

Effect of Heavy Metals on Cement Solidification of Municipal Solid Waste Incineration Residues

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1. INTRODUCTION

In light of the current situation in Japan, incineration residue (bottom ash and fly ash) accounts for about 80% of the landfill waste at final disposal sites for general waste¹⁾. Therefore, the authors aim to establish a "waste solidification disposal system²⁾" that reduces landfill capacity consumption, improves environmental safety, and stabilizes landfill sites quickly while taking advantage of the characteristics of incineration residues. Specifically, this reclamation method applies coal ash solidification technology³⁾ and mixes incineration residue with cement and water, then compresses it by applying high-frequency vibration to form a solidified ground. During the study, it was confirmed that incineration residue causes differences in the strength development of cement-mixed solidified products⁴⁾ (hereafter referred to as "solidified incineration residues"). Reclaimed ground with delayed strength development in solidified landfills creates reclamation construction management problems, such as avoiding heavy equipment travel over these areas. The reason for this was thought to be the high heavy metal content and leaching of the solidified incineration residues. In this study, in order to clarify the effect of heavy metals on the strength development of solidified incineration residues, we added heavy metals to solidified mixture samples and conducted strength tests and physical property analysis of specimens prepared by varying the amount of heavy metal addition. Then, we determined the relationship between uniaxial compressive strength and the concentration of eluted heavy metals.

2. SAMPLES AND METHODS

2-1 Samples

The samples were bottom ash and fly ash collected from the R incineration plant in F City. The bottom ash (wet ash), from which coarse grains were removed (hereafter referred to as incineration ash), and the fly ash, from which chelated fly ash (hereafter referred to as fly ash).

2-2 Selection of heavy metals to be added

We selected three heavy metals (copper, lead, and zinc) with the highest percentage in the incineration residues

Table 1. Moisture content and properties of incineration residue

Samples	Water content ratio		Remarks
	Bottom ash	Fly ash	
FR	27.4	19.9	Incinerator ash is from the bottom of a 40 mm sieve

and the highest retarding effect on cement solidification^{5), 6)}. A solution of chloride compounds of the three heavy metals was added because lead and zinc are particularly chloride-rich in fly ash⁷⁾.

2-3 Preparation of solidified incineration residues

Each incineration residue solidified product material was prepared under the conditions shown in Table 2. Incineration ash and fly ash were mixed at a dry mass ratio of 3:1 (hereafter referred to as "incineration residue"). Blast furnace cement Type B was added to the incineration residue at a dry mass ratio of 10%. Tap water in which each heavy metal was dissolved was added so that the water content ratio was 27%. The target elution concentrations were determined based on the general effluent standard values (Copper: 3.0 mg/L, Lead: 0.1 mg/L, Zinc: 5.0 mg/L) specified in the Japanese Water Pollution Control Law. The amount of each heavy metal added was calculated from these values. Each heavy metal was added to the sample as an aqueous solution of a chloride compound for uniform addition. After kneading, the mixture was placed in a cylindrical formwork with an inner diameter of 10 cm and a height of 20 cm, vibrated, and compacted for 150 seconds at a vibration frequency of 75Hz and an amplitude of approximately 0.5 mm using a small table vibrator (TV500 x 500 manufactured by Exen). The mold was then sealed and cured indoors (10–18 °C) for 28 days. After that, they were demolded and subjected to uniaxial compression tests.

Table 2. Kneading conditions for each incineration residue solidifier

Samples	Bottom ash (wet) [kg]	Fly ash (wet) [kg]	cement [kg]	water [kg]	added heavy metals	Measured elution concentration [mg/L]			Measured elution concentration [mg/L]		
						Cu	Pb	Zn	Cu	Pb	Zn
A-1					-	-	-	-	-	-	-
A-2						1.00	-	-	0.273	-	-
A-3					Cu	2.00	-	-	0.556	-	-
A-4						3.00	-	-	0.820	-	-
B-1	19.1	6.00	2.22	1.17		-	0.03	-	-	0.683	-
B-2					Pb	-	0.07	-	-	1.376	-
B-3						-	0.10	-	-	2.059	-
C-1						-	-	1.67	-	-	0.014
C-2					Zn	-	-	3.33	-	-	0.027
C-3						-	-	5.00	-	-	0.041

3. RESULTS AND DISCUSSION

3-1 Relationship between uniaxial compressive strength of solidified incineration residues and heavy metal leaching concentration of incineration residue

Figure 1 shows the relationship between uniaxial compressive strength (7, 28, and 91 days of age) and heavy metal leaching concentrations of copper, lead, and zinc in solidified incineration residue. The uniaxial compressive strength was measured for three specimens under each condition, and the maximum, minimum, and average values are shown in Figure 1. For the 7-day intensity, no change in intensity was observed with changes in the elution concentrations of the three heavy metals. For the 28-day-old specimens, the strength of copper decreased as the leaching concentration increased. On the other hand, the decrease in strength for lead and zinc was slightly above the certain leaching concentration, and the strength can be considered almost constant. As for the 91-day strength, it was confirmed that the rate of decrease in strength with heavy metal addition was lower than that of the 7-day and 28-day strengths.

3-2 Relationship between uniaxial compressive strength of solidified incineration residue and heavy metal content of incineration residue

Figure 2 shows the relationship between uniaxial compressive strength (7, 28, and 91 days of age) and copper, lead, and zinc content in solidified incineration residue. No significant strength changes were observed for the 7-day-old specimens with increasing heavy metal content. For the 28-day-old specimens, the strength of copper decreased with increasing content. On the other hand, the decrease in strength for lead and zinc is insignificant when the content exceeds a certain value, and the strength can be considered almost constant. The difference in the strength of the 91-day-old specimens was smaller than that of the 28-day-old specimens,

suggesting that the effect of inhibition of strength development was smaller. The relationship between the heavy metal content in the incineration residue and the uniaxial compressive strength of the specimens was similar to the relationship between the heavy metal leaching concentration in the incineration residue and the uniaxial compressive strength.

3-3 Time Dependence of Uniaxial Compressive Strength of Incineration Residue Solidified with Heavy Metals

Figures 1 and 2 show that the strength of each specimen had the highest loss at 28 days of age, with a lower rate of strength loss at 91 days of age. Therefore, Figure 3 summarizes the time variation of the uniaxial compressive strength of solidified incineration residue with the addition of heavy metals and the time required to reach the target strength for developing solidification-type disposal systems (5 N/mm²). A significant decrease in strength with increasing addition was observed for the copper-added solidified products at 28 days of age. When zinc was added, the strength decreased in small amounts for solidified products. The decrease in strength with the increasing amount of heavy metal additions was the decrease in strength with increasing heavy metal additions. For the solidified product with lead added, a decrease in strength was observed at small amounts, but no significant decrease in strength was observed with increasing amounts of the heavy metal added. However, no significant decrease in strength was observed with increasing the amount of heavy metal. The strength loss rate of the specimens with the three heavy metals was the largest at 28 days, while the strength loss rate was the smallest at 91 days. The strength loss rate of the specimens with the three heavy metals was the largest at 28 days, while the strength loss rate was the smallest at 91 days. In addition, focusing on the time to reach the development target, it became clear that the target

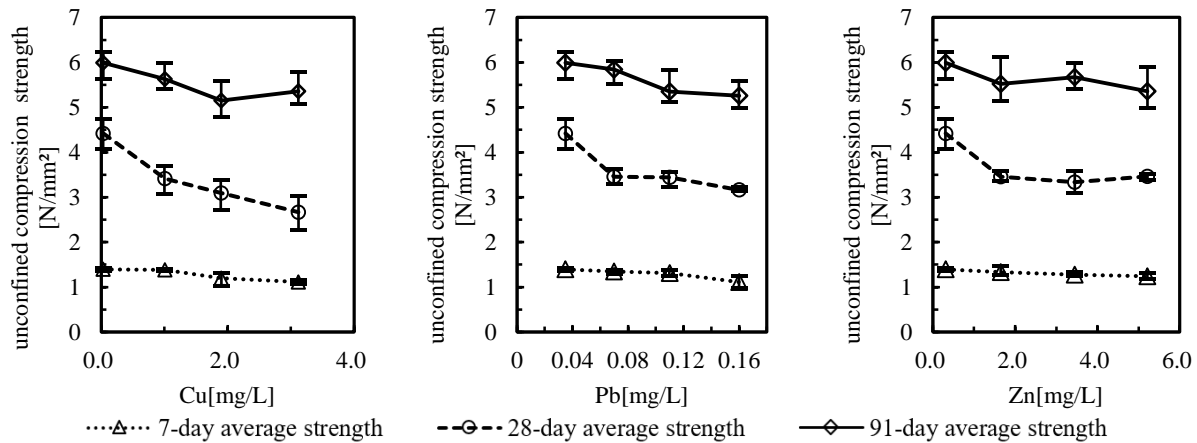


Figure 1. Relationship between heavy metal leaching concentration of incineration residue and uniaxial compressive strength of solidified incineration residue.

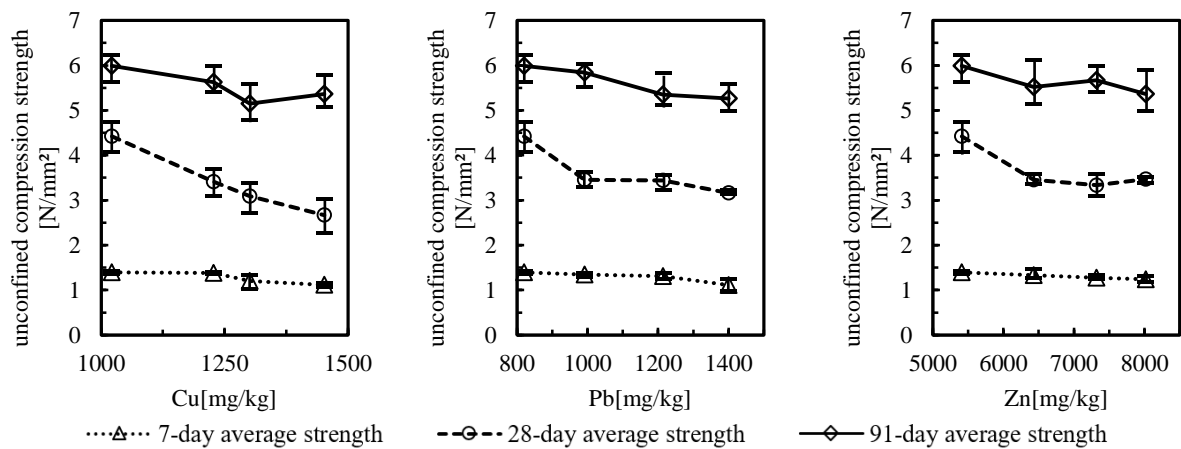


Figure 2. Relationship between Heavy Metal Content of Incineration Residue and Uniaxial Compressive Strength of Solidified Incineration Residue.

strength was fully met, although the cement solidification delay was occurring. The effect of solidification inhibition by heavy metals as a delay in cement solidification significantly affects the initial stage of cement solidification reactions. Simultaneously, it has a negligible impact on long-term strength. As a possible mechanism of inhibition of cement solidification by heavy metals, copper and lead react with hydroxyl ions to form compounds with lower solubility than calcium hydroxide, inhibiting the formation of calcium hydroxide necessary for the reaction in the aluminate phase (C_3A)⁸⁾. It is also known that metal chlorides of Cu and Zn may interact with cement silicates and aluminates to form complex substances that may affect strength development⁹⁾. As for lead, insoluble lead salts form a gelatinous film over the main component of the cement, acting as an anti-diffusion agent against water. This slows the rate of hydration and consequently the rate of curing¹⁰⁾. In addition, with regard to zinc, it is believed that calcium zincate, which is formed by the reaction of calcium and

zinc in cement, forms over C-S-H and causes delayed solidification¹¹⁾.

4. CONCLUSIONS

For the 7-day-old specimens, no significant change in strength was observed with increasing the amount of the three heavy metals (copper, lead, and zinc). However, for the 28-day-old specimens, the higher the leached concentration of heavy metals in the incineration residue, the lower the strength of the solidified incineration residue. On the other hand, the effect was more negligible for the 91-day-old specimens. The highest rate of strength loss was observed at 28 days for the specimens with the three heavy metals, while the rate of strength loss was lower at 91 days of age. Therefore, the effects of each heavy metal can be summarized as follows. As for copper, a significant decrease in the strength of the solidified product was observed at the 28-day age of the material as the added amount of copper increased. Moreover, the effect of delaying solidification was the most significant. Finally, as for lead, no increase

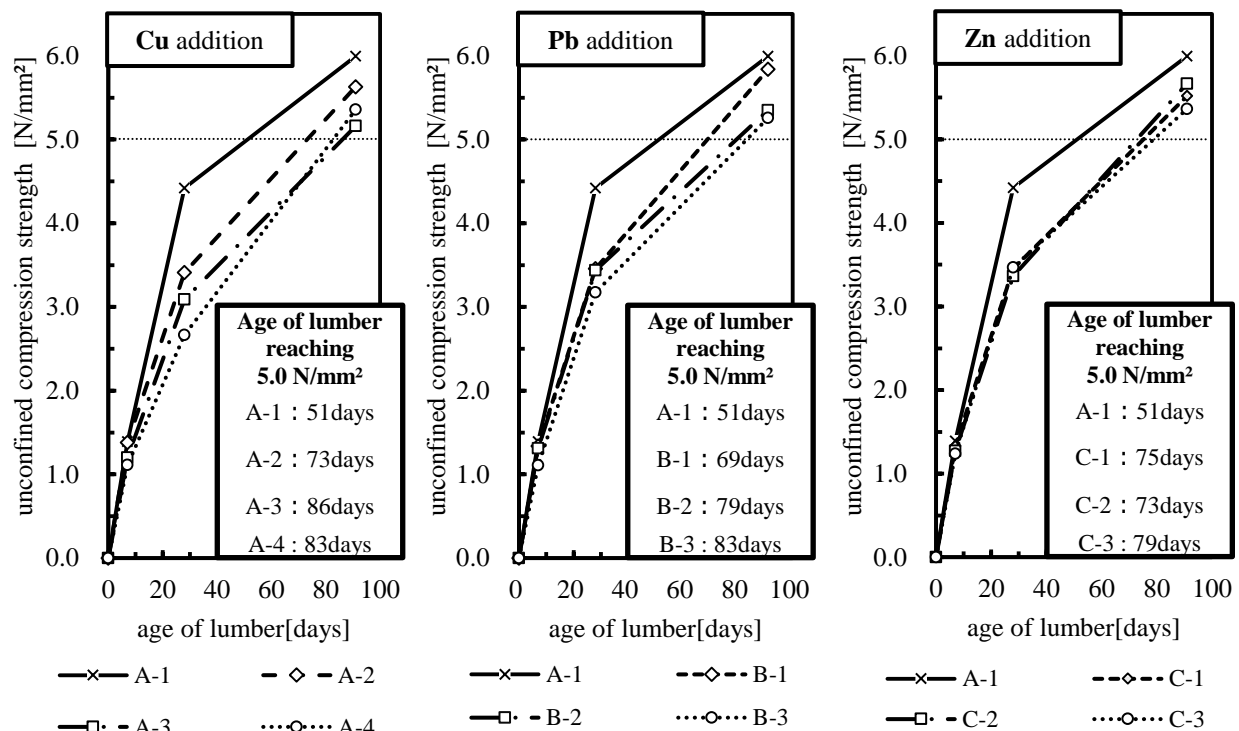


Figure 3. Time Dependence of Uniaxial Compressive Strength of Incineration Residue Solidified with Heavy Metals.

was observed in the retardation effect of solidification with increasing heavy metal additions. However, a decrease in strength was observed with small additions. It became clear that within the range of conditions in this study, the effect of heavy metals on long-term strength is negligible and fully meets the development target (5.0 N/mm²). However, some delay in strength development occurs due to heavy metals.

5. REFERENCES

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