



Effects of a defoamer on the compressive strength and tensile behavior of alkali-activated slag-based cementless composite reinforced by polyethylene fiber



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ABSTRACT

The pore characteristic is a factor that influences on the mechanical properties of composites; the characteristic can be controlled by a defoamer. This paper presents an experimental study on the effect of a defoamer on the compressive strength and tensile behavior of alkali-activated slag-based cementless composite reinforced by polyethylene fiber. Three types of mixtures were made according to the amount of defoamer and the compressive strength, tensile behavior, density, and pore size distribution were measured. Test results show that the compressive strength and tensile behavior of the alkali-activated slag-based polyethylene fiber reinforced composite investigated in this study can be improved by including a small amount of defoamer in the composite.

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1. Introduction

A cementitious construction material such as concrete and mortar exhibits inherently low tensile strength (about 10% of compressive strength) and more brittle behavior under tension than under compression. Therefore the structural performance of members made from a cementitious construction material can be improved by improving its tensile behavior.

Many studies have been performed to improve the tensile behavior of cementitious construction material. In the early 1990s, the first versions of engineered cementitious composites (ECC), which were micromechanically designed and showed extremely high tensile ductility, were developed by adopting short polyethylene (PE) fiber [1–3]. PE-ECC showed high tensile strain capacity of 5%, approximately 500 times that of normal concrete, as well as high tensile strength up to 5.5 MPa. Following that, because the cost of PVA fiber is lower than that of PE fiber, polyvinyl-alcohol (PVA)-ECC was also developed to lower the cost of materials [3]. The main challenge of adopting PVA fiber was its high hydrophilic property, which resulted in too strong bond between the fiber and the matrix, and led to brittle behavior of

the PVA fiber reinforced composite. Li et al. [3] achieved a tensile strain capacity of about 4% and a tensile strength of 4.5 MPa by tailoring the interfacial properties between the fiber and the matrix through surface oil-coating of the PVA fiber.

Wang and Li [4] demonstrated that saturated multiple cracking and high ductility can be achieved in ECC through the tailoring of pre-existing flaw (or pore) size distribution in a matrix. Kang et al. [5] applied this concept to ultra-high performance concrete (UHPC) and demonstrated that the tensile behavior, including the tensile ductility and the cracking patterns of UHPC, can be controlled. From a review of the literature, it was confirmed that the characteristics of the matrix pores are a key factor influencing the tensile behavior of a high ductile fiber reinforced cementitious composite.

A defoamer is usually used to eliminate and reduce the formation of foam, i.e., unintentional large pores that form during the manufacturing process of materials. Therefore, a defoamer influences the amount, size, and distribution of pores in a matrix, and can lead to a change of fracture toughness and cracking strength of the matrix as well as to changes of the interfacial properties between the matrix and the fiber [6–8].

Previous studies have reported that alkali-activated materials show a mechanical performance similar to that of cement-based materials [9,10]. The main advantage of alkali-activated materials

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is the material greenness. The cement industry produces about 5% of global manmade carbon dioxide [11,12]. On the other hand, because by-products such as slag and fly ash are used as a source material in alkali-activated materials, alkali-activated materials produce less carbon dioxide than do cement-based concrete. Although recent studies have reported that high tensile strain capacity and tensile strength can be achievable in alkali-activated slag-based cementless fiber reinforced composites [13–16], the study of the effects of defoamers on the mechanical behavior of alkali-activated slag-based composites has been fairly limited.

The purpose of this study is to investigate experimentally the effect of a defoamer on the compressive strength and tensile behavior of an alkali-activated slag-based cementless PE fiber reinforced composite with ultra-high tensile ductility.

2. Materials and methods

2.1. Materials and mixture proportion

The materials and mixture proportions are listed in Table 1. Alkali-activated slag was used as a binding material. Ground-granulated blast furnace slag (GGBS) was the source material. The specific surface area and density of the GGBS were 4030 cm²/g and 2.91 g/cm³, respectively. The chemical compositions of GGBS are listed in Table 2. Values were obtained by X-ray fluorescence (XRF) analysis, three samples were used. Two types of alkali-activators, i.e., calcium hydroxide and sodium sulfate, were used. The alkali-activators were of powder type to prevent quick setting. The mixtures were designed to investigate the effects of a defoamer on the compressive strength and uniaxial tensile behavior, as listed in Table 1. The ratio of GGBS to the alkali-activators and the water-to-binder ratio were fixed. Aggregates were excluded because they can influence the effect of defoamers on properties of the matrix and lead to high matrix toughness. A high-range water-reducing agent (HRWRA) was added to control the plastic viscosity of the matrix to ensure good fiber dispersion. The amounts of defoamer in the D1 and D2 mixtures were 0.1 wt.% and 0.2 wt.% of the binding material, respectively. The defoamer used in this study was a mixture of surface active agents and mineral substances without silicone; usage of this defoamer was able to ensure a fast escape of air entrapped during the manufacturing process. An ultra-high molecular weight PE fiber with high tensile strength (up to 2700 MPa) was used as a reinforcing fiber, the physical properties of fiber are listed in Table 3. A synthetic fiber comprising 2% of the total volume is generally used for high performance fiber reinforced cementitious composites (HPFRCC) [17]; however, a fiber comprising 1.75% of the total volume was used in this study because the fiber has high strength and high aspect ratio.

2.2. Specimen preparation

Each component was mixed using a planetary mixer. The binding materials including GGBS and the alkali-activators were mixed for three minutes. The water, HRWRA, and defoamer were added

into the mixer, and the mixture was mixed for another five minutes. After achieving the proper rheological properties of the mixture, PE fibers were added to the mixer and the mixture was mixed for another five minutes. Following that, each mixture was poured into a mold to make specimens for the compression test, tension test, and density test. Six 50 mm cubes (three for the compression test, and another three for the density test and the pore size distribution test) and five dog-bone shape specimens for the tension test were made. Plastic sheets were put on the surface of each specimen to prevent the evaporation of water. All specimens were cured in a control room at a room temperature of 23 °C ± 3 °C for 2 days. The hardened specimens were removed from the molds and then cured in water at 23 °C ± 3 °C until an age of 28 days. For the mercury intrusion porosimetry (MIP) test, a diamond saw was used to cut the 50 mm cube specimens into 10 mm cubes. Before the MIP test, the cubes were vacuum-dried in a chamber at 10 °C for 3 days; this was done to prevent further hydration and/or polymerization during oven-drying of the alkali activated slag matrix.

2.3. Experimental tests

With 50 mm cube specimens, the compressive strength was measured according to ASTM C109 [18]. The uniaxial tensile behavior, which can be quantitatively expressed by the first cracking strength, tensile strength, tensile strain capacity, and toughness, was investigated by uniaxial tension testing of the specimens in accordance with the Japan Society of Civil Engineers (JSCE) recommendation [17]. The gauge length of the specimens was 80 mm, and the size of the cross section within the gauge length was 13 mm × 30 mm. Fig. 1 shows the dimensions of the specimens and the test setup. Tensile load was applied under displacement control of 0.1 mm/min, induced by an electrical universal testing machine. Two linear variable differential transducers were attached to each specimen to measure the elongation within the gauge length. The tensile stress and strain were calculated from the tensile load and displacement. The cracking pattern, which can be quantitatively expressed by the number of cracks, the crack spacing, and the crack width, was investigated by measuring the number of cracks within the gauge length. The number of cracks was manually counted on both sides of each unloaded specimen after the tension test. The crack spacing was calculated by dividing the gauge length by the number of cracks. It was assumed that all deformation occurred at the cracks because the elastic deformation of the matrix is relatively much smaller than the crack widths. Therefore, the average crack width was calculated by dividing the total deformation at maximum tension load by the number of cracks.

In order to analyze the pore size distribution of each mixture at nano- and micro-scale, mercury intrusion porosimetry (MIP) was applied in accordance with ASTM D4404 [19]. Automatic MIP equipment (AutoPore™ IV, Micromeritics Instrument Corp., US) was used; its reliable measurement range was from 3 nm to 10 μm. In addition, to evaluate the larger pores in the composite, which pores could not be analyzed by the MIP test, visual observation was performed of the cross-section of the hardened specimen

Table 1
Mix proportions.

Mixture	Binding material			Water	HRWRA	Defoamer	Fiber (vol.%)
	GGBS	Ca(OH) ₂	Na ₂ SO ₄				
D0	0.895	0.075	0.03	0.30	0.004	–	1.75
D1	0.895	0.075	0.03	0.30	0.005	0.001	1.75
D2	0.895	0.075	0.03	0.30	0.005	0.002	1.75

Note: Mass ratios of binding material weight except fiber.

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