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Use of waste glass in alkali activated cement mortar

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HIGHLIGHTS

- An alkali-activated cement (AAC) mortar containing waste glass is developed.
- The addition of glass cullet and powder in AAC mortar improves the workability.
- The glass-based AAC mortar has good strength and fire resistance performance.
- Combined use of glass powder and cullet in AAC mortar for non load bearing partitions is feasible.

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ABSTRACT

This paper presents a study on alkali activated cement (AAC) mortar produced with waste soda-lime-silica glass. The waste glass was used simultaneously as a precursor and fine aggregates in the alkali activated fly ash-slag mortar. The influences of waste glass in cullet and powder forms on workability, compressive and flexural strengths, fire resistance of the AAC mortar were investigated. The experimental results showed that the workability was gradually increased as the replacement level of natural sand by glass cullet was increased, and it was significantly improved with decreasing aggregates-to-binder ratios. The mechanical properties data indicated that the compressive strength was reduced as the glass cullet content increased. However, for the flexural strength, the optimum percentage of glass cullet replacement was 50%. Due to the low reactivity, a reduction in strength was observed when the glass powder was used to replace the fly ash and slag. Nevertheless, in terms of fire resistance, the incorporation of glass cullet could improve the resistance of the AAC to high temperature exposures (800 °C). In particular, the AAC mortar prepared with the glass powder as a precursor exhibited remarkable resistance to high temperature. The use of waste glass in AAC material was feasible from the mechanical properties and fire resistance points of view.

1. Introduction

1.1. AAC material

It is generally known that the Portland cement industry produces 5–8% of the anthropogenic CO_2 [1] emission, which contributes significantly to the increase in greenhouse gas. Therefore, there is a need to develop alternate concrete binders other than Portland cement. According to previous studies [2,3], the properties of alkali activated cement (AAC) are comparable or even superior to Portland cement. A number of studies have demonstrated that the AAC exhibits high compressive strength [4,5], excellent sulphate and seawater resistance [6,7], good performance in the environment of acid corrosion [8,9], good resistance to chloride penetration [10] and freeze–thaw cycles [11,12]. These advantages are attributed to the special nature of the hydration products and the lower porosity and permeability of the AAC. Due to its high strength and excellent durability properties, the AAC mortar/concrete has potential applications in a range of applications. In Australia, pre-mixed alkali-activated concrete has been commercialized for the construction of a bridge upgrade project [13]. Also, AAC precast footpath panel segments produced from blends of fly ash, slag and alkaline activators has been successfully demonstrated in an industrial application [14]. In Ukraine, alkali activated blast furnace slag cement has been used in the construction of apartment buildings, road sections, pipes, drainage and irrigation channels, flooring for dairy farms, precast slabs and blocks [15]. Another known application for AAC was in the production of railway sleepers. Spain led the development of pre-stressed

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steam-cured sleepers based on alkali activated fly ash [16]. Basically, this AAC material can be produced through the alkaline activation of aluminosilicate materials such as coal fly ash (FA) and ground granulated blast furnace slag (GGBS). But in Hong Kong, there is no any steel plants for producing GGBS and almost all FA has already been used up by the construction industry.

1.2. Waste glass

Waste glass bottle (soda-lime silicate glass) is a significant solid waste type in the municipal solid waste (MSW) stream in Hong Kong. Due to the lack of a glass manufacturing industry, the current recycling rate of waste glass bottles is low (less than 10%) [17]. By contrast, based on the European Container Glass Federation [18], 11.6 million tons of waste glass bottles were collected in 2014 and the glass recycling rate has reached 74% in Europe.

The Hong Kong SAR government plans to promote the recycling of waste glass beverage bottles in Hong Kong by introducing a producers' responsibility legislation to be implemented in late 2017. It has been estimated that about 50 kt/annum of waste glass beverage bottles will be collected after the scheme is implemented. There is an urgent need to find practical outlets for the collected waste glass.

Previously, Poon and co-workers in the Hong Kong Polytechnic University have spent much effort on developing practical methods for recycling waste glass cullet as fine aggregates in concrete blocks or mortar production [19–29]. The results indicated that the incorporation of glass cullet as natural fine aggregates could reduce the drying shrinkage [19,20] and water absorption due to the non-absorbent nature of glass [20]. The replacement of river sand by glass cullet enhanced the fresh properties of concrete since the glass particles had smooth surfaces and low water absorption [21]. Also, the addition of glass cullet could improve the resistance to acid attack [22] and high temperature exposures [23]. Furthermore, the use of glass cullet as aggregates could reinforce photocatalytic activities because of its light transmittance property [24]. Based on our past research, it was demonstrated that it was feasible to use the glass cullet as partial substitution of fine aggregates in producing cement based building materials. And several practical and potential applications have been developed such as eco-glass concrete paving blocks [25], glass-based self-compacting concrete [26] and architectural mortars [27,28]. In particular, the eco-glass concrete paving block technology developed has been commercially transferred to the local block manufactures and the blocks have already been put into successful uses at various different sites in Hong Kong [29].

Additionally, after the further grinding to the glass cullet, the produced waste glass powder (WGP) with proper particle size can be used as a Portland cement replacement since it has been proven in many studies [30–34] that the WGP has pozzolanic activities. Therefore, efforts have been made in the concrete industry to use WGP as a supplementary cementitious material [33–35] due to there are large quantities of amorphous silica and calcium in the glass. Also, attempts have been made to use WGP as an alkali-silica-reaction suppressor although it has a high alkali content [36–38]. Recently, more studies have also pointed out that the finer glass powder showed significantly improved ability to enhance durability characteristics of concrete products [39,40].

During the past few years, there has also been increasing research efforts [41–50] directed to recycle WGP into AAC taking advantage of its chemical instability in alkaline environments and high content of silica-rich glassy phase. These WGPs include waste cathode ray tubes glass [41], post-consumer window glass [42,43], waste solar panel glass [44], spent linear fluorescent lamps [45] and waste LCD glass [46]. However, there is a lack of information on the alkali activation of soda-lime silicate glass [47–50]. It is expected that the high alkali and silicon contents of soda-lime silicate glass would facilitate the alkali-activation reaction [48,51] making it an attractive material for partial replacement of FA or GGBS in the production of AAC. Furthermore, it is also believed that using waste soda-lime silicate glass cullet to partially replace natural aggregates in the AAC is feasible.

1.3. Research significance

This research will contribute to the environmental improvement and conservation of Hong Kong by recycling waste glass and develop new technologies on waste glass recycling. Waste glass was reused in two forms: (1) using waste glass powder to replace FA and GGBS in AAC mortar, (2) using the waste glass cullet to replace natural aggregates for producing AAC mortar. Therefore, this study focused on developing a novel way to maximize the re-utilization of waste soda-lime silicate glass both as a precursor and aggregates for producing AAC materials. It is anticipated that recycled glass would constitute about 60% by mass of the novel construction product developed. One intended use of the products can be precast partition wall blocks with enhanced fire rating performance.

2. Experimental work

2.1. Materials

The materials used to fabricate the AAC mortar were natural fine aggregates (river sand), recycled soda-lime silicate glass, FA, GGBS and an alkaline activator. Natural fine aggregates (NFA) and recycled waste glass were sourced from aggregate suppliers and waste recycling facilities in Hong Kong, respectively. The soda-lime silicate glass was crushed by the glass bottle recycler in Hong Kong to obtain suitable particle sizes for use as fine aggregates. The collected waste glass cullet (WGC) was washed to remove most of the contaminants in the waste glass. The gradation and appearance of the NFA and WGC are presented in Fig. 1a. From the gradation curves of NFA and WGC, it can be found that the WGC has a lower fineness than the NFA. The alkaline activator used in this study was a commercially available sodium hydroxide (NaOH).

For the glass powder, the WGC was furthered ground with a specified milling time (2 h) by a laboratory ball mill. Two types of commonly used mineral admixtures, i.e. FA and GGBS, were used in this study. FA was produced as a by-product during the generation of electricity from coal fired power plants. GGBS (supplied from China, a byproduct of steel production) was sourced from a commercial source. The particle size distributions of the FA, GGBS and WGP were determined by a laser scattering technique (see Fig. 2d). In addition, the surface areas (Blaine method) of FA, GGBS and WGP were determined and they were 3252 cm^2/g, 3163 cm^2/g and 1899 cm^2/g, respectively. The chemical compositions of the FA, GGBS and WGP are shown in Table 1. Scanning electron microscopy (SEM) was employed to observe the morphologies of FA, GGBS and WGP (Fig. 2). The micrographs show that the FA was consisted of many spherical particles in micrometer range, and GGBS and WGP were made up of vitreous structure with a smooth surface texture, irregular shape with sharp edges.

2.2. Mixture proportions

As a benchmark, 30% FA and 70% GGBS by mass were used as precursors in the control alkali-activated binder due to their high calcium and aluminum contents. The NFA (river sand) in the AAC mortar was replaced by the WGC at 0, 25%, 50%, 75%, 100% to