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Conditioned MSWI ash-slag-mix as a replacement for cement in cement mortar

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ABSTRACT

Fly-ash and scrubber-ash are byproducts of municipal solid waste incinerators (MSWIs) that require further treatment before disposal to avoid polluting soil and groundwater with heavy metals. Recycling scrubber-ash is not feasible because it is extremely difficult to melt this material. In this study, fly-ash and scrubber-ash from MSWI were pre-mixed, then added to fly-ash from foundry sand and vitrified into slag by melting. The amount of that the latter was adjusted to maintain a basicity (CaO/SiO_2) of 1.1. Slag-blended cement mortar (SCM) specimens were molded with 0–40 wt.% cement replaced by slag powder. Toxicity characteristic leaching procedure (TCLP) tests and compressive strength tests were performed. TCLP test results revealed that the concentrations of leached heavy metals were substantially below the regulatory thresholds. Compressive strengths of the SCM specimens were higher than those of the control group after curing for 7 days or longer. Those that had been cured for 28–90 days were about 124–148% stronger in compression than those in the control group. The Pozzolanic reaction accounts for the strengthening effect in the context of the added slag. It is thus feasible to simultaneously recycle MSWI fly-ash, scrubber-ash and fly-ash from foundry sand into useful resources.

1. Introduction

Most municipal solid waste (MSW) is incinerated in Taiwan. Municipal solid waste incinerators (MSWIs) in Taiwan produce about 250,000 tons of fly- and scrubber-ash annually. The resulting ash waste contains hazardous heavy metals. A chelating agent and 20 wt.% cement are added to the ash, which is then solidified for safe disposal in landfill sites. However, leaching of heavy metals is still possible in the long term [1–4].

To reuse fly-ash, Al-Rawas et al. investigated the effects of various replacement ratios of sand or cement in a cement mortar using MSWI fly-ash [5]. Water-permeable pavement bricks can be made from the molten slag of MSWI fly-ash [6]. Partial substitution of cement in mortar by using molten and pulverized slag has recently been of interest due to the ease with which fly-ash can be vitrified [7–11].

However, it is extremely difficult to vitrify MSWI scrubber-ash due to its high concentration of CaO and insufficient SiO_2. Lee et al. added waste glass to a mixture of fly-ash and scrubber-ash to successfully vitrify these substances and investigated a mortar that featured 20 wt.% cement replacement with slag powder [12,13]. Heavy metals were barely detected in Toxicity characteristic leaching procedure (TCLP) tests of the modified slag-cement mortar, and the compressive strengths were reported to be acceptable after curing for more than 28 days.

Waste glass is a very useful resource and can be recycled in many ways. The use of waste glass in recycling MSWI fly- and scrubber-ash may not be cost-effective. For the sake of economical feasibility, it would be advantageous to identify cheap sources of SiO_2 other than waste glass. This is the motivation behind this study.

Foundry sands are typical foundry industry wastes. They are classified into waste wet molding sand, water glass sand, resin sand and ceramic shell molding sand. Collectively, they are commonly called waste foundry sands. Fly-ash in waste foundry sand is collected from the air pollution control equipment in the foundry. Around 6 kg of fly-ash is produced per ton of cast iron produced, and 21,000 tons of foundry fly-ash is produced annually in Taiwan. Both waste foundry sand and foundry sand fly-ash are hazardous and need to be carefully processed.

Guney et al. investigated the reuse of foundry sand modified mixtures for sub-based layers of highways [14]. The resistance of foundry sand-based specimens to winter conditions is generally better than that of typical sub-base reference materials. Siddique et al. used several types of byproducts of used foundry sand in the manufacture of controlled low strength materials and concrete [15]. The results revealed that this approach is not only economical but also helps to reduce the disposal problem. Siddique et al. further evaluated the mechanical properties of concrete mixtures in which the fine aggregate was partially replaced with used foundry sand [16]. The test results indicated that used foundry sand creates good quality concrete and construction materials. To the best of our knowledge, to date there have been no studies on how best to recycle the fly-ash of foundry sand.

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Table 1
Contents of the constituents in ordinary cement mortar (OCM) and slag-blended cement mortar (SCM) specimens (proportion weights per nine specimens).

Mix design (g)	Notation of mortar specimens				
	OCM[b]	SCM[c] (10%)	SCM (20%)	SCM (30%)	SCM (40%)
Cement	740	666	592	518	444
Modified slag[a]	0	74	148	222	296
Sand	2035	2035	2035	2035	2035
Water	359	359	359	359	359

[a] Particle size of slag powder < 38 μm (<sieve #400).
[b] Ordinary Portland cement mortar.
[c] Slag-cement mortar, where in percentage in the bracket is the cement replacement ratio.

In this study, the fly-ash of foundry sand, which is rich in SiO_2, was used to supplement the SiO_2 of MSWI fly- and scrubber-ash for successful melting into slag. It has been reported that, by vitrification, heavy metals can be immobilized in the amorphous Si–O network to form a highly stable slag; hence, these toxic metals are not easily leached [7,9,17]. This is the reason why we used a melting process and applied the slag as a partial cement replacement for molding mortar specimens in this study.

2. Materials and methods

2.1. Materials

2.1.1. MSWI fly-ash

Fly-ash was supplied from an MSWI in northern Taiwan. It is a yellowish or light gray color and has a specific gravity (S.G.) of 2.91.

2.1.2. MSWI scrubber-ash

Scrubber-ash collected from the bag filter of the MSWI is grayish with an S.G. of 2.61.

2.1.3. Cement

The cement used was Type I ordinary Portland cement (OPC), manufactured by Taiwan Cement Company. This cement has an S.G. of 3.15 and a fineness of 3520 cm^2/g. Its physical and chemical properties meet ASTM C150 specifications.

2.1.4. Sand

The reference sand was Ottawa-type sand consistent with ASTM C778 specifications. This sand has an S.G. of 2.63.

2.1.5. Fly-ash of foundry sand

This was provided by a foundry company in Taiwan. It is a black-brown powder with an S.G. of 1.88 and a fineness of 1993 cm^2/g.

2.1.6. Ash mixture

Fly- and scrubber-ash were uniformly mixed at a weight ratio of 1:3, according to the ratio of their output volumes from the MSWI. We call the result "ash-mix." The ash-mix was mixed with a suitable amount of fly-ash of foundry sand to adjust its basicity (CaO/SiO_2) to 1.1. We call the result "modified ash-mix."

2.1.7. Vitrifying the modified ash-mix into slag

Modified ash-mix was placed in an aluminum oxide crucible, heated in an electrical oven at 1400 °C for half an hour and then poured into water for quenching. The result was a black-green and glassy slag of irregular shape. The slag was ground to form powder with particle sizes of less than 38 μm (<sieve #400). The S.G. was about 2.44, and the fineness was 6330 cm^2/g. This powder was used to replace cement in various proportions in preparing cement mortars.

2.2. Methods

2.2.1. SEM/EDS analyses

A scanning electron microscope (SEM, JEOL, JSM-5600, Japan) was used to study fly-ash, scrubber-ash, ash-mix and modified ash-mix slag powder. No pretreatment, except drying, was required. For the cured slag-cement mortar specimen, cut samples were first oven-dried at 100 °C for 24 h and then cooled in a desiccator. The sample was then secured onto a sample holder and coated with a thin platinum layer (no thicker than 20 nm, in order not to interfere with the EDS analysis). An energy dispersive X-ray spectrometer (EDS, Oxford, 6587, UK) attached to the SEM was used to analyze the chemical composition.

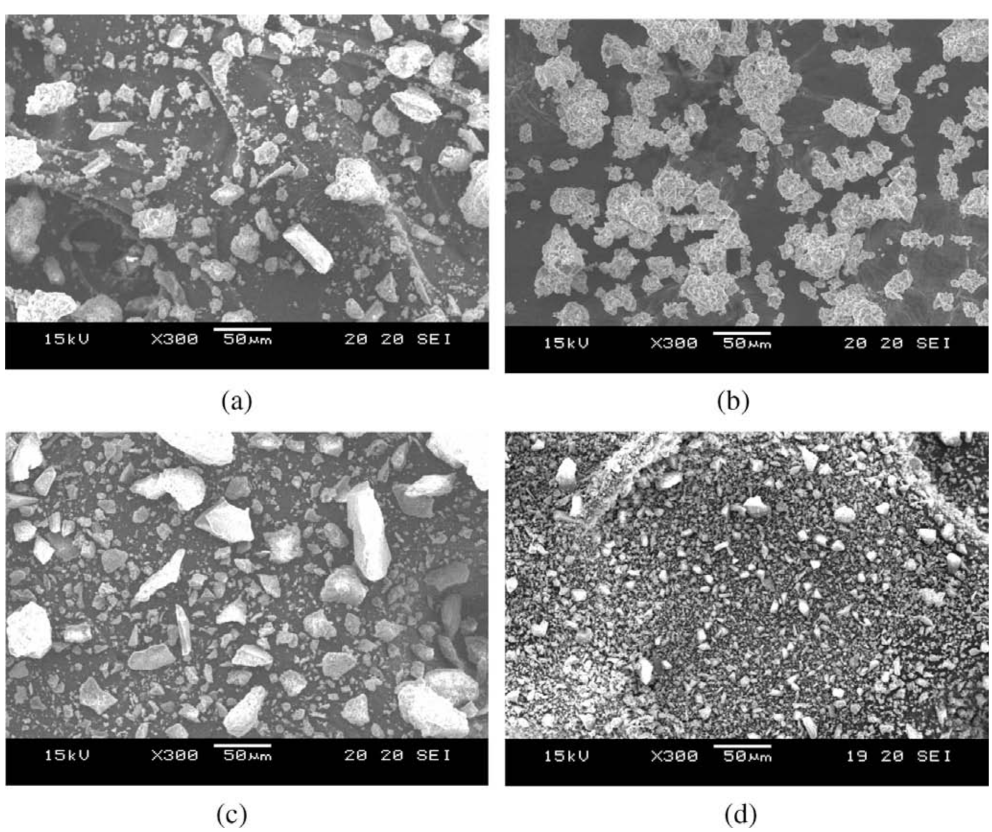

Fig. 1. SEM micrographs of (a) MSWI fly-ash, (b) MSWI scrubber-ash, (c) fly-ash of foundry sand and (d) modified ash-mix slag.