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Feasible use of large volumes of GGBS in 100% recycled glass architectural mortar

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ABSTRACT

The use of 100% recycled glass as aggregates in architectural mortar is regarded as an environmentally friendly, cost-effective and attractive feature for construction applications due to the natural characteristics of glass (e.g. aesthetic pleasing, impermeability, chemical resistance properties). However, the need to use large quantities of white cement for architectural products may increase the overall cost of production. Therefore, the possibility of using a near-white coloured ground granulated blast furnace slag (GGBS) to replace white cement for architectural mortar production is an attractive option. This paper reports a study which is an extension of our previous work aiming to investigate the feasibility of using large volumes of GGBS (ranging from 15% to 75% white cement replacements) to produce self-compacting-based architectural mortars. To improve the appearance (whiteness) of the mortar, a small quantity of titanium dioxide (TiO_2) was added to the selected mixes for comparison purposes. Fresh and hardened properties of the mortar including mini-slump flow, density, water absorption, flexural strength, equivalent compressive strength, drying shrinkage, alkali silica reaction (ASR) and acid attack resistance were investigated. The overall performance showed that it is feasible to use GGBS for the production of architectural mortar and 60% replacement of white cement by GGBS was determined to be optimal. The replacement significantly increased the flexural strength, and reduced the drying shrinkage and risk of ASR expansion, as well as improved the ability to resist acid attack of the mortar produced.

1. Introduction

In Hong Kong, the recovery rate of discarded beverage glass bottles in 2012 was recorded to be less than 5% and most of the glass bottles were disposed of at landfills [1]. Without a glass manufacturing industry, recycling glass waste in the construction industry is regarded as the most effective way to tackle the glass waste problem (about 300 tonnes daily) in Hong Kong. In the last decade, extensive research works have been carried out worldwide to determine the possible use of recycled glass in concrete and the results are promising [2–5]. Recently, the recycling glass waste for making construction products has become more widely accepted by the local authority in Hong Kong.

Previous studies by the authors have found that it is feasible to use 100% recycled glass (RG) to replace fine aggregates in the production of different concrete products, including semi-dry concrete blocks [6], self-compacting concrete [7] and architectural mortars [8]. The most marked difference in the physical properties of the recycled glass are its nature of impermeability, near to zero water absorption, smooth surface texture and better resistance to chemical attack as compared to natural aggregates. Although these characteristics reduce the bond strength and mechanical properties of the concrete products, it can enhance their performance in terms of workability, drying shrinkage and chemical resistance compared to similar products made with natural aggregates [5]. Use of the alkaline reactive glass aggregate, however, in new concrete mixes, requires careful consideration of the potential of alkali–silica reaction (ASR) which induces expansion and hence cracking. Findings by Ling et al. [8] suggested that the use of 20% metakaolin (MK) by cement mass in the mortar is able to suppress the potential ASR risk.

Ground granulated blast furnace slag (GGBS) is a by-product material generated from steel manufacturing. Compared to another supplementary cementitious material, dark-grey fly ash generated from coal-fired power plants, the use of the near-white coloured GGBS can produce whiter products for architectural and fair-faced concrete finishes. Compared to fly ash, GGBS as a latent hydraulic material making it suitable to be used as a high volume supplementary cementing material (SCM) to replace cement and is an effective suppressing agent of ASR in concrete [9,10]. In terms of

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cost, the price of GGBS is only about 10% of MK and 50% of white cement; thus it would be of cost advantages to use more GGBS rather than MK for the architectural mortar. The present study is an extension of our previous work [8] aiming to investigate the feasibility of using high volumes of GGBS for the production of self-compacting-based 100% recycled glass architectural mortar.

2. Experimental details

2.1. Materials

A white ordinary Portland cement (WC), a near-white ground granulated blast furnace slag (GGBS) and a white metakaolin (MK) were chosen as the cementitious materials. These materials were selected for producing architectural mortars with good aesthetic quality. The chemical compositions of the cementitious materials are shown in Table 1. It is noted that the MK used had a high loss of ignition value probably due to the incomplete calcinations process during manufacturing. A commercially available nano-TiO_2 powder (P25, Degussa) was used as the photocatalyst. The particle size of the TiO_2 was 20–50 nm, with a specific BET surface area of $50 \pm 15\ m^2\ g^{-1}$.

Recycled glass cullet (RG) with 90% of it passing the 2.36 mm sieve and a fineness modulus of 3.12 was used as the aggregate in the mixes. The chemical compositions of the RG are presented in Table 1. The recycled glass used in this study was derived from post-consumer green beverage bottles obtained locally from a waste glass recycler. A superplasticizer ADVA-109 without the presence of chloride and with a density of 1.045 ± 0.02 kg/L was used to control the workability.

2.2. Mix proportions

Based on our past experience [8] for the production of self-compacting-based architectural mortars, the total cementitious material content was kept at $776\ kg/m^3$ to maintain a high volume fraction of fine materials in the mixture. Throughout the study the cementitious-to-aggregate and water-to-binder (w/b) ratios were proportioned at 1:2 and 0.4, respectively. The usage of superplasticizer was ranged from 0.65% to 2.95% by weight of cementitious material to acquire the specified mini-slump flow value of 250 ± 10 mm.

A total of ten groups of mixes were prepared in this study. The details of the mix proportions are shown in Table 2. The first two groups are the control mixes with (1) 100% of WC and (2) 15% MK and 85% WC. The other five groups were proportioned with 15%, 30%, 45%, 60% and 75% of WC replaced by GGBS by mass (namely as GGBS15 to GGBS75 mixtures) respectively. For the last three groups, the addition of 2% TiO_2 was applied in the mixes (control, MK15 and GGBS15) to examine the influence of TiO_2 on the colour (brightness) of the resultant architectural mortars.

Table 1
Physical and chemical properties of white cement, metakaolin, GGBS and recycled glass.

Chemical composition	White cement (%)	Metakaolin (%)	GGBS (%)	Recycled glass
SiO_2	22.97	51.39	43.8	66.7
Al_2O_3	4.74	32.91	14.1	1.80
Fe_2O_3	0.19	0.58	1.1	0.37
CaO	65.25	0.01	33.6	10.3
MgO	0.82	0.01	4.4	1.20
Na_2O	0.06	0.39	1.1	14.81
K_2O	0.08	0.98	–	0.61
TiO_2	–	–	–	0.05
SO_3	2.64	–	1.2	–
Loss on ignition (%)	2.87	13.57	0.3	0.30
Density (g/cm^3)	3.1	2.62	2.97	2.49
Specific surface area (cm^2/g)	3280	–	5340	–

2.3. Sample preparation

Architectural mortar mixtures were prepared in a standard rotating drum-type mixer with a maximum capacity of 8 kg. Initially, fine aggregates (surface dried) and cementitious materials were mixed for about 90 s to obtain a uniform mix in dry conditions. Then, the superplasticizer (thoroughly mixed with water) was added to the mix, and the mechanical mixing process was resumed for another 90 s. To avoid the dry materials becoming stuck at the bottom part of the mixer, the mixture was mixed manually by turning it over twice or thrice using a steel trowel. Finally, the mixture was mechanically mixed for an additional 2 min to complete the whole mixing process.

A total of 18 40 × 40 × 160 mm prisms and six 25 × 25 × 285 mm prisms were prepared in each mix proportion group. The prisms were demoulded after 1 day and cured in a 25 °C water tank until the testing ages. The 40 × 40 × 160 mm prisms were used for the determination of the flexural and compressive strengths, assessing the water absorption and resistance to acid attack, whereas, the 25 × 25 × 285 mm prisms were used for the drying shrinkage and the alkali–silica reaction (ASR) tests.

2.4. Test methods

2.4.1. Fresh properties

The fresh properties of the architectural mortars were determined using a mini-slump flow cone with a 100 mm internal diameter according to EFNARC [11]. The cone was first filled with the freshly produced mixture and then the cone was lifted in the vertical direction to allow the mixture to spread out by its own weight. Two perpendicular spread diameters of the mortar were measured and recorded.

2.4.2. Density, permeable voids and water absorption

The hardened density of the specimens was determined by using a water displacement method according to ASTM C 642 [12]. The permeable voids and water absorption tests were conducted at 90-day to assess the water permeability characteristics of the architectural mortar samples. The results of the average of three specimens are reported.

2.4.3. Flexural strength

A three-point flexural strength test in conformity with ASTM C348 [13] was performed at 1, 7, 28 and 90 days after casting. The architectural mortar specimens with a size of 40 × 40 × 160 mm were tested under a central line load while being simply supported over a span of 120 mm. For this test, a universal test machine with a load capacity of 50 kN with a displacement rate of 0.10 mm/min was used.

2.4.4. Equivalent compressive strength

The equivalent compressive strength test was carried out within 30 min after the completion of the flexural strength test according to ASTM C349 [14]. The equivalent compressive strength test used the same specimens previously used for the flexural strength test. The compressive strength was determined using a Denison compression machine with a load capacity of 3000 kN on the broken pieces (portions of the prisms broken in flexure). The reported test results were the average of six measurements.