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Development of Value-added Lucent: Transparent Glass Using Hazardous MSWI Fly Ash

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Abstract: Municipal solid waste incineration (MSWI) fly ash (FA) containing hazardous metals (especially Pb and/or Cd), high water-soluble chloride (Cl^-), and other complex constituents bring on a traditional treatment of solidification/stabilization (S/S) and landfill disposal in most countries. In this paper, a MSWI FA sampled from M Plant was studied for developing an innovative method of fabricating value-added lucent/transparent glass. The analysis of MSWI FA shows that TCLP-Pb was 36.0 mg/L exceeding regulatory limit (5.0 mg/L) and Cl^- content was 32.84%. Composition analysis of MSWI FA illustrates that total chloride (Cl_T) of 35.39% was the largerest constituent and Cl^-, occupying nearly 93%, is the majority of Cl_T. Other abundant constituents were Ca (25.17%), Na (7.07%), K (5.01%) and Pb (2.68%) etc., revealing the possibility of fabricating glass. Unfortunately, Fe content in FA was 0.6%, larger than 0.1%, which may display green color in glass. Pre-experiments of fabricating glass using MSWI FA, silica sand (SiO_2) and flux (Na_2CO_3) concluded that 30%: 40%: 30% and 1,300°C firing temperature was the optimal fabrication condition but a green glass was also generated. Further efforts including pre-treating FA by magnetic removal of iron constituents and adding decolorizer (CaF_2) were explored. Finally, a lucent/transparent glass fabricated by the combination of pre-treatment of FA and adding 10% of CaF_2 was obtained. Further application of this simple and quick method, replacing the traditional S/S and landfill disposal, to fabricate value-added glass and achieve circular economy is highly expected.

Key words: municipal solid waste, incineration, fly ash, glass, circular economy

1. Introduction

Municipal solid waste incineration (MSWI) has been widely applied in developed and some developing countries because it can considerably reduce waste volume and recover thermal energy to generate electricity. However, MSWI residue, about 18–20wt% of MSW, will be generated [1]. Normally, MSWI residue includes 80wt% of bottom ash (BA) and 20wt% of fly ash (FA). BA is usually identified as non-hazardous waste since it can pass the regulations of toxicity characteristic leaching procedure (TCLP) and dioxins (DXN), and the screened BA can usually be recycled as a low-level of aggregate material. Unfortunately, MSWI FA is typically identified as a hazardous waste because of failing TCLP, especially in Pb and/or Cd [1, 2]. Moreover, MSWI FA can pass DXN regulation unless those fly ashes generated under abnormal conditions (e.g., wastes containing high organic chloride and aromatic precursor compounds, and low combustion temperature).

Besides TCLP and DXN for MSWI FA, people intensely notice the water-soluble chloride (Cl^-) content in MSWI FA even Cl^- content is not included in the regulation of hazardous waste [2]. The most reason of concern is Cl^- has corrosive characteristics that will damage iron or steel containing constructions and reduce structure strength gradually. Thus, cement solidification/stabilization (S/S), a convenient but defective method for treating hazardous MSWI FA, is

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usually applied in most of countries (including Taiwan, Mainland China, and most of European countries). The S/S of MSWI FA will increase 50% weight and the solidified FA will be transported and finally dumped in isolated landfill sites. This S/S and landfill disposal method not only occupies much landfill space but also has the risk of leaching out hazardous matters (e.g., heavy metals and DXN) and contaminating the soil and water environment. Conclusively, developing an innovative method for replacing S/S and landfill disposal and benefitting MSWI FA recycle is definitely urgent and important.

Glasses can be classified according to its shape and function as flat glass, container glass, car glass, and tube glass etc., and flat glass and container glass are the majority [3]. Most of the flat glass and container glass are SiO_2-based silicate glass. In addition, SiO_2-based silicate glass can be further divided into four categories according to its color: transparent (or colorless), brown, green, and variegated. Transparent glass can be recycled as transparent glass and added into other color glasses. Therefore, transparent glass has the highest value among all color glasses. In this paper, a transforming MSWI FA into value-added lucent/transparent glass method is presented. Iron compound, lager than 0.1% in the raw material of glass, will cause green color [3, 4]. Unfortunately, the iron compound in MSWI FA is normally lager than 0.1%. So several efforts in this paper to reduce the iron effect will also be studied.

2. Material and Methods

2.1 Sampling and Property Analysis of MSWI FA

MSWI FA generated in a MSWI plant (M Plant) located at central of Taiwan, ROC, was sampled and taken to laboratory. After drying and mixing, MSWI FA was stored in a close box for use. The physico-chemical properties of MSWI FA were measured in accordance with the standard methods of Environmental Protection Administration (EPA) of ROC and Chinese National Standard (CNS), including pH value (NIEA R208.04C, EPA), TCLP (NIEA R201.15C, EPA), water-soluble chloride content (refer to CNS 13407), metal concentrations (atomic absorption spectrometer), and composition analyses (SEM/EDS and FPXRF).

2.2 Glass Fabrication Experiments Using MSWI FA

Pre-experiments for finding out the optimal ratio of MSWI FA: silica sand (SiO_2): flux (K_2CO_3) and optimal firing temperature to fabricate glass were carried out firstly. Next, MSWI FA was pre-treated by magnetic removal for reducing iron compound and then fabricated according to the optimal condition of pre-experiments. Moreover, adding CaF_2 as a decolorizer was also explored and therefore the best glass with lucent/transparent characteristics would be attained after the comparison of all fabricated glasses.

2.3 Leaching Test of Fabricated Glass

A leaching test in accordance with the standard method of ISO 7086-1:2000 (release of Pb and Cd of glass hollowware in contact with food) was conducted for the best fabricated glass to ensure its safety and feasibility in future application.

3. Results and Discussion

3.1 Physico-Chemical Properties of MSWI FA

The pH of MSWI FA was 11.7 as shown in Table 1, indicating that MSWI FA is a highly alkaline waste because of FA containing many alkali metal oxides and alkaline earth metal oxides. TCLP-Pb concentration (36.0 mg/L) exceeding regulatory limit (5.0 mg/L) means that MSWI FA was a hazardous waste. Additionally, water-soluble chloride content was up to 32.84%, implying that a certain of organic chloride compounds containing wastes (e.g., PVC, rubber, and leather) were combusted.

3.2 Composition Analysis of MSWI FA

The composition analysis by SEM/EDS was shown in Table 2 and presented as follows: Cl (35.39%), Ca

(25.17%), O (19.13%), Na (7.07%), K (5.01%), Pb (2.68%), S (1.66%), Si (1.64%), Zn (1.14%), Al (0.59%), Mg (0.31%), and Cu (0.22%). The largest constituent was Cl (i.e., total chloride, Cl_T, including water-soluble chloride and water-insoluble chloride), 35.39%, and the water-soluble chloride was 32.84%; revealing that water-soluble chloride, occupying nearly 93%, is the majority of chloride in MSWI FA. The second largest constituent was Ca because of abundant Ca in waste and lime adding in air pollution control devices (APCDs).

3.3 Primary Metal Contents in MSWI FA

The analysis of primary metal contents in MSWI FA by FPXRF was shown in Table 3 and presented as follows: Zn (12,540 ppm), Fe (6,260 ppm), Pb (2,354 ppm), Cu (1,092 ppm), Cr (263 ppm), and Cd (188 ppm). Fe content of 6,260 ppm (i.e., 0.626%), larger than 0.1%, indicates a green color glass might be fabricated.

Table 1 The physico-chemical properties of MSWI FA.

	pH	TCLP (mg/L)					Cl^- (%)
		Cd	Cr	Cu	Pb	Zn	
MSWI FA	11.7	ND	ND	0.17	36.0	2.7	32.84
Regulatory limit	2.0 < pH < 12.5	< 1.0	< 5.0	< 15.0	< 5.0	< 25.0*	N/A

* Regulatory limit before 2001.

Table 2 The composition of MSWI FA.

Element	Weight (%)					
	Sample 1	Sample 2	Sample 3	Min.	Max.	Avg.
O	19.08	18.91	19.39	18.91	19.39	19.13
Na	7.13	7.17	6.92	6.92	7.17	7.07
Mg	ND	0.47	0.45	ND	0.47	0.31
Al	0.58	0.36	0.84	0.36	0.84	0.59
Si	1.69	1.57	1.65	1.57	1.69	1.64
S	1.63	1.65	1.71	1.63	1.71	1.66
Cl	35.18	35.78	35.2	35.18	35.78	35.39
K	4.74	5.04	5.26	4.74	5.26	5.01
Ca	25.08	25.73	24.7	24.7	25.73	25.17
Cu	0.65	ND	ND	ND	0.65	0.22
Zn	1.51	0.34	1.56	0.34	1.56	1.14
Pb	2.74	2.98	2.32	2.32	2.98	2.68
Total	100	100	100	100	100	100

Table 3 Primary metal contents in MSWI FA.

	Sample 1	Sample 2	Sample 3	Min.	Max.	Avg.
Cd (ppm)	186	186	191	186	191	188
Cr (ppm)	267	248	274	248	274	263
Cu (ppm)	1,103	1,114	1,058	1,058	1,114	1,092
Fe (ppm)	6,880	5,930	5,970	5,930	6,880	6,260
Pb (ppm)	2,414	2,288	2,359	2,288	2,414	2,354
Zn (ppm)	12,750	12,450	12,420	12,420	12,750	12,540

3.4 Glass Fabrications Using MSWI FA

The fabricated glasses by using MSWI FA were shown in Fig. 1. Green glass shown in Fig. 1(a) was caused by Fe content (0.626%) in FA. Magnetic removal of iron resulted in a light green glass shown in Fig. 1(b) because magnet can only remove ferromagnetic irons (e.g., Fe^0 and Fe_3O_4) and most of FeO (tending to display green color in glass) and Fe_2O_3 (tending to display yellow-green color in glass) were still remained. A significant more light green, yellow-green, glass shown in Fig. 1(c) was decolored by CaF_2. Finally, the combination of magnetic removal and adding 10% CaF_2 could fabricate a lucent/transparent glass as shown in Fig. 1(d).

3.5 Leaching Test of Fabricated Glass

Leaching test result of the best fabricated glass was shown in Table 4. The concentrations of Cd and Pb were ND, indicates that no any hazardous Cd and Pb will release during the glass contacting with food; therefore, the safety of glass made from hazardous MSWI FA was ensured. However, future application for non-food contacting glasses usages is suggested.

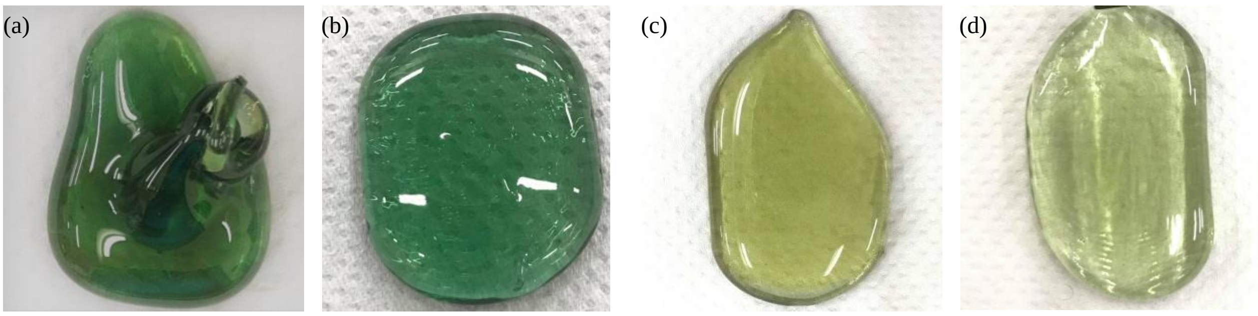

Fig. 1 Glasses fabricated by using MSWI FA in FA : silica sand (SiO_2) : flux (K_2CO_3) = 30% : 40% : 30% and 1,300°C of firing temperature. (a): original FA, (b): magnet pretreated FA, (c) original FA + 10% CaF_2, and (d): magnet pretreated FA + 10% CaF_2.

Table 4 Leaching test result of the best fabricated glass.

	Concentration	Regulatory limit*
Cd (mg/dm^2)	ND	< 0.07
Pb (mg/dm^2)	ND	< 0.8

* According to ISO 7086-2: 2000

4. Conclusion

MSWI FA as a hazardous waste was traditionally treated by S/S and landfill disposal. An innovative method for recycling MSWI FA and successfully fabricating value-added lucent/transparent glass was developed and presented. Replacing the traditional treatment of MSWI FA is highly expected in the future. Although the result of leaching test conducted in accordance with ISO 7086-1:2000 presented as ND for Cd and Pb, all the glasses fabricated by using MSWI FA are recommended for non-food contacting usages for avoiding any argument.

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