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Effect of waste glass addition on lightweight aggregates prepared from F-class coal fly ash

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HIGHLIGHTS

- F-type coal fly ash can be recycled as lightweight aggregate (LWA) via sintering.
- Waste window glass addition enhances coal fly ash sintering due to its rich flux.
- When sintering temperature is too high, more open pore volume will be created.

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ABSTRACT

Waste window glass powders are mixed with F-type coal fly ash and fired in an attempt to prepare lightweight aggregates (LWAs) at relatively lower sintering temperatures. The mixtures are formed into cylindrical green pellets with a press operated at 3000-psi pressure. The green pellets are then fired (sintered) in an electric furnace at 1050–1300 °C for 10 min without any pre-heating step, thus simplifying the sintering process and saving energy. Results show that all fired pellets, except that made from pure coal fly ash at 1050 °C, have a particle density less than 2 g cm^{-3} meeting the LWA standard generally accepted by construction industry. The waste glass powders promote flux content in the mixtures, reducing the temperature required to successfully sintering green pellets into LWAs. Pellets lose their weight up to 4.5 weight percent after firing. The weight loss does not go up with increased sintering temperature. Due to enhancing formation of viscous layer to capture gases, addition of glass powder to coal fly ash tends to suppress weight loss when the temperature is above 1175 °C, while such suppression phenomenon in the fired two-component pellets does not occur unless the temperature is greater than 1200 °C. When coal fly ash is sintered above 1175 °C, more big round pores surrounded by glassy layer can be observed on pellets' microstructure morphologies. However, extremely big pores of distorted shape without distinct solid walls are developed in core fragments at 1300 °C, indicating that the viscosity of viscous layer is too low to capture gases and the fired pellets are just about to melt. After sintering the mixture at 1050 °C and 1250 °C, diopside ($MgCaSiO_6$) and wollastonite ($CaSiO_3$) are formed as new crystalline phases. They are beneficial to sintering reaction because of their relatively low melting points and good sealing property.

1. Introduction

Lightweight aggregates (LWAs) have extensive practical application. They can be used in environmental engineering as a substrate on which bacteria are grown, in horticulture due to their ability to hold water inside their pore structure and gradually release it, and in civil engineering as construction materials. Tall building can be found almost everywhere in Taiwan nowadays owing to its extremely dense population and limited land space. The thriving activities in construction sector have caused a dramatic depletion in the natural resources serving as construction materials. To ease the situation of natural resource shortage and to minimize negative environmental impact from quarrying natural coarse aggregates, manufacturing LWAs from recycled raw materials [1] and various wastes, such as sand sludge, mining and industrial waste, for replacing fractional coarse aggregates in concrete has become an unavoidable trend [2–7].

Having a lower density, LWAs generally weigh less than three-fourths of normal-weight aggregates. As a result, the use of LWAs can lessen the demand of reinforced steels and cement, thereby cutting down construction cost. Furthermore, LWAs can reduce heat conduction rate in virtue of their abundance of pores, saving energy cost in both winter and summer for the users of heaters

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and air conditioners. During a fire occasion, LWAs can also prevent a rapid temperature surge in the rooms next or close to fire origin by retarding heat transference rate. Moreover, level of sound transmission can be lowered through destructive wave interference as sound wave passes through the porous structures of LWAs.

Power source in Taiwan mainly includes fossil fuels, renewable energies, and nuclear power. The development of renewable energies is very limited due to Taiwan's isthmian territory and dense population; it merely represented 3.56% of the total power consumption in 2011. As to extracting power from nuclear source, there has been strong nationwide resistance against it because of the severe damage caused by the nuclear accidents occurred in Japan in 2011 and because of the difficulty in properly handling radioactive wastes. As a result, constructing nuclear power plants takes long drawn-out time in policy debate. In contrast, the resistance to new construction of fossil-fuel plants is much less owing to the rapid advance in pollution control technologies with the capability to considerably abate pollutant emissions. Hence, acquiring power from fossil-fuel power plant seems to be a better alternative for meeting the growing demand of power in Taiwan in near future. Currently, coal-fired power accounts for 49.47% of the total power consumption in Taiwan and the annual output of coal fly ashes is approximately two million tons. Although currently major part of the fly ashes are recycled as an additive in cement and brick manufacturing, still, about one tenth of them remains as un-recycled. The percentage of un-recycled coal fly ash is increasing because brick demand in construction sector is declining. Further, the capacity of landfill for properly treating the fly ash is very limited in Taiwan considering the fact that 23 million people are residing on a 36 thousand square-kilometer island of which approximately 70% is covered with mountains and hills.

Worldwide annual coal fly ash production rate is 900 million tons and expected to increase to approximately 2 billion tons in 2020. Some developed countries even dispose of more than 50% of their coal fly ash in open dump sites. Coal fly ash disposal in open dumps is of great environmental and human health concerns such as ground water contamination by toxic metals and polycyclic aromatic hydrocarbons. Therefore recycling of coal fly ash is critical for sustainable society.

The present study aims to recycle coal fly ash as LWAs that are increasingly demanded by Taiwan's construction sector and most of the LWAs are presently imported from other countries. Nevertheless, sintering pure coal fly ash into LWAs requires high temperature, or considerable energy input. The sintering temperature can be lowered if substances rich in flux are blended with coal fly ash. Currently, waste window glass in Taiwan is suffering from poor recycling activity due to a non-rewarded policy practiced by Taiwan government. Their final destiny is to go to incinerator with municipal wastes and then mostly become bottom ashes. Because waste window glass mainly consists of silica and sodium oxide, it can be blended with coal fly ash as raw materials for preparing LWAs. Recycling of coal fly ash and waste window glass as LWAs can not only meet Taiwan government's zero-waste goal in accordance with the principle of sustainable development, but also reduce reliance on imported LAWs whose price is going up due to worldwide growing environmental concern on quarrying natural resources as LWAs.

2. Experimental

2.1. Materials

The F-class coal fly ash was collected from a coal-fired power plant in Taiwan, oven dried at 105 °C, ground to pass a 50-mesh sieve (less than 297 μm), and stored in PE bottles for subsequent experiments. The ash powders aggregate; thus, for better mixing with waste glass powders, they were subjected to an easy grinding for 15 s. By the way, the coal fly ash is grey in color and low in lime, thus being less desired as cement additive by local cement producers. Waste window glass was coarsely ground into powders with a blade-type shredder, dried at 105 °C, and passed through a 50-mesh sieve for subsequent experiments. Fig. 1 shows the appearance of both coal fly ash (magnification: ×400) and waste window glass powders (magnification: ×200). The glass powders are basically in triangle-like shape while coal fly ash particles are mostly spherical, and the former is much bigger in size.

2.2. Equipment

A constant-temperature oven (RHD-120L, max. temperature 200 °C, Risen, USA) was used to dry the raw materials, coal fly ash and waste window glass powders. The appearance of raw material powders were observed with a microscope (BX 5 system microscope, Olymlus corp., Tokyo, Japan). To analyze chemical compositions of the raw materials, a microwave oven (MWS-2, Berghof Laborprodukte GmbH, Germany) was employed for sample digestion and an inductively coupled plasma atomic emission spectrometer (ICP-AES) (Profile plus, Teledyne Leeman Labs, New Hampshire, USA) was used to quantify the compositions. Thermal property of the raw samples was investigated with a thermogravimetric analyzer/differential scanning calorimetry (TGA/DSC) (Pryis diamond TGA/DSC, Perkin Elmer, Massachusetts, USA). Experiments carried out with a laser diffraction particle analyzer (LS230, Beckman Coulter, Washington, USA) gave particle size distribution of the raw materials. The to-be-sintered cylindrical green pellets were made by pressurizing the raw material powders with a high-pressure press (maximum shaping pressure 8500psi, Pan-Chum Corp., Taiwan). Then, the green pellets were sintered into LWAs in a sintering furnace (maximum temperature 1450 °C, Chung-Lien High Heat Industrial Co. Ltd, Taiwan), and compressive strength of the sintered pellets was measured by the use of a crushing strength machine (HCH-239-20T, Jin-Ching-Her Co. Ltd., Taiwan). An X-ray diffractometer (XRD) (D8 Advantac, Bruker AXS, Germany) was employed to identify the crystalline phases present in both the raw materials and sintered pellets. The morphologies of core fragment of the sintered pellets were studied with an environmental scanning electron microscope (ESEM) (FEI Quanta 400F, Oregon, USA).

2.3. Method

Fig. 2 is the experimental flowchart depicting the procedure from sample pretreatment, instrumental analysis for raw materials, firing of green pellets, to characterization of fired pellets.

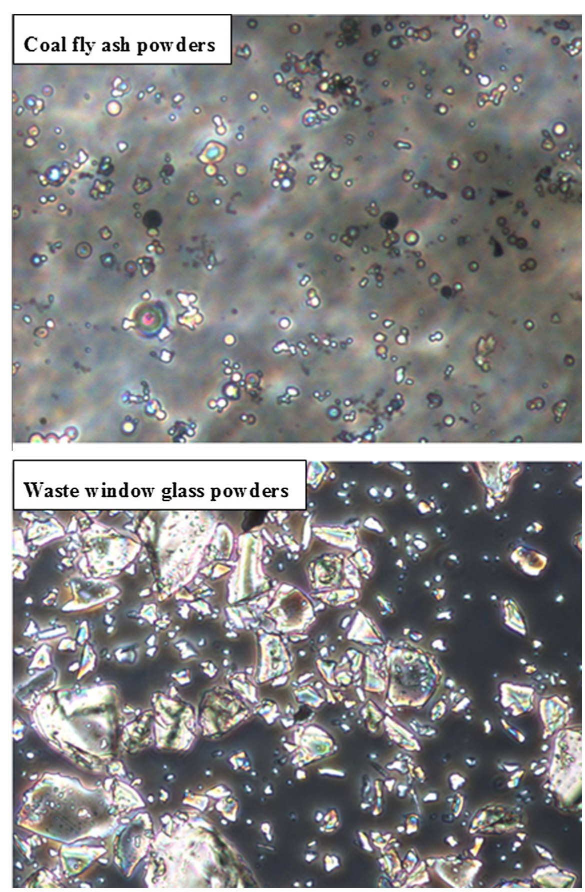

Fig. 1. Appearance of coal fly ash (×400) and glass powders (magnification: 200).