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Original Research Paper

Utilization of Portland Cement and Municipal Solid Waste Incineration Fly Ash for Solidification/Stabilization of Sewage Sludge

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ABSTRACT

A solidification/stabilization (S/S) process by using municipal solid waste incineration (MSWI) fly ash was applied to sewage sludge in order to find a safer way for the two wastes (sewage sludge and MSWI fly ash) disposal. The behaviour of pastes fabricated with various mass ratios of Portland cement/MSWI fly ash has been analysed in terms of mechanical strength, microstructure and leaching characteristics. The results showed that the unconfined compression strength (UCS) of solidified sludge decreased with the mixing amount of MSWI fly ash. However, with the addition of 5% MSWI fly ash represented 28 days UCS of 0.31 MPa, satisfying the landfill threshold of 0.3MPa. Scanning electron microscopy investigations revealed that a large amount of ettringite was present in solidified sludge, leading to a crystallizing network in the solidified products, and therefore, the enhancement of the strength. Environmental assessment of the final products in compliance leaching tests demonstrated that the concentration of heavy metals was below the detection limits.

INTRODUCTION

Sewage sludge represents the major solid waste from biological wastewater treatment processes and it can not be disposed off directly to the land due to the risk of environmental contamination. Due to a dramatic increase in the volume of wastewater treated in China, over 9.18 million tons of wet sewage sludge are generated every year (Deng et al. 2009) and the disposal of sewage sludge is one of the most critical environmental issues of today. Solidification/stabilization (S/S) is known as a treatment process of sewage sludge to reduce sludge handling or disposal problems by its encapsulation into a solid matrix as physically and/or chemically stable as possible (Malliou et al. 2007, Walter et al. 2006). Several binder systems are currently available and widely used for S/S process (Goran et al. 2011, Ma et al. 2010, Samaras et al. 2008, Valderrama et al. 2013, Zhang et al. 2008), and Portland cement is one of the most ordinary binders (Zhen et al. 2012, Song et al. 2013).

On the other hand, municipal solid waste incineration (MSWI) fly ash is classified as hazardous waste in China owing to the presence of heavy metals and must be disposed off by landfill after the stabilization and solidification of the heavy metals. In recent years, several researchers have studied the possibility of using fly ash in cement-based materials (Mulder 1996, Collivignarelli et al. 2002). The results showed that similar behaviour was observed in concrete produced with Portland cement. Bertolini et al. (2004) replaced part of part of the Portland cement with MSWI fly and bottom ashes for concrete production and concluded that these wastes show good pozzolanic behaviour and so contribute to the development of the strength of the concrete. Therefore, if MSWI fly ash could replace part of Portland cement and be used in sewage sludge S/S process, the saving of not only cement materials but also the landfill space for MSWI fly ash will be available. The objective of this study is to investigate the potential of using MSWI fly ash as a binding material for co-disposing sewage sludge by S/S process. The influences of the ratios of MSWI fly ash/Portland cement and MSWI fly ash/sludge, strength development, SEM and leaching test on the S/S process were analysed and the S/S mechanism was discussed.

MATERIALS AND METHODS

Materials: The sewage sludge and MSWI fly ash used in this study were obtained from the Wastewater Treatment Plant of Hanxi in Wuhan and Suzhou Wastes Incineration Plant in Suzhou. The sludge was first dried in an oven at 103°C and subsequently grounded to less than 8mm in size to aid workability of the sludge-ash-cement matrix during casting. Sewage sludge sample was characterized using the standard methods of analysis (CJ/T 221-2005, China HUD 2007), and the results are given in Table 1. The standard method for determining the leaching toxicity of solid wastes by horizontal vibration extraction procedure (GB5086.2, 1997) (China EPA 1997) was used to evaluate leaching concentrations of heavy metals from the raw sludge and MSWI fly ash. The results are given in Table 2. The chemical

Table 1: Main characteristics of the sewage sludge.

Moisture (%)	pH	Organic matter (%)	Unconfined compressive strength (kg/cm^2)	Density (g/cm^3)
80.5	7.2	67.5	0.085	1.02

composition of MSWI fly ash is given in Table 3.

Preparation of specimens: Samples were prepared by mixing sewage sludge, Portland cement and MSWI fly ash in definite ratios as listed in Table 4. The moisture content of sewage sludge was higher than 80%, hence addition of water was not required and the equal workability of all the mixtures could be obtained. The mixing procedures are as follows: the wet sludge was placed in a mixer first, all materials with a designed content were then added and the mixture stirred for 30min. After homogenization, the mixtures were solidified in steel molds with a size of 40mm × 40mm × 160mm for 24h, and the resultant products were extruded and cured in airtight condition of 20°C±0.5 for different times.

Analytical Methods: ***Unconfined compression strength (UCS)*****:** UCS was measured in compliance with SL237-020-1999 (China). It was tested using the unconfined compression machine with a maximum load of 5kN. And the specimens were mechanically tested in 3, 7, 14 and 28 days. For each mortar and curing age, three specimens were tested.

Scanning electron microscopy (SEM) analysis**:** Scanning electron microscopy (Quanta 200 FEG, FEI Company, USA) was used for the microstructural analysis of the hydrated samples. The crushed samples were mounted on Al-stubs and gilt with Au, with a working voltage of 15 kV.

Leaching test: Leachability of solidified sewage sludge was evaluated using standard leaching method: Toxicity characteristic leaching procedure (TCLP). The TCLP test used in this study followed the standard procedures described by U.S.EPA. The leachate was tested using ICP emission spectrometry. TCLP results were also compared with the concentration limits allowed for landfill given by the Singapore Ministry of the Environment (ENV).

Table 2: Leaching concentration of sewage sludge and MSWI fly ash.

Leaching concentration of sewage sludge (mg/L)	Sludge	MSWI fly ash
Cu	11.2	19.4
Zn	58.3	164.3
Pb	0.2	55.8
Cd	0.1	29.2
Cr	1.8	3.2
Ni	1.9	1.7

RESULTS AND DISCUSSION

Unconfined compression strength: Unconfined compression strength of the pastes solidified by different mix proportions of cement and MSWI fly ash is given in Fig. 2. Unconfined compressive strength is one of the important parameters for solidified effect. It can be seen that the mix ratio of cement/MSWI fly ash played an important role in strength development of solidified sludge. The highest strength of 0.62 MPa could be obtained for paste A-4 after 28 days of hydration. The corresponding values were 0.31, 0.4, 0.51 MPa, respectively, for paste A-1, A-2, A-3. However, sample A-1 with the addition of 5% MSWI fly ash represented 28 days UCS of 0.31 MPa, satisfying the landfill threshold of 0.3MPa. This result confirmed the usefulness of fly ash as a cementation binder. The paste A-4, with pure Portland cement, also exhibited the highest early strength value of 0.37 MPa after 3 days of curing. It can be noticed that mortars with the lower amount of MSWI fly ash content gave better results in unconfined compression strength.

Furthermore, the results of UCS tests for all A-1 to A-4 samples showed that the UCS values obtained for samples cured for 28days were nearly twice those obtained for samples cured for 3 days. Accordingly, it can be said that a solidification period of 14 days for sludge solidification is not sufficient.

Scanning electron microscopy analysis: In order to inves-

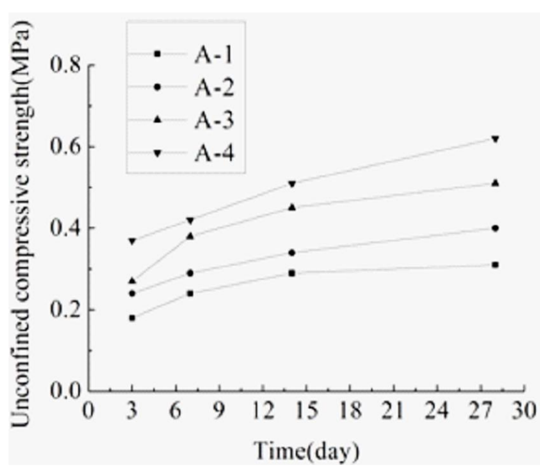
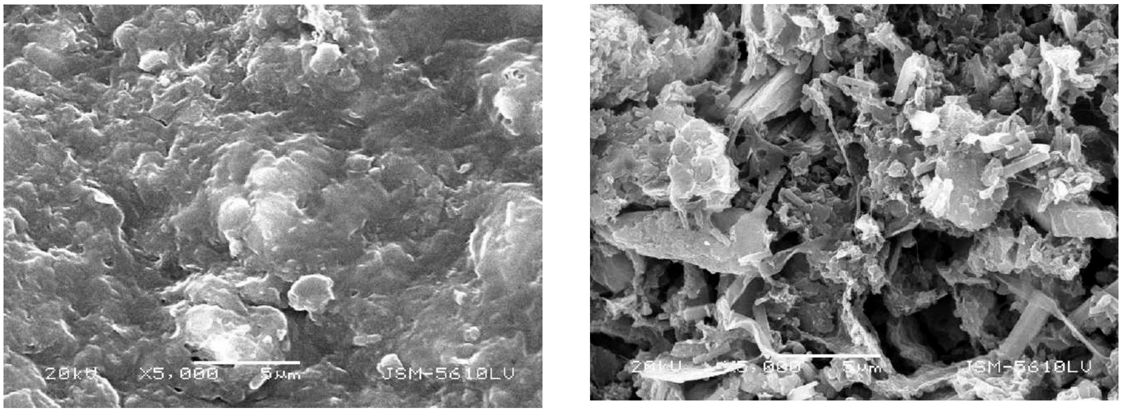


Fig. 1: Unconfined compression strength of all the samples.



(a) (b)

Fig. 2: Scanning electron microscopy images of the samples: (a) unsolidified sewage sludge and (b) sample A-2 cured under laboratory conditions for 28 days.

Table 3: Chemical composition of MSWI fly ash (wt %).

	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O
MSWI fly ash	20.6	37.8	15.5	1.3	2.7	3.4	3.7

Table 4: Different mix proportions (wt. %).

Mix	Portland cement (%)	MSWI fly ash (%)	Sludge (%)
A-1	5	15	80
A-2	10	10	80
A-3	15	5	80
A-4	20	0	80

Table 5: Leaching results of heavy metals in sludge samples before and after solidification.

Sample	Heavy metal concentration (mg/L)					
	Cu	Zn	Pb	Cd	Cr	Ni
Raw sludge	11.2	58.3	0.2	0.1	1.8	1.9
MSWI fly ash	19.4	164.3	55.8	29.2	3.2	1.7
A-1	4.2	16.9	8.5	18.2	1.6	0.9
A-2	3.1	13.4	6.2	16.4	1.2	0.4
A-3	2.4	10.5	4.4	8.8	0.4	0.2
A-4	1.5	8.7	1.7	4.7	0.2	0.1
ENV standard	<100	<100	<5	<15	<5	<5

tigate the microstructure changes of solidified samples, the raw sludge sample and the paste A-2 after 28 days of hydration were subjected to SEM analysis. The results are displayed in Fig. 2. The platy construct of unsolidified sewage sludge is disordered and incompact in Fig. 2a. Fig. 2b shows the SEM photo of the paste A-2 after 28 days of hydration. SEM observations confirmed the presence of a large amount of ettringite with high crystallinity with homogeneously distributed in the paste. These hydration phases filled the pores in the mortar and interconnected the sludge particles as physically or chemically as possible. The filling effect decreased the porosity, altered the morphological characteristics and subsequently made the mortar denser and stronger in compression. The tight connection between the sludge particles in solidified sample might be the reason for the significant high compressive strength of solidified samples.

Effect of binders on leaching of the S/S mortars: The solidified products were evaluated by the leaching test, aiming to understand the potential toxic contaminants leaching hazard. The concentrations of heavy metals leaching from raw sludge, MSWI fly ash and the solidified samples after 28 days of curing time are given in Table 5. It can be found that addition of Portland cement and MSWI fly ash into sludge constituting a sludge-binder matrix played a positive role in fixing of the heavy metals. However, addition of 5% and 10% MSWI fly ash had a less effectiveness on the fixing of heavy metals and part of heavy metals such as Pb were still over the limit allowed for landfill after 28 days of curing time. It was also shown that further improvement of fixing capacities can be made when Portland cement was added into sludge-MSWI fly ash system. According to the SEM results, this may be related to the hydration products-ettringite. Ettringite is an important phase for the solidification and stabilization of heavy metals in traditional cement matrix. The potential contributions of ettringite phase to fix heavy metals has been well focused (Maria & Dimitris 2006, Magalhães et al. 2004). The fixing mechanism included chemical binding and physical and chemical adsorption as well. Thus, it can be inferred that the amount of hydration product-ettringite increased with the MSWI fly ash mixing amount and the heavy metals fixing capacity increased correspondingly. Besides, it can be seen that all data in Table 5 are lower than the detection limits, suggesting that there were no notable hazardous effects that could cause to potential environmental and human health.

CONCLUSIONS

The combined use of Portland cement and MSWI fly ash is useful for sludge solidification/stabilization. The addition of cement significantly enhanced the sludge solidification/stabilization performance. With the increase of cement content, the unconfined compression strength and the heavy metals fixing capacity were both improved. In addition, assessment of environmental compatibility of the final products indicated that with the addition of 15% cement and 5% MSWI fly ash, the concentration of heavy metals in the leachates was below the ENV standard limits.

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