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The Investigation of the MSWI Bottom Ash Fines (0-2 mm) as Binder Substitute After Combined Treatments

P. Tang[1], M.V.A. Florea[2], P. Spiesz[3], H.J.H. Brouwers[4]

Abstract

In this study, a series of treatments is used to upgrade the quality of the MSWI bottom ash fines (0-2 mm) from a waste-to-energy plant in the Netherlands. The efficiency of combined treatments on upgrading the quality of fine bottom ash particles to be used as cementitious material is studied. The leaching properties of treated bottom ash fines are analyzed according to the Dutch legislation. Additionally, their physical and chemical properties (density, chemical composition, hydration influence, etc.) are characterized. Finally, the hydration of the cement mixed with treated bottom ash is investigated by calorimetric measurements.

Keywords: MSWI bottom ash, treatments, binder

1. INTRODUCTION

MSWI bottom ash, as the main by-product of waste-to-energy plants, has similar properties to natural building materials ingredients such as sand and aggregates, indicating its application potential in the building field [1–4]. However, heavy metals and salts it contains create an environmental risk which should be reduced before application according to the environmental legislation [5,6]. Therefore, a number of treatments is applied to upgrade the quality of MSWI bottom ash, such as physical separation, washing, weathering, etc. [7], which can clean the coarse bottom ash sufficiently to make its properties comply with the legislation. However, for the fine bottom ash particles (0-2 mm) which contain more heavy metals and salts, these methods are not sufficient because of the smaller particle size of the material. Hence, the fine bottom ash particles need to be treated using different methods to make them environmentally acceptable and suitable as an ingredient for future use in building materials. The literature shows that thermal treatment could reduce the leaching amount of elements in bottom ash and increase its reactivity [8–10]. Moreover, in recent years the replacement of cement by alternatives to decrease the environmental impact and consumption of raw materials have attracted much attention [11,12] . There are studies about the use of incineration bottom ash as cement replacement, for instance Al-Rawas et al. [4] suggested that 20% of cement replacement by bottom ash can reach a 28-days compressive strength of 27.4 MPa (27.3 MPa for the reference). Juric et al. [13] reported that up to 15% of cement can be replaced by bottom ash considering the safety factor. Li et al. [14] investigated the application of municipal solid waste incineration bottom ash in blended cement and suggested that the amount of the bottom ash should be kept below 30%.

Considering the reduction of landfilling of MSWI bottom ash and its use as cement replacement, the main aim of this study is to investigate the appropriate treatment upgrading the properties of MSWI bottom ash fines and the potential of applying the treated bottom ash as cement replacement. Thermal treatment and

[1] *Corresponding author: Eindhoven University of Technology, 5600 MB, Eindhoven, The Netherlands. P.tang@tue.nl*
[2] *Eindhoven University of Technology, 5600 MB, Eindhoven, The Netherlands. m.v.a.florea@tue.nl*
[3] *Eindhoven University of Technology, 5600 MB, Eindhoven, The Netherlands. p.spiesz@tue.nl*
[4] *Eindhoven University of Technology, 5600 MB, Eindhoven, The Netherlands. jos.brouwers@tue.nl*

milling are used in this study to upgrade the bottom ash properties. The characteristics of the treated bottom ash are investigated and the hydration of cement with treated bottom ash additions is studied.

2. METHODS AND MATERIALS

The MSWI bottom ash is provided by the waste-to-energy plant (Attero, the Netherlands), which has an incineration capacity of around 630.000 tons. The received bottom ash is firstly dried at 105 ˚C until a constant mass is obtained. Then, the dried bottom ash is sieved and the fraction of bottom ash particles under 2 mm is chosen to be investigated in this study. The bottom ash is treated as follows:

- Method 1: milling the bottom ash using a planetary ball mill to reduce its particle size, the sample is labelled as BA;
- Method 2: thermal treatment of the bottom ash in an oven under 550 ˚C, and then mill the treated bottom ash, the sample is labelled as 5T;
- Method 3: firstly milling the bottom ash, followed by a thermal treatment at 550 ˚C or 750 ˚C in the oven before use, the samples are labelled as M5T and M7T;
- Method 4: thermal treatment of bottom ash in an oven at 550 ˚C, followed by selecting of the particles below 63 µm after milling, the sample is labelled as 5T/63.

The cement used is Ordinary Portland Cement (OPC) CEM I 52.5 R for all the mixtures in this study; the treated bottom ash after the above mentioned treatments is used as cement replacement by 30% by weight. The chemical compositions of the treated bottom ash and cement are determined by X-ray fluorescence (XRF) and the crystalline phases are observed by X-ray diffraction (XRD, Cu tube, 40 kV, 30 mA, 5-90˚, 0.02˚/step, 2˚/min). The column leaching test is performed on the bottom ash samples following the Dutch standard NEN 7383 (2004). The hydration process of the cement paste with treated bottom ash as replacement is investigated by calorimetric measurements (TAM air calorimeter).

3. RESULTS

3.1. Characteristics of materials

After the thermal treatment at 550 ˚C and 750 ˚C, the colour of the bottom ash changes from dark to red, this is caused by the oxidization of iron and decomposition of organic matter. It can be seen inFigure 1 that the bottom ash particles surface is rough and covered by a dust-like reddish layer after the thermal treatment.

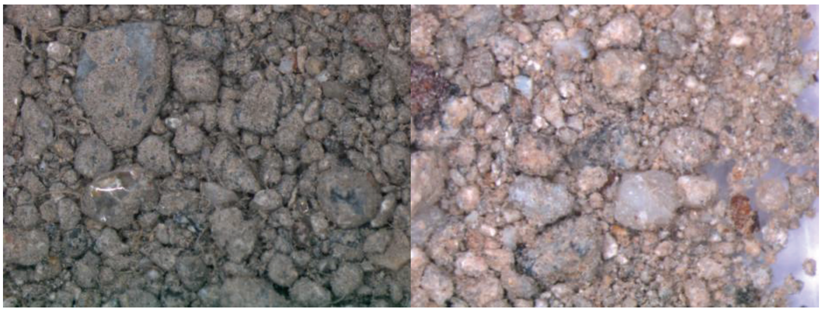

Figure 1. Bottom ash particles before (left) and after (right) 550 ˚C treatment (Optical microscopy)

The chemical compositions of the OPC and treated bottom ashes are shown in Table 1. It is obvious that the bottom ash fines (0-2 mm) mainly has similar compositions as the OPC, such as SiO_2, CaO, Al_2O_3 and Fe_2O_3, which accounts in total for about 70% - 90% wt. of the bottom ash. Compared with the OPC, the treated bottom ashes contain more SiO_2, Al_2O_3 and Fe_2O_3, less CaOand a considerable amount of alkali and alkali-earth oxides, such as Na_2O and K_2O, MgO, etc. Comparing the chemical compositions of the treated bottom ashes, it is noticed that the thermal treatment at different temperatures will not change the chemical compositions.However, after treatment of method 4, the bottom ash fractions below 63 µm contain less SiO2, Fe_2O_3 and higher amount of CaO, Al_2O_3, Cl and SO_3than other treated bottom ashes. This could be due to the removal of the dust-like layer of the coarse particles of bottom ash which contains high amount of salts and other elements.

Table 1 Chemical compositions of Portland cement and treated bottom ash

Element (wt.%)	CEM I 52.5 R	BA	5T	M5T	M7T	5T/63
SiO_2	17.39	39.27	37.26	42.10	41.81	26.70

CaO	66.05	21.88	22.56	20.23	20.32	29.96
Al_2O_3	3.88	10.07	10.33	9.80	9.97	11.80
Fe_2O_3	3.64	12.73	12.76	12.19	12.27	9.83
MgO	1.58	2.02	2.07	2.05	2.12	2.43
Na_2O	-	1.49	1.54	1.55	1.92	1.44
K_2O	0.17	1.29	1.14	0.98	1.11	1.16
CuO	0.02	0.46	0.58	0.51	0.54	0.69
ZnO	0.15	0.90	0.94	0.82	0.83	1.23
P_2O_5	0.64	1.16	1.18	1.11	1.16	1.19
TiO_2	0.27	1.22	1.20	1.17	1.18	1.40
MnO	0.09	0.17	0.18	0.17	0.17	0.20
Cl	0.02	0.76	0.77	0.66	0.57	1.11
SO_3	4.04	5.68	6.11	5.44	5.31	9.24

The XRD results (Figure 2) show that the main crystalline phases in bottom ash fines are quartz (SiO_2), anhydrite ($CaSO_4$), calcite ($CaCO_3$) and hematite (Fe_2O_3). After the thermal treatment at 550 ˚C, the intensity of the hematite peaks increased and the peaks representing calcite decreased. After a 750 ˚C treatment, the peaks indicating calcite are not found and the hematite peaks are higher. The bottom ash after method 4 treatment has higher peaks of calcite and lower peaks of quartz than the other treated bottom ashes. It can be stated that the thermal treatment at 550˚C benefits the oxidation of iron, at the 750 ˚C calcite decomposed and the oxidation of iron is more efficient; the method 4 treatment reduces the amount of quartz (similar result is reported by Qiao et al. [10]).

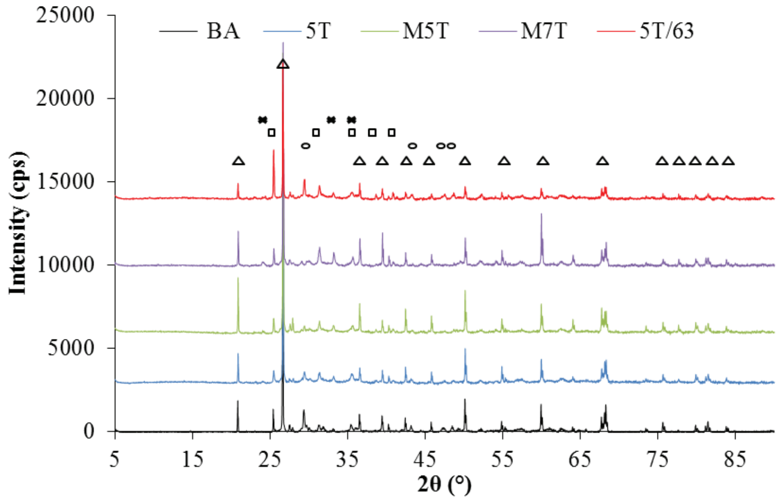

Figure 2. XRD patterns of treated and untreated bottom ash (quartz △ calcite ○anhydrite □hematite ×)

3.2. Leaching properties

According to the Dutch legislation (Soil Quality Decree), the leaching concentration of elements should be below the limiting values, considering the environmental impact and human health. The column leaching test (NEN 7383) is performed on the treated and untreated bottom ash fines and the results are shown in Table 2

The leaching concentration of most elements in the bottom ash from the plant is below the limits and the leaching of antimony (Sb), copper (Cu), molybdenum (Mo), chloride (Cl) and sulphate (SO_3) mostly exceed the limit level. It is obvious fromTable 2 that the leaching concentration of the untreated bottom ash fines is higher than the limit except molybdenum.Afterthe thermal treatment, the leaching of antimony and copper decrease and are well under the limits. However, the leaching of molybdenum is increased, and the fine particles of bottom ash after treatment contain more leachable molybdenum, which can be observed from the leaching of sample 5T/63. The leaching of chloride and sulphateshows no significant change after the thermal treatment, and the leaching of chloride decreases and sulphate increases slightly. It can also be seen that the leachable elements mainly concentrated in fine particles as well as in the dust covering surfaces of larger bottom ash particles.

Table 2. The leachability of elements in treated bottom ash which exceed the limiting value

Elements	Limit value (mg/kg ds)	BA	5T	5T/63
Sb	0.16	0.79	0.037	0.023
Cu	0.9	3.6	<0.050	0.3
Mo	1	0.67	1.4	2.6
Cl	616	4400	3300	6600
SO3	1730	16000	20000	23000

3.3. Hydration properties

It can be seen in Figure 3that the OPC mixed with untreated and treated bottom ash have typical calorimetric curve and the addition of bottom ash influences the heat release rate. The maximum rate of hydration heat relative to the OPC content increases when the OPC is replaced by bottom ash and after about 21 hours of hydration the shoulder which represents the hydration of tricalcium aluminate is more visible than for pure OPC and this shoulder occurs earlier than for pure OPC.

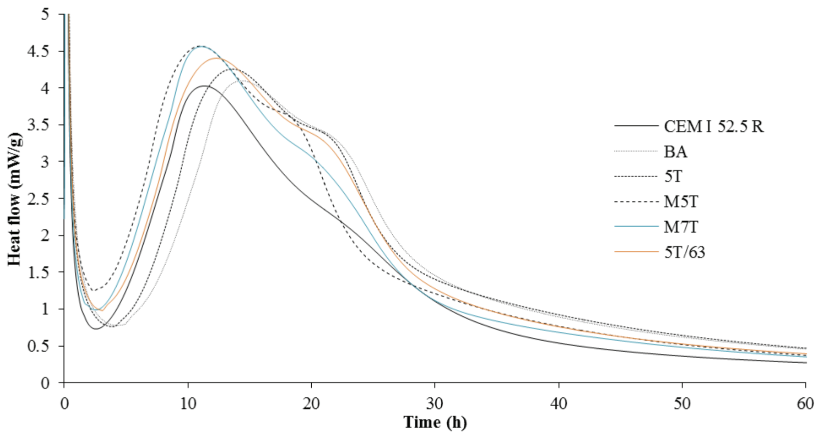

Figure 3. The rate of heat of hydration relative to the OPC content

The replacement of OPC by untreated bottom ash results in a slight increase and delay of the maximum rate of hydration heat relative to the OPC content, these may be attributed to the organic content, anhydrite and low pozzolanic property of untreated bottom ash. After the thermal treatment, the addition of the treated bottom ash increases the maximum rate of the heat release and the delay is decreased, this may due to the anhydrite, and increased pozzolanic properties of the treatedbottom ash [15].

4. CONCLUSION

The properties of the untreated and treated MSWI bottom ash fines (0-2 mm) are studied and the potential of its application as cement replacement is investigated. The following conclusions can be drawn:

1) The characterization of the MSWI bottom ash fines shows that it contains mainly quartz, calcite, anhydrite, etc. and its main chemical compositions are very similar to that of OPC, which indicates its potential to be used as cement replacement.

2) The thermal treatment can reduce the organic content in the bottom ash, and increase its pozzolanic properties. The higher temperature is more efficient on the oxidation of iron, burning of organic matter and decomposition of calcite, which subsequently attribute to the higher pozzolanic properties.

3) The leaching of antimony and copper is reduced and well under the legally prescribed limit after the thermal treatment. However, the leaching of chloride and sulphate is not significantly changed due

to the thermal treatment. The leachable elements mainly concentrate in the dust and fine bottom ash particles, which have large surface area.

4) The replacement of cement with treated bottom ash increases the maximum hydration rate of OPC. Additionally the hydration of the tricalcium aluminate is accelerated and the shoulder which represents this reaction is more visible. Therefore, it could be assumed that the treated bottom ash can potentially be used as cement replacement; however, its leaching should still be considered.

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BIOGRAPHY

P. Tang *studies as a PhD candidate at Eindhoven University of Technology, department of Built Environment since 2011.*

Tang received her BSc in Civil Engineering in 2009 from Xuchang University, Henan, China, and her MSc in Structural Engineering in 2011 from Wuhan University of Technology, Hubei, China. She is now a PhD candidate on secondary raw materials at Eindhoven University of Technology.

She can be contacted at p.tang@tue.nl