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Static mechanical properties and impact resistance of amorphous metallic fiber-reinforced concrete

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ABSTRACT

This study examined the effect that the thin plate shape of the amorphous metallic fibers has on the attainability of the mixing conditions, the static mechanic properties, and the impact resistance of concrete and cement composites (mortar) to those of hooked-end steel fibers. The amorphous metallic fiber-reinforced concrete was found to lose a significant amount of its flowability as a result of mixing, relative to the hooked-end steel fiber reinforced concrete. The hooked-end steel fiber exhibited pull-out from the matrix after the peak pull-out load was attained, while the amorphous metallic fiber with the large bond-specific surface area was not pulled out from the matrix, but was instead cut off. In terms of impact resistance, the amorphous metallic fiber reinforced concrete was found to be more effective at resisting cracking than the hooked-end steel fiber reinforced concrete. Therefore, amorphous metallic fiber should be used in fiber reinforced cement composite materials and structures, for structural materials, and for protection panels.

1. Introduction

Concrete materials are weak in tension, and can deform only very slightly, giving them brittle fracture characteristics. This makes it difficult to control crack initiation and propagation. To increase their tensile performance, different types of concrete including fiber-reinforced concrete (FRC), into which short fibers are mixed during its manufacture, and fiber-reinforced cement composite (FRCC) have been developed and applied to a range of structures. In FRC and FRCC, the crosslinking behavior of the reinforcing fibers controls the stress dispersion and crack initiation, increasing the concrete's performance under flexure and tension. To ensure the safe performance of concrete when subjected to high-velocity impacts and explosions, the performance of both the FRC and FRCC composite materials were carefully considered [1–5].

The improvement in the flexural and tensile strengths of the FRC is largely influenced by the fiber's shape, aspect ratio (L/D), tensile strength, volume fraction (V_f), fiber–matrix bond strength, pull-out properties, and the type and strength of the matrix [6]. Therefore, various shapes of short fibers have been developed for concrete reinforcement, and their applicability is being evaluated. In general, steel fiber reinforced concrete (SFRC) is most commonly used for, and is very effective for, increasing the tensile strength, deformability, and crack propagation resistance of concrete. Also, to enhance its fiber–matrix bond strength, the shape of the steel fibers has been optimized, adopting the likes of hooked and twisted shapes [7,8].

An amorphous metallic fiber has recently been developed. This features tensile strength, corrosion resistance, and wear resistance that were improved by quenching the molten metal at a rate of 10^5–10^6 °C/s. Because amorphous metal is manufactured through a melt-spinning process, in which liquid metal is quenched, as shown in Fig. 1, it has an amorphous (non-crystalline) structure, unlike other metals with crystalline structures. Therefore, it has a higher tensile strength and corrosion resistance than common steel fibers. In addition, because the amorphous metal is formed into a thin plate as part of the manufacturing process of quenching liquid metal, as shown in Fig. 2, the surface area of adhesion is increased, along with the bond strength, because the fiber's surface is roughened. In addition, because it is ultralight, there are more individual amorphous metallic fibers in the matrix for the same volume fraction, relative to more commonplace steel fibers. Therefore, by using amorphous metallic fiber as a concrete reinforcement material, the concrete's crack resistance, flexure, and tensile strengths are expected to improve, while the corrosion issues experienced with common steel fibers can effectively be alleviated by its corrosion resistance.

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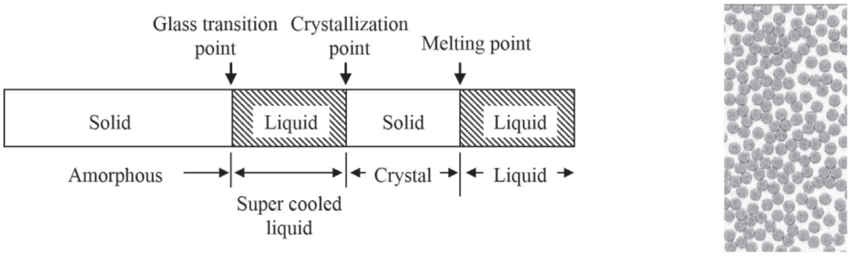
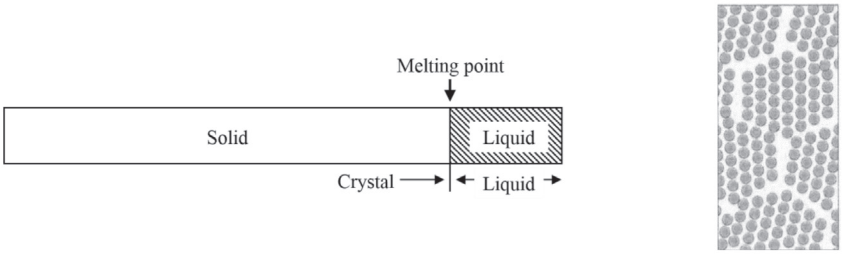


(a) Amorphous metal



(b) Crystal metal

Fig. 1. Overview and structure of amorphous metal and crystal metal.

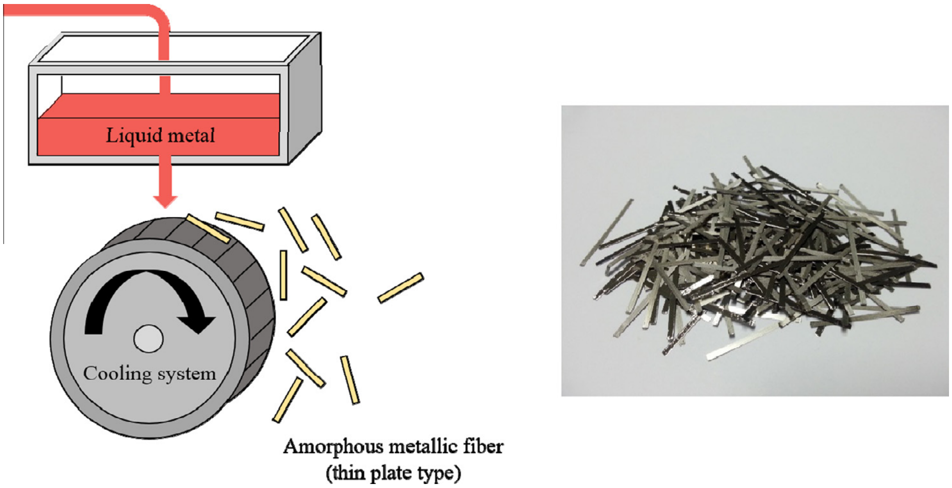


Fig. 2. Manufacturing process of amorphous metallic fiber.

Ku et al. conducted research into the flexural properties of amorphous metallic fiber reinforced concrete. Their study found that amorphous metallic fiber reinforced concrete has a greater flexural strength than hooked-end steel fiber reinforced concrete. After crack initiation, however, the residual strength decreases sharply, so the flexural toughness was regarded as being similar [9]. Park et al. conducted a study of the crack behavior and tensile property strengthening effect of hooked-end steel fiber and amorphous metallic fiber reinforced concrete. Their results showed that, relative to hooked-end steel fiber reinforced concrete, amorphous metallic fiber reinforced concrete better resists the initiation and propagation of splitting cracks, and it has a greater tensile property strengthening effect [10]. Won et al. determined that, although amorphous metallic fiber has a greater bond strength than hooked-end steel fiber, it's pulling motion resulted in brittle fracture. Also, with the fiber's greater bond strength and number per unit volume of concrete, amorphous metallic fiber reinforced concrete was found to have greater flexural strength than the hooked-end steel fiber, but exhibited a sharp decline in residual strength after crack initiation [11,12]. Choi et al. evaluated corrosion resistance under various degradation conditions, and found that amorphous metallic fiber had a residual strength in excess of 96% of its original value. On the other hand, the residual pull-out strength of hooked-end steel fiber decreased by 3.06–10.3% relative to amorphous metallic fiber, and its surface was corroded. In addition, the compression strength of amorphous metallic fiber was found to be greater than that of hooked-end steel fiber, PP (polypropylene) fiber, and PVA (polyvinyl alcohol) fiber [13]. Rashid et al. found that the high bond strength of amorphous metallic fiber offers efficient resistance to the micro-cracks that arise in crack openings, and that the hooked-end steel fiber control macro-cracks effectively. Also, the combination of these two types of fibers in hybrid fiber-reinforced concrete was found to increase the flexural strength [14].

In previous these studies, it was found that, when used as a concrete reinforcing material, amorphous metallic fiber enhances the