Construction and Building Materials xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Construction and Building Materials

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

Fresh properties of cement pastes or mortars incorporating waste glass powder and cullet

Jian-xin Lu, Zhen-hua Duan, Chi Sun Poon *

Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

HIGHLIGHTS

- There is a good correlation between the hydration and the stiffening or flow.
- The stiffening is highly controlled by fineness and morphology of glass powder.
- An increase of glass powder fineness results in a reduction in the flow of mortar.
- It is feasible to produce architectural mortar containing glass powder and cullet.

ARTICLE INFO

Article history:
Received 19 May 2016
Received in revised form 20 October 2016
Accepted 2 November 2016
Available online xxxx

Keywords:
Fresh property
Waste glass powder (WGP)
Heat of hydration
Stiffening
Flowability

ABSTRACT

This work was aimed at studying the fresh properties of cement-based mixtures containing waste glass powder (WGP) and waste glass cullet (WGC) obtained from crushed post-consumer beverage bottles. The experimental results show the setting time of the WGP modified pastes were prolonged due to the lower rate of hydration. Irrespective of the addition WGP, a good correlation between the early hydration characteristics and the stiffening or flowability can be established. However, during the first 30 min of hydration, the fresh properties of the WGP modified mortars were predominantly dependent on the particle size and the morphology of the WGP investigated.

1. Introduction

Waste glass has become an important component in the municipal solid waste (MSW) stream. According to the Hong Kong government [1], the amount of waste glass disposed of at landfills was about 300 tons per day in 2014. Due to the low commercial value and the lack of a glass manufacturing industry in Hong Kong, the recovery rate of waste glass is less than 10%. For this reason, it is very essential to find ways that can increase the recycling rate of waste glass and reduce the amount of waste glass requiring disposal at landfills effectively.

In Hong Kong, due to the lack of sources of pozzolanic materials (such as coal fly ash, granulated blast furnace slag or silica fume), the use of glass powder as a partial replacement for cement in concrete can be attractive. This would not only reduce cement consumption (lower the production cost and the emission of CO_2) and the amount of waste requiring disposal, but also reduce the reliance on the external sources of pozzolanic materials.

Generally, there are two main forms for the applications of waste glass in concrete: one is using the waste glass cullet (WGC) as aggregates, the other is using waste glass powder (WGP) as a supplementary cementitious material (SCM). As reported, the use of WGC as aggregates to produce concrete paving blocks has been successfully applied in Hong Kong [2], and it has been demonstrated that it is also feasible to utilize the WGC to prepare self-compacting concrete [3] and mortars [4]. However, a major concern with the use of glass aggregates in cement-based construction is the deleterious alkali-silica reaction (ASR) between the silica-rich glass and the alkali in the concrete or mortars [5]. Also, a high replacement level (more than 20%) of waste glass as aggregates in concrete could lead to a reduction of strength [6] [7]. Therefore, Pasetto and Baldo [8] recently designed a controlled low-strength road sub-base containing waste glass, fly ash and other recycled materials and stated that the fly ash used probably contributed to preventing the ASR damage. Furthermore, WGC was further grinded to become WGP to prevent the ASR problem as WGP with proper particle size possesses pozzolanic activities and can be used as a cement replacement [9–11]. Shao et al. [9] and Shi et al. [10] also showed that the addition of finer WGP had

* Corresponding author.
E-mail address: cecspoon@polyu.edu.hk (C.S. Poon).

http://dx.doi.org/10.1016/j.conbuildmat.2016.11.011
0950-0618/© 2016 Elsevier Ltd. All rights reserved.

beneficial effects in inhibiting the ASR and enhancing the strength. Therefore, combined use of WGC and WGP is considered to have good application values.

Traditional SCMs, namely fly ash, granulated blast furnace slag, metakaolin and silica fume, are used to improve the strength and durability performance of concrete [12–16]. Also, several related studies reported that these SCMs have significant effects on the fresh properties of concrete [16–20]. According to earlier publications, the inclusion of glass aggregate in concrete mixes is able to improve the flowability [21,22] or reduce superplasticizer dosages [4]. But, as the percentage of recycled glass cullet in concrete increased, severe bleeding and segregation were observed due to the smooth surface and non-absorbent nature of glass cullet [23]. Whether the excessive use of glass materials in concrete result in a less cohesive mix may be a concern. Therefore, it is necessary to study the influence of WGP as cement replacement on the fresh properties of cement mixes, especially when the natural aggregates are fully substituted by the WGC.

From economic and operational considerations during practical production, this study first focused on studying the setting time and hydration process of cement pastes containing WGP with different fineness, ground by using a ball milling approach for specified periods (0.5 h, 1 h, 2 h, 4 h respectively). On this basis, the early stiffening behavior and flowability of architectural mortars incorporating both WGP and WGC were further investigated in this study.

2. Experimental programs

2.1. Materials

2.1.1. Cementitious materials

White Portland cement (WPC) was used in this study to provide a better aesthetic effect of the produced architectural mortars. Besides, WGP of four different fineness, grinded from the WGC by using a laboratory ball milling machine for 0.5 h, 1 h, 2 h and 4 h respectively (namely as WGP-0.5 h, WGP-1 h, WGP-2 h, WGP-4 h), were adopted to partially replace the WPC. The detailed chemical compositions of the WGP and WPC (TAIHEIYO Cement Corp., Japan) are listed in Table 1.

As regards the particle size distribution, a comparison of different types of WGP with the WPC are presented in Fig. 1. The scanning electron micrographs of WGP-2 h (glass cullet milled for 2 h) particles are shown in Fig. 2, which exhibit a smooth surface texture and irregular shape.

2.1.2. Aggregates

WGC with a mixed colour, obtained from a local glass recycling plant, was derived from crushing of collected post-consumer beverage bottles. The washed glass cullet was oven-dried for a minimum of 24 h at 105 °C before use. The gradation and density of WGC used in this study is shown in Table 2.

Table 1
Chemical composition of WPC and WGP (ms%).

	WPC	WGP
SiO_2	21.36	73.5
Al_2O_3	5.27	0.73
Fe_2O_3	0.2	0.38
CaO	67.49	10.48
MgO	1.14	1.25
K_2O	0.077	0.69
Na_2O	0.048	12.74
TiO_2	0.14	0.087
SO_3	2.6	–
Loss in ignition	1.58	–

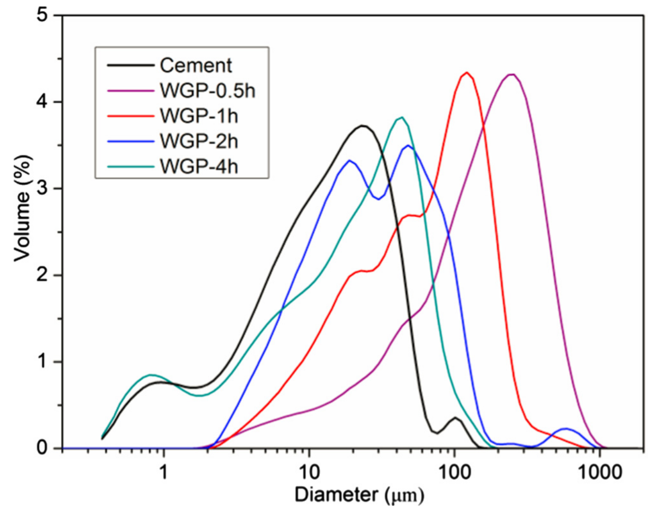

Fig. 1. Particle size distributions of cement and WGP.

2.2.. Mix design

According to the previous study for the production of architectural mortar, the binder-to-aggregate and water-to-binder (w/b) ratios were adopted at 1:2 and 0.4, respectively. A superplasticizer (SP) ADVA-109 was employed to achieve the desired workability. Additionally, the use of SP was at 0.6% by weight of the cementitious material. The mix proportions of the mortars are listed in Table 3. It should be noted that the control mortar (M-Control) without WGP was prepared as a reference mixture and the other four groups were proportioned with 20% of cement replaced by WGP obtained separately after 0.5 h, 1 h, 2 h, 4 h of grinding (namely as M-WGP0.5 h, M-WGP1 h, M-WGP2 h, M-WGP4 h).

2.3. Test methods

2.3.1. Setting time

The setting time of pastes with and without WGP was assessed in accordance with BS EN 196-3: 2005 + Al: 2008 [24]. In order to be comparable with the w/b of the mortars, the w/b of the pastes was also brought to 0.4. The pastes prepared with and without WGP were named P-Control, P-WGP0.5 h, P-WGP1 h, P-WGP2 h, P-WGP4 h, respectively.

2.3.2. Heat of hydration

The heat hydration test was utilized to investigate the incorporation of WGP on the early hydration of cement. During the test, 20% of WGP was used to replace WPC. The cement and WGP were firstly mixed in an insulated container thoroughly, then 60 g of this mixture were mixed with 24 g of water (w/b = 0.4) for 2 min in the container used for the heat of hydration test. Having completed the above steps, the container was sealed and then placed into the isothermal calorimeter (Calmetrix I-CAL). The instrument was set to a constant temperature of 20 °C. After 48 h, the measurement was stopped and the data were exported and analyzed.

2.3.3. Stiffening

The purpose of this test was to determine the degree of the early stiffening of the cement mortars. The cement mortars containing different particle sizes of WGP as SCM and WGC as aggregates were prepared and tested according to ASTM C359 [25]. As the early hydration of mortar was low, the testing time was extended to up to 30 min. The method uses a modified Vicat apparatus to measure the resistance to penetration at 5 min, 8 min,

Please cite this article in press as: J.-x. Lu et al., Fresh properties of cement pastes or mortars incorporating waste glass powder and cullet, Constr. Build. Mater. (2016), http://dx.doi.org/10.1016/j.conbuildmat.2016.11.011