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Spent fluorescent lamp glass as a substitute for fine aggregate in cement mortar

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ABSTRACT

In recent years, recycled waste materials have been widely used to produce construction materials in an effort to reduce the utilization of natural resources and post-consumer wastes entering landfills. In this paper, the results of an experimental programme on studying the feasible use of spent fluorescent glass (FG) as a fine aggregate replacement in cement mortar are presented. Two types of FG were adopted in this study, one with (FG-A) and one without (FG-B) heating treatment at around 375 °C, to ensure the removal of mercury within the broken FG. The use of FG up to 40% to replace sand showed no obvious difference in density, but demonstrated an enhancement in workability and less shrinkage in the cement mortar. In comparison, the reduction of mechanical strength for a given content of FG-A usage in mortar is relatively lower than that of FG-B. This could be due to the FG-A (after the heating treatment) being free from the organic lacquer and the smooth coating, resulting in a better bond with the cement paste matrix. All the FG samples experienced big length changes due to the alkali-silica reaction (ASR), associated with their high solubility and the original microcracks present in the interior of the thin FG particles. The Toxicity Characteristic Leaching Procedure (TCLP) results indicated that utilizing of both FG-A and FG-B in the cement mortar could effectively reduce the leachability of mercury, from 12.99 mg/L and 70.55 mg/L (determined original FG-A and FG-B values before they were incorporated into the cement mortar) to below the permissible limit of 0.5 mg/L. However, the replacement ratio of FG should be limited to 30% or below.

1. Introduction

Glass is a transparent material and present in different forms and products, such as glass containers, flat glass, bulb glass, cathode ray tube (CRT) glass, etc. (Rafat, 2008). All these products have a limited lifetime, and some of them require proper recycling or treatments prior to disposal to avoid environmental impacts. For example, concerns caused by Pb leaching from CRT led to stringent controls on CRT glass (Bedekovic, 2015). The glass components of CRT are normally separated into different parts and crushed into glass cullet for further treatment (Ling and Poon, 2012a). Our previous studies have demonstrated that using an acid treatment step can remove most of the lead from the crushed funnel glass surface, and the treated CRT glass is safe to be re-utilized in cement mortar (Ling and Poon, 2011), heavyweight concrete (Ling and Poon, 2012b) and concrete blocks (Ling and Poon, 2014). A similar finding was also reported by Romero et al. (2013).

Unlike CRT glass, post-consumer beverage glass or soda-lime glass does not require any treatment prior to its reutilization in concrete. For the past few decades, the feasible use of recycled glass derived from beverage glass bottles has been extensively discussed in the literature. The potential benefits and shortcomings of using recycled glass in concrete products have been well reported (Shi and Zheng, 2007; Castro and Brito, 2013; Rashad, 2014). It is generally agreed that the mechanical strength of concrete gradually decreases as the amount of glass content increases (Castro and Brito, 2013). Apart from strength, the use of recycled glass in concrete may result in dimensional expansion due to the alkali-silica reaction (ASR) (Shi and Zheng, 2007). However, its impermeability and smooth surface nature plays a vital role in enhancing the workability, water absorption, drying shrinkage and durability properties of the glass mortar or concrete (Ling et al., 2013).

With the widespread use of energy-efficient fluorescent lamps

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for lighting purposes, environmental concerns related to the disposal of mercury-containing fluorescent lamps have become progressively important (Rey-Raap and Gallardo, 2012; Taghipour et al., 2014). In fact, most of the mercury is present in phosphor powder form deposited on the surface of the fluorescent glass (Park and Rhee, 2016). In Hong Kong, the Fluorescent Lamp Recycling Programme (FLRP) for households has been launched by the lighting industry with support from the Environmental Protection Department (EPD), to provide free collection and treatment of all used mercury-containing lamps (EPD, 2016). The goal of this programme is to collect 400,000 spent lamps from households every year and reduce the environmental risk from the improper disposal of these lamps.

In Hong Kong, all the collected spent fluorescent lamps are processed at the Chemical Waste Treatment Center which is equipped with special handling and storage arrangements. In the facility, electromagnets and densimetric tables are used to separate glass, metal and other lamp components. A mercury recovery technology (MRT) system is run automatically to break/crush the spent fluorescent lamps under negative pressure and the phosphor powder is collected at the same time. The mercury bearing powder is then heated in a Bath Process Distiller (BPD) to the boiling point of mercury (375 °C) to collect and recover the mercury for recycling (EPD, 2016).

The drawback of the current technology is that only the mercury bearing powder is vapourized but the phosphor powder on the glass may not be fully removed. Therefore, the processed fluorescent glass (FG) cullet from the recycling plant still requires a further step of treatment before being sent to the landfill for disposal. In order to promote green and environmental sustainability, it is important to find better alternatives for the disposal of such FG waste. Although the use of various types of recycled glass for the production of cement mortars has been widely studied (Wang, 2011; Ling and Poon, 2013; Penacho et al., 2014), the information regarding the use of mercury-containing FG is still very limited. The objective of this study was to investigate the feasibility of utilizing FG in cement mortars. Two types of FG were studied, namely FG-A (previously treated in a BPD) and FG-B (broken fluorescent glass without going through BPD treatment), so that a more comprehensive evaluation of the effect of different mercury contamination of FG on the properties of cement mortar could be obtained. The fresh and hardened properties as well as the potential of ASR expansion and leachability of mercury of the mortar mixes containing 0%, 10%, 20%, 30% and 40% FG-A and FG-B aggregates were investigated.

2. Experimental programme

The detail of the experimental programme including materials, mix proportions and preparation of samples adopted in this study for cement mortar as well as the test methods are discussed in the following section.

2.1. Materials

The materials used to prepare cement mortars consisted of ordinary Portland cement, natural river sand, spent fluorescent lamp glass and water.

2.1.1. Cementitious materials

For this experimental study, an ASTM Type 1 ordinary Portland cement (OPC) and a ground granulated blast furnace slag (GGBS) were used as the cementitious materials. Table 1 shows the chemical composition and physical properties of cement and GGBS.

2.1.2. Natural river sand

Natural river sand with a particle size of less than 1.18 mm and a fineness modulus of 1.88 was used as the fine aggregate. The water absorption and density of sand are shown in Table 2. The particle size distribution curve of the sand is shown in Fig. 1.

Table 1
Chemical compositions and physical properties of OPC and GGBS used in this study.

Contents	OPC	GGBS
SiO_2	19.61	43.8
Al_2O_3	7.33	14.1
Fe_2O_3	3.32	1.1
CaO	63.15	33.6
MgO	2.54	4.4
Na_2O	0.13	1.1
K_2O	0.39	–
TiO_2	–	–
SO_3	2.13	1.2
Loss on ignition (%)	2.97	0.3
Specific gravity (g/cm^3)	3.16	2.97
Specific surface (cm^2/g)	3519	5340

2.1.3. Spent fluorescent glass

The spent fluorescent glass (FG) used in this study was obtained from a local chemical waste treatment and recycling plant, the Chemical Waste Treatment Center. In the present study, two types of FG were studied, namely FG-A (previously treated in a BPD to remove mercury bearing powder) and FG-B (broken fluorescent glass without going through the treatment in a BPD). The TCLP leachable mercury values of 12.99 mg/L and 70.55 mg/L were recorded for FG-A and FG-B, respectively, rendering them as hazardous materials based on the regulatory thresholds of the Toxicity Characteristic Leaching Procedure (TCLP) (EPA, 2011). This drives the need for more research on finding a better way to dispose of FG waste. The physical properties of fluorescent glass and its chemical composition obtained by X-ray fluorescence (XRF) analysis are shown in Tables 2 and 3. Particle size distribution curves and photographs of both FG-A and FG-B are shown in Figs. 1 and 2, respectively.

2.2. Mix proportions

The mix proportions designed in this study with a constant mass ratio of 0.75:0.25:2.5:0.45 (cement:GGBS:sand:water) are common practical mix designs for most cement mortar applications. Crushed fluorescent glass (FG-A and FG-B) cullet was used to replace sand by mass at 10%, 20%, 30% and 40%. The details of the mix proportions of all the mortar specimens are shown in Table 4.

2.3. Mortar specimen preparation

All the samples were mixed by a standard laboratory drum type mixer. The fresh mortar samples were placed into steel moulds in two layers (of approximately equal depth) and they were then vibrated by a mechanical vibration table. The samples were cured in the laboratory at room temperature and covered with a thin plastic sheet to prevent moisture loss. After curing for 24 h, all the samples were demoulded and further cured in a water tank at 25 ± 3 °C until the day of testing.

Table 2
Physical properties of river sand and spent fluorescent glass.

Properties	River sand	FG-A	FG-B
Density (OD), kg/m^3	2636.1	2501.7	2531.7
Density (SSD), kg/m^3	2677.2	2501.7	2531.7
Water absorption, %	1.56	0	0
Fineness modulus	1.88	2.40	2.34