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Waste glass sludge as a partial cement replacement in mortar

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HIGHLIGHTS

- Waste glass sludge (WGS) can be used as a partial replacement of cement.
- The strength of mortars containing the WGS is higher than the OPC mortar in 28 days.
- The ASR expansion of the mortars can be reduced by incorporating WGS.
- The reactivity of the WGS is found higher than fly ash.

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ABSTRACT

This paper presents the results of a study conducted to evaluate the possibility of utilizing the waste glass sludge (WGS) from the cutting and polishing process of glass plates, as a partial replacement of cement. A total of seven mortar mix proportions were prepared, by replacing ordinary Portland cement with WGS and/or fly ash (FA). The influences of WGS and FA on the compressive strength of mortars and ASR expansion of mortars were investigated. In addition, X-ray diffraction analysis was performed, to evaluate the pozzolanic activity. The results show that the incorporation of the WGS yields mortars with improved strengths at the later age (28 days), in comparison with that of a control mortar (ordinary Portland cement only); while the WGS caused a lower early strength than that of control, but higher than that of mortars containing FA. The ASR expansion of the mortars can be reduced by incorporating WGS as effectively as by fly ash. It is found that the consumption rate of calcium hydroxide for the paste with the WGS was faster than that of paste with FA, up to 28 days. These results indicate that the WGS has a higher reactivity than FA; and therefore, the WGS can be used as a pozzolanic admixture in cement composites.

1. Introduction

Due to its chemical compositions and physical characteristics, waste glass, produced from window panes, and glass containers (bottles and jars) for beverages, food, and other commodity items, has been reused as a construction material. Since the end of the 1970s, many researchers have studied the incorporation of waste glasses as aggregate or cement replacement in concrete [1–10]. However, using waste glass as coarse and fine aggregate in concrete can lead to expansions, due to the alkali-silica reaction (ASR) [11–13]. On the other hand, a significant increase in the property and durability of concrete was reported, when the glass with fine particles was used as cement replacement [8,14–23]. Schwarz et al. [15] reported that fine glass powder passing through 45 μm at 72% by mass, has the potential to improve the durability of concretes. Shi et al. [16] found that finely ground glass powders having a Blaine fineness of 262 m^2/kg, 467 m^2/kg, and 582 m^2/kg exhibited a very high pozzolanic strength activity index, and the pozzolanic behavior of glass powder increases, as its fineness increases. Shao et al. [17] showed that ground glass having a particle size finer than 38 μm exhibited a pozzolanic behavior. They demonstrated that a smaller glass particle size led to a higher reactivity with lime, a higher compressive strength in concrete, and a lower expansion related to alkali-silica reaction. Idir et al. [20] reported that fine glass powders having specific surface areas ranging from 180 to 540 m^2/kg reduce the expansions of mortars subjected to alkali-silica reaction.

The glass powders used in these researches as a pozzolanic admixture are finer than, or equal to, ordinary Portland cement (OPC) and fly ash (FA). They were usually prepared by crushing and grinding the bottles and jars glass in a ball mill, and by sieving the glass powder to the desired particle size. In order to reduce its particle size to an effective size, these processes should be

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repeated, and the glass powder crushed using a ball mill has a broader wide particle size spectrum, as compared to cement or FA, even though the average glass particle size is fine [15,16].

Waste glass sludge (WGS) is a byproduct from various glass industries, where glass products have been cut and polished for manufacturing processes. Currently most of the WGS, unlike waste glass bottles and jars, is disposed of by landfilling after dewatering, and such practice is causing an environmental problem. Generally, the physical characteristics of mixtures containing a pozzolanic admixture are dependent on its pozzolanic activity, characterized by the sum of SiO_2 and Al_2O_3, and its surface area. WGS has a high content of SiO_2 and Al_2O_3, and has very fine particles. In addition, WGS needs less effort than glass powder to obtain an efficient fineness, because WGS consists of fine glass particles having uniform size. Therefore, if WGS is utilized as a cement replacement material for a concrete, the improved mechanical properties of the concrete may be expected. Kim et al. [24] reported that WGS enhanced the resistance of freezing and thawing with and without de-icing salts, the chloride ion penetration and the resistance of surface scaling of the concrete.

The aim of this study is to investigate a possible use of the WGS as a pozzolanic admixture in mortar. Firstly, material characterizations of WGS in terms of chemical composition, particle distribution, crystal structure and morphological analysis were examined. Portland cement Type I was replaced with WGS at 5%, 10%, and 20% by the weight of cement, and mixtures with FA, hybrid mixture with WGS and FA, and the control cement mixture were prepared for comparison. The compressive strength, ASR expansion of the mortar specimens, and X-ray diffraction (XRD) of the pastes were investigated.

2. Experimental program

2.1. Materials

In this study, commercially available ASTM Type I Portland cement and an ASTM Type F fly ash (FA) were used. Natural sand was used as fine aggregate, having a specific gravity of 2.62, and water absorptions of 1.53%. Wet waste glass sludge cake with a 60% water content, which had gone through a flocculation and dewatering process, was obtained from a glass plant, as shown in Fig. 1a. After drying in the air at ambient temperature of 20–30 °C for two days, the percentage of water content of the sludge was 35%. However, the percentage should be below 20% to reduce the sludge to a very fine powder by using the Raymond mill. Therefore, the glass sludge was micronized into a fine powder, after drying at a temperature of 100 °C for 12 h.

The physical and chemical properties of the cement, FA and WGS are given in Table 1. WGS has similar SiO_2 and Al_2O_3 contents in comparison with glass powder [15–18,20,21], but the Na_2O which is a source for alkali silica reaction (ASR) was lower than that of the glass powder in the above references.

2.2. Methods

2.2.1. Compressive strength test

The mortar mixtures containing the WGS and the FA were prepared by ASTM C109 [25]. Cube specimens of size 50 × 50 × 50 mm were used for the compressive strength test. Specimens of mortar containing 5%, 10%, and 20% of WGS by weight of cement were prepared. The mortars with the WGS were compared with the mortars having the same percent replacement level of cement by 10% and 20% FA, as well as with the pure cement mortar. In addition, the hybrid mixture with 10% WGS and 10% FA was prepared as proposed by Shi and Zheng [6]. According to ASTM standard, a water to binder ratio of 0.485 was utilized for all batches, and the mixture proportions are given in Table 2. The test was performed at the age of 3, 7, 14 and 28 days. The strength reported was the average of three specimens for each mixture.

2.2.2. ASR expansion

In order to investigate the influence of WGS on the expansion caused by the alkali-silica reaction (ASR), expansion studies were performed, according to ASTM C1260 [26]. In order to activate the ASR, a part of natural sand was replaced with crushed bottle-glass in the size of 4.75 mm (No. 4) – 1.18 mm (No. 16) [18,20,27,28]. Three mortar bars (25 × 25 × 285 mm) containing WGS of 10% and 20%, and FA of 10% and 20% by weight were prepared. Hybrid mixture mortar bars

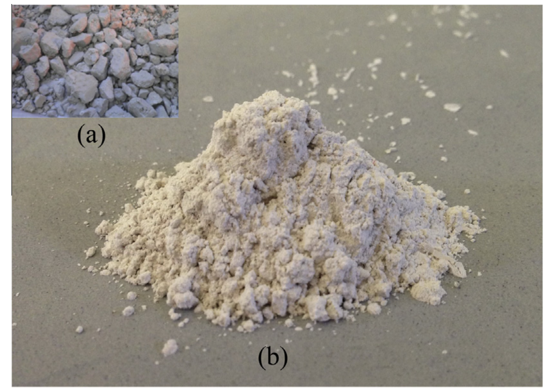

Fig. 1. Waste glass sludge (a) cake, and (b) powder.

Table 1
Physical–chemical properties of materials.

Component	Content (%)		
	Cement	FA	WGS
Silica (SiO_2)	18.8	48.5	68.2
Alumina (Al_2O_3)	4.18	27.5	10.1
Iron oxide (Fe_2O_3)	3.76	10.5	0.242
Calcium oxide (CaO)	65.3	5.76	9.90
Magnesium oxide (MgO)	2.43	1.30	2.94
Potassium oxide (K_2O)	1.10	2.68	0.229
Sodium oxide (Na_2O)	0.146	0.282	7.62
Sulfur trioxide (SO_3)	3.28	0.463	0.367
Loss on ignition	2.8	2.9	1.1
Specific surface (Blaine)	335 m^2/kg	338 m^2/kg	414 m^2/kg
Density	3140 kg/m^3	2210 kg/m^3	2630 kg/m^3

Table 2
Mortar mixture proportions.

Mixes	Quantities (g)				
	Water	Cement	WGS	FA	Sand
Control	368.6	760	0	0	1862
WGS (5%)		722	38	0	
WGS (10%)		684	76	0	
WGS (20%)		608	152	0	
FA (10%)		684	0	76	
FA (20%)		608	0	152	
WGS (10%)+FA (10%)		608	76	76	

with 10% WGS and 10% FA, and control mortar bars with Portland cement were also prepared for comparison. The length change of the prisms was measured up to 16 days.

2.2.3. X-ray diffraction (XRD)

The pastes containing WGS and FA were analyzed with X-ray diffraction (XRD), to evaluate the pozzolanic activity. XRD patterns of all samples were recorded with Rigaku D/Max-2200, using Cu Kα radiation at 40 kV and 150 mA, between 5° and 80° (2θ), at a step size of 0.01°. The intensity of calcium hydroxide ($Ca(OH)_2$) was compared, because the extent of pozzolanic reaction can be demonstrated by monitoring the decrease in calcium hydroxide over time [27,29,30].

3. Experimental results and discussion

3.1. Characteristics of the WGS

It is known that the glass powder possess a high pozzolanic reactivity, when the glass powder with high amorphous silica content exists as fine particles (less than 100 μm) [6,15–17]. The WGS had the sum of major acidic oxides (silicon dioxide, SiO_2, aluminum oxide, Al_2O_3, and iron oxide, Fe_2O_3) of 78.54%, which was above the 70% limit specified for pozzolan by ASTM C618 [31]. Furthermore, X-ray diffraction (XRD) patterns of the WGS shows amorphism of between 20 and 30, and no crystals were found, as shown in Fig. 2; that is, all the compositions in the WGS were the same. It is evident that WGS is a typical amorphous material.