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Sintering of Municipal Solid Waste Incineration Bottom Ash

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Abstract: *The sinterability of the bottom ashes from two municipal solid waste (MSW) incinerators in Thailand was investigated. Initially, the bottom ashes were chemically and mineralogically characterised by X-ray fluorescence (XRF) and X-ray diffraction (XRD). Both bottom ashes consisted mainly of CaO and SiO_2, with a relatively high CaO content. After sintering over a temperature range of 1000°C–1125°C, the physical properties, flexural strength, crystalline phases and leaching of heavy metals were examined. Based on the results, the bottom ashes from these two incinerators were able to sinter to high final density without any sintering aid at 1100°C, and the sintered materials had good physical and mechanical properties that complied with the standard.*

Keywords: Bottom ash, municipal solid waste, incinerator, sintering, properties

1. INTRODUCTION

Landfills are a simple and inexpensive method for municipal solid waste (MSW) management. Nevertheless, this method creates long-term environmental effects to the soil, groundwater and atmosphere. Incineration has therefore become an attractive alternative because it can reduce the volume of waste by approximately 90%.[1–3] However, the incineration process still leaves a large amount of solid residues, i.e., bottom and fly ashes, which require space and high management cost for their disposal. To solve the problem of incineration ash disposal, there have been many attempts to reuse these ashes as raw materials in ceramic products such as cement, cement-based products, brick, glass and glass-ceramic.[1–8]

This study is the first part of a research work focused on the reuse of the bottom ash from incinerators in Thailand as a raw material for the production of ceramic materials. The sinterability of MSW incineration bottom ash from two incinerators was investigated and the properties of the sintered materials are analysed in this paper.

2. EXPERIMENTAL

The raw materials used in this study were the bottom ashes collected from two MSW incineration plants located in Phuket and Samui, two islands located in southern Thailand. Before characterisation, both ashes were dried at low temperature (100°C) for 24 hours to eliminate moisture. Their chemical compositions were determined by X-ray fluorescence (XRF; Philips PW1400). The mineralogical crystalline phases present in the bottom ashes were identified by powder X-ray diffraction (XRD; JEOL, JDX-3530) with CuK_{α} radiation.

As-received ashes were filtered through a 140-mesh sieve, and the ashes with particle size less than 1 mm were selected for use in the sample preparation process. After filtration, the bottom ash powders from the two incinerators were wet-milled with alumina media by a conventional process for 18 hours. Next, the slurries were dried at 100°C for 24 hours and passed through a 100-mesh sieve. The green compacts were obtained by uniaxially pressing the ash powders into test bars ($6 \times 7 \times 40$ mm^3) under a load of 7 MPa. The sintering was conducted in a high temperature electric furnace at temperatures of 1000°C–1125°C for 30 min.

The density and water absorption of the sintered samples were determined using the Archimedes method according to ASTM C373-88.[9] The room temperature flexural strength was measured with a universal testing machine (Instron model, 55R4502) by a four-point bending test at a constant crosshead speed of 0.5 mm/min. The crystalline phase was investigated using an X-ray diffraction technique (XRD, JEOL JDX-3530). Characterisation of the leachability of the heavy metals was performed following the toxicity characteristic leaching procedure (TCLP) method 1311.[10] The leached out concentration was then analysed with atomic absorption spectrometry (AAS).

3. RESULTS AND DISCUSSION

3.1 Raw Materials Characterisation

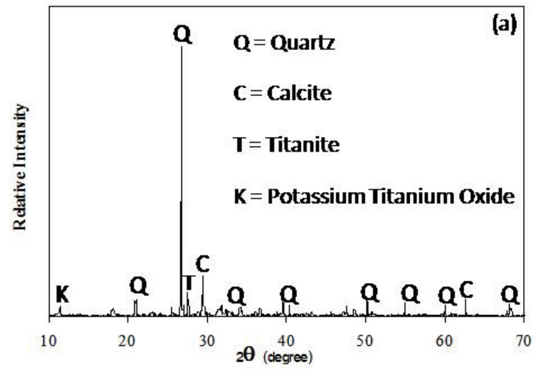
The chemical compositions of the bottom ashes are given in Table 1, in which the data are shown in terms of wt% of oxides. The results show that the bottom ash contains some oxides similar to those found in ceramic and glass raw materials. Both bottom ashes mainly consisted of CaO and SiO_2, with a relatively high content of CaO. The bottom ash from the incinerator in Samui contained a lower CaO content than that of Phuket. Other oxides such as Al_2O_3,

Fe_2O_3, Na_2O, MgO, K_2O and P_2O_5 were also found as minor constituents together with a small amount (< 1 wt%) of TiO_2, ZnO, Mn_2O_3, ZrO_2 and PbO.

Table 1: Chemical composition of the bottom ashes.

Oxides	Composition (wt%)	
	Phuket	Samui
CaO	41.53	37.46
SiO_2	27.73	29.93
Al_2O_3	4.61	7.35
Fe_2O_3	6.20	4.55
P_2O_5	4.24	5.24
SO_3	4.41	1.66
Na_2O	3.27	4.36
K_2O	1.58	2.77
MgO	1.58	1.24
TiO_2	0.93	0.79
PbO	0.09	0.23
ZnO	0.49	0.30
Mn_2O_3	0.21	0.13
ZrO_2	0.03	0.03
Cr_2O_3	< 0.01	< 0.01

Figure 1 shows the XRD patterns of the bottom ashes. The XRD spectra in this figure reveal that several mineralogical crystalline phases are present in the bottom ashes. SiO_2 and $CaCO_3$ were detected as the major crystalline phases in the bottom ash from the incinerator in Phuket, and the minor phases were $K_3Ti_8O_{17}$ and $CaTiO(SiO_4)$. Similarly, the bottom ash from the incinerator in Samui was composed of SiO_2 and $CaCO_3$ as the main phases with some other phases containing $(K,Na)Li_3Ca_7(Ti,Fe,Mn)_2(Si_6O_{18})_2(OH,F)_2$, NaCl and $K_2Ti_8O_{17}$.



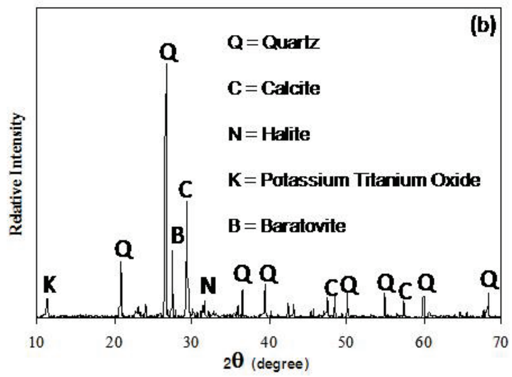


Figure 1: X-ray diffraction patterns of the dried bottom ash from (a) Phuket and (b) Samui.

3.2 Properties of Sintered Samples

To study sintering behaviour, the physical and mechanical properties, including the mineralogy were examined. The bulk densities of the sintered samples after sintering at different temperatures are shown in Figure 2. The densification of the samples increased with an increment in sintering temperatures up to 1100°C. Sintering at a higher temperature resulted in decreased densities of the samples, and the samples melted due to overfiring. Maximum densities of 2.38 and 2.00 g/cm^3 were obtained for the bottom ash sintered at 1100°C from incinerators in Phuket and Samui respectively.

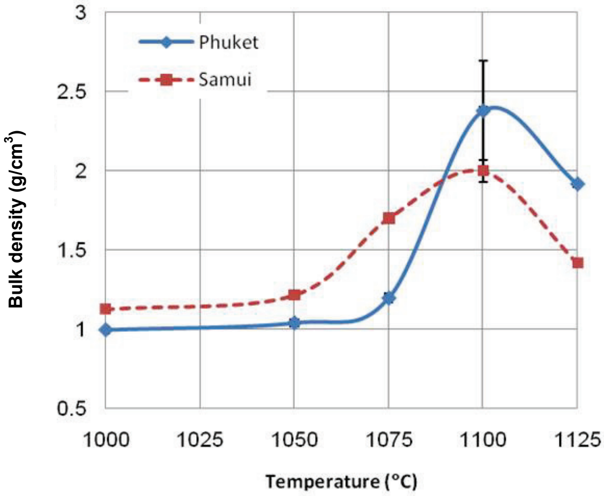


Figure 2: Bulk density of the sintered bottom ashes.

Figure 3 shows the water absorption of the sintered samples as a function of temperature, where the water absorption of the samples decreased as the sintering temperature increased. The samples showed significant reduction of open porosity after sintering at 1100°C, with low water absorption from 0.2–7% for both bottom ashes. The above results indicated that the bottom ashes had the ability to sinter and that they could be sintered to high density at temperatures around 1100°C.

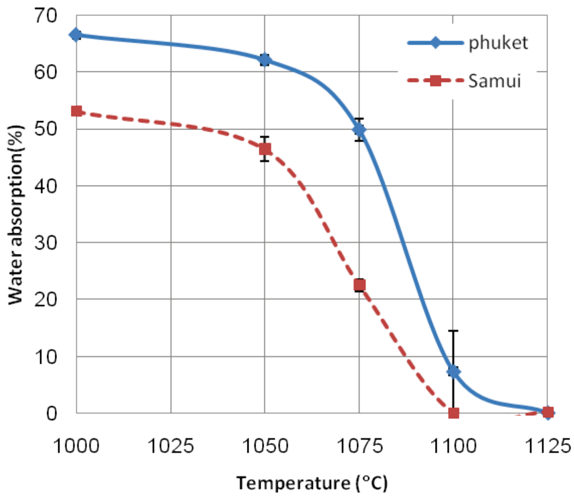


Figure 3: Water absorption of the sintered bottom ashes.

The XRD patterns of the sintered samples are shown in Figure 4. The figure reveals that new crystalline phases different from those found in the starting bottom ash were formed during sintering. Additionally, there were no differences in the crystalline phases detected between the sintered samples produced from the two bottom ashes. Calcium silicate in the form of $CaSiO_3$ was clearly observed as the major crystalline phase together with Ca_2SiO_4 in both of the bottom ashes after sintering at 1100°C.

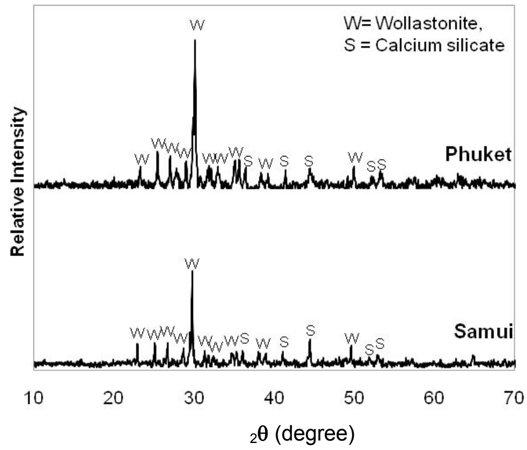


Figure 4: XRD patterns of bottom ash sintered at 1100°C.

The effect of the sintering temperature on the flexural strength is shown in Figure 5. The strength of the samples increased with increasing sintering temperature until 1100°C. Above 1100°C, the strength dropped rapidly. This behaviour was also observed in the density analysis. It should be noted that the strength of the samples is related to their density. The highest strengths of 76 and 52 MPa were obtained for the bottom ash sintered at 1100°C from incinerators in Phuket and Samui, respectively.

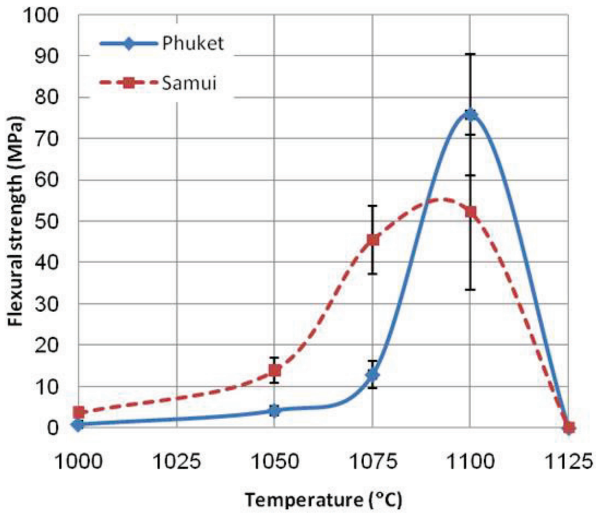


Figure 5: Flexural strength of sintered bottom ashes.

According to ISO 13006, water absorption is used to classify dry-pressed ceramic tile. Water absorption of ≤ 0.5% is classified as the low water absorption tile group BI_a, and the water absorption range of 6–10% is classified as tile group BII_b.[11] Therefore, the water absorption of both of the sintered samples met the standard requirement. In addition, the standard indicates that the minimum strength limit of dry-pressed ceramic tile is 35 MPa for tile group BI_a and 18 MPa for tile group BII_b.[11] The strength values obtained in both samples in the study were higher than the values of the standard. This implies that the sintered bottom ash can be used in building materials such as wall, floor and pavement tiles.

Although the MSW incinerator bottom ash is classified as non-hazardous waste,[2,5] it contains heavy metals of environmental concern such as zinc (Zn), chromium (Cr) and lead (Pb) as seen in Table 1. Thus, it is necessary to test the leachability characteristics of the heavy metal elements in the sintered samples to guarantee the safety of the product for applications.

The leached concentrations of heavy metal elements are given in Table 2. The U.S. regulatory limits [US EPA (40 CER 261)] are also listed in the table.[10,12] Both sintered bottom ashes exhibited very low leached concentrations of heavy metals. By comparison with the regulations, the product is satisfactory for use in applications.

Table 2: Leached concentrations of heavy metals in the bottom ashes sintered at 1100°C.

Elements	Concentration (ppm)		US EPA limit [10,12] (ppm)
	Phuket	Samui	
Zn	1.02	0.23	500
Pb	< 0.10	< 0.10	5
Cr	< 0.10	< 0.10	5

4. CONCLUSION

The characterisation and sintering of the bottom ashes from two MSW incinerators in Phuket and Samui, Thailand were performed, and the results demonstrated the following:

- Both bottom ashes consisted of CaO and SiO_2 as the main constituents together with Al_2O_3, Fe_2O_3, Na_2O, MgO, K_2O and P_2O_5. The content of CaO present in both bottom ashes was relatively high.
- The bottom ashes from the two incinerators were able to sinter to high density without any sintering aid at a temperature of 1100°C. The maximum density obtained was 2.38 g/cm^3 for the bottom ash from incinerator in Phuket and 2.00 g/cm^3 for the bottom ash from incinerator in Samui.
- Sintering at 1100°C produced sintered samples with strengths of 76 MPa for bottom ash from the incinerator in Phuket and 52 MPa for bottom ash from the incinerator in Samui.
- The sintered bottom ash from the incinerators in Phuket and Samui had water absorptions in the range required for dry-pressed ceramic tile according to the ISO standard, and they also had good strength that compiled with the standard. Thus, it is possible to use the sintered bottom ash as building tiles.

5. ACKNOWLEDGEMENT

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