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Hydrothermal solidification behavior of municipal solid waste incineration bottom ash without any additives

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ABSTRACT

Municipal solid waste incineration (MSWI) bottom ash could be solidified with and without slaked lime (calcium hydroxide) addition by a hydrothermal method under steam pressure of 1.56 MPa at 200 °C for up to 72 h. Experimental results showed that CSH gel or tobermorite exerted a main influence on strength development, and without any additives CSH gel was easy to form, while slaked lime addition favored to form tobermorite. Tobermorite seemed to exert a larger effect on the strength development than CSH gel. Leaching results showed that the concentrations of heavy metals dissolved from the solidified specimens were effectively reduced after hydrothermal processing. The immobilization was mainly due to the tobermorite or CSH gel formation, and Pb^{2+} and Zn^{2+} seemed to be fixed more readily than Cr^{6+}, which might be the reason that the structural Ca^{2+} within tobermorite or CSH gel was exchanged by Pb^{2+} and Zn^{2+} more easily than Cr^{6+}. In addition, there existed a close relationship between leaching concentration and strength enhancement, and a higher strength seemed to exert a larger effect on immobilization of heavy metals.

1. Introduction

The disposal of municipal solid waste becomes one of major concerns to environmental management, and incineration has served as a competitive candidate due to its volume reduction, pathogenic agent destruction and possible energy recovery (Chang et al., 1998; Wan et al., 2006). At the end of 2009, there were 93 municipal solid waste incinerators with a treatment capacity of 71,000 t d^{-1} in China (China National Bureau of Statistics, 2010). Although 18% of total municipal solid waste generated was only occupied now, the amount of municipal solid waste incineration is still growing quickly due to urbanization. Incineration process is companied by the generation of MSWI ash (fly ash and bottom ash), and the bottom ash accounts for 80% of the overall MSWI ash produced (Chimenos et al., 1999). Furthermore, heavy metals including Cr, Cu, Ni, Zn and Pb within bottom ash need special control procedure, which influences the recycling of MSWI bottom ash (Hyks et al., 2011; Zhang et al., 2008).

The application of MSWI bottom ash is mainly focused on construction fields including aggregates for concrete (Wainwright and Robery, 1991), cement materials (Filipponi et al., 2003) and road construction (Nonneman et al., 1991). However, the ash used in above methods was just a small portion of the volume of MSWI ash produced. Recently, a hydrothermal treatment technology was reported in treatment of wastes including MSWI bottom ash, and the hardening mechanism was ascribed to the formation of tobermorite and/or CSH (Jing et al., 2007b, 2010). The molar ratio of CaO/SiO_2 (C/S) was regarded as the most important factor for synthesis of tobermorite. In favor of the formation of tobermorite, the C/S of starting materials should fall about the stoichiometric C/S of tobermorite (0.83). Thus additives, such as cement, lime, quartz, even blast furnace slag and MISW fly ash, were introduced so as to make reactants attain the ideal composition (Etoh et al., 2009; Jing et al., 2007b, 2010; Naganathan et al., 2010; Shan et al., 2011).

The C/S of raw MSWI bottom ash obtained from Shanghai (China) is 0.72, which is near to the stoichiometric C/S of tobermorite (0.83). The MSWI bottom ash, therefore, might be solidified hydrothermally without any additives. As far as our knowledge concerns, the hydrothermal solidification of MSWI bottom ash without any additives, and its hardening mechanism have rarely been investigated.

The present work is aimed to explore how to solidify MSWI bottom ash from Shanghai, China hydrothermally, and in order to understand the hardening mechanism better, the hydrothermal solidification of MSWI bottom with slaked lime addition was also investigated. The safety of the solidified specimens was evaluated

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by leaching tests and the effects of curing time on leaching performance were inspected to provide practical information in wide application of hydrothermal treatment of MSWI bottom ash.

2. Experimental

MSWI bottom ash used in this research was collected from an incineration plant in Shanghai, China. The MSWI bottom ash was, after all metal and unburned materials were removed, ground using a rotary corundum ball mill. The chemical composition (Table 1), particle size distribution (Fig. 1) and phase abundance (Fig. 2) of the MSWI bottom ash were measured by X-ray fluorescence (XRF, SRS3400, Bruker), laser particle-size analysis (LPSA) (model X100, Microtrac) and powder X-ray diffraction method (XRD, D/maxrB12KW, Rigaku) respectively.

The ground MSWI bottom ash powder mixed with or without slaked lime was used as starting materials to compare both hardening mechanisms. The starting material was first mixed manually in a mortar with 15 mass% of distilled water and then the mixture was compacted in a rectangular-shaped mould by 30 MPa. The demoulded green specimens underwent hydrothermal solidification at 200 °C for up to 72 h using a Teflon–lined stainless steel autoclave which was described in detail in our previous work (Jing et al., 2007a,b). After hydrothermal treatment, all the solidified specimens were dried at 80 °C for 24 h.

The dried specimens (15 mm length × 40 mm width × 7 mm height) were first used to measure the three point flexural strength, employing the Japanese industrial standard (JIS R1601) (for the hydrothermal specimens, compressive strength = (4–5) × flexural strength). The flexural strength used is because our hydrothermal products will be used as pavement materials (e.g. tiles). The strength values presented here are average of the measurements conducted in triplicate by a strength testing machine (XO-106A, Xie Qiang Instrument Technology) at a loading rate of 0.5 mm/min. The crystalline phase abundance of the cracked specimens was, then, characterized by XRD. The functional groups of those phases were also tested by Fourier transform infrared spectroscopy (FTIR, Tensor 37, Bruker). Scanning electron microscopy (SEM, Quanta 200FEG, FEI) combined with energy dispersive X-ray spectroscopy (EDX, Genesis X4 M, EDAX) was conducted on cross section of cracked specimen for the investigation of microstructure and morphology. Mercury intrusion porosimetry (MIP, Poremaster 33, Quantachrome) was used to measure porosity performances.

Leaching tests were conducted to investigate effect of hydrothermal curing time on the leaching behavior of solidified specimens in accordance with "Test method standard for leaching toxicity of solid wastes—Roll over leaching procedure" of China, GB 5086.1-1997 (State Environmental Protection Administration of China, 1997), i.e., specimens were first broken into particles less than 5 mm in diameter and the ground particles was subsequently mixed with pure water at liquid-to-solid ratio of 10:1, then the mixtures were shaken at a speed of 30 rpm for 18 h. The leachates

Table 1
Chemical composition of MSWI bottom ash.

	Wt%		Wt%
SiO_2	37.2	TiO_2	0.86
CaO	25.3	ZnO	0.36
Al_2O_3	6.89	BaO	0.23
Fe_2O_3	5.19	MnO	0.13
P_2O_5	4.63	CuO	0.14
SO_3	2.54	PbO	0.05
MgO	2.33	SrO	0.06
Na_2O	2.89	Cr_2O_3	0.04
K_2O	1.56	Cl	1.29

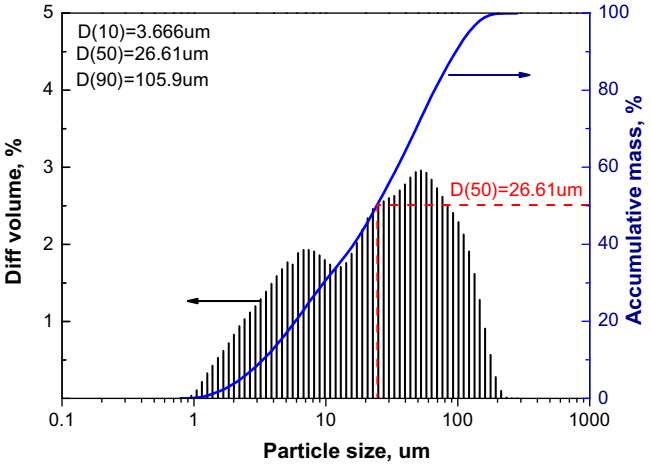

Fig. 1. Particle size distribution of MSWI bottom ash.

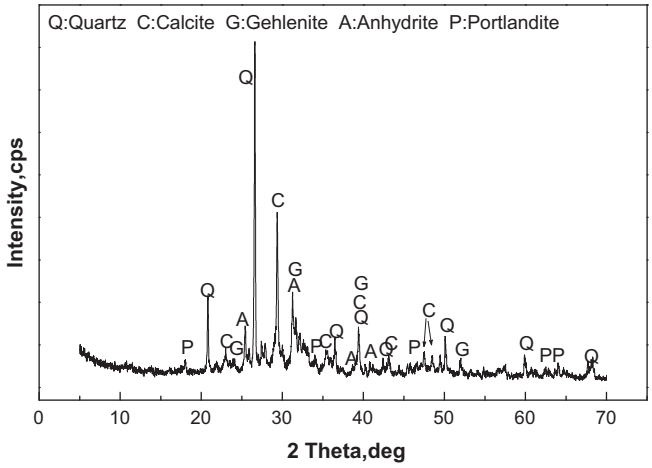

Fig. 2. X-ray diffraction (XRD) pattern for MSWI bottom ash.

of the WSWI bottom ash and solidified specimens were all alkaline (~pH:10–12). Because pH is one of the most important factors for heavy metals dissolution, the pHs of leachates were adjusted to 5.8–6.3 by adding HCl during the leaching tests (referenced by the notification no. 13 of the Environmental Agency of Japan). Because the pH of leachate reflects the pH of the environmental of treatment, it was adjusted before treatment (shaking treatment) so as to give the same pH environmental for all leaching specimens. Before and during leaching tests, the triangular flask was sealed. After the leaching procedure, the leachants were settled for 30 min and then filtered through a 0.45-μm membrane filter (Millipore) for determining the concentration of heavy metals by inductively coupled plasma mass spectroscopy (ICP-MS, Agilent7700).

It should be notice that the method standard of GB 5086.1-1997 used in this study is relate to waste handling but not to construction application judging because it is only tool in the current regulatory system in China. Although the method cannot provide a perfect leaching behavior of the specimens when used in construction application, the leaching results at least could be used to evaluate an influence of curing time on evolution of concentration of heavy metals dissolved from the solidified specimens. Hence, the requirement to develop a rule for use of waste in construction is necessary. As mentioned before, the above leaching tests were conducted at a fixed pH (5.8–6.3), however, the heavy metals leaching