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Influence of a fine glass powder on cement hydration: Comparison to fly ash and modeling the degree of hydration

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Abstract

This paper reports the results of an investigation carried out to understand the influence of a fine glass powder on cement hydration. The pozzolanicity of the glass powder and a Class F fly ash for comparison was evaluated using strength activity index over a period of time, and a rapid electrical conductivity based method. Flame emission spectroscopy and electrical conductivity tests were used to quantify the alkali release from glass powder, and gain information on the rate of alkali release. It was found that the glass powder releases only a very small fraction of sodium ions into the solution. It was observed that the glass powder modified pastes show higher non-evaporable water contents than the plain paste and fly ash modified pastes, indicating that glass powder facilitates enhancement in cement hydration. An expression has been developed for the change in non-evaporable water content as a result of enhancement in cement hydration and the hydration of the cement replacement material. The efficiency of any cement replacement material with age in the paste system can be quantified using this parameter. Based on this parameter, a 5% cement replacement with glass powder was found to be effective at the chosen water-to-cementing materials ratio (w/cm), whereas at higher replacement levels, the dilution effect dominates. A model to predict the combined degree of hydration of cement pastes incorporating more than one cementing material is outlined. The measured and predicted combined degrees of hydration agree well.

Keywords: Glass powder; Fly ash (D); Cement paste (D); Alkalis (D); Hydration (A); Degree of hydration (B); Non-evaporable water content

1. Introduction

Supplementary cementing materials (SCM) have become an integral part of Portland cement concrete. They are useful in improving the mechanical and durability properties of concrete by beneficially impacting the material microstructure. The properties of common SCMs like fly ash and silica fume, and performance of concrete incorporating such materials are well documented. A variety of other waste or recycled materials with supplementary cementing potential are available, and their use in concrete becomes an increasingly attractive option if there are environmental issues related to their disposal. Fine glass powder is one such material, which is the focus of this paper. Glass contributes a major share of the total solid waste that is disposed every year. The recycling of waste glass is a major issue in urban areas of developed countries [1,2], which has resulted in significant interest of late in utilizing it in concrete.

Crushed glass has been used as a coarse aggregate in concrete [3–6]. Attempts were made to use waste glass as a raw siliceous material in the production of Portland cement [7,8]. The use of coarse glass powder as a hydration enhancing filler has been explored [9,10]. However, value addition of glass in concrete is best achieved if it is used as a cement replacement material. Glass is amorphous and has high silica content, which are the primary requirements for a pozzolanic material. A particle size of 75 μm or less is reported to be favorable for pozzolanic reaction [11]. The high alkali content of glass is a typical concern for its use in concrete, but studies [1,2] have shown that finely ground glass does not contribute to alkali–silica reaction.

A few studies have investigated the potential of finely ground waste glass powder as a pozzolanic material [2,11–14].

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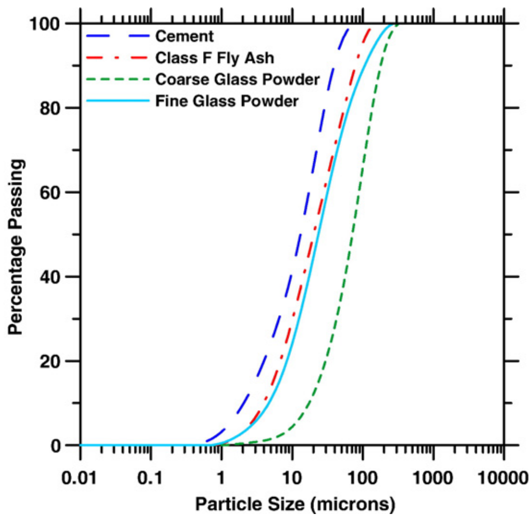

Fig. 1. Particle size distribution of cement, glass powders, and fly ash used in this study.

These studies have investigated the particle sizes, mechanical property development, and alkali–silica reactivity of mortars incorporating glass powder. This paper focuses on (i) examining the alkali release characteristics of the glass powder, (ii) influence of glass powder on cement hydration in pastes, and its comparison to fly ash, and (iii) a model to predict the total degree of hydration (both of the cement and the SCM) in pastes incorporating a SCM. Though a series of other tests to characterize the glass powder and compare it to fly ash like determination of flow value, setting times, compressive strengths, calcium hydroxide contents using thermal analysis, and heats of hydration were also carried out, they are not elaborated in this paper. Some of those results are reported in [15].

2. Experimental program

2.1. Materials and mixtures

Type I ordinary Portland cement conforming to ASTM C 150, fly ash conforming to ASTM C 618, and a fine glass powder are used to prepare the cement pastes used in this study. The particle size distribution (PSD) of these materials, along with that of a coarse glass powder (for comparison) is shown in Fig. 1. The chemical composition and physical characteristics of the cement, fine glass powder, and fly ash used in this study can be found in Table 1. The cement pastes were prepared with a water-to-cementitious materials ratio (w/cm) of 0.42. Cement was replaced by either glass powder or fly ash at rates of 5%, 10%, and 20% by mass. Mortar specimens in which glass powder or fly ash replaced 20% of the cement were also prepared as per ASTM C 311 to determine the strength activity indices.

Table 1
Chemical composition and physical properties of cement, glass powder, and fly ash used in this study

Composition (% by mass)/ property	Cement	Fine glass powder	Fly ash
Silica (SiO_2)	20.2	72.5	50.24
Alumina (Al_2O_3)	4.7	0.4	28.78
Iron oxide (Fe_2O_3)	3	0.2	5.72
Calcium oxide (CaO)	61.9	9.7	5.86
Magnesium oxide (MgO)	2.6	3.3	1.74
Sodium oxide (Na_2O)	0.19	13.7	0.96
Potassium oxide (K_2O)	0.82	0.1	–
Sulfur trioxide (SO_3)	3.9	–	0.51
Loss on ignition	1.9	–	2.8
Fineness, % passing (sieve size)	97.4 (45 μm)	80 (45 μm)	80 (45 μm)
Specific surface area (m^2/kg)	388	–	–
Density (kg/m^3)	3150	2490	2250

2.2. Test methods

The strength activity indices of the plain and modified pastes were determined in accordance with ASTM C 311. The alkali release from glass powder was qualitatively determined using electrical conductivity tests, and confirmed using flame emission spectroscopy.

The loss on ignition method was used to determine the non-evaporable water content at all selected ages of hydration. Small pieces from the samples (approximately 1–2 mm in size) cured in saturated limewater were pulverized and soaked in acetone to stop further hydration. The pulverized samples were heated in an oven at 105 °C for 24 h, followed by heating in a muffle furnace at 1050 °C for 3 h. The non-evaporable water content (w_n) was obtained as the difference in mass between the sample heated at 105 °C and 1050 °C normalized by the mass after heating to 1050 °C, and correcting for the loss on ignition of unhydrated cement (or of the unhydrated cement and the replacement material multiplied by their respective mass fractions). In addition to the pastes described above, plain and modified pastes were made with a w/cm of 0.80 and cured in saturated limewater for 140 days. The non-evaporable water content of these high w/cm pastes was determined to facilitate the calculation of degrees of hydration of the 0.42 w/cm pastes at various ages.

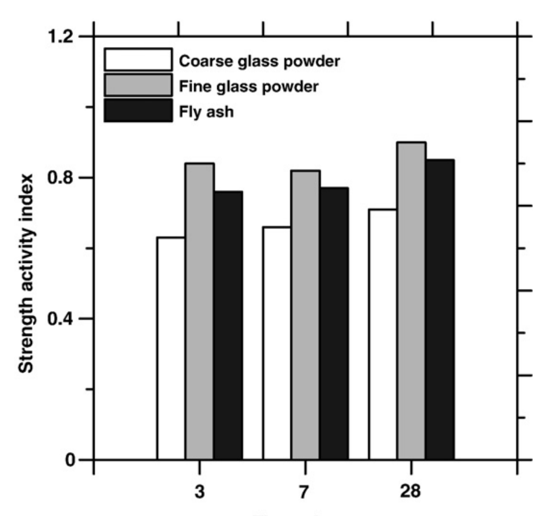

Fig. 2. Strength activity indices of glass powder and fly ash modified pastes.