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Influence of different particle sizes on reactivity of finely ground glass as supplementary cementitious material (SCM)

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ABSTRACT

Finely ground glass can be pozzolanically reactive and serve as a supplementary cementitious material (SCM). In this study, the pozzolanic reactivity of three narrow size ranges of green glass cullet, 63–75 μm, 25–38 μm, and 0–25 μm was investigated in order to understand the effects of particle size on glassy SCM reactivity. Isothermal calorimetry, chemical shrinkage, thermogravimetric analysis, and leaching tests were used to measure cement and glass dissolution and reactions. Images taken by scanning electronic microscope (SEM) in backscattered (BS) mode were analyzed to measure glass degree of hydration. In addition, mortar compressive strength and water absorption of samples containing glass powder at different curing temperatures and ages were used to relate reaction degree to performance. Results showed that hydration degree of the glass particles could be directly accounted for through linear correlation with particles surface area.

1. Introduction

Waste glass can either be landfilled or recycled after collection. The worldwide volume of landfilled glass is estimated to be 200 million tons per year [1]. However, because landfill use has some issues such as limited capacity and environmental concerns [2], an increased tendency for glass recycling has been observed within past decades. In 2010, glass recycling increased to 3.13 million tons in the United States [3]. Even though waste glass theoretically can be completely recycled without any reduction in physical quality, recycling is limited because of different color glass becoming mixed [4]. Although large glass particles can be color-sorted using recycling device optical sensors, sorting small particles is not economical, and so they are most often disposed in landfills. For example, 1.65 million tons of waste glass is landfilled yearly in the U.K because they are non-recyclable [5]. Considering these economic and environmental concerns, alternatives for reusing glass particles must be considered. One possible alternative involves using waste glass in concrete, either as aggregate or supplementary cementitious material (SCM).

Previous hesitation in regards to the utilization of glass particles in concrete as aggregate include durability concerns prompted by the reaction between alkali found in pore solutions and amorphous silica found in glass, i.e., alkali-silica reaction (ASR). This issue has resulted in limited use of glass aggregate in concrete [6]. Conversely, since glass contains high amounts of amorphous silica – a prerequisite for pozzolanic reaction – it can be a supplementary cementitious material if ground to the size range of 38 – 300 μm [2,7–14]. As shown by Eq. (1), the pozzolanic reaction is comprised of the consumption of calcium hydroxide (CH or portlandite) by silica in the SCM to create additional calcium silicate hydrate:

$$Ca(OH)_2 + SiO_2 \rightarrow (CaO)(SiO_2)(H_2O) \quad (1)$$

Finely ground glass not only increases concrete strength, but could also produce more sustainable and durable concrete. Most research has studied pozzolanic reactivity of finely ground glass through the mechanical properties of concrete, i.e., compressive strength and ASR expansion [15,16]. Some studies however have accounted for the effect of small fraction size ranges of glass cullet on pozzolanicity [11,13,14,17,18]. A previous study performed on glass powder of varying fineness showed that particle size distributions that contained glass smaller than 81 μm could be pozzolanically reactive. Because the size distributions tested contained a continuous gradation of particles below that value, it cannot be ascertained from that study which particle size below that gradation was responsible for the reactivity [13]. This study investigates the pozzolanic behavior of carefully prepared narrow glass size ranges in concrete rather than just different fineness of grinding to investigate the effects of particle size on reactivity, with a specific focus on microstructural as well as mechanical properties. The uniform composition of glass particles also makes it an ideal

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Table 1
Chemical components of portland cement.

Cementitious materials	Chemical components						
	SiO_2	Al_2O_3 (%)	CaO (%)	Na_2O (%)	K_2O (%)	Cr_2O_3 (%)	$CaCO_3$
OPC	19.66	4.71	62.74	0.12	0.56	–	2.2
Green glass	73.10	1.65	10.55	12.34	0.58	0.24	–

Table 2
Potential composition of cement based on Bogue equations.

C_3S (%)	C_2S (%)	C_3A (%)	C_4AF (%)
58	11	7	10

Table 3
Sieving strategy for collection of glass powder with different size ranges.

Size ranges (μm)	Dry sieving	Wet sieving	No. of sedimentation
63–75	√	√	2–4
25–38	–	√	4–6
0–25	–	√	–

model system for examining the effects of particle size for glassy SCMs in general. The influence of three size ranges of very finely ground glass particles (63–75 μm, 25–38 μm, and 0–25 μm) on reaction kinetics, mechanical and water absorption properties have been studied. In addition, the apparent activation energy concept has been used to describe temperature sensitivity of the three size ranges in order to quantify reaction rate changes while curing temperatures vary [19].

2. Materials

ASTM C 150 M [20] type I/II Ordinary portland cement (OPC) was used for this study. Table 1 shows the chemical properties of the portland cement obtained by X-ray fluorescence (XRF) analysis.

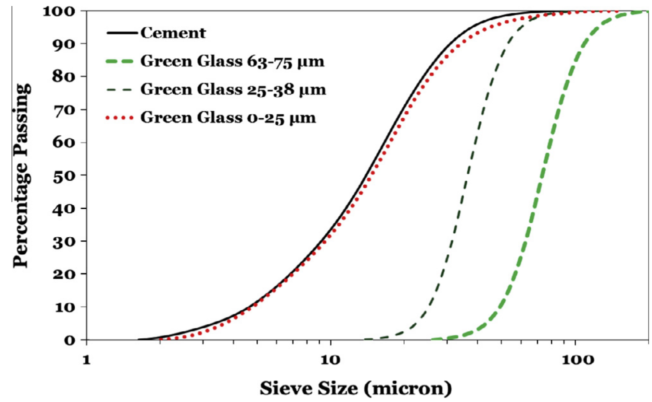

Fig. 1. Gradation of cementitious materials.

Table 4
Density and Blaine surface area of cementitious materials.

Materials	Density (kg/m^3)	Blaine surface area (m^2/kg)
OPC	3150	395
Green glass 63–75 μm	2501	53
Green glass 25–38 μm	2501	126
Green glass 0–25 μm	2501	476

Table 2 shows the potential compositions of the cement based on Bogue equations. Distilled water was used for the mixing water.

Results of some studies have shown that green glass often has higher reactivity than other types of soda-lime glass such as clear and amber glass [11]; thus, green glass was used in this study. Results of X-ray fluorescence (XRF) analysis of green glass and portland cement are shown in Table 1. Glass powder with very narrow particle size distributions were prepared for use in this study. To obtain the desired size ranges, 63–75 μm, 25–38 μm, and 0–25 μm, six steps were followed which included: washing, crushing, milling, dry sieving, wet sieving, and sedimentation. The glass was

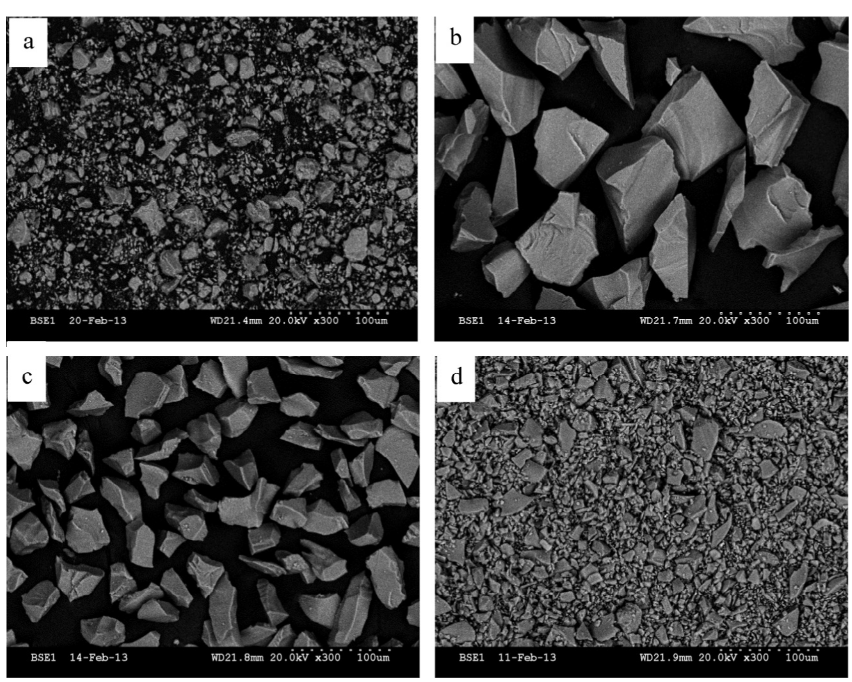

Fig. 2. SEM images: a. Cement grain, b. Green glass 63–75 μm, c. Green glass 25–38 μm, and d. Green glass 0–25 μm.