ENVIRONMENTAL SCIENCES 2001 Vol. 10, No. S-2, 89~95
Bulletin of the Korean Environmental Sciences Society

Solidification and Leaching Characteristics of Cyclone Ash from Industrial Incineration Plant

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(Manuscript received on April 23, 2001)

The solidification and leaching characteristics of cyclone ash collected from an industrial incineration plant were investigated. Cement and calcium hydroxide were used as the solidifying materials. The leaching characteristics of the solidified cyclone ash were found to vary depending on both the quantitative and the qualitative aspects of the solidifying materials. Except for copper and lead, all the heavy metal ions in the leachate of the solidified material composed of 10~20 % cement or 10~20 % calcium hydroxide were found to be within their standard limit. Moreover, all the heavy metal ions were also observed to be within satisfactory limits in the leachate obtained from the solidified material composed of 30 % cement or 30 % calcium hydroxide. Therefore, to satisfy the standard compressive intensity and permissible limits of heavy metal ions leached from solidified material, it would appear that a 30 % proportion of either additive in the solidification product can meet the required standard for the leachate. The cost of solidifying cyclone ash per ton for ash-30 % cement and ash-30 % lime was calculated as 26,750 and 26,070 won, respectively. Accordingly, significant reductions in the waste toxicity and mobility as well as an improvement in the engineering properties of the solidified products were successfully achieved.

Key words : Solidification, cyclone ash, portland cement, calcium hydroxide, incineration

1. Introduction

Hazardous waste generation continues to increase in response to the ever-growing consumer demand in industrialized countries. Korea, currently emerging as an industrialized nation, is no exception. With the affirmation of the productivity of incineration processes in the treatment of hazardous waste[1,2], the use of incineration plants has rapidly increased in Korea. Besides other prevalent detoxification technologies, incineration plants currently make a sizeable contribution to keeping Koreas toxic waste under satisfactory limits. According to an estimate, the amount of incinerated waste will increase to 20 % by the end of 2001, whereas in 1998 it was only 9 %, similarly the production of cyclone ash from incineration plants keeps on increasing annually[3]. The cyclone ash produced from incineration plants contains toxic materials and heavy metal ions and is largely dumped directly underground without proper treatment. This direct dumping then causes secondary environmental pollution, like heavy metal leaching[4]. Heavy metals are extremely toxic because, as ions or in compound form, they are soluble in water and can be transferred to the human body through the food chain[5,6]. Some of these metals, even in small amounts, can cause severe psychological and health problems. All hazardous material in cyclone ash can be mobilized and stabilized through a solidification process that significantly reduces the leaching of undesirable components into the surrounding environment. Yet the strength of the solidified material and its leaching characteristics vary widely depending upon the amount of the additive. Therefore, to establish a standard limit for the compressive intensity of the solidified material, the optimum dosage of the additive needs to be determined. In Germany[5], the standard limit of compressive intensity is regulated as 200 kN/m^2. In Korea, in compliance with hazardous waste solidification regulations, the amount of cement used as the solidifying material should be more than 15% of the total weight of the solidified product in order to meet the standard limits of compressive intensity and leachate concentration.

The current study was carried out to evaluate ways to minimize the effects of secondary environmental pollution based on solidifying cyclone ash prior to landfill[7,8]. The characteristics of solidified waste material, such as heavy metal leaching, suitability of additives, compressive intensity, and reaction time, were all investigated. The evaluations were based on the quantitative and qualitative aspects of the final solidified products after introducing highly cost-effective remedial measures to produce environmentally friendly solidified material.

2. Materials and Methods

2.1. Characteristics of Cyclone Ash

Cyclone ash was collected from the centrifugal ash collection box of an industrial incineration plant located in K city. For experimental purposes, the cyclone ash was used as collected without anyfurther treatment. Table 1 summarizes the concentrations of pollutants found to be present in the raw sample of cyclone ash.

2.2. Characteristics of Additives

Portland cement and calcium hydroxide were used as additives[9]. The portland cement(35F) was purchased from S company and its price was 90,000 won/ton. Cement-based stabilization is best suited for inorganic waste, especially that containing heavy metals, as the high pH of cement means that the metals are retained in the form of insoluble hydroxide or carbonate salts within the hardened structure[10,11]. Previous studies have shown that lead, copper, zinc, tin, and cadmium are likely bound in the matrix by chemical fixation, thereby forming insoluble compounds, while mercury is predominantly held by physical microencapsulation[12,13]. The other additive, calcium hydroxide $Ca(OH)_2$, was purchased from D company and its price was 15,000 won/ton. Lime-based stabilization is best suited for inorganic contaminants and has been widely employed for metal sludge[14]. The solidified material is formed based on the reaction between the calcium in the lime and the alumino-silicates in the waste. Tables 2 and 3 summarize the physical and chemical characteristics of portland cement and calcium hydroxide, respectively.

Table 1. Leaching characteristics of cyclone ash

(Unit : mg/l)

Parameters	Pb	Cu	As	Hg	Cd	Cr^{6+}	CN	Org. P	TCE	PCE
[a]Standard limit of H.W.	3.00	3.00	1.50	0.005	0.30	1.50	1.00	1.00	0.00	0.00
[b]Cyclone ash	3.11	5.41	1.23	0.008	0.34	1.25	0.52	0.00	0.36	0.12

[a]Leachate, [b]Present study

Table 2. Physical and chemical characteristics of portland cement

Chemical characteristics (%)					Physical characteristics		
SiO_2	Al_2O_3	CaO	SO_2	Ignition loss	Fineness	*Cg. time	*Cg. strength
21.9	5.73	61.3	2.05	1.30	3.31 cm^2/kg	[a]260 min [b]6.21 h	3day : 208 kg/cm^2 7day : 270 kg/cm^2 28day : 383kg/cm^2

* Congregation time and strength, aInitial setting time, bFinal setting time

Table 3. Chemical characteristics of calcium hydroxide

Chemical composition %				
CaO	Al_2O_3	SiO_2	Fe_2O_3	MgO
89.15	1.100	1.440	0.3000	0.8000

2.3. Solidification

Measured quantities of cyclone ash and the additives were mixed with water for hydration, then the prepared paste was filled into a cylindrical-shaped plastic mould with a 10 cm height and 10 cm diameter. The compressive strength of the samples was measured in each mould as a function of the reaction time. Readings were taken at different time intervals every day using a pocket penetrometer. The measurable range of the compressive strength of the pocket penetrometer was 25～450 kN/m^2. Other samples were then prepared to measure the final compressive strength, which was higher than 450 kN/m^2. Mixed samples were also filled into a cylindrical-shaped mould made of PVC material with a15 cm height and 5 cm diameter. The solidification time was extended to 40 days. After completion of the solidification reaction time, the one-axial unconfined compressive strength of each solidified cylindrical-shaped sample was measured.

The amount of portland cement and calcium hydroxide mixed with the cyclone ash was 10～30 %, respectively. Since cement and calcium hydroxide have different water absorption capacities, the amount of water supplied to each sample differed depending on the nature and quantity of the additive supplied. The water contents of the samples ranged between 30～40 %. Table 4 shows the experimental conditions applied during the solidification processes.

2.4. Leaching Test

Leaching tests of the heavy metals and volatile organic compounds(VOCs) were performed using the toxicity characteristic leaching procedure[15)] (TCLP) after the completion of the solidification experiment. To analyze the leaching characteristics of the organic matter, samples were prepared by mixing the solidified materials with nitric acid-perchloric acid. The heavy metals(Pb, Cu, As, Hg, Cd, Cr^{6+}) present in the leachate were analyzed using an atomic absorption spectrophotometer (Stetra AA-400, Varian company). The VOCs, trichloroethylene(TCE), perchloroethylene(PCE), and other organic matter were analyzed using gas chromatography(Star 3400-C, Varian company).

3. Results and Discussion

3.1. Compressive strength

The results from the solidification experiments showed an increasing trend in the compressive strength of the solidified materials with an increase in the reaction time and amount of additive. The compressive strength of the solidified material composed of 10～30 % cement increased to 200 kN/m^2 within a reaction period of 1～2 days(Fig. 1). However, in the case of a 10 % additive, the compressive strength reached the measurable limit of the penetrometer i.e., 450 kN/m^2 within a reaction period of 10 days(Fig. 2). When considering the compressive strength, a moderate reaction time period, and economic feasibility, the results of the 10 % dosage of the cement additive

Table 4. Experimental conditions with different additives

Additive	Solidification			
	Weight of cyclone ash(g)	Dosage rate of additive(%)	Weight of additive(g)	Amount of water(ml)
Cement	900	10	100	400
	800	20	200	360
	700	30	300	375
$Ca(OH)_2$	900	10	100	600
	800	20	200	570
	700	30	300	580

were acceptable. Figure 1 shows the variations in the compressive strength of the solidified material as a function of the reaction time. Figure 2 shows the variations in the compressive strength of the solidified materials as a function of the amount of additive relative to the reaction time.

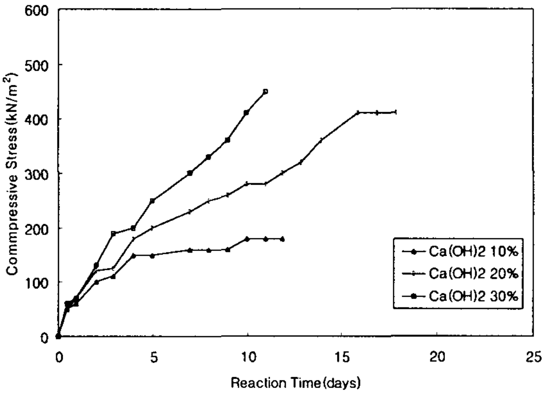

Fig. 1. Reaction time vs. compressive strength of solidified cyclone ash with cement.

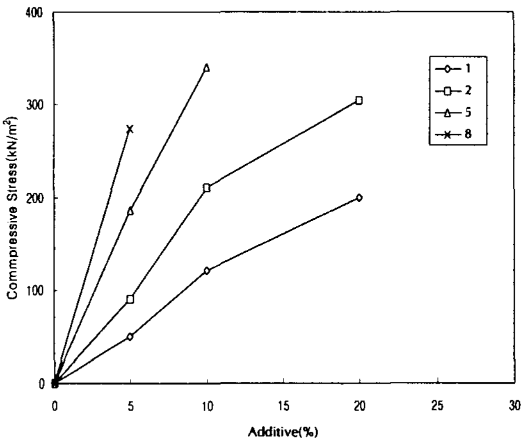

Fig. 2. Cement dosage vs. compressive strength of solidified material relative to time.

The compressive strength of the solidified material with calcium hydroxide increased with an increase in the amount of additive and reaction time. With an added amount of 10~30 % calcium hydroxide, the compressive strength increased to 200 kN/m^2 within a reaction period of 4~5 days (Fig. 3). In the case of a 10 % additive, the compressive strength reached a maximum value of 140 kN/m^2 within the same reaction time period. Therefore, to obtain such results within a 10 day reaction time period, an additive dosage of over 20 % would appear to be sufficient. Figure 3 shows the variations in the compressive strength as a function of the reaction time relative to different dosages of calcium hydroxide. Figure 4 shows the variations in the compressive strength as a function of the additive dosage relative to the reaction time.

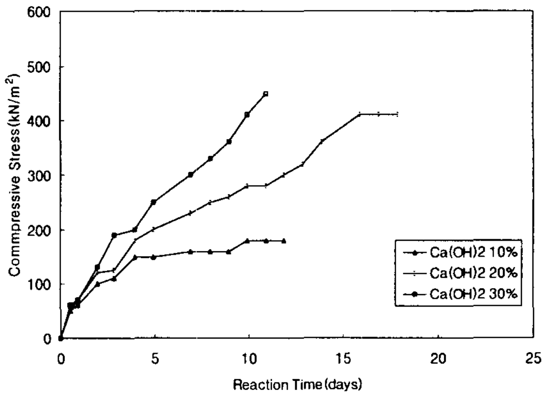

Fig. 3. Reaction time vs. compressive strength of solidified cyclone ash with calcium hydroxide.

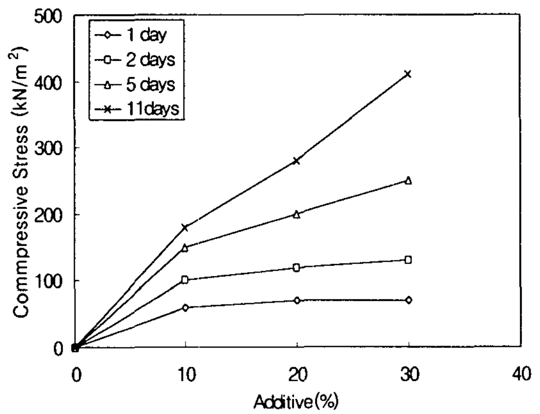

Fig. 4. Calcium hydroxide dosage vs. compressive strength of solidified material relative to time.

3.2. One-axial unconfined compressive strength

The final compressive strength of the solidified material was measured using a one-axial unconfined compressive strength measuring instrument. The samples prepared for the measurement of the one-axial-compressive strength were regimented for 30~40 days. The compressive strength of the solidified samples composed of 10, 20, and 30 % cement at an axial transformation rate of 6~6.5 was found to be 680, 950, and 1,450 kN/m^2, respectively. In contrast, the compressive strength of the solidified samples composed of 10, 20, and 30 % calcium hydroxide at an axial-transformation-rate of 6.7 was 290, 520, and 930 kN/m^2, respectively. These values were lower than the values obtained when using cement as the additive. Figures 5 and 6 show the variations in the compressive strength with respect to the axial strain relative to different dosages of cement and calcium hydroxide, respectively.

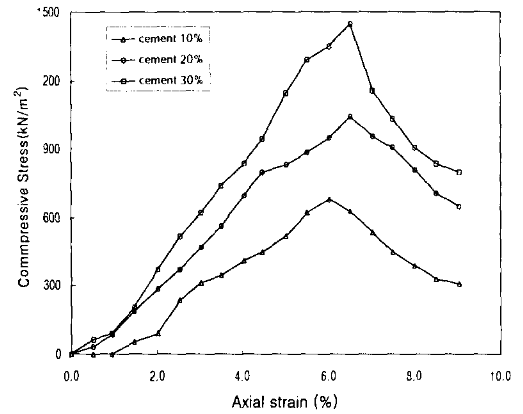

Fig. 5. Axial strain vs. compressive strength of solidified ash relative to cement dosage.

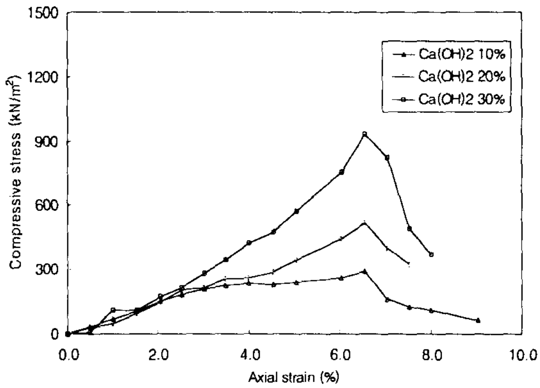

Fig. 6. Axial strain vs. compressive strength of solidified cyclone ash relative to calcium hydroxide dosage.

3.3. Leaching Characteristics

The leaching concentration of the heavy metals showed a decreasing trend with an increase in the additive dosage. The concentration of Cu leached from the solidified material composed of 10, 20, and 30 % cement was found to be 4.335, 3.335, and 1.557 mg/l, respectively. However, none of the other contents, including Cd, Pb, Cr^{6+}, As, Hg, organic phosphorous, TCE, and PCE, were leached and all were found to be within their standard limits when the solidified material was composed of more than 20 % cement. Figure 7 presents the leaching characteristics of the solidified cyclone ash relative to the cement dosage.

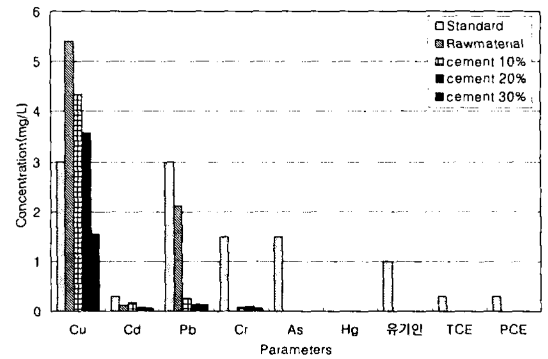

Fig. 7. Leaching characteristics of solidified cyclone ash relative to cement dosage.

The content of Cu leached from the solidified material composed of 10, 20, and 30 % lime, was found to be 5.31, 4.43, and 2.91 mg/l, respectively. In the case of lead, a concentration 2~3 times higher than that in the raw sample was detected in the leachate obtained from the solidified material composed of 10% lime. Jeannet *et al.*[16] discussed the role of minerals in the leachate obtained from the bottom ash of a municipal solid waste incinerator and stated that leachates are unsaturated with respect to common secondary minerals, such as oxides, carbonates, sulfate, and phosphate. The exceptions are copper(hydroxy) carbonates and lead phosphate, yet further evidence of their possible role in controlling the leaching of Cu and Pb from the bottom ash of a municipal solid waste incinerator has not been found. Another theory is that more amphoteric Pb is leached with a low concentration of lime. Kim *et al.*[17] also reported that that solubility of lead increases at a high pH (pH 10~12). As such, it would appear the lime increased the pH of the solidified material and facilitated the mobility of Pd ions into the leachate. Yet, no enhanced mobility of Pb ions was observed in the leachate obtained from the solidified material composed of 30 % lime. Therefore, with a higher concentration of lime, it would seem that the chemical reactive forces between the lime and the Pb compounds outweighed the factors that impart mobility to Pb ions. Accordingly, to keep the leaching concentration of Cu and Pb within the standard limits, a dosage of about 30 % lime is required. Other pollutants, like Cr^{6+}, As, organic phosphorous, TCE, and PCE, were not leached and found to be within their standard limit at a dosage of 20 % lime. Figure 8 presents the leaching characteristics of the solidified cyclone ash relative to the calcium hydroxide dosage.

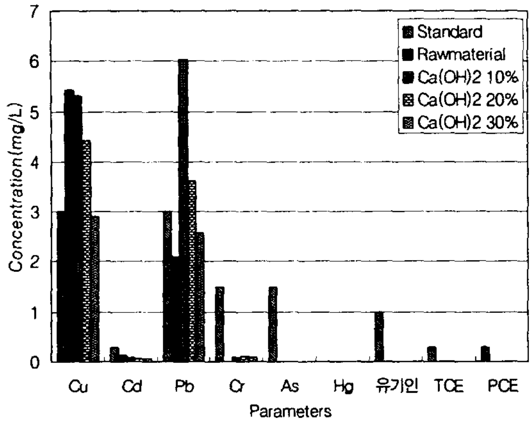

fig. 8. Leaching characteristics of solidiied cylone ash relative to calcium hydroxide dosage.

3.4. Economic aspect of solidification of cyclone ash in terms of additive

The cost of using cyclone ash as landfill is 98,000 or 48,000 won/ton when taken as hazardous waste or municipal solid waste, respectively. The cost of solidifying cyclone ash with 30 % cement is 60,000 won/ton and the solidified material is considered as municipal solid waste as regards landfilling applications. As such, a significant amount can be saved, 38,000 won/ton, when comparing the landfill cost of cyclone ash as hazardous material or municipal solid waste after solidification. Accordingly, the solidification of cyclone ash makes its use as landfill more economically viable and more eco-friendly.

4. Conclusions

The characteristics of cyclone ash solidified with cement or lime were investigated and summarized. The compressive strength of the solidified material varied depending on the amount and nature of the additive and was significantly influenced by the reaction time. The optimum dosage of cement and lime for a solidified material with a compressive strength of up to 450 kN/m^2 was found to be 10% and 20 %, respectively, provided a reaction period of 10 days. All the heavy metal ions and VOCs were found to be within their satisfactory limit when the solidified material was composed of more than 20 % cement or about 30 % lime. The cost of solidifying cyclone ash per ton for ash-30 % cement and ash-30 % lime was 26, 750 and 26, 070 won, respectively.

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