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Long-term mechanical stability of cemented incineration bottom ash

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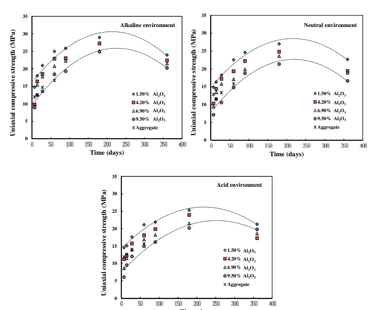
HIGHLIGHTS

- As Al_2O_3 increases, uniaxial compressive strength and tensile strength will decrease.
- The strength of the specimen in the acid solution is lower than alkaline solution.
- As the age increases, the strength of specimen will increase, but the strength converts to decrease after 180 days.
- Long term stability of bottom ash with high Al_2O_3 is not suitable for application.

GRAPHICAL ABSTRACT

The strength clearly decreased as the Al_2O_3 proportion increased and this trend existed in the short-term (14 days) and long-term (365 days). Therefore, regardless of whether the bottom ash was cemented or not, the increase in Al_2O_3 content was disadvantageous to its mechanical properties, including friction angle, compressive strength, tensile strength, and deformation modulus. Therefore, the Al_2O_3 content should be strictly controlled during bottom ash recycling to ensure that the incineration bottom ash has better engineering properties.



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ABSTRACT

Al_2O_3 is a major constituent of municipal solid waste (MSW) bottom ash that may cause swelling and weakening failure. This paper explores the influence of Al_2O_3 on the long-term mechanical properties of bottom ash. Experimental results indicate that increased Al_2O_3 corresponds to decreases in both the uniaxial compressive and tensile strengths of cemented bottom ash. More specifically, the strength and Young's modulus of cemented bottom ash with high Al_2O_3 content (9.2%) decreased by 22.1% and 40.1%, respectively, after 365 days. Therefore, the long-term mechanical stability of bottom ash with a high Al_2O_3 content is unsuitable for engineering applications.

1. Introduction

Taiwan's municipal solid waste (MSW) is currently primarily treated by means of incineration. Since 2008, approximately 97% of collected waste has been treated by incineration, which can reduce the mass of the MSW by 70–85% after treatment and the volume by 90–96% [1]. There are 24 large incineration plants in Taiwan at present, which dispose of approximately six million tons of waste annually. They produce approximately one million tons of incineration bottom ash and 300,000 tons of fly ash. Table 1 shows the amount of incineration and ash products produced by incinerators in Taiwan from 2007 to 2014 [2]. Previously, incineration bottom ash was mostly treated by sanitary landfilling. However, as resources gradually became exhausted and the "zero waste"

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Table 1
Incineration and ash products produced by incinerators in Taiwan from 2007 to 2014.

Year	Waste treatment by incineration (tons/year)	Bottom ash (tons/year)	Fly ash (tons/year)
2007	5,948,765	1,134,090	264,562
2008	6,110,838	943,930	264,554
2009	6,092,929	951,361	271,113
2010	6,235,310	992,583	301,846
2011	6,355,422	1,079,353	278,204
2012	6,404,987	1,060,376	289,157
2013	6,349,913	999,096	285,347
2014	6,294,479	937,177	290,016

Source: [2].

Table 2
Chemical compositions of the MSW bottom ash from various countries.

Chemical composition	Country			
	Taiwan[a]	Japan[b]	Singapore[b]	USA[b]
SiO_2 (%)	43.1–56.5	34.7–39.9	26	39.2–44.7
CaO (%)	11.8–21.6	11.1–18.2	16.8	10.5–14.8
Fe_2O_3 (%)	5.6–19.1	7.1–8.6	13.1	9.2–10.4
Al_2O_3 (%)	6.98–14.4	12.3–16.5	12.3–25.5	17.0–17.4
Na_2O (%)	5.79	1.8–2.6	1.9–2.5	6.46–8.1
MgO (%)	1.35–1.8	2.2–4.5	1.0–2.0	1.5–3

[a] Source: Taiwan EPA [2].
[b] Source: Pera et al. [7].

Table 3
Main chemical composition ratio of adopted bottom ash.

Chemical composition	Al_2O_3 (%)	SiO_2 (%)	CaO (%)	Fe_2O_3 (%)
Average percentage	1.5	82.3	13.5	2.7

concept arose, the reutilization of incineration bottom ash, which is extensively applied in construction, has become a trend.

The size distribution of incineration bottom ash approximates the well-graded gradation of geo-material, but it may have long-term instability. According to the literature on incineration bottom ash application systems [3,4], when bottom ash is applied to road concrete and substrate materials as aggregate and other substrate materials, over time the swelling effect of bottom ash may cause cracks, strength reduction, and even structural damage. This undesirable effect may originate from the complex and heterogeneous composition of incineration bottom ash, which has properties that are very different from natural aggregate.

According to previous studies [5,6], the specific gravity of incineration bottom ash is 1.7–2.4, whereas the specific gravity of natural aggregate is usually 2.6–2.9. Thus, incineration bottom ash has a lighter weight because of its porosity. With regards to the chemical composition of incineration bottom ash, because of the oxidation of incineration, most of elements exist in the oxidation state [6,7]. Incineration bottom ash mainly consists of SiO_2, CaO, Fe_2O_3, and Al_2O_3, as shown in Table 2, which account for approximately 95% of its total weight. Incineration bottom ash has a higher content of Fe_2O_3 and Al_2O_3 than natural aggregate. In addition, the pH value of fresh incineration bottom ash is relatively high, in the approximate range 11.1–12.6 [8,9].

The chemical compositions of different incineration bottom ashes differ. Several researchers have investigated the influence of different bottom ash compositions on the mechanical properties of materials. Weng et al. [10] found that the proportion of main constituent materials (SiO_2, CaO, Fe_2O_3, and Al_2O_3) of incineration bottom ash can influence the friction angle of the material. Specifically, they found that friction angle increases with Fe_2O_3 content and decreases with increasing Al_2O_3 content. Lin et al. [6] researched the mechanical properties of bottom ash from four actual plants and found that the friction angle decreases with increasing Al_2O_3 content. Thus, it is clear that changes in the Al_2O_3 content influence the mechanical properties of bottom ash.

Cementation of bottom ash as concrete is a common bottom ash recycling method. According to the literature, the strength of bottom ash-based concrete is not much different from that of general concrete [11]. However, when a concrete specimen made from bottom ash is stored for a period of time (approximately 3 months), apparent swelling effects occur, with maximum swelling capacity as high as 2%. Pecqueur et al. [3] indicated that the Al_2O_3 in bottom ash might be the primary cause of swelling failure. The chemical equation for Al_2O_3 is expressed as

$$\begin{array}{l} 4Al + 16OH^- \rightarrow 4Al_2O^- + 8OH^- + 12e^- \\ \underline{12H_2O + 12e^- \rightarrow 6H_2 + 12OH^-} \\ 4Al + 4OH^- + 4H_2O \rightarrow 6H_2 + 4AlO_2^- \end{array} \quad (1)$$

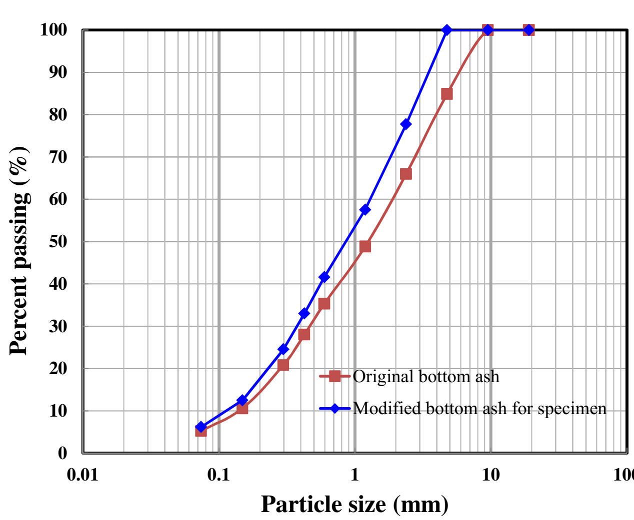

Fig. 1. Particle size distribution of the original bottom ash and that used for the cemented specimen.

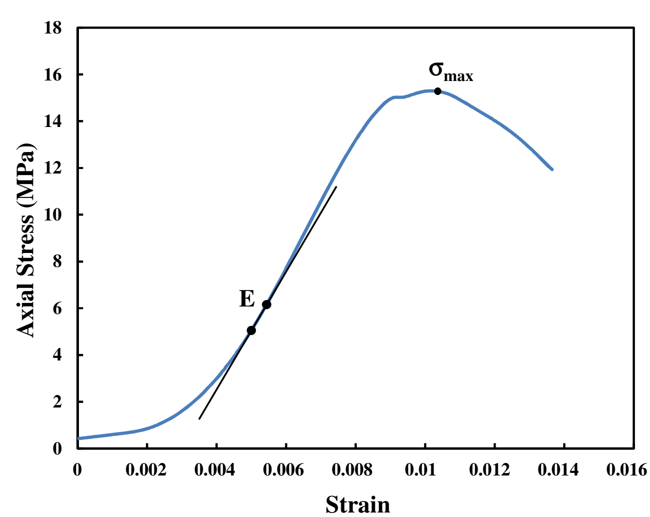

Fig. 2. Schematic illustration of the determination of uniaxial compressive strength and Young's modulus.