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Mechanical performance of concrete combined with a novel high strength organic fiber

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HIGHLIGHTS

- OMP can enhance toughness and residual flexural strength of concrete significantly.
- OMP can substitute steel fiber to improve the anti-seismic performance of concrete.
- An adequate mixing time should be implemented to prevent the uniting of fibers.

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ABSTRACT

A novel organic modified polypropylene fiber (OMP), with a lower specific gravity and greater anti-corrosive property than steel fiber, was used in this study. The mechanical properties of OMP, namely the compressive strength, flexural strength, and flexural toughness, were tested using the four points bending test. The results indicated that, at 7 days, the concrete combined with OMP had a significantly lower compressive strength than the plain concrete, and maintained that status at day 28. The peak value of the concrete's flexural strength when combined with OMP was lower than that of plain concrete, which corresponded with the compressive strength. The OMP enhanced the toughness, especially the residual flexural strength, of the concrete significantly. As shown in the displacement–load curves, the flexural strength increased with an increase in the OMP added to the concrete. Similarities between the concrete with OMP and concrete with steel fiber were found in the displacement–load curves. Thus, OMP could fully or partially substitute steel fiber in order to improve the anti-seismic performance of concrete while increasing its resistance to corrosion. However, an adequate mixing time should be implemented in order to prevent internal defects caused by the fusion of fibers.

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1. Introduction

A brittle material [1], concrete's tensile strength accounts for barely 6% of its compressive strength. Fiber is usually added to concrete [2] in order to minimize this weakness. The added fiber acts as a reinforcing material, primarily controlling the propagation of cracks [3]; limiting the crack widths at micro and macro levels [4,5]; improving the mechanical performance providing effective bridging; reducing the spread of instability; and significantly enhancing the strength, toughness, and ductility of concrete [6–9].

The effects of fiber added to concrete depend on the type, size, density, and distribution of the fiber, as well as the interfacial effort between the concrete and fibers. Many scholars have researched fiber reinforced concrete in the last four decades [10]. Due to its high specific gravity and extreme vulnerability to corrosion [11], steel fiber is of great significance to studies concerning the improvement of concrete performance. According to the modulus of elasticity, fibers can be classified as low modulus and high modulus fibers [12]. Low modulus fibers can only alter a few of the physical properties of concrete, e.g., toughness, while high modulus fibers, such as steel fiber, are able to extensively boost the tensile strength and stiffness of concrete beyond the toughness.

A novel high strength organic modified polypropylene fiber (OMP), with a lower specific gravity and greater anti-corrosive property compared to steel fiber, was used in this study. Four varying dosages of fibers in mass fractions were chosen to evaluate the impact of OMP on the mechanical properties of concrete.

2. Materials and experiment

2.1. Materials

Portland cement (C, P.II52.5, *Common Portland cement*, GB175-2007), fly ash (FA, *grade II, Fly ash used for cement and concrete*, GB/T 1596-2005), and ground granulated blast furnace slag powder (GGBFS, grade S95, *Ground granulated blast furnace*

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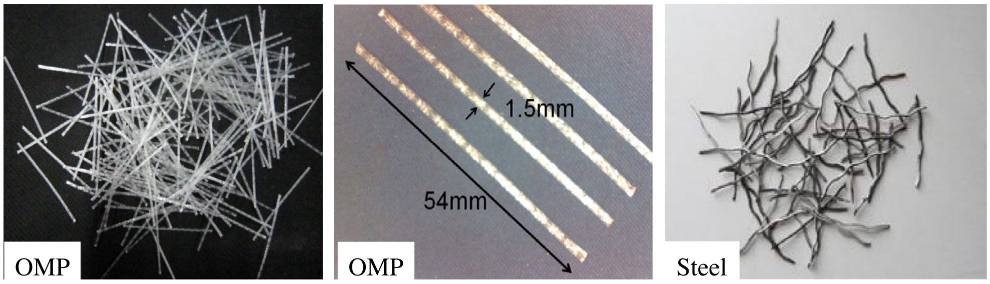


Fig. 1. OMP and steel fiber.

slag used for cement and concrete, BG/T 18046-2008) were obtained from Anhui Hailuo Cement Co., Ltd., Shanghai Baogang self-provided power plant, and Shanghai Baotian New Materials Co., Ltd., respectively. Polycarboxylate super plasticizer, with an active content of 25%, was obtained from *Jangsu New Material Co., Ltd.* Natural sand and stone, with continuous gradings and diameters ranging from 5 to 35 mm, were used separately as fine and coarse aggregates. OMP was supplied by *Elasto Plastic Concrete (China) Co., Ltd*. OMP and steel fiber samples are shown in Fig. 1, and their physical properties are displayed in Table 1.

Table 1 indicates that OMP has a similar tensile strength and much lower specific gravity compared to steel fiber.

2.2. Preparation of the sample

The concrete was mixed using a rotary pan mixer with a capacity of 160 L. Firstly, the coarse and fine aggregates and the binders were premixed in a dry environment for 2 min. Next, the water and super plasticizer was added and mixed for another 2 min. Then, the OMP was dispersed into the concrete by hand in order to achieve a uniform distribution and mixed for 2 min. The work-ability of the concrete was measured using the orifice tube test. The entire mixing and testing process was completed within 15 min.

According to the Standard Test Method for Fiber Reinforced Concrete (CECS13:2009), 100 × 100 × 100 mm cube specimens were prepared to measure the compressive strength of the concrete; the flexural toughness of the concrete was evaluated using square specimens with 600 × 600 × 100 mm dimensions and circular plate specimens with Φ800 × 75 mm dimensions; concrete beams with 550 × 150 × 150 mm dimensions were also molded to test the flexural toughness and strength. All of the specimens were removed from their molds after 24 h and then cured in the standard curing environment, i.e., a constant temperature of 20 ± 1 °C and a relative humidity greater than 95%.

2.3. Testing device and method

A type SYE-2000 machine, with a measuring range of 100 tones, was obtained from *Wuxi Building Material Instrument Co., Ltd., China* and used to test the compressive strength of the cube specimens at 7 and 28 days with a loading rate of 15 N/mm^2/min. The square plate and concrete beams were tested with a universal testing machine (SANS-SHT5605) obtained from *Shanghai Baisui Instrument Technology Co., Ltd., China*. The circular plates were tested using a machine from *TSE Pty Co., Ltd. Australia*. These testing devices are shown in Fig. 2.

The tests were executed according to the *Standard Test Method for Fiber Reinforced Concrete* (CECS13:2009).

3. Results and analysis

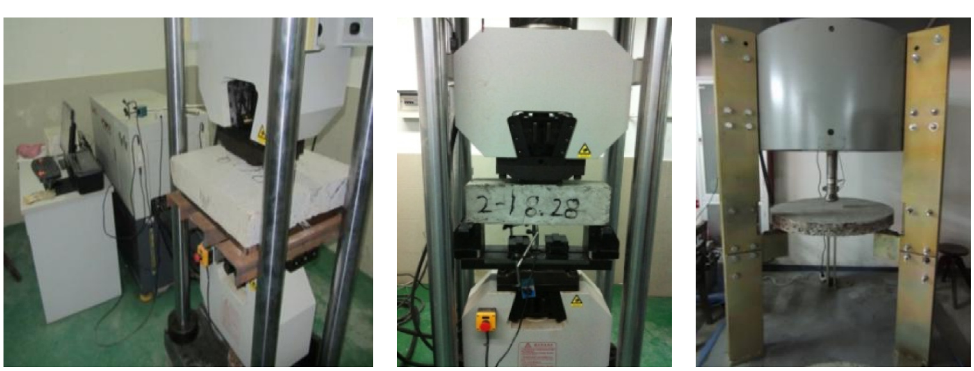
3.1. Compressive strength

Grade C45 concrete was designed with a slump ranging between 170 and 190 mm. The dosage of the super plasticizer was adjusted according to the mass fraction of the fiber. The mixture's proportion, slump, and compressive strength testing results are shown in Table 2.

As indicated in Table 2, the plain concrete exhibited the highest strength at 7 days, and the strength of the fiber concrete decreased significantly as the fiber dosage increased. The strength of the plain concrete was also slightly greater than that of the fiber reinforced concrete on day 28, and a slight augmentation in strength was seen as the fiber dosage increased.

Table 1
Properties of OMP and steel fiber.

Code	Tensile strength (MPa)	Surface texture	Young's modulus (GPa)	Melting point (°C)	Ignition point (°C)	Specific gravity
OMP	550–640	Continuously embossed	7.1–10.0	150–170	>450	0.90–0.92
Steel fiber	380–600	Continuously embossed	200–210	1515	–	7.85



(a) for the square slabs **(b)** for the beams **(c)** for the circular plates

Fig. 2. Testing devices.

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