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Rheological and hardened properties of mortar incorporating high-volume ground glass fiber

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HIGHLIGHTS

- Ground glass fiber was incorporated as a cement replacement in mortar mixtures.
- Binary and ternary systems with up to 50% cement replacement were investigated.
- Rheological and mechanical properties, shrinkage, and durability were investigated

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ABSTRACT

The present research investigates the performance of mortar prepared with high-volume ground glass fiber (GGF) incorporated as partial replacement of Portland cement. Several binary and ternary mixtures with up to 50% cement substitution were investigated to evaluate rheological properties, heat of hydration, strength development, drying shrinkage, electrical resistivity, and carbonation. The incorporation of up to 50% GGF was found to reduce yield stress by up to 50% compared to control mortar without any GGF. On the other hand, this resulted in up to 100% increase of plastic viscosity of mortar in comparison with the Reference mortar cast with 100% Portland cement. The rate of structural build-up at rest of the tested mortars, that reflects the thixotropic nature of the mortar, decreased from 7.1 to 0.8 Pa/min with cement substitution by 50% of GGF. Reduction in 91-day compressive strength from 34 to 28 MPa was observed with 50% cement substitution by GGF. The coefficient of pozzolanic activity of mortar cast with 10% to 50% GGF ranged from 0.18 to 0.71 at 91 days, compared to mixtures containing 50% cement substitution with Class F fly ash (FA-F), Class C fly ash (FA-C), or blast furnace slag (SL) where the 91-day coefficient of pozzolanic activities were 1.80, 1.46, and 1.21, respectively. The incorporation of 10% to 50% GGF reduced the 91-day drying shrinkage by 0–20%. At 50% GGF replacement, the electrical resistivity was enhanced from 10 to 88 kΩ.cm at 91 days, while the carbonation coefficient increased by about 100%. The incorporation of 15% or 25% GGF in ternary systems containing either FA-C, FA-F, or SL was effective in enhancing compressive strength, with values ranging between 34 and 49 MPa. The best performance was observed in the case of the GGF/FA-C ternary binders, followed by the GGF/SL, and GGF/FA-F systems where 91-day compressive strength gains of up to 45%, 28%, and 10%, respectively, were observed compared to the Reference mixture with 100% Portland cement.

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1. Introduction

Enhancing the engineering properties, along with reduction in material costs have urged the incorporation of supplementary cementitious materials (SCMs) in concrete production. In addition, mitigating environmental impact associated with cement production constitutes another major motivate for incorporation of cement replacements. With an approximate rate of 0.6–0.7 ton of CO_2 per ton of cement, the production of Portland cement accounts for about 8% of CO_2 emission worldwide [1,2]. SCMs are typically by-products of industrial and/or agricultural activities with mechanisms of influence that depend on the chemical composition and physical properties of the SCM. Fly ash (Class C or F), blast furnace slag (SL), silica fume (SF), metakaolin, zeolite, and rice husk ash are the most widely used types of SCMs. The presence of anhydrous

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calcium silicate phases in such SCMs as SL, can contribute to hydraulic reaction in alkaline environment. On the other hand, the high concentration of amorphous silica and aluminate phases, as in the case of SF, can lead to high pozzolanic reactions by means of converting part of the calcium hydroxide (CH) to calcium silicate hydrate (C—S—H).

Ground glass fiber (GGF) is a relatively new type of SCM/filler, obtained from recycling waste glass fibers, with potential applications in concrete production [3]. Historically, waste glass fiber is deposited in landfills. The use of GGF as a partial replacement for Portland cement can result in recycling of up to 500,000 tons of glass fiber waste, annually [3]. Glass fibers are typically produced with a specific type of glass that secures high electrical resistivity, which is known as E-Glass [4]. The raw material incorporated in production of glass fiber is an amorphous vitreous calcium aluminio-silicate (VCAS) powder. The production of VCAS involves heating a blend of ground silica, lime, and alumina compounds to a molten state, followed by solidifying by quench cooling, and grinding to a fine white colored powder [5].

Given the uniform physical and chemical properties, and considering the aluminate-silica rich composition, the incorporation of GGF as cement replacement was suggested by Hemmings [3]. Incorporation of GGF along with an alkaline solution of sodium hydroxide was proposed for development of alkali activated cements in a series of studies by Tashima et al. [6–8]. Limited studies have focused on use of GGF as a cement replacement in concrete production. Neithalath et al. [9] investigated the use of up to 15% GGF as a cement replacement in the production of binary cement paste with water-to-cementitious materials ratio (w/cm) of 0.42. The GGF had a median particles size of 8 μm and 54%, 24%, and 18% of SiO_2, CaO, and Al_2O_3, respectively. Based on the data obtained from thermo-gravimetric analysis (TGA) followed by monitoring the variations in calcium hydroxide concentration, it was reported that GGF had no hydraulic qualities [9]. However, the pozzolanic activity observed for up to 15% substitution of such GGF was reported to be higher than that of Class F fly ash and lower than that of SF. Hossain et al. [5] also investigated the effect of substitution of Portland cement with 6%, 9%, and 15%, by mass, of GGF with mean particle size of 3 μm, in concrete made with w/cm of 0.4 and 0.5. The authors found that the 15% GGF substitution resulted in an increase in slump from 75 to 200 mm in mixtures proportioned with 0.50 w/cm and no water reducing admixture (WRA) [5]. No significant difference in plastic shrinkage and cracking potential was reported for such concrete. The authors reported a decrease in sorptivity from 0.80 to 0.62 $kg/m^2/h^{0.5}$ due to the use of 15% GGF replacement in concrete proportioned with 0.40 w/cm [5]. The moisture diffusion coefficient was also reduced from 3.31×10^{-5} to 2.66×10^{-5}, 0.92×10^{-5}, and 1.55×10^{-5} m^2/h with the use of 6%, 9%, and 15% GGF. Rashidian and Rangaraju [4] investigated the performance of concrete made with up to 30% GGF substitution of cement in mixtures made with 0.40 w/cm and 355 kg/m^3 of binder. The authors reported reduction in the 56-day compressive strength from 55.0 MPa in the case of the Reference mixture to 51.0, 47.0, and 52.5 MPa associated with cement substitutions with GGF of 10%, 20%, and 30% GGF, respectively. It was also reported that the incorporation of up to 30% GGF was helpful in mitigating the expansion of mortar bars exposed to alkali silica reaction (ASR) test environment. The 28-day mortar expansion values were reduced from 1.2% in the case of the Reference mixture, to 0.25%, 0.2%, and 0.1% due to 10%, 20%, and 30% GGF incorporation, respectively [4].

Despite the investigations presented here, there is limited information dealing with the effect of recycled glass fiber in cementitious systems. Given the variations in chemical composition and physical properties, further experimentation is needed to understand the fresh and hardened properties of binary and ternary mixtures made with GGF. The present research investigates the properties of mortar proportioned with high substitutions of Portland cement with up to 50% of GGF, by mass. Ternary systems were prepared with up to 25% GGF along with either SL, Class C fly ash (FA-C), or Class F fly ash (FA-F), by mass. The testing program involved the evaluation of the effect of binder composition on key properties of mortar made with 0.40 w/cm (the GGF is consider as part of the cementitious materials). The investigated properties included rheological properties, heat of hydration, strength development and pozzolanic activity, shrinkage, electrical resistivity, and carbonation.

2. Experimental program

The constituent materials, mixtures proportioning, and testing protocols are elaborated below. The study was conducted on mortar mixtures proportioned with 587 kg/m^3 of cementitious materials, w/cm of 0.40, and 1530 kg/m^3 of sand.

2.1. Materials and mixing procedure

2.1.1. Materials

Type I/II Portland cement (OPC), GGF, FA-C, FA-F, and SL were used in this study. The chemical composition and physical properties of these binder materials are summarized in Table 1. Fig. 1 shows scanning electron microscopy (SEM) images of these powder materials. Both types of fly ash had spherical particles, while the OPC, GGF, and SL particles were angular.

A siliceous river-bed sand was used. The fineness modulus, specific gravity and water absorption of sand were 2.47, 2.63 and 0.4%, respectively. A lignosulfonate based WRA with a solid content of 37% and a specific gravity of 1.2 was used. The WRA dosage was adjusted to secure an initial mini slump value of 140 ± 20 mm.

2.1.2. Mixing procedure

A Hobart mixer with 10-liter capacity was used. The mixing procedure consisted of: (1) mixing the sand at low speed for 1 min; (2) adding half of the mixing water and mixing for 1 min; (3) introducing the cementitious materials and mixing for 0.5 min at low speed; (4) incorporating the WRA diluted with the rest of the water and mixing at high speed for 2.5 min, followed by 2 min of rest and 3 min of final mixing at high speed.

Table 2 summarizes the mixture compositions of the 19 mortars that were investigated in this study. A mortar cast with 100% OPC was considered as the Reference mixture. The test matrix included binary systems with mass substitutions of cement by 10%, 20%, 30%, 40%, and 50% of GGF. Ternary binders made with 15% GGF along with 35% of FA-F, FA-C, or SL as well as 25% GGF and 25% of FA-F, FA-C, or SL were investigated. Similarity, ternary blends made without any GGF containing 15% or 25% SL with 35% or 25% of FA-C or FA-F were also considered.

2.2. Test methods

2.2.1. Fresh properties

Immediately after mixing, a sample of fresh mortar was extracted to evaluate the mini slump using a conical mold with height and base diameter of 50 and 100 mm, respectively. The cone was filled in two layers, and each layer was tamped 20 times. The cone was gently raised, and two diameters of the mortar were measured in orthogonal directions after the cease of the spread. The mini slump value corresponds to the average of the two duplicate tests.

Fresh mortar samples were used to determine rheological properties using a coaxial cylinder type rheometer. The sample was

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