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Improvement of early-age properties for glass-cement mortar by adding nanosilica

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ABSTRACT

Poor early-age performance (e.g. lower early strength, longer setting time) is an important technical challenge for the application of blended cementitious materials containing low reactivity or high volumes of supplementary cementing materials. In this study, the mechanism of using nanosilica (NS) to improve the early-age properties for cement mortars blended with glass powder (GP) and glass aggregates has been investigated. The results indicate that the addition of NS into glass-based cement mortar largely improved the early stiffening which was dependent on high specify surface area of the NS rather than cement hydration. Combining the use of NS and GP was conducive to compensate the delayed setting times and the strength losses caused by the incorporation of GP. These beneficial behaviors were associated with the physical, acceleration, pozzolanic and pore refinement effects of NS. In terms of heat of hydration, the inclusion of NS intensified and accelerated the appearance of the third exothermic peak (AFt to AFm) due to the absorption of sulfate ions by the increased C-S-H formation. Also, the total hydration heat liberated was found to correlate linearly with the corresponding early-age compressive strength. Microstructural analysis suggest that NS significantly helped to densify the microstructure of the GP blended cement matrix and improved the interface between the GP particle and the binder matrix. This was verified by the contribution of NS on refining the coarse pore size caused by the use of GP as a replacement of cement.

1. Introduction

1.1. Background

Soda-lime-silica glass has been widely used for producing beverage containers due to its chemical stability [1]. On the other hand, the management of the post-consumer beverage glass bottles has become an urban waste issue. In Hong Kong, there were nearly 275 tones waste glass bottles being generated per day in 2015 [2]. However, it is not easy to establish waste glass recycling industries when land is scarce and costly, especially for handling the waste glass with lower recyclable value. Currently, less than 10% of the waste glass was recycled in Hong Kong, that is to say, more than 90% of waste glass has to be disposed at landfills. But according to estimation of the government, the three large, modern state-of-the-art landfills built will reach their designed capacities one-by-one by 2019 [3]. Therefore, waste glass recycling is an important element of the local waste management framework, which not only help to conserve natural resources but also reduce demand for valuable landfill space.

Recycling waste glass for the production of cement-based construction materials has attracted a lot of interests in the past few years [4–19]. The main forms of waste glass employed in concrete or mortars were glass cullet as fine aggregates [4,5] and glass powder as a supplementary cementitious material (SCM) [6–16]. A comprehensive experimental programme including studying the fresh, mechanical and durability properties of concrete or mortars incorporating waste glass has been conducted. Furthermore, to maximize the utilization of waste glass, several researchers simultaneously used glass aggregates and glass powder in concrete [17,20] or mortars [19]. Based on the experimental and field results, it is possible to use waste glass in the production of cement-based construction products in either aggregates form or powder forms.

Recently, the research group in the Hong Kong Polytechnic

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University developed a novel recycled glass architectural mortar, which could fully utilize the aesthetic nature of waste glass [21,22]. The waste glass is used as decorative aggregates not only making use of the appealing colors of the mixed glass cullet but also reducing virgin aggregates consumption. In addition, the potential applications of recovered glass materials in architectural mortars could diversify the recycling outlets and relieve environmental stresses on landfill disposal.

As for the performance of concrete or mortar incorporating glass aggregates (GA) to replace natural aggregates, there are many advantages. The inclusion of GA contributed to increasing the workability of the concrete [4] and mortars [5] due to the smooth surface texture of the glass. Also, since the GA had lower water absorption values, the transport properties of the concrete were improved as the GA content increased [4]. Meanwhile, the increase in GA content led to a reduction in drying shrinkage of the concrete [23] and mortars [5,24]. The addition of GA into the concrete also could effectively improve the resistance to chloride ion penetration [23,24] and sulfate attack [21,25]. Furthermore, increasing the content of GA in the mortar produced a gradually beneficial effect on the residual compressive strength and elastic modulus after the mortar was exposed to 800 °C [26].

However, several detrimental effects were also incurred by using glass cullet as aggregates. The substitution of the fine aggregates by the GA resulted in reductions in the compressive, flexural, splitting tensile strengths and elastic modulus of the concrete because of the weaker ITZ between the GA and the matrix [4,5,17,24]. Even worse, the alkali-silica-reaction (ASR) induced by the GA was the major obstacle for its application in cement-based systems [5,27]. Our recent works have proven that the use of the different SCMs could improve the mechanical and durability performance of the architectural mortars containing 100% GA [19,28]. In particular, combining the use of waste glass powder (GP) was able to overcome the drawbacks resulting from the incorporation of GA (i.e. reduced strength and ASR expansion). This encouraging result provided an effective way for maximizing the use of waste glass in cement mortars. However, compared to other SCMs, the GP has a lower reactivity [28], which is in particular detrimental to the early-age properties. Indeed, the previous results showed that the early strengths were significantly reduced [19] and the setting times were also delayed [18] as the GP was introduced to replace the cement. Therefore, there is a need to improve the early-age properties of the architectural cement mortar with a view to enhancing the production efficiency.

Recently, nanosilica (NS) has been successfully used in fly ash–concrete/mortars to improve the mechanical properties at early stages [29–31]. Hence, it is expected the use of NS can counteract the undesirable early-age properties of the glass-based cement mortars. Previously, a limited number of investigations had been carried out to study the effect of a hybrid combination of NS and waste glass on the properties of concrete or mortars [32,33]. But, few studies have been done with respect to the early-age properties of cement mortars containing NS and waste glass. Thus, this work aimed to using NS to improve the early-age properties of the cement mortar prepared with GA as fine aggregates and GP as a cement replacing material. In addition, a novel calender extrusion method is designed to produce the glass-based architectural cement mortar with a view to enhancing the production efficiency (see Fig. 1), considering the processing requirement for the architectural cement mortar, related properties including workability, stiffening time, setting time and early strength were investigated. Furthermore, the corresponding heat of hydration and microstructure (SEM, TG, MIP) analyses were also determined to understand the roles of NS in the glass-based cement mortar.

1.2. Research significance

Generally, SCMs are understood to increase the long-term strength of cementitious materials through the pozzolanic reaction while decrease early-age strength due to the dilution effect (i.e. less Portland cement). This is of particular concern when attempting to replace cement with high volumes of SCMs. Therefore, one of the challenges that arise from increasing the use of SCMs or incorporating SCMs with very low reactivity (such as GP) is to improve the early-age properties of such blended materials. In this study, NS was employed into the GP-containing pastes/mortars to optimize the early age properties the cementitious materials.

2. Materials and experimental methodology

2.1. Materials

2.1.1. Cement and glass powder (GP)

For purpose of producing architectural mortar with aesthetic appearance, a white ordinary Portland cement manufactured by PT. Indocement Tunggal Prakarsa Tbk in Indonesia was used for this experiment. This white cement (WC) type was CEM I (52.5N), conforming to BS EN 197-1. GP was obtained by grinding waste glass cullet (see 2.1.3 section) with a laboratory ball mill for 1 h. The

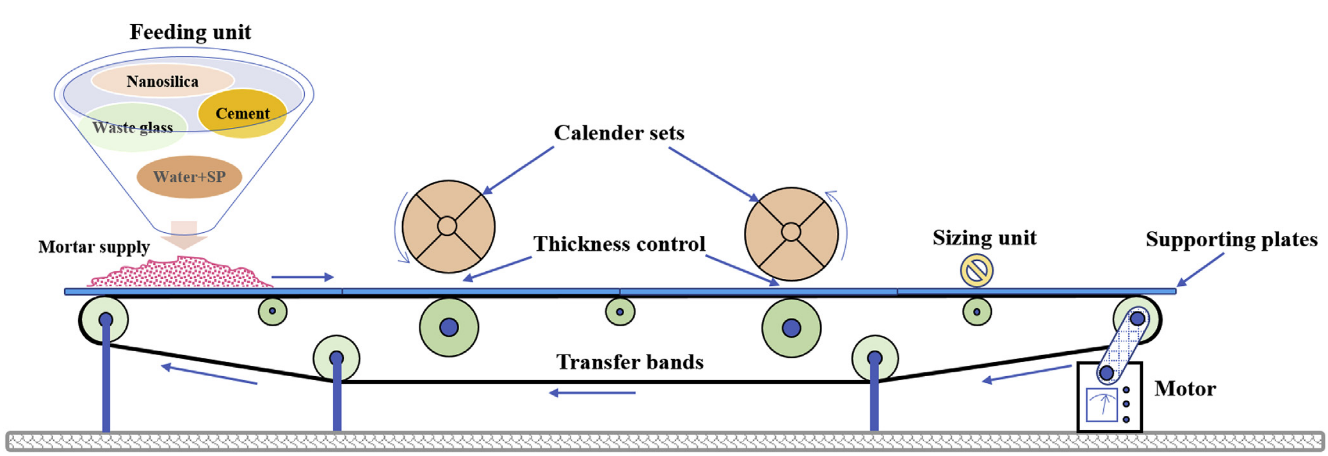

Fig. 1. Calender extrusion method in the production of recycled glass architectural mortar.