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Comparison of flexural property between high performance polypropylene fiber reinforced lightweight aggregate concrete and steel fiber reinforced lightweight aggregate concrete

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HIGHLIGHTS

- The optimal content of SF and HPPF were proposed, respectively.
- JG/T 472-2015 was more appropriate for measuring the flexural toughness of FRLWCs.
- HPPF's effect on post-peak behavior was higher than its effect on pre-peak behavior.
- SF's effect on pre-peak behavior was better than on its effect post-peak behavior.

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ABSTRACT

The main purpose of this study was to investigate the flexural property of high performance polypropylene fiber reinforced lightweight aggregate concrete (HPPLWC) and steel fiber reinforced lightweight aggregate concrete (SFLWC). Firstly, two widely used standards (ASTM C1609 and JSCE SF-4) were used to evaluate their flexural toughness. Meanwhile, the advantages and disadvantages of these two methods in evaluating the flexural toughness of HPPFLWC and SFLWC were analyzed. Then, a new toughness evaluating method specified in JG/T 472-2015 was used. In addition, the optimal fiber content was proposed according to the flexural toughness of fiber reinforced lightweight aggregate concrete. The results showed that the optimal high performance polypropylene fiber (HPPF) content and steel fiber (SF) content were 1.1 vol% and 2.0 vol% respectively. SFs performed better on improving the equivalent initial flexural strength and equivalent residual flexural strength than HPPFs. HPPFs' effectiveness on post-peak behavior was higher than its effectiveness on pre-peak behavior. However, SFs performed better on pre-peak behavior than its effect on post-peak behavior.

1. Introduction

Nowadays, lightweight aggregate concrete (LWC) has been widely used in construction industry due to its unique advantages [1–3], including lower density, higher specific strength, superior thermal insulation, and better durability, etc. However, the brittleness characteristic and low flexural tensile strength have prevented it from being widely used [4,5]. As it is known to all, the addition of fibers can significantly increase the flexural tensile strength, impact resistance and post-cracking ductility of LWC [6–9]. High performance polypropylene fiber (HPPF) is a new type of strengthening and toughening material. Compared with SF, it is ease of dispersion. In addition, it has the advantages of light mass, low cost and corrosion-resistance [10]. Besides, HPPFs can increase concrete's ability of crack resistance, impact resistance, flexural toughness and anti-fatigue property [11].

Flexural toughness is an important index that can reflect the effectiveness of fiber on fiber reinforced concrete (FRC) characteristic [12,13]. However, currently there is no consensus on the definition of flexural toughness in the academia. Similarly, the method to calculate the flexural toughness index is still not unified. ASTM C1018 [14] and JSCE SF-4 [15] methods are widely used to evaluate the flexural toughness of FRC [16]. However, due to the difficulty of determining the first crack point in deflection-load curves, ASTM C1018 is replaced by ASTM C1609 [17] gradually.

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In the previous literature, there were few studies on the comparison between the flexural toughness of HPPLWCs and that of SFLWCs. In addition, the studies on the methods of evaluating the flexural toughness of fiber reinforced lightweight aggregate concrete (FRLWC) were quite few. Hence, the research aimed to solve these two aspects mentioned above. At the first step, the basic information (such as the slump, oven density, specific strength and compressive strength) was investigated. Then, the flexural test was conducted on four-point bending equipment. Flexural toughness evaluation methods, including ASTM C1069, JSCE SF-4 and JG/T 472-2015 [18], were applied to calculate the flexural toughness. In the end, the author compared the above methods to analyze what kind of method was more appropriate for evaluating the flexural toughness of FRLWCs.

2. Experimental program

2.1. Raw materials

P·O 42.5R OPC complying with GB175-2007 [19] was used. Two types of fibers, i.e., SFs (Fig. 1(a)) and HPPFs (Fig. 1(b)), were used as reinforcement materials. The former was produced by Ningbo Dacheng Advanced Material Co., Ltd and the latter was produced by Tianjin Wuji Technology Development Co., Ltd. Lytag with round shape and a particle size of 5–20 mm was used as coarse aggregates (Fig. 1(c)), provided by Baotou Jingzheng Building Materials Co., Ltd. Middle river sand with a nominal maximum size of 5.0 mm and a fineness modulus of 2.9 was used. To ensure the workability of mixtures and reduce the balling effect of fibers, a polycarboxylic type superplasticizer (SP) with a water reducing ratio of 20% was used. The physical and mechanical properties of cement and coarse aggregates are given in Tables 1 and 2, respectively. The characteristics of SFs and HPPFs are shown in Table 3.

2.2. Mixture proportions

The control LWC grade of LC30 is designed, due to the fact that the concrete grade of C30 has been widely used in the construction industry. The control mixture proportions are shown in Table 4. HPPFs with volumes of 0.5%, 0.7%, 0.9%, 1.1% and 1.3% and SFs with volumes of 0.5%, 1.0%, 1.5%, 2.0% and 2.5% were used individually. In the following sections, the specimen codes HPP05, HPP07, HPP09, HPP11 and HPP13 denoted the control LWC reinforced with HPPFs in the volumes of 0.5%, 0.7%, 0.9%, 1.1% and 1.3%, respectively. Similarly, the specimen codes SF05, SF10, SF15, SF20 and SF25 denoted the control LWC reinforced with SFs in the volumes of 0.5%, 1.0%, 1.5%, 2.0% and 2.5%, respectively. For each mixture, the SP content was fixed at 0.7 wt% of cement.

The mixing procedure was as follows: Firstly, the ingredients (sand, cement and coarse aggregate) were poured into mixer and dry-mixed for 30 s. To avoid the occurrence of fiber balling, the fibers were gradually fed into mixer by hands and mixed for 60–120 s. Secondly, the SP and net water were added into the mixer and mixed for about 150 s. After mixing, the fresh mixtures were filled into moulds and consolidated on a vibration table. Then, the specimens were covered with plastic sheets for 24 h. After demolding, the specimens were stored in a curing room with the temperature of 20 ± 2 °C and the RH of 95% until test time.

2.3. Test methods

To reduce the undesirable loss of workability, the coarse aggregates were prewetted with required water for 1 h [10]. The slump test was conducted immediately after mixing according to ASTM C 143 [20]. For each mixture, three cubic specimens (150 × 150 × 150 mm) and three prismatic beams (100 × 100 × 400 mm) were cast for compressive strength test and flexural test, respectively. A total of thirty-three cubic specimens were prepared and the compressive strength test was performed as per ASTM C39 [21]. Similarly, a total of thirty-three prismatic beams were cast and the flexural test was conducted in accordance with the ASTM C1609 recommendation.

3. Results and discussion

3.1. Slump and density

Fig. 2(a) and (b) show HPPFs' and SFs' influence on the slump and oven density of LWC, respectively.

According to Fig. 2, it was clear that the addition of HPPFs and SFs into concrete significantly decreased the slump of mixtures. The following reasons can explain the above phenomenon: (1) SFs and HPPFs have higher specific surface area compared with aggregates, which requires more cement mortar to wrap it. It leads to the increase in viscosity of concrete mixtures and resulted in lower workability [22]; (2) the randomly distributed fibers in concrete form three-dimensional network, which restricts the movability of aggregates [23].

It can also be found that the addition of HPPFs decreased the oven density of mixtures while SFs increased its density. It was due to the fact that HPPF was lighter than concrete matrix and SF. For SFLWCs, when the fiber content was more than 2.0%, the density of SF25 was lower than that of SF20 because adding excessive fibers into concrete decreased the compactness of concrete [5].

3.2. Compressive strength and specific strength

Fig. 3 shows the results of compressive strength. When the HPPFs content varied from 0% to 1.3%, the compressive strength was in the range of 35.5–39.5 MPa. Within the given content, SFs had a stable effect on improving the compressive strength of LWC. The maximum compressive strength of 42.6 MPa was obtained by SF20, which was 13.6% higher than that of specimen PC. It indicated that the addition of HPPFs and SFs had no evident improvement on the compressive strength of LWC. According to Fig. 3(a), when 0.9% of HPPFs was added into LWC, a significant decrease in compressive strength could be found. The following reasons might explain it. Firstly, during the curing process, the heating system in curing room was unstable and there were a lot of pieces in the curing chamber. Besides, the temperature of the position where specimen HPP09 was placed was lower than other

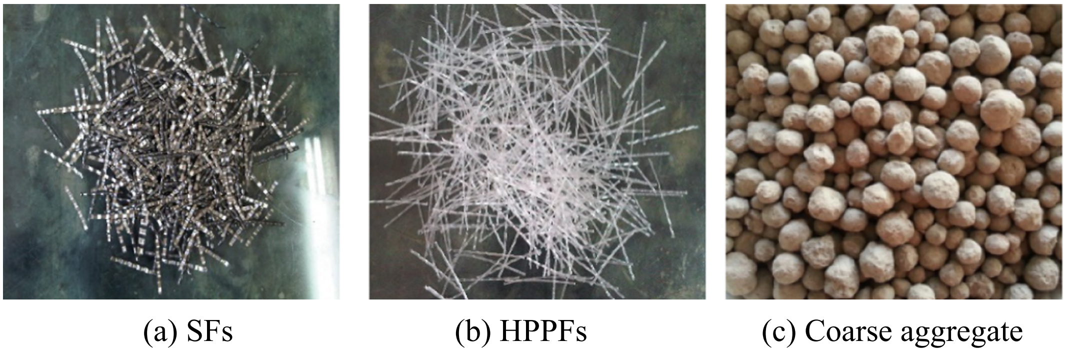
(a) SFs (b) HPPFs (c) Coarse aggregate

Fig. 1. Raw materials.