Pozzolanic Properties of Municipal Solid Waste Incineration (MSWI) Fly Ash Under the Actions of Three Different Activators

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Abstract. This study investigated the pozzolanic capacity of MSWI fly ash in the solidification process. The MSWI fly ash were solidified by using three kinds of activators, i.e., Na_2CO_3, $CaSO_4$ and Na_2SiO_3, they were all cured for 7 and 28 days. Each of them involved two cases, i.e., the activator mixing proportions were 3 and 6% in dry mass basis, respectively. After that, the unconfined compressive strength (UCS) test and water immersion test were conducted on the solidified samples, to investigate the influence of the kind and proportion of activator on MSWI fly ash solidification. The results showed that all the three kinds of activators had played a role in promoting the solidification process, and the Na_2CO_3 performed best. The UCS value of the samples with the action of Na_2CO_3 enhanced with the increase of activator mixing proportion and curing time. The 28-day UCS value of the sample with Na_2CO_3 mixing proportions of 6% reached 2.924 MPa, and the solidified sample also showed a good water tolerance. The effect of $CaSO_4$ on the MSWI fly ash solidification was complex. The UCS value increased with the curing time when the $CaSO_4$ mixing proportion was 3%, however, it decreased with the curing time when the $CaSO_4$ mixing proportion was 6%.

Keywords: MSWI fly ash · Pozzolanic property · Activator
Unconfined compressive strength · Water tolerance

1 Introduction

Incineration is one of the most widely used methods to treat the MSW. Even though incineration is efficient for treating MSW, one of the shortcomings of this technology is the significant production of solid residues, e.g., fly ash [1]. MSWI fly ash is regarded as hazardous material mainly due to its high content of heavy metals. Therefore, MSWI fly ash needs solidification/stabilization treatment before landfill disposal [2]. A deep understanding of the pozzolanic properties of MSWI fly ash has important theoretical significance in the solidification/stabilization treatment of MSWI fly ash.

At present, many studies have been conducted to investigate the pozzolanic properties of coal fly ash, mineral powder and other materials. Zhang et al. [3] studied the pozzolanic properties of mineral slag, steel slag and coal fly ash under the action of NaOH. The results showed that the mineral slag obtained the best effect, followed by

L. Zhan et al. (Eds.): ICEG 2018, ESE, pp. 3–9, 2019.
https://doi.org/10.1007/978-981-13-2224-2_1

steel slag and coal fly ash. Shi et al. [4] found that 4% $CaCl_2.2H_2O$ can significantly improve the later strength of lime-pozzolan cement. Sivapullaiah et al. [5] found that the adding of $CaSO_4$ accelerated the increase of UCS value of coal fly ash. Sun et al. [6] studied the effect of different alkali activator (NaOH, Na_2CO_3, Na_2SiO_3) on slag and coal fly ash, and the alkali activator constituted of NaOH and Na_2SiO_3 performed the best. It is seen from the above studies that the effects of activators adding on the pozzolanic behaviors of coal fly ash, mineral slag and steel slag have been well studied. However, few researches have been carried out to focus on the pozzolanic properties of MSWI fly ash.

The aim of this study is to investigate the pozzolanic properties of MSWI fly ash in the solidification process. Four groups of solidification tests were conducted on the MSWI fly ash samples, which were solidified by deionized water, Na_2CO_3, $CaSO_4$ and Na_2SiO_3 solutions, respectively. After that, the UCS and water immersion tests were carried out on the solidified samples to investigate the influence of the kind and proportion of activators on the pozzolanic properties.

2 Materials and Methods

2.1 Materials

MSWI fly ash. The MSWI fly ash used in this study was collected from a MSWI plant with the burning environment of circulating fluidized bed in Hangzhou, China. The MSWI fly ash is dark yellow in colour, as shown in Fig. 1. The chemical composition was determined by an energy dispersive X-ray spectrometer. The test result was shown in Table 1. It was observed that the MSWI fly ash contained a certain amount of CaO, SiO_2, Al_2O_3 and Fe_2O_3, and the content of CaO was as high as 44.1%.

Fig. 1. MSWI fly ash

Activator. Three types of activators were used in this study, i.e., Na_2CO_3, $CaSO_4$ and Na_2SiO_3. Na_2CO_3 was selected to take into account the high CaO content in fly ash. Na_2CO_3 not only plays a role in activating the pozzolanic reactivity [5], but also reacts with CaO to generate the precipitate of $CaCO_3$ to produce a function of auxiliary cementation. $CaSO_4$ is a widely used activator [6], which may generate hydration

Table 1. Chemical compositions of MSWI fly ash (%)

Compound	CaO	SiO_2	Fe_2O_3	Al_2O_3	MgO	Na_2O	K_2O	SO_3	P_2O_5	Cl	Others
Percent (%)	44.07	9.82	5.47	9.85	3.13	3.99	3.19	2.89	3.56	10.32	3.71

reaction with pozzolanic materials. Na_2SiO_3 is an activator which is commonly used to promote the solidification process of Portland cement [7].

2.2 Experimental Process

Four groups of solidification tests were conducted on the MSWI fly ash samples, as shown in Table 2. B0 was solidified by water with a water-cement ratio of 0.35, and cured for 7 and 28 days, which served as the reference group. B1-1 and B1-2 was solidified under the similar condition to B0, except that 3% and 6% Na_2CO_3 was added to the fly ash, respectively. 3 and 6% $CaSO_4$ were added in B2-1 and B2-2, respectively, and 3 and 6% Na_2SiO_3 were used in B3-1 and B3-2, respectively. The groups B1, B2 and B3 were performed to investigate the effects of Na_2CO_3, $CaSO_4$ and Na_2SiO_3 adding and their proportions on the solidification capacity of MSWI fly ash.

Table 2. Program of solidification/stabilization treatments

Number	Liquid solid ratio	Activator	Proportion (dry mass basis) (%)
B0	0.35	–	0
B1-1		Na_2CO_3	3
B1-2		Na_2CO_3	6
B2-1		$CaSO_4$	3
B2-2		$CaSO_4$	6
B3-1		Na_2SiO_3	3
B3-2		Na_2SiO_3	6

Taking B2-1 for an example, the experimental processes were presented as follows:

(a) The MSWI fly ash samples were dried at the temperature of 105 ± 5 °C, and mixed with 3% Na_2CO_3, then stirred at a water-cement ratio of 0.35. After that, the mixture was filled into a self-designed moulding cylinder in three lifts. As shown in Fig. 2, the moulding cylinder consists of a split PVC tube with the inner diameter of 36 mm and the height of 80 mm, a layer of geotextile lined between the sample and the PVC tube, and two porous stones placed on the bottom and top of the PVC tube, respectively. After filling and compacting of the mixture, the moulding cylinder was placed in an incubator with a temperature of 20 ± 2 °C and a humidity of $\geq$95% for curing. After curing for 24 h, the moulding cylinder was removed, and the sample was continued to be maintained for 7 and 28 days.

(b) Subsequently, the UCS test was conducted on the solidified sample by using a servo mechanical press (CMT4000, China). The servo mechanical press can supply a maximum force of 30 kN with an accuracy of 1 N and a loading rate of

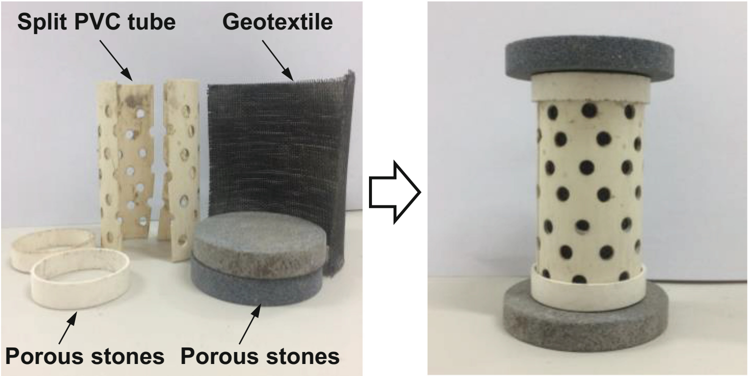


Fig. 2. Cylindrical mold for solidifying fly ash

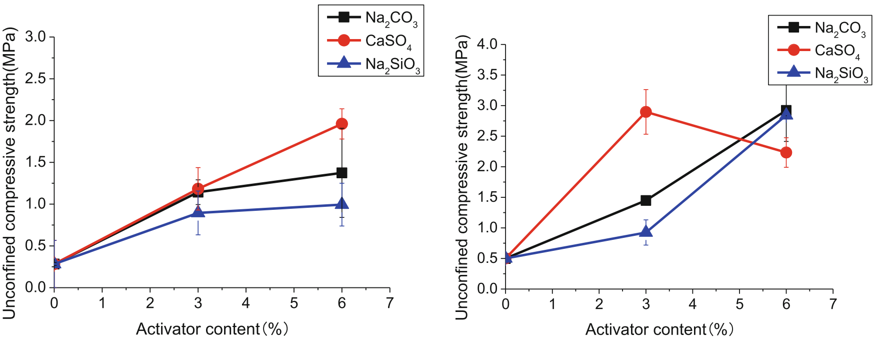
2 mm/min. The UCS value was determined by using the formula: P = F/A, where P is the compressive strength (MPa), F is the total maximum load recorded at the point of fracture (N), and A is the area of loaded surface (mm^2).

(c) The water immersion test was also conducted on the solidified sample after curing for 7 days. The sample bulk with an area of about 2 cm^2 was immersed by deionized water in a beaker. Then, the sample bulk was kept immersion and observed the shape change carefully. The time durations for recording the observations were 10, 30 min, 1, 2, 4, 12 h, 1, 3, 7, 10, and 14 days.

3 Results and Analysis

3.1 Effect of Activator Proportion on the UCS Value

Figure 3 shows the UCS value of the solidified MSWI fly ash samples. The UCS value of the reference group (0% activator added) was obtained as 0.28 and 0.50 MPa after curing for 7 and 28 days, respectively. It was observed that the UCS value of the solidified samples under the action of the activators significantly improved when compared with the reference group. This indicated that all the three activators were likely to stimulate the pozzolanic capacity of the MSWI fly ash. As seen from Fig. 3(a), the UCS value of the solidified samples after curing for 7 days tended to increase with an increase in activator proportion. Among the three activators, $CaSO_4$ performed best. When the adding proportions of $CaSO_4$ were 3 and 6%, the UCS values of the solidified samples reached 1.18 and 1.96 MPa, respectively, which were 318.02 and 592.58% higher than that of the reference group. As shown in Fig. 3(b), the UCS values of the solidified samples cured for 28 days also remarkably increased with the activator proportions for the cases of adding Na_2CO_3 and Na_2SiO_3. However, the UCS value of the solidified sample achieved the peak value of 2.90 MPa for the case of adding 3% $CaSO_4$, and decreased to 2.23 MPa when the $CaSO_4$ proportion was raised up to 6%. This might be associated with the formation of ettringite (AFt) in the fly ash solidification process under the action of $CaSO_4$. The AFt has the characteristic of swell effect, which tended to cause the solidified samples to slightly break [8]. This phenomenon was also found in the solidification process of sludge by the authors and was verified by scanning electron microscopy (SEM) [9].



(a) 7d (b) 28d

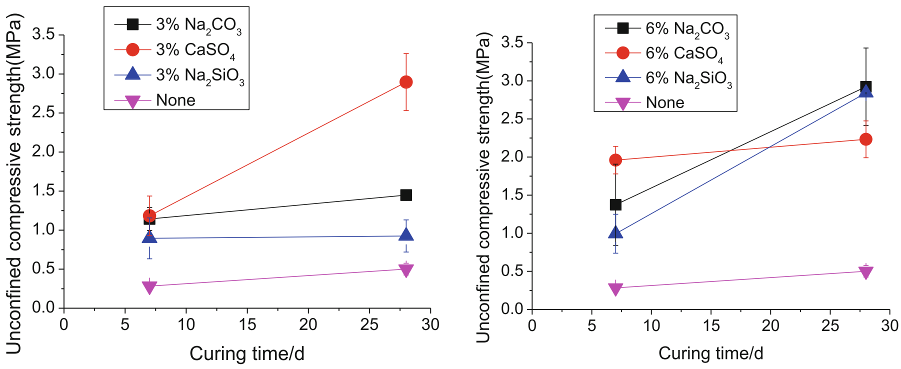
Fig. 3. UCS values of the solidified samples with different activator proportions

3.2 Effect of Curing Age on the UCS Value

The effects of curing age on the UCS value of the solidified MSWI fly ash samples are given in Fig. 4. As the curing age increased, the UCS values of solidified samples increased, which implied that the solidification processes were likely to progress with time. It was observed in Fig. 4(a) that $CaSO_4$ performed the best on stimulating the pozzolanic activity among all the three activators when the adding proportion was 3%. When activated by $CaSO_4$, the UCS values of the solidified samples after curing for 7 and 28 days reached 1.18 and 2.90 MPa, respectively, which were 318.02 and 478.24% higher than that of the reference group. The performance of Na_2CO_3 took the second place, and followed by Na_2SiO_3. As shown in Fig. 4(b), when the adding proportion of activators was 6%, the case of adding $CaSO_4$ again performed the best after curing for 7 days, however, the UCS value of this case increased slightly after curing for a longer time of 28 days. For the curing time increased from 7 days to 28 days, the UCS values of the solidified samples significantly increased from 1.37 to 2.92 MPa for the case activated by Na_2CO_3, and from 0.99 to 2.84 MPa for the case activated by Na_2SiO_3.

3.3 Water Immersion Behavior

The water immersion behaviors of the solidified samples are showed in Table 3. The sample of the reference group gradually collapsed after immersing in the water for 7 days. Similar results were also observed in the cases of adding 3 and 6% $CaSO_4$, and the samples were damaged in 7 and 10 days, respectively. This may be associated with



(a) proportion of 3% (b) proportion of 6%

Fig. 4. UCS values of the solidified samples under different curing ages

Table 3. Water immersion test results

Number	Activator	Proportion (%)	Damage time
B0	/	/	7 d
B1-1	Na_2CO_3	3	No damage was seen in 14 d
B1-2	Na_2CO_3	6	No damage was seen in 14 d
B2-1	$CaSO_4$	3	7 d
B2-2	$CaSO_4$	6	10 d
B3-1	Na_2SiO_3	3	No damage was seen in 14 d
B3-2	Na_2SiO_3	6	No damage was seen in 14 d

the structural weakness induced by water. However, no visible damage was observed in the samples solidified by adding Na_2CO_3 and Na_2SiO_3 after immersing in the water for 14 days.

4 Summary and Conclusion

The findings from this study are summarized as follows

(1) The reference group, with no activator added, had UCS values of 0.28 and 0.50 MPa after curing for 7 and 28 days, respectively. The solidified sample cured for 7 days collapsed after immersing in the water for 7 days.

(2) When the sample was solidified with the action of the activator Na_2CO_3, its UCS value increased with increasing Na_2CO_3 mixing proportion and curing time. The 28-day UCS values reached 2.92 MPa for the samples with Na_2CO_3 mixing proportion of 6%, which was 483.43% higher than the reference group. No collapse was observed in the 7-day solidified sample even if it was immersed in the water for 14 days. Similar behavior was observed in the solidified sample added

with Na_2SiO_3, however, its UCS value was lower than that added with Na_2SiO_3 under the given mixing proportion and curing time.

(3) When the sample was solidified with the action of $CaSO_4$, its UCS value achieved the peak value of 2.90 MPa for the case of adding 3% $CaSO_4$, and decreased to 2.23 MPa when the $CaSO_4$ proportion was raised up to 6%. The solidified samples cured for 7 days collapsed after immersing in the water for 7–10 days.

From the perspectives of compressive strength and water tolerance of the solidified MSWI fly ash, the optimal activator among the three ones studied in this work was Na_2CO_3, followed by Na_2SiO_3, and the last was $CaSO_4$.

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