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Improving the performance of architectural mortar containing 100% recycled glass aggregates by using SCMs

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HIGHLIGHTS

- The architecture mortar with good aesthetic appearance was prepared with waste glass.
- The addition of SCMs resulted in comparable strengths to the control mortar.
- The inclusion of SCMs improved the fire resistance of glass architectural mortar.
- SCMs blended mortar showed favorable resistance to ASR expansion and acid attack.
- Glass powder could effectively improve the performance of glass architectural mortar.

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ABSTRACT

An experimental study was carried out to evaluate the mechanical and durability properties of architectural mortar prepared with 100% glass aggregates and using supplementary cementitious materials (SCMs) to replace cement. The mechanical properties were assessed in terms of compressive and flexural strength, whilst the durability characteristics were investigated in terms of drying shrinkage, resistance to high temperature exposure, alkali-silica-reaction (ASR) and acid dissolution.

Experimental results suggested that strengths of glass-based architectural mortar incorporating SCMs (fly ash, ground granulated blast-furnace slag, metakaolin and waste glass powder) were comparable or even superior to that of the pure cement mortar when the cement replacement levels was up to 20%. In particular, waste glass powder (GP) as a pozzolanic material performed better than the other SCMs for flexural strength development of the glass-based mortar. The durability results also indicated that the addition of the SCMs could significantly reduce the drying shrinkage of the glass-based architectural mortar. All the recycled glass architectural mortars prepared with SCMs showed favorable resistance to expansion due to the ASR and less strength loss after heating to 800 °C. GP and ground granulated blast-furnace slag (BS) blended mortars gave better performance below 600 °C as compared to fly ash (FA) and metakaolin (MK) blended mortar. Also, the glass-based mortar containing GP exhibited the best performance of resistance to acid attack. Therefore, there is a potential to produce high performance architectural mortars with excellent mechanical and durability properties by reutilizing recycled glass to fully replace natural aggregates and partially replace cement.

1. Introduction

With minor variation in composition, soda-lime-silica glass containers are widely used for packaging beverage. On the other hand, statistics from the Hong Kong Environmental Protection Department [1] indicate that per capita waste glass containers generation in Hong Kong in 2013 reached up to 13.1 kilograms (obtained by dividing annual waste glass containers generated in kilograms by mid-year estimate of population). And, most of the containers are post-consumer beverage bottles with various sizes, shapes and colors. Currently, due to the lack of a glass manufacturing industry in Hong Kong, most of the waste glass containers are destined for disposal at local landfills. In addition, the mixed colors glass containers with contaminates are difficult to be reused for the manufacture of new glass. Thus, the recovery rate of waste glass in Hong Kong is much lower than that in Europe (about 10% vs. 73%) [1,2]. For the purposes of recycling valuable resources and relieving environmental stresses on landfill disposal, government and

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industry have strong interests to develop environmental-friendly technologies which offer new and practical ways to promote glass recycling.

Glass presents several advantages as a packaging material, such as its chemical inertness, low permeability, and high intrinsic strength [3]. For these reasons, a novel channel for the recycling of mixed glass is to reuse it as a replacement of natural aggregates in architectural mortars. A typical glass-based architectural mortar produced with white cement for decorative application is shown in Fig. 1. The aesthetic appearance takes advantages of the appealing colors of the waste glass cullet which is used to fully replace natural fine aggregates (e.g. river sand). However, the main component of soda-lime-silica glass is amorphous SiO_2, so that a major concern about the utilization of glass cullet in cement based materials is alkali-silica (glass) reaction (ASR). When the pH reaches 12, the siloxane bonds in the glass may be hydrolysed by the hydroxide ions [4]. Compared to other aggressive agents, the corrosion caused by alkaline solution is usually more rapid because the attacks could happen to all the components contained in the glass [5]. The ASR between the reactive glass cullet and the alkaline pore solution of the cement paste may develop deleterious expansion. Besides, it has also been reported that the inclusion of waste glass as aggregates in cement based materials might lead to a modest decrease in compressive strength resulting from the relative weaker interface between the cement paste and the smooth glass cullet aggregates [6,7]. Therefore, efforts need to be taken to improve these aspects.

It is widely accepted that the inclusion of traditional supplementary cementitious materials (SCMs) (i.e. fly ash (FA), ground granulated blast-furnace slag (BS), silica fume, metakaolin (MK)) into concrete can effectively improve its mechanical and durability performance [8–13]. Therefore, for using glass cullet for applications like architectural mortars which usually require good durability and aesthetic appearance, appropriate SCMs should be incorporated. In recent years, use of glass powder (GP) as a pozzolanic material for preparation of mortar and concrete has received considerable interests [14–16]. Experimental results have shown that the incorporation of finer GP in cement based materials has a strong ability to reduce gas permeability [17] and chloride ions diffusivity [17,18], whilst improving the resistance to ASR [18,19], sulfate attack [20], freeze–thaw cycle [16]. More importantly, the color of GP is close to white cement, hence it will not cause any adverse impacts on the aesthetic properties of the architectural mortar. Meanwhile, if the waste GP can be used to partially replace white cement in the architectural mortars, the added-value of waste glass will be further enhanced in terms of reduction in cement consumption.

Similarly, taking into account that the color of MK is also nearly white and MK blended concrete exhibits considerable enhancement in durability properties [21,22], the introduction of MK to glass-based architectural mortars is envisioned to compensate for the deficiency of utilization of waste glass in cement based materials although the cost of using MK is high. Compared to the MK, the FA and BS are the primary SCMs in the production of sustainable construction materials because they are less costly. However, the use of FA and BS tends to darken the color of the architectural mortars due to the presence of carbon and iron sulfide [23], respectively.

Previously, there have been many studies focusing on use of the glass aggregates or glass powder in concrete or mortars [24–28]. But few studies have been done to make use of the appealing colors of the mixed glass cullet for the production of architecture mortars [29,30]. Also, the effect of using different SCMs (GP, FA, BS and MK) as partial cement replacements on the performance of the architecture mortar prepared with 100% mixed glass cullet have not been investigated. Thus, a comparative study was carried out with a view to producing desired performance of architecture mortars by using appropriate SCMs. Given the architecture mortars with good aesthetic appearance will have potential to be applied in the indoor areas (e.g. cooking bench, floor tile, countertop), the mechanical (compressive and flexural strengths) and related durability (drying shrinkage, ASR expansion, resistance to acid attack, fire resistance) properties, have been assessed and reported in this paper.

3. Materials and experimental methodology

2.1. Materials

2.1.1. Cement and supplementary cementitious materials (SCMs)

The cement used for the experiment was a white ordinary Portland cement (WC) due to the aesthetic requirement of architectural mortar. The chemical composition of the WC is listed in Table 1. Waste glass powder (GP) was obtained by grinding glass cullet collected from a local glass recycler with a laboratory ball mill for 2 h. Fly ash (FA) was obtained from a local coal-fired power plant. Ground granulated blast-furnace slag (BS) and metakaolin (MK) were supplied from China. BS was a byproduct of steel production and MK was sourced from a commercial source.

The chemical compositions of the SCMs were determined by using X-ray fluorescence spectroscopy (XRF), as given in Table 1. The particle size distributions of the cement and SCMs are shown in Fig. 2, which indicates that the mean diameter of MK is smallest, while the average particle size of GP is larger than that of cement

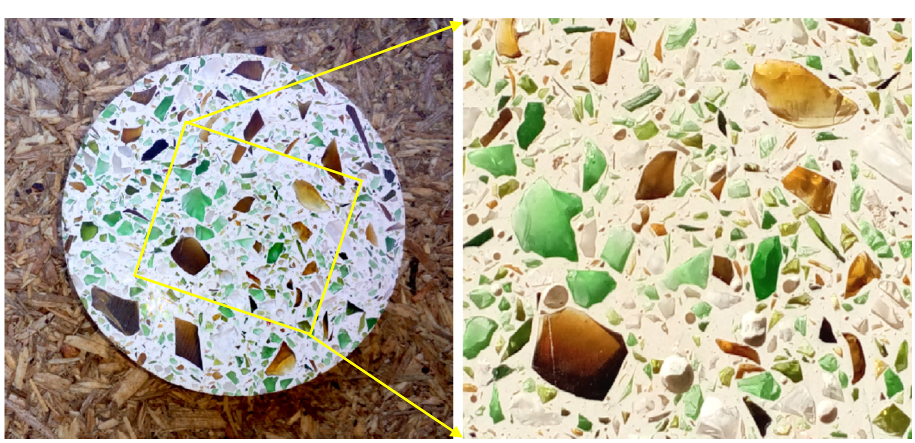

Fig. 1. Architectural mortar produced with waste glass cullet.