Materials and Design 135 (2017) 102–111

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Using glass powder to improve the durability of architectural mortar prepared with glass aggregates

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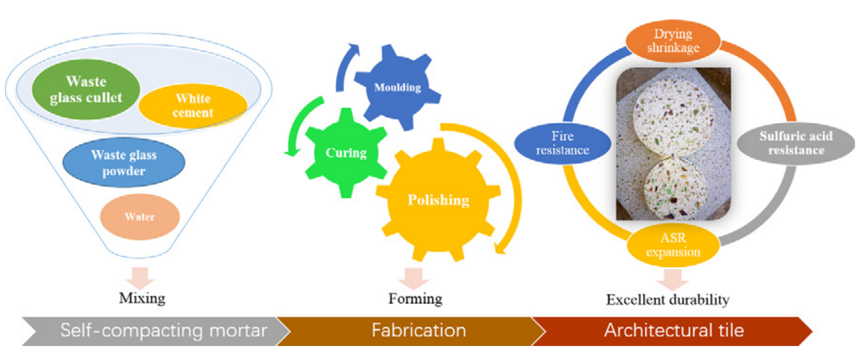
HIGHLIGHTS

- A novel architectural tile containing more than 70% waste glass (by weight) is designed.
- Using glass powder to counteract the drawbacks of glass cullet in cement mortar is feasible.
- The glass-based architectural mortar exhibits good durability and aesthetic appearance.
- Waste glass was used both as decorative and pozzolanic materials in Eco-building materials.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 July 2017
Received in revised form 21 August 2017
Accepted 8 September 2017
Available online 9 September 2017

Keywords:
Glass powder
Glass aggregates
Durability
Architectural mortar

ABSTRACT

This study designed a novel cement-based architectural tile prepared with more than 70% waste glass content (by weight). The waste glass was employed not only as decorative aggregates but also as a supplementary cementitious material in the architectural mortar. In terms of shrinkage, the incorporation of glass powder (GP) could significantly reduce the drying shrinkage of the glass mortars regardless of its fineness. When the glass mortars were subjected to high temperature (800 °C), the inclusion of GP into the mortars was more able to mitigate the flexural and compressive strengths losses as compared to the control glass mortar prepared without the use of GP. Furthermore, using the GP and glass aggregates simultaneously could effectively improve the resistance of the glass mortars to sulfuric acid attack and the positive effect was more pronounced when finer GP was incorporated. In particular, an encouraging result shows that the replacement of 20% cement by fine GP successfully suppressed the deteriorative alkali-silica-reaction (ASR) expansion caused by the glass aggregates. Also, the glass mortars incorporated with fine GP exhibited comparable or even superior durability properties than that of the fly ash blended glass mortar.

1. Introduction

Due to the excellent characteristics of glass, such as optical transparency, chemical inertness, high intrinsic strength and low gas permeability [1], glass container is the most commonly used form of packaging beverage material. The most common type of beverage glass containers used is soda-lime-silica glass, which usually contains 10–20 mol% Na_2O, 5–15 mol% CaO and 70–75 mol% SiO_2 [2]. Data from the Environmental Protection Department (EPD) indicated that, in Hong Kong, 275 tonnes waste glass bottles were generated per day in 2015 [3]. Based on the European Container Glass Federation statistic [4], the average recycling rate of container glass in Europe has reached

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http://dx.doi.org/10.1016/j.matdes.2017.09.016

74% in 2014 and most of them were reused for manufacturing new glass. But in Hong Kong, most of the waste glass containers were disposed of in landfills rather than being recycled due to a lack of a local glass manufacturing industry. In order to enhance the recovery rate of waste glass beverage containers in Hong Kong, the Hong Kong Government has announced to implement a new mandatory Producer Responsibility Scheme on glass beverage containers [5], to provide support in waste glass recycling. Therefore, efforts need to be taken to explore potential strategies with a view to broadening the applications of recovered waste glass.

Recently there has been an increasing interest in recycling waste glass for the production of cement-based construction materials. Generally, the main attention has been focused on the use of recycled glass as a replacement of aggregates or cement in concrete and mortar.

For the incorporation of waste glass as aggregates replacement in concrete/mortar, there are contradictory opinions about the influence of glass aggregates on the workability. Several researchers [6–8] found that slump value of fresh concrete was reduced with an increasing percentage of glass aggregates. They attributed this behavior to the edged and angular grain shapes of the glass aggregates impeding the flow of the cement paste. Furthermore, additional cement paste was needed to coat the irregular glass aggregates resulting in less available cement paste for the fluidity. On the contrary, some investigators [9–11] reported that the replacement of natural aggregates by waste glass led to an improvement of workability due to the non-absorbent nature of glass. Moreover, severe bleeding and segregation occurred when 100% fine aggregates were replaced by recycled glass aggregates [12]. According to the study of Castro and De Brito [13], the different impacts of the glass aggregates on workability may be due to the workability was highly dependent on the particle size of the aggregates replaced. In terms of mechanical properties, the increasing contents of glass aggregates were reported to decrease the compressive, flexural strengths [7,14] and splitting tensile strength [15,16] of concrete. The reduction of strengths was also observed in the case of cement mortar with a high content of glass aggregates [10,17]. The possible reason was thought to be the presence of micro-cracks in the glass aggregates during the crushing process and the smooth surface of waste glass, which resulted in weaker bond strength between the glass surface and the cement paste.

With respect to the durability of glass cement-based materials, the inclusion of glass aggregates effectively improved the surface resistivity and sulfate attack with increased amounts of glass sand replacement [7]. The chloride ion penetrability and drying shrinkage of concrete decreased when the glass aggregates content increased [18]. However, because of the presence of a high amount of amorphous silica in waste glass, it cannot be used as aggregates without taking alkali-silica-reaction (ASR) problem into account. In recent years, preventive actions were taken to mitigate the detrimental ASR expansion by incorporating fly ash [18,19], metakaolin [19,20], ground blast furnace slag [20,21], silica fume [22,23], glass powder [20,24], steel fiber [23], lithium nitrate [25].

The influence of waste glass powder as cement replacement on the properties of the cement-based materials has been extensively studied. According to a recent study by Lu et al. [26], the workability of architectural mortar was highly dependent on the particle size and morphology of the glass powder used. It was found that larger particle sized glass powder resulted in a reduction of the flow and the finer glass powder contributed to improving the workability. The reason was attributed to the fact that the larger and irregular glass particles could hinder the movement of the paste, while the finer glass powder could optimize the gradation of the mixture and reduce the friction between the particles. Many studies had been carried out to evaluate the mechanical properties of concrete containing glass powder, which has been proved to possess some pozzolanic activity [27–29]. The chemical compositions [30] and fineness [31] of glass powder were considered as important factors governing the reactivity of glass powder. From the study of Bignozzi et al. [30], the funnel and soda lime glass exhibited higher pozzolanic activity than the fluorescent lamps and crystal glass. Generally, the finer the particle size of glass powder, the higher was the strength of cement-glass blends [27,28,32]. However, replacement of cement by glass powder decreased the early compressive strength, although it increased the later compressive strength [33,34]. Several studies also reported that the compressive strength increased to a desired level up to a certain percentage of replacement and then decreased. Soliman et al. [34] stated that the optimum percentage of glass powder addition was 20% in ultra-high-performance concrete. Afshinnia et al. [33] and Aliabdo et al. [35] observed that inclusion of 10% of glass powder was considered to be optimum. In addition, from the study of Omran et al. [36], incorporation of glass powder in concrete improved the long-term mechanical performance (compressive strength, splitting-tensile strength, flexural strength, and elastic modulus) as a result of the pozzolanic activity of the glass powder and the enhancement of the microstructure. As far as durability is concerned, the replacement of cement by glass powder in concrete or mortar could significantly improve the resistance to chloride-ion permeability [36–38], water penetration [39], sulfuric acid attack [40], freeze–thaw cycles [41] and ASR expansion [20,24,42]. Also, Kamali and Ghahremaninezhad [43] reported that the glass powder could significantly improve the electrical resistivity of cement paste compared to the control cement paste and fly ash blended cement paste, which was probably attributed to the pore refinement in the microstructure resulting from the pozzolanic reaction of glass powder.

However, most of the above-mentioned studies focused on investigating the effect of using glass as a cement or as an aggregate replacement individually on the properties of concrete/mortar. Few studies have been done to study the simultaneous use of glass aggregates and powder for the production of cement-based construction products [20,44]. Therefore, this study aimed to design an architectural mortar combining the use of glass aggregates and powder and utilize the glass powder to counteract some drawbacks of the glass aggregates in the architectural mortar. On the basis of waste glass recycling, it would be more effective to jointly use the waste glass in powder form as a cementitious material and in cullet form as aggregates. Furthermore, a novel channel for the recycling of mixed glass is to reuse it in architectural mortars/tiles so that the aesthetic appearance can be enhanced by taking into the advantage of the appealing colors of the waste glass cullet. This glass-based architectural mortar/tile for decorative applications (as shown in Fig. 1) is expected to replace the epoxy-based materials, which is not environmentally-friendly and has poor resistance to high temperature. Therefore, the objective of this work was to study the feasible use of waste glass powder to improve the durability of architectural mortar containing 100% glass aggregates. The influence of different particle sizes of glass powder on the durability of glass-based architectural mortar has been evaluated in terms of drying shrinkage, high

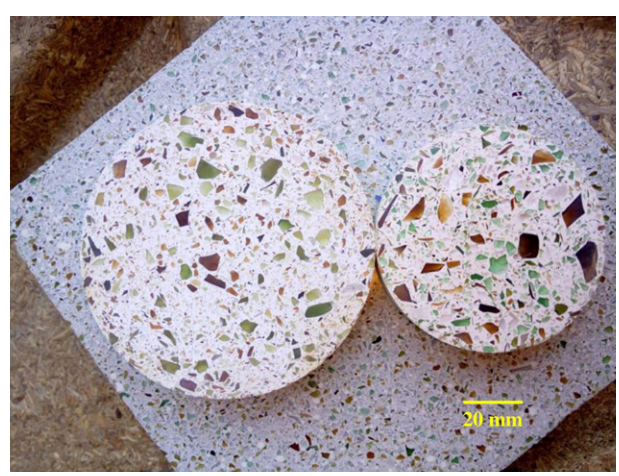

Fig. 1. Architectural mortar produced with waste glass cullet and glass powder.