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The different properties of lightweight aggregates with the fly ashes of fluidized-bed and mechanical incinerators

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HIGHLIGHTS

- Reuse of MSW fly ash from fluidized-bed and mechanical-bed for lightweight aggregates were compared.
- The properties of lightweight aggregates with different fly ash ratios and sintered at different temperatures were evaluated.
- Fly ash of fluidized-bed MSW incinerator has better recycling and reusing potentials due to its composition and properties.

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ABSTRACT

The properties of lightweight aggregates (LWAs) manufactured from the fly ashes of municipal solid waste (MSW) fluidized-bed (FB) incinerators and mechanical-bed (MB) incinerators were compared and investigated. The fly ashes from FB and MB incinerators were mixed with the reservoir sediment and sintered at 1000–1200 °C to produce LWAs. Experimental results show that each LWA product complied with the TCLP standards. Adding MB fly ash to LWA obtained relatively higher crushing strength than adding FB fly ash. However, the LWAs with FB fly ash were less hazardous, lighter in weight, lower in water absorption, and higher in stability than those with MB fly ash. The reuse of FB fly ash in LWA has great recycling potential from the perspective of environmental sustainability.

1. Introduction

Incineration is a main waste treatment method in many developed countries owing to its irreplaceable advantages. However, waste incineration inevitably generates particulate and gaseous pollutants which must be removed by air pollution control devices (APCDs) with the addition of adsorbents (such as $Ca(OH)_2$ and activated carbon). The fly ash, adsorbents, and reaction by-products are known as APCD residues. Many researches have shown that these residues contained various hazardous metals and salts. Conventionally, APCD residues are subjected to stabilization and solidification processes and then landfilled [1–4]. The landfill of solidified APCD residues consumes lots of land space and the hazardous constituents may be released to the surrounding environment. This solution is not sustainable for the final disposal of APCD residues. The recycling and reuse of APCD residues has become an important research subject. Previous studies indicated that the properties and chemical compositions (silica and aluminum) of the MSWI fly ash enabled it as the preferable reused in brickmaking, roadbeds, structural concretes, and LWAs [1,5–7]. Therefore, the recycling and reuse value of APCD residues (or fly ash) is feasible and worthy of further study.

LWAs are the typical example of reusing the fly ash in porous construction materials. The conventional production method of LWAs involves mixing the binder of natural materials rich in SiO_2 and Al_2O_3 (such as clay and slate) with the foaming and fluxing agents, and the materials are transformed into LWA pellets by high-temperature sintering [8–10]. The APCD residues typically contained 15–25% SiO_2 and Al_2O and the other chemical compounds such as Fe_2O_3, CaO, MgO, Na_2O, and K_2O. They can serve as the foaming and fluxing agents, as well as help to reduce the required sintering temperature to form LWAs [11,12]. Except for the natural materials, the fly ash was also considered as good additives in the production of LWAs from the viewpoint of resource conservation and reducing the treatment cost of fly ash [8,13,14]. Liao [15] and Chen [14] have demonstrated the LWAs of low density but high crushing strength can be produced from using

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the reservoir sediment as a binder and different ratios of fly ash at appropriate sintering conditions. A ternary diagram proposed by Riley [16] can be applied to make preliminary judgments on whether the reservoir sediment and fly ash were within the appropriate scope of LWA's chemical composition.

Table 1 summarizes the results of related researches on the topics of LWAs. The following highlights are remarked: (i) the water absorption of LWAs were reduced with increasing the sintering temperature and retention time [25–28]; (ii) the type and composition of binders influenced the density, water absorption, and other physical properties of the LWAs [10,21,23,25]; (iii) the mechanical performances of LWAs were proportional to the amount of binder added [14,29]; (iv) alkaline earth metals contributed to the fluxing and strengthening of the sintered surface of LWAs [30]; (v) increasing the amount of Si in LWAs by adding waste glass improved the mechanical performance and reduced the water absorption [29]; and (vi) the ratio of fly ash added in LWAs can be increased by pre-washing the fly ash [14,17].

The properties of fly ash in a particular incinerator are affected by the compositions of feed waste, the type of incinerator, the operational conditions, and the other parameters. The combustion temperature of the mechanical-bed (MB) incinerator is usually controlled at 1000 °C, and more $Ca(OH)_2$ was injected into the APCD. The combustion temperature of the fluidized-bed (FB) incinerator is generally lower than that of a MB incinerator; and additional SiO_2 sand was required to serve as the fluidized medium. Therefore, the fly ash of MB incinerators contained more Ca while the fly ash of FB incinerator contained more Si [31,32]. The fly ashes of thermal power plants have been wildly reused in the LWAs in previous studies because they were non-hazardous [9,11,19,22]. Recently, more and more scholars conducted the researches and experiments by using the fly ash from MSW incinerators [8,14,17]. Most MSW incineration plants use the mechanical-bed incinerators. However, the fly ashes of MSW MB incinerators are hazardous and usually exceed the limits of toxicity characteristic leaching procedure (TCLP). The recycling and reuse of MSW fly ash is therefore restricted. Additionally, higher levels of Ca in MSW fly ash cause the water absorption of the LWAs increased. Therefore, Chen [14] suggested an upper limit on the ratio of MSW fly ash in LWAs to be 30%. Because the fluidized-bed medium (silica sand) was added into the FB incinerators, the combustion efficiency and pollution control were improved significantly. Previous researches revealed that the MSW fly ashes from FB incinerators were nonhazardous and the direct reuse of them was permitted [31]. Compared with the MB fly ash, the reuse of FB fly ash can reduce the pre-processing costs of fly ash and lower the environmental risk. However, the feasibility of reusing FB fly ash for LWA was still unclear.

Therefore, this study investigated the application of APCD residues from MB and FB incinerators in manufacturing the LWAs. The influences of different sintering temperatures and ratios of fly ash on the physical and chemical properties of LWAs were examined. The properties of LWAs manufactured from the FB and MB fly ashes were compared and discussed.

2. Materials and methods

2.1. Raw materials

MSW fly ashes were collected from different incineration plants and reservoir sediment from north Taiwan was used as the binder for LWAs. The capacity of the FB incinerator was 400 ton/day, and the operation temperature was 850–950 °C. A baghouse was equipped as the APCD. The capacity of the MB incinerator was 1350 ton/day, and the operation temperature was 1100 °C. A cyclone, a semi-dry scrubber injecting $Ca(OH)_2$ and activated carbon, and a baghouse were equipped as the APCDs. The detailed processes of the two incinerators are illustrated in Figs. 1 and 2. The feeding wastes of these two incinerators were general unhazardous MSW. Fly ashes were collected from each APCD and mixed thoroughly. The reservoir sediment and APCD fly ash were dried at 105 °C for 24 h. Their inorganic composition levels were analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-AES, Jarrell-Ash, ICAP 9000).

2.2. Production of lightweight aggregate

LWAs were fabricated by adding specific amounts (5, 10, and 15%) of fly ashes from the MSW FB and MB incinerators to the reservoir sediment and mixing thoroughly with 30% deionized water. Spherical pellets 16 ± 1 mm in diameter were formed by hand and dried at 105 °C for 24 h [17]. Sintering was performed by a programmable high-temperature furnace in the laboratory. The sintering temperature was controlled at a heating rate of 2 °C/min from room temperature to 1000, 1100, and 1200 °C and lasted 15 min. After sintering, the LWA products were cooled down

Table 1
Previous studies of lightweight aggregates and concrete with fly ash.

Binder	Incinerator	Fuel	Main results	References
Nature clay	MB	MSW	APC residues do not possess expansive (bloating) properties; incorporation into the LWA is only possible in moderate quantities, such as 3–5%	[17]
Reservoir sediments	MB	MSW	The maximum content of MSWI fly ash should be less than 30%. LWA with specific gravity in the range of 0.88–1.69 g/cm^3 and crushing strength as high as 13.43 MPa	[8]
Reservoir sediments	MB	MSW	The MSW ash is not in the limits of the expandable region of Riley's ternary diagram due to the low content of SiO_2. Therefore, it can only be used as an additive	[14]
Nature clay	FB	Sewage sludge	Major crystalline phases present in both as-received and sintered sewage sludge ash were SiO_2, $Ca_7Mg_2P_6O_{24}$, and Fe_2O_3	[18]
Bottom ash of coal	Power plant	Coal	Sintering of lignite combustion residues is an efficient method for production of LWA for structural and insulating purposes	[19]
Nature lime	Power plant	Coal	An addition of 8% clay was necessary to obtain green pellets with sufficient green strength. A good quality of LWA can be produced with fly ash with high free lime content	[20]
Bentonite & glass powder	Power plant	Coal	Increasing binder content reduced water absorption at all temperatures	[21]
Sludge	Power plant	Coal	The water absorption values were dependent on the size and amount of each type of pore (open or closed)	[9]
Sludge	Power plant	Coal	Adding coal ash brings about the lower loose bulk density, the lower dry and apparent particle density, the lower water absorption, and the higher compressive strength	[22]
Sludge	Power plant	Coal	Adding coal ash improved (decreased) the sintering temperature while effectively decreasing the pore size and increasing the compressive strength of the product	[11]
Nature clay	Power plant	Coal	The properties of aggregates depend on the type of binder and its dosage. The binders used did not alter the chemical composition, while they did influence the microstructure	[23]
Nature clay	Power plant	Coal	Sintering processes can accommodate fly ash with fairly high carbon content, while the other processes prefer low carbon fly ash	[24]
Bentonite & Kaolinite	Power plant	Coal	Finer fly ash exhibits higher pelletization efficiency	[13]