (0.1–2 mm) fraction of MSWI bottom ash generated from a grate furnace (SF) and coarse fraction of a fly ash generated from a fluidized bed incinerator (BFA), could not be used as a fine aggregate in cement mortar due to the presence of deleterious components, particularly elemental Al, high amounts of sulphate in both ash samples and organic matters in SF [7]. The presence of elemental Al in these wastes generates H_2 gas and $[Al(OH)_4]^-$. At high pH, $[Al(OH)_4]^-$ can combine with SO_4^{2-} and Ca^{2+} to form expansive products including ettringite, which drastically reduce the compressive strengths of the mortars. Sulphate may also form expansive sulphate minerals in hardened concrete (delayed ettringite formation), which can deteriorate the durability performance of concrete. The SF also contains small amounts of organic impurities, consisting mainly of fulvic and humic acids along with a hydrophylic portion [24]. We have already shown that the organic impurities present in SF are deleterious in nature to use as a fine aggregate in cement mortar or concrete [7]. Therefore it is necessary to treat BFA and SF before any type of application in cement based products development.

Treatment of MSWI ash by water and NaOH solution considerably improves their properties by converting Al into aluminates [15,17]. Treatment of MSWI fly ash by Na_2CO_3 solution before phosphate-based stabilization was also reported [2,25]. The stabilized MSWI fly ash exhibited significant hydraulic reactivity in cement mortar. The proposed treatment also removed the swelling of cement mortar, which was observed due to the mixing of untreated MSWI fly ash with cement [25]. Several other treatment methodologies were also proposed to remove deleterious components from the various types of MSWI ash samples [8,22,26–28].

In this paper, the results of a study on the removal of deleterious components from both ash samples are reported. The major inorganic deleterious components of BFA and SF are metallic aluminium and sulphates [7]. Both samples were therefore treated by using water and aqueous Na_2CO_3 solutions with two different concentrations. The increase in pH > 10, due to the addition of water and Na_2CO_3 solution can convert expansive metallic Al into some other non-expansive aluminium compounds. Additionally, the addition of Na_2CO_3 solution can remove sulphates from the ash samples by converting less soluble $CaSO_4$ type minerals into more soluble Na_2SO_4 (solubilities of Na_2SO_4 and $CaSO_4$ in water at 25 °C are 195 g L^{-1} and 3 g L^{-1} respectively). On the other hand, heat-treatment is necessary to remove the organic fractions from SF.

Aubert et al. also studied the removal of Al and sulphates from MSWI fly ash using sodium carbonate solution before phosphoric acid based stabilisation process [2,25]. However, there are some basic differences between current study and Aubert et al. study such as the differences in the chemical and physical properties of used ash samples and the differences in treatment methodologies. Unlike the present study, where MSWI bottom ash was used as a partial replacement of sand in cement mortar, in Aubert et al. study, MSWI fly ash was used as cement additive. Similarly, in Aubert et al. study, the treatment was done before phosphate based stabilization techniques. On the other hand, in this investigation, only sodium carbonate treatment was done for BFA sample and heat-treatment along with sodium carbonate treatment was done for SF sample.

The changes in mineralogical compositions of both ash samples during treatment were identified by XRD analysis. The mechanical and environmental performances of cement mortars containing treated wastes as a partial replacement of sand were also reported. From the results, we will show that these treatments may be useful for using these types of wastes in preparations of cement mortar and concrete.

2. Materials and methods

2.1. Materials

The details about the generation and characterisation methods of sand fraction (SF) of MSWI bottom ash and the boiler and fly ash (BFA) produce in a fluidized bed incinerator that treats both sludge and high calorific MSW were already reported [7]. The ash samples were collected from the same location as reported in previous publication [7]. The chemical compositions of ash samples were analysed by standard procedures using inductively coupled plasma-mass spectrophotometric (ICP-MS) techniques [7]. The results of particle size analyses of both ash samples are presented in Table 1.

2.2. Treatment of ash samples

Following treatments were adopted to improve the quality of the ash samples.

2.2.1. Water treatment

Since the pH of BFA and SF containing aqueous slurries were ⩾10.4, therefore water treatment of these ash samples can remove elemental Al. This can be represented by the following chemical equations [7]:

$$Al + 2OH^- + H_2O \rightarrow [AlO(OH)_2]^- + H_2\uparrow \quad pH > 7 \tag{1}$$

$$[AlO(OH)_2]^- + H_2O \rightarrow Al(OH)_3 + OH^- \quad pH = 9 - 10 \tag{2}$$

Water can also remove soluble salts such as chlorides and some water soluble sulphates from ash samples.

Table 1
Particle size distribution of BFA and SF.

Sieve size (mm)	Retained (%)			
	BFA		SF	
	Individual	Cumulative	Individual	Cumulative
9.50	0	0	0	0
4.75	0	0	0.92	0.92
2.36	0	0	3.79	4.71
1.18	0.06	0.06	18.77	23.48
0.630	0.50	0.56	16.42	39.90
0.315	28.24	28.80	20.36	60.26
0.150	31.93	60.73	20.96	81.22
0.075	7.71	68.44	5.04	86.26
Bottom tray	31.56	100	13.74	100