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Assessment of waste packaging glass bottles as supplementary cementitious materials

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HIGHLIGHTS

- Adhesion of residual packed materials to waste glass bottles were studied.
- Particle size, pozzolanic activity and alkali-silica reaction were evaluated.
- The results of pozzolanic activity of different glass types is acceptable.
- Low expansion of glass/cement blend are safe to be used in practice.

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ABSTRACT

Adhesion of residual packed materials to waste glass bottles, as well as particle size, pozzolanic activity and alkali-silica reaction (ASR) of waste glass powder, are important indexes to choose waste glass bottles to be utilized as supplementary cementitious materials (SCMs).

Five different sources of waste glass bottles were selected, characterized and tested to be used as supplementary cementitious materials. The pozzolanic behavior of waste glass powders was examined by different methods. The compressive strength development of mortars containing uncolored, green or brown soda-lime ground glass types exhibited good pozzolanic behavior confirmed by a chemical test. The formation of calcium silicate hydrate (CSH) was demonstrated by XRD and TGA-DTA analysis. The alkali-silica reaction was monitored for the five glass powders.

The results of pozzolanic activity, as well as the expansion results due to ASR, show that the powder of uncolored, green and brown soda-lime glass types is acceptable to be used as SCMs and the ions responsible for the color have no effect on the performance.

1. Introduction

The environmental policy approach focusses on avoiding pollution, reducing waste and carbon dioxide emissions and accomplishing continual improvement in environmental performance [1]. An effective way to achieve this is through feeding back recycled materials into the production process.

In Egypt, there is insufficient information about the number of waste glass bottles generated, but according to non-government assessment, it is about 4 million tons annually. This massive number of waste glass bottles from households, as well as university chemistry laboratories is discarded every year without a recycling strategy. Waste glass bottles impose a problem for many countries and the current practice is still to landfill most of the nonrecyclable glass bottles [2]. Since the glass is not biodegradable and remains stable, landfills do not provide an eco-friendly solution.

Although all commercial glass bottles consist mainly of amorphous silica, reusing and recycling of waste glass bottles in Egypt is limited due to an absent strategy. Deficiency of a glass manufacturing industry, mixed color bottles and problem in the collection process increases the cost of recycling. The construction sector is considered as an attractive solution to reuse waste glass bottles. This is because of the large quantity needed and fairly low-quality requirements [3–9].

Many authors attempted to use waste glass as fine or coarse aggregates in concretes [10–12] to enhance its performance. But a failure in concrete is observed at long ages due to the expansive reaction between alkalis in cement and reactive silica [13–16]. In contrast, the use of finely ground waste glass, with high pozzolanic activity, as a partially cement replacement material enhanced specific properties of cement paste, mortar and concrete [17–23].

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Moreover, its uses will have environmental and energy impacts by decreasing the use of Portland cement and hence decreases the carbon dioxide emissions and energy consumptions in cement industry [24,25].

Soda-lime (uncolored and colored) and borosilicate glasses are the most frequent glass types. Soda-lime glass is commonly used to produce glass container (packaging bottles, jars), flat glass (windows of buildings) and domestic glass (drinkware, dishes). Borosilicate glass is used for laboratory equipment, pharmaceutical use and lighting (as bulbs for high-power lamps) [26]. Uncolored soda-lime and borosilicate waste glasses have been recycled effectively [27–29]. However, there no work has focused on evaluation of different waste glass bottles and their powders to decide if it is suitable to be used as cement replacement materials.

Different aspects should be considered for appropriate choice of waste glass bottles to be used as partially cementitious materials such as adhesion of residual packed materials to waste glass bottles as well as particle size, pozzolanic activity and alkali-silica reaction (ASR) of bottles powder. This work presents an assessment of different waste glass bottles from different sectors to be used as supplementary cementitious materials.

2. Experimental procedure

2.1. Materials

2.1.1. Portland cement

A typical local commercial type I 42.5R Portland cement (CEM I 42.5R), was supplied from Suez Cement Company, that complies with the requirements of specification ASTM C 150-07 [30] was used as a testing cement, its chemical composition is presented in Table 1.

2.1.2. Waste glass powders

Five types of waste glass bottles and jars were collected from households' trash as well as waste disposal area of chemistry labs in practical faculties. The waste glass bottles were subjected to washing with hot water in presence of an anionic emulsifier (sodium dodecyl sulfate) [31], rinsing with water, drying prior to crushing and dry milling in a ball mill. The ground waste glasses were sieved using 20 μm sieves.

2.2. Methods

2.2.1. Emulsion adhesion to packaging glass:

The amount of adhered materials to the packaging glass bottles (W_{ad}) were measured using a simply designed device as shown in Fig. 1.

The residual packing materials (juice, solvent, oils,.…..etc.) were held back in the middle to of an 80° tilted surface of different types of glass bottles. Subsequently, it was allowed to flow down and the weight remaining on the glass sheet surface after flow had stopped was measured using four digital precision balance.

$$\text{Deposit Weight } (W_{ad}\%) = \frac{\text{solid weight after flow}}{\text{solid weight before flow}} \times 100$$

The stand was adjusted at the selected angle like most selected bottles design and the sheet length was fixed at 10 cm with width 3 cm. 5 ml of each oil was dropped through Pasteur pipette. Calculations of the adhered oil were determined by the weight difference between before and after dropping process.

Many oils of different viscosities and function groups were selected as most adhered packed materials in comparison with water and organic solvents. Designing of a grinding system requires glass free from any organic materials which can be charring during grinding. Additionally, it requires cement mixture based on wettability efficient of different ingredients to form a strong binder. Therefore, ground glasses have to be free from any oils, solvents and contaminated sources which will decrease the wettability percentage of pozzolanic glass particles.

2.2.2. Chemical and phase composition

The X-ray fluorescence analysis was conducted on Axios, sequential WD-XRF spectrometer, PANalytical, USA to determine the chemical composition of cement and glass materials, as depicted in Table 1. X-ray diffraction (XRD) analysis was carried out to examine the crystallinity of the investigated glass powders using PANalytical Xpert Pro MRD Diffractometer, Amsterdam, Netherlands.

2.2.3. Particle size and surface area

NICOMP 380 ZLS, Dynamic light scattering (DLS) instrument (PSS, Santa Barbara, CA, USA), using the 632 nm line of a HeNe laser as the incident light with angel 90° was used to determine the particle size distribution of waste glass powders.

Nitrogen adsorption-desorption measurements were carried out at 77.35 K on (a Nova Touch LX4 Quantachrome, USA) to determine the Brunauer-Emmett-Teller (BET) surface area of OPC and waste glass powders. Before measurements, samples were kept in a desiccator until testing. Samples were cooled with liquid nitrogen and analyzed by measuring the volume of gas (N_2) adsorbed at specific pressures. The pore volume was taken from the adsorption branch of the isotherm at $P/P_o = 0.995$ assuming a complete pore saturation.

Table 1
Chemical composition of OPC and waste glass powders.

Chemical composition	Weight (%)					
	OPC	USL1	USL2	GSL	BSL	UBs
SiO_2	20.42	74.11	75.20	71.78	73.08	77.29
Al_2O_3	4.70	0.01	0.63	0.01	0.03	3.76
Fe_2O_3	3.42	0.12	0.04	0.50	0.41	0.10
CaO	61.51	10.01	12.55	10.83	11.77	4.79
MgO	2.28	2.60	0.01	1.30	0.91	0.41
K_2O	0.27	0.25	0.04	0.35	0.23	2.06
Na_2O	0.31	12.40	11.10	14.61	12.76	9.83
B_2O_3	–	–	–	0.032	0.009	3.61
BaO	–	0.088	0.084	0.086	0.088	0.795
Cr_2O_3	–	0.0003	0.0003	1.462	0.0131	0.0007
TiO_2	–	0.03	0.03	0.16	0.1	0.04
SO_3	3.35	–	–	–	–	–
Cl^-	0.04	–	–	–	–	–
Free-CaO	1.32	–	–	–	–	–
L.O.I	3.7	0.27	0.31	0.32	0.40	0.32