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Shrinkage and corrosion resistance of amorphous metallic-fiber-reinforced cement composites

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ABSTRACT

This study evaluated the corrosion resistance and plastic shrinkage control properties of amorphous metallic fiber used to reinforce cement composites. Amorphous metallic fibers, based on amorphous metals, are typically thin and are believed to be highly corrosion resistant. After exposing amorphous metallic fibers to five different types of degradation environments for 30, 60, and 90 days, a tensile test was conducted to evaluate corrosion resistance and reduction in tensile strength. Also, a plastic shrinkage crack test of amorphous metallic-fiber-reinforced cement composite was carried out, and comparisons were made with conventional steel-, polypropylene-, and polyvinyl-alcohol-fiber-reinforced cement composites. Test results show that amorphous metallic fibers displayed higher corrosion resistance than did steel in every degradation environment, and plastic shrinkage crack control performance was excellent.

1. Introduction

Cement composite has been used as a construction material because it is advantageous economically and has excellent mechanical properties, such as compressive strength, durability, and rigidity. However, it has the disadvantages of relatively low tensile, flexural, and impact strength, and it exhibits brittleness and low energy-absorption capacity [3–6].

The evaporation of water from cement composites while they are in a plastic state, along with the water loss that accompanies hydration, can result in a volume reduction of over 1% of the absolute volume in dried cement [6,18]. When the rate of water loss exceeds 0.5 kg/m^2/h, especially from very young cement composites, tensile stresses can arise from external or internal restraints [6]. As a result, plastic shrinkage cracking may occur at the point at which the tensile stress exceeds the cracking strength of the cement composites [3,4,18]. In the case of the plastic shrinkage cracks, which can occur in the early hardening of cement composite, cracks destroy the surface area of the composite, making the penetration of external deteriorating material easier, which decreases durability. One of the methods for preventing plastic shrinkage cracks is to introduce curing, which can prevent water loss at early age. But it is very difficult to prevent plastic shrinkage cracks by applying the curing method alone [1–4]. Crack prevention becomes easier by introducing, in addition, temperature control, prevention of wind exposure of the cement composite material, and a shrinkage-reducing agent such as an expansive admixture [5,6]. Besides the above methods, one of the most effective methods to control plastic shrinkage cracks is to apply crack-prevention reinforcing fiber [7–9]. The growth of plastic shrinkage cracks is suppressed by the bridging effect of uniformly distributed synthetic, metallic, and natural fiber, which intersects cracks [10,11].

Hence, distributing irregularly discontinuous and single-phase fiber in the cement matrix not only improves its mechanical properties, such as inducing ductility in the brittle behavior of cement composite and enhancing resistance to tension, but is also very effective in suppressing the introduction and growth of local cracks occurring unavoidably in cement composite [1,3–6].

The behavior of steel-fiber-reinforced cement composites is well known in the case of a first short-term loading. However, the durability of their vital character in structural applications still remains largely unexplored. The long-term behavior of operational structures reinforced with steel fiber in the cracked mode depends on the capacity of the fiber to bridge the two lips of cracks. Corrosive attack through the cracks left by the fibers in steel-fiber-reinforced cement composites may result in bursting of the cement matrix by the swelling that accompanies the development of corrosion products. On the other hand, the crack-bridging capacity of the fibers can be weakened by corrosion, which reduces their cross section [16,17].

This study evaluated the shrinkage-control characteristic of amorphous micro-metallic-fiber-reinforced cement composite, as well as the corrosion resistance of steel fiber that may become exposed within cracks.

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2. Materials and mixture proportions

2.1. Amorphous metallic fiber and steel fiber

The amorphous metallic fiber is made of amorphous alloy, which has no particle boundaries because it is made by cooling the liquid metal as quickly as 105 K/s. In general, metal with particle boundaries exhibits anisotropy due to crystallographic orientation, whereas amorphous metal has no internal boundaries and exhibits relative toughness. Hence, amorphous metal is known to have much better strength and tensile strength than typical metal and excellent resistance to both acid and water [12].

The amorphous metallic fiber used in this study had a length of 30 mm and thickness of 0.029 mm, and the steel fiber was a hooked-ends type with a length of 30 mm, diameter of 0.50 mm, and aspect ratio of 60. The shape and mechanical characteristics of the fiber used are shown in Fig. 1 and Table 1. The shrinkage control characteristic of the polypropylene (PP)-fiber- and polyvinyl alcohol (PVA)-fiber-reinforced cement composites were compared with those of the amorphous metallic-fiber-reinforced cement composite.

2.2. Cement and aggregate

This study used Type I ordinary Portland cement of density 3.15, with river sand of density 2.6 as fine aggregate.

2.3. Mix proportion

To evaluate the shrinkage control of amorphous metallic-fiber-reinforced cement composite, a mortar plastic shrinkage test was conducted using the mix proportions shown in Table 2. PP and PVA fiber were applied to the volume fraction of 0.1 vol.%, which is generally used to control plastic shrinkage cracks, and steel fiber was used up to the fraction of 0.25 vol.%, or 0.5 vol.% of the total volume. For comparison with a varying fiber volume fraction, the amorphous metallic fiber was applied in proportions of 0.1, 0.25, and 0.5 vol.%. The specimens were denoted by a combination of PP, PVA, AF, or SF volume fraction and specimen number, depending on fiber type. AF stands for amorphous metallic fiber, and S for steel fiber. For example, AF-0.1-1 means the first specimen with amorphous metallic fiber volume fraction of 0.1%. The experimental plastic shrinkage variables of the amorphous metallic-fiber-reinforced cement composite used in this study are listed in Table 3.

3. Experiment

3.1. Corrosion resistance

After immersing the fiber for a given time in an environmental solution that simulated the degradation environment to evaluate the corrosion resistance of the amorphous metallic fiber, the corrosion was inspected visually, the fiber tensile strength was evaluated according to ASTM A 370, and the residual tensile strength was derived [14]. The fiber tensile-strength test used a 50-kN capacity displacement control type UTM (Instron 3369, USA) with a grip for the plane. The test was conducted by setting up the fiber unit distance as 10 mm and loading at the speed of 0.3 mm/min. The tensile strength test setup is shown in Fig. 2.

The degradation environment that stimulated metal corrosion was prepared by applying water, sulfate, salt, acid, and alkali solutions. These are explained in detail as follows.

3.1.1. Distilled water

The amorphous metallic-fiber-reinforced cement composite specimens were immersed in distilled water to evaluate their corrosion resistance in water. The tests were performed after they had been immersed in distilled water for 90 days.

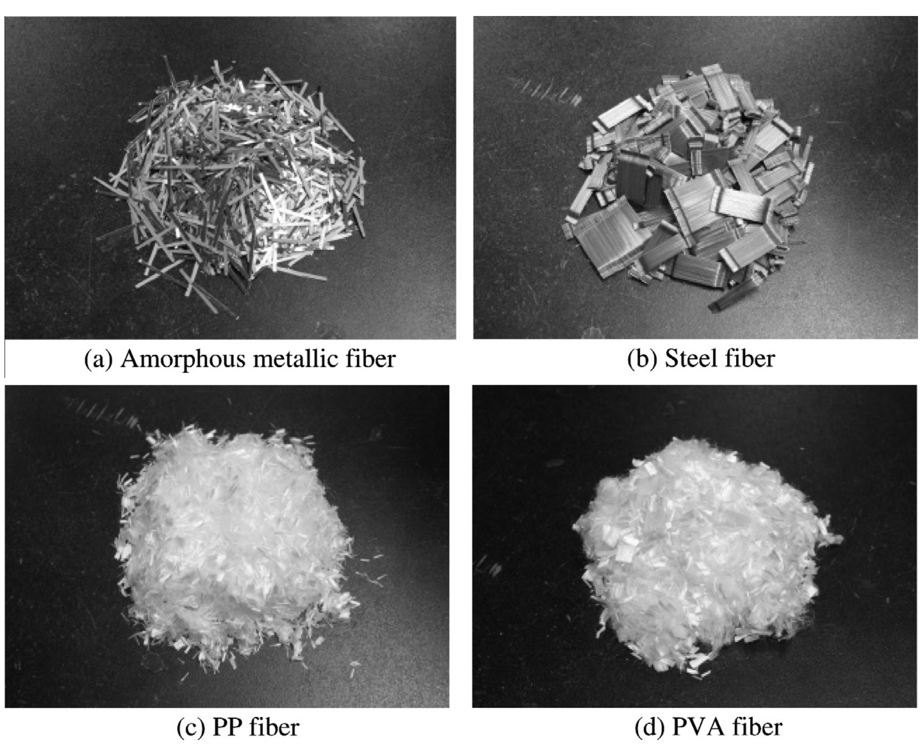

Fig. 1. Morphology of the fiber used.