Pre-Treatments Of Mswi Bottom Ash For The Application As Supplementary Cementitious Material In Blended Cement Paste

Chen, Boyu; Sun, Yubo; Jacquemin, Loic; Zhang, Shizhe; Blom, Kees; Lukovic, Mladena; Ye, Guang

Publication date
2019

Document Version
Final published version

Published in
Proceedings of the International Conference on Sustainable Materials, Systems and Structures

Citation (APA)
Chen, B., Sun, Y., Jacquemin, L., Zhang, S., Blom, K., Lukovic, M., & Ye, G. (2019). Pre-Treatments Of Mswi Bottom Ash For The Application As Supplementary Cementitious Material In Blended Cement Paste. In M. Serdar, N. Štirmer, & J. Provis (Eds.), *Proceedings of the International Conference on Sustainable Materials, Systems and Structures* (Vol. 1, pp. 187-193). (RILEM Proceedings; Vol. 128). RILEM publications.

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

International Conference on Sustainable Materials, Systems and Structures (SMSS 2019)
New Generation of Construction Materials
20-22 March 2019 – Rovinj, Croatia

PRE-TREATMENTS OF MSWI BOTTOM ASH FOR THE APPLICATION AS SUPPLEMENTARY CEMEMTITIOUS MATREIAL IN BLENDED CEMENT PASTE

Boyu Chen (1), Yubo Sun (1), Loic Jacquemin (1), Shizhe Zhang (1), Kees Blom (2) Mladena Luković (3) Guang Ye (1)

(1) Microlab, Section Materials and Environment, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands

(2) Gemeente Rotterdam, Ingenieursbureau, the Netherlands

(3) Concrete Structures, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands

Abstract

At present, most municipal solid waste incineration (MSWI) bottom ash, as being disposed of as waste, is directly landfilled, raising concern about the environmental issue and potential loss of resources. Given that the natural raw materials used for cement production are being depleted, the recycling of MSWI bottom ash for the application as building materials is meaningful and promising. The feasibility of using MSWI bottom ash as mineral additives in concrete has been demonstrated in the literature. In this research, as-received MSWI bottom ash has high mineral content and shows stable leaching behaviour. But, when used as cement substitute, the residual metallic Al in bottom ash always causes matrix swelling and strength loss by reacting with $Ca(OH)_2$ and releasing H_2 gas. In this research, dry and wet pre-treatment methods were performed to remove the metallic Al in as-received bottom ash (0-2mm). The results show that both of these two methods are effective. When comparing these two methods, wet method is time-consuming but can remove the metallic Al completely; dry method is fast but always has limitation that it can only reduce the metallic Al content by 80%. Regarding compressive strength, the decrease introduced by 10% dry-treated bottom replacement in cement paste is less than that of wet-treated bottom ash. The lower strength development observed in wet-treated bottom ash blended cement may be due to the removal of soluble reactive phases during the treatment.

Keywords: MSWI bottom ash, cement substitute, metallic Al, pre-treatment, compressive strength

1. INTRODUCTION

According to the research conducted by the Worldwatch Institute for its Vital Signs Online service, the growing prosperity and urbanization could double the volume of municipal solid waste (MSW) from today's 1.3 billion tons per year by 2025, challenging environmental and public health management worldwide [1]. Currently, the waste-to-energy technology [2] is considered as an efficient method to deal with the increasing amount of MSW. The incineration process reduces the mass and volume of solid waste [3] dramatically (by 70% and 90%, respectively [4, 5]), as well as the demand of landfilling [6]. But this waste treatment method is always accompanied by the production of new types of solid wastes that include fly ash (FA) and bottom ash (BA). Compared with fly ash, the utilization of bottom ash is more important and shows greater potential, due to its large available quantities and stable leaching behavior. However, several significant drawbacks have been found limiting the utilization of MSWI BA in concrete structures. For example, the reactivity of BA is much lower than Portland cement [7]. For this reason it is commonly used as aggregates alternatives for primary sand and gravel. However, the addition of BA aggregates always causes severe volume expansion and cracking due to the release of hydrogen gas from the redox reaction of the metallic Al that BA contained in the alkaline environment [8]. The goal of this research is to eliminate the metallic Al contained in as-received bottom ash via two different pre-treatment methods and access the possibility of using pre-treated bottom ash as supplementary cementitious material in blended cement paste.

2. MATERIALS AND METHODS

The MSWI bottom ash used in this research, having particle size of 0-2mm, was collected from one of the Dutch waste-to-energy plants. Two pre-treatment methods were selected to remove the residual metallic Al that is hard to extract in the process of metal recovery. Method one is called "dry method", in which metallic Al was sieved out by allowing milled bottom ash to pass through the sieve of 63μm, after enlarging its surface through low-speed ball milling. Method two is to dissolve metallic Al by immersing bottom ash in 0.1 molar NaOH solution for more than one week, and is called "wet method".

In this study, both dry- and wet-treated bottom ash were used as Portland cement substitute. For this purpose, dry-treated bottom ash (<63μm) was used without further treatment and is called "DBA". On the other hand, after wet treatment, the immersed bottom ash was filtered, washed, dried and further milled into fine powder. The bottom ash obtained here is called "WBA".

Cement paste samples were prepared according to EN 196-1. Each specimen has the dimension of 20mm × 20mm × 20mm. After casting, cement paste specimens were firstly cured at room temperature for 24 hours, then de-moulded and wet cured (room temperature, 95% RH) until 28 days. Details of mix design are listed in **Error! Reference source not found.**, where 10 wt.% Portland cement was replaced by treated bottom ash. The water to solid ratio of all the paste was 0.5. Pure Portland cement (CEM I 42.5N) samples were prepared as the reference.

Table 1 Mix design for blended cement paste

Materials			Water to solid ratio (w/s)
CEM I 42.5N	DBA	WBA	
100%			0.5
90%	10%		
90%		10%	

The chemical compositions of as-received and treated bottom ash were determined by X-ray fluorescence (XRF). The mineralogical compositions of treated bottom ash were measured by X-ray diffraction (XRD). The Al content in the bottom ash was calculated by measuring the gas volume generated upon its chemical reaction with NaOH solution.

3. RESULTS AND DISCUSSION

3.1 Metallic Al content

Table 2 shows that both dry- and wet-methods are highly effective in removing residual metallic Al. After dry-treatment, the average metallic Al content was reduced by around 80%. Comparatively, the metallic Al was removed almost completely after wet treatment. This can be attributed to the pores and cracks exist in bottom ash particles (as shown in Figure 3), which make metallic Al easily exposed to the NaOH solution even if it is incorporated inside the bottom ash particles.

Table 2 Metallic Al content in as-received and treated bottom ash

Materials	As-received BA	DBA	WBA
Metallic Al content (wt.%)	0.80 ± 0.03	0.13 ± 0.05	0.03 ± 0.03

3.2 Chemical and mineralogical compositions

The XRF results (in Table 3) indicate that in as-received and treated bottom ash the main components are SiO_2, CaO, Fe_2O_3, and Al_2O_3. When compared with Portland cement, the SiO_2 content in as-received MSWI bottom ash is 37.28%, almost two times of that in cement, but the CaO content (23.86%) is much less, only one-third of that in cement. Besides, much more Al_2O_3 and Fe_2O_3 were found in as-received MSWI bottom ash. After pre-treatment, more SiO_2, but less CaO, Fe_2O_3, and Al_2O_3 were detected in both dry- and wet-treated bottom ash. The Na_2O content in wet-treated bottom ash is slightly higher than as-received bottom ash. This is mainly introduced by the NaOH solution used in wet treatment. The content of heavy metals such as Pb and Cr are very small, less than 1% in both untreated and treated bottom ash.

Table 3 Chemical composition of CEM I 42.5N and MSWI bottom ash

Elements (wt.%)	CEM I 42.5N	MSWI bottom ash		
		As-received	DBA	WBA
SiO_2	18.34	37.28	50.40	49.82
CaO	66.15	23.86	18.34	17.4
Fe_2O_3	3.46	15.27	12.94	10.58
Al_2O_3	4.41	10.48	9.84	10.2
Na_2O	-	0.83	0.56	2.96
K_2O	0.46	1.02	0.82	0.79
MgO	2.16	2.68	2.21	2.52
ZnO	-	0.9	0.75	1.4
PbO	-	0.17	0.67	0.1
Cr_2O_3	-	0.16	0.12	0.09
Cl	-	1.33	0.12	0.13
SO_3	2.63	2.32	0.86	0.36
Others	0	3.71	2.36	3.63

The XRD results (in Figure 1) show that both as-received and treated bottom ash are highly crystalline, with quartz and calcite being the two main crystalline phases along with other phases including akermanite and the main Fe-containing phase magnetite. Compared with as-received bottom ash, the mineralogical composition remains unchanged after both dry and wet treatment.

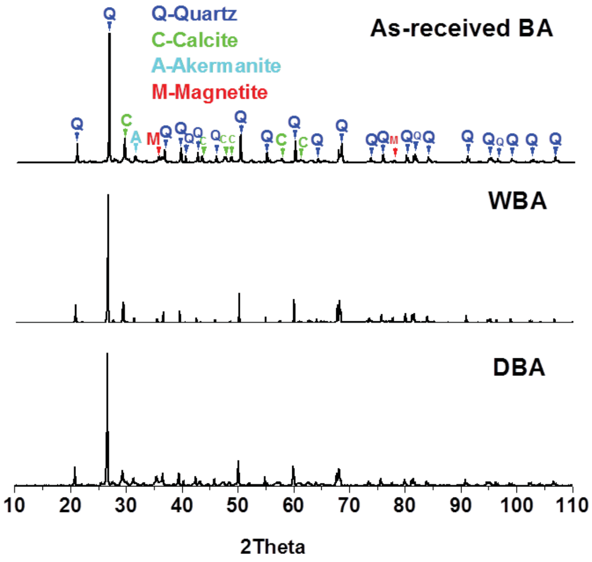

Figure 1: XRD pattern of as-received and treated MSWI bottom ash

3.3 Particle size distribution

In terms of particle size, both dry and wet treatment would lead to material loss and particle size reduction. As illustrated in Figure 2, as-received bottom ash is mainly concentrated in the range of 2-4 and 0.5-1.6mm, while the size of most wet-treated bottom ash is between 0.125-1.6mm. This is because as-received bottom ash particles have an irregular shape and are full of cracks and voids (as shown in Figure 3). When immersed in NaOH solution, the metallic Al embedded inside the particles could be dissolved easily, resulting in particles splitting. In addition, wet-treatment always leads to material loss, especially for the particles as small as dust, which easily adhere to filter paper, and are difficult to remove.

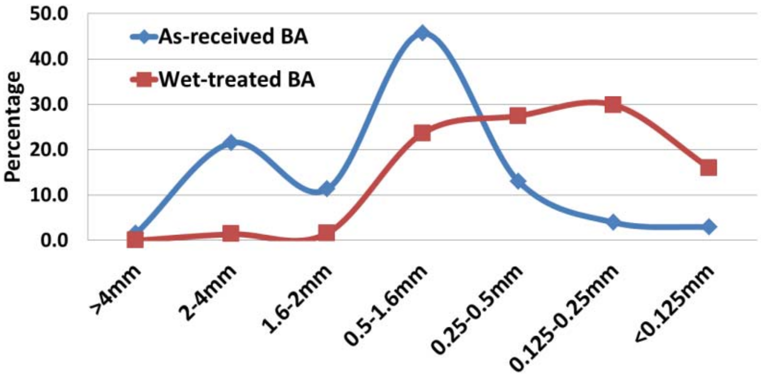

Figure 2: Particle size distribution of as-received and wet-treated bottom ash after sieve analysis

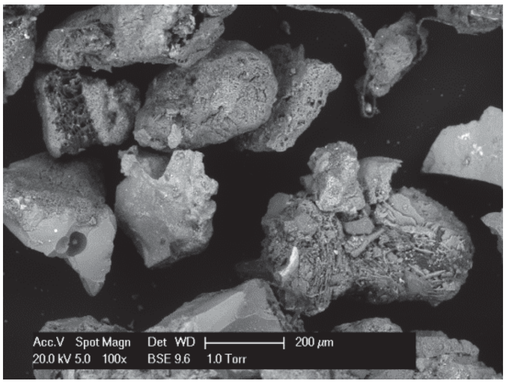

Figure 3: Morphology of as-received MSWI bottom ash (100×)

Figure 4 depicts the particle size distribution of 42.5R cement (D_{50}=35.7µm) and the bottom ash used for sample preparation including DBA and WBA. It is evident that cement has the largest particle size among these three. Besides, it is worth mentioning that considering bottom ash particles become smaller after wet treatment (as shown in Figure 2), less milling time but the same speed was applied in ball mill grinding process, to obtain similar particle distribution as DBA. However, with quartz as its main component, the abrasion resistance of wet-treated bottom ash particles remains the same. The WBA obtained having D_{50} of 27.4µm is coarser than WBA (D_{50}= 14.5µm).

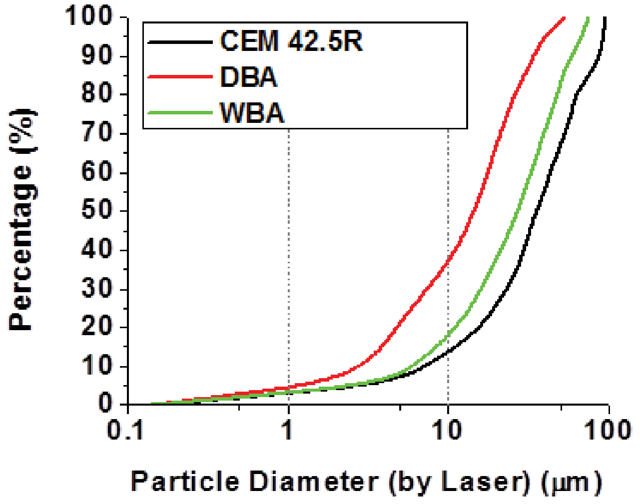

Figure 4: Particle size distribution of materials used for sample preparation

3.4 Compressive strength

As can be seen in Table 4, the replacement of cement with only10% of WBA or DBA could already lead to dramatic decrease in compressive strength after 28 days of curing: around 62% for CEM-WBA and 40% for CEM-DBA. This can be explained by the fact that the reactive phases in treated bottom ash are deficient. Some of the WBA and DBA components may have adverse effect on the cement hydration. When comparing WBA and DBA, WBA has larger particle size, and its negative impact, due to low reactivity, on strength development seems to be higher than DBA. This can be attributed to the possible removal of soluble reactive amorphous phases in wet treatment and the high alkalinity of WBA derived from NaOH immersion. More investigation is needed in these aspects.

Table 4 Average 7- and 28-day compressive strength of pure cement and 10% WBA and DBA substituted cement specimens.

Compressive strength (MPa)	7-day	28-day
CEM	18.7 ± 1.1	41.8 ±1.9
CEM-WBA	12.3 ± 5.3	16.0 ±6.0
CEM-DBA	14.7 ±1.8	25.3 ±3.4

4. CONCLUSIONS

- Both dry- and wet-treatment are effective in removing the metallic Al presented in as-received bottom ash. Dry treatment is fast but has limitation that the maximum metallic Al it can reduce is 80%. Wet treatment is time-consuming, but it can remove the metallic Al completely.
- The mineralogical composition of bottom ash remains unchanged after dry- and wet-treatment, while the chemical composition shows small changes in the main components.

- The use of only 10% of treated bottom ash as cement substitute would decrease more than 40% of the 28-day compressive strength of pure cement. This can be attributed to the deficiency of reactive phase in treated bottom ash and the adverse impact induced by some of the components that are present in treated bottom ash on cement hydration.
- Before the application of bottom ash as supplementary cementitious material, it is necessary to improve its reactivity and remove the harmful components; further research is required in this area.

ACKNOWLEDGEMENTS

Boyu Chen would like to thank Chinese Scholarship Council for their support for her PhD study. Financial support by AVR-Afvalverwerking B.V. and Gemeente Rotterdam are acknowledged. Ruud Hendrix at the Department of Materials Science and Engineering of the Delft University of Technology is acknowledged for the X-ray analysis. Ron Penners, Maiko van Leeuwen, Ton Blom, Arjan Thijssen, and John van de Berg, from the Stevin lab and Microlab at the Faculty of Civil Engineering and Geosciences, Delft University of Technology, are acknowledged for their support for all the experiments.

REFERENCES

[1] http://www.worldwatch.org/bookstore/vital-signs
[2] Leckner, B., Process aspects in combustion and gasification Waste-to-Energy (WtE) units. Waste management, 2015. 37: p. 13-25.
[3] Wiles, C.C., Municipal solid waste combustion ash: State-of-the-knowledge. Journal of hazardous materials, 1996. 47(1-3): p. 325-344.
[4] Li, M., et al., Characterization of solid residues from municipal solid waste incinerator. Fuel, 2004. 83(10): p. 1397-1405.
[5] Sabbas, T., et al., Management of municipal solid waste incineration residues. Waste management, 2003. 23(1): p. 61-88.
[6] Bosmans, A., et al., The crucial role of Waste-to-Energy technologies in enhanced landfill mining: a technology review. Journal of Cleaner Production, 2013. 55: p. 10-23.
[7] Gunning, P.J., C.D. Hills, and P.J. Carey, Production of lightweight aggregate from industrial waste and carbon dioxide. Waste management, 2009. 29(10): p. 2722-2728.
[8] U. Müller, K. Rübner, The microstructure of concrete made with municipal waste incinerator bottom ash as an aggregate component, Cement & Concrete Research 36 (2006) 1434-1443.