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Investigation on flexural toughness evaluation method of steel fiber reinforced lightweight aggregate concrete

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HIGHLIGHTS

- A slight change on Deng's proposed technique for flexural toughness was made.
- The steel fiber effectiveness on pre-peak behavior was superior over the post-peak behavior.
- The interfacial zone at aggregates/paste was not the weakest link in SFLWC.
- The optimal steel fiber of 2.0% was proposed in SFLWC.

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ABSTRACT

The main purpose of this paper was to investigate the influence of steel fiber (SF) content on the flexural properties of steel fiber reinforced lightweight aggregate concrete (SFLWC) and propose a suitable method for evaluating flexural toughness. At the first step, the effects of SF content on the basic properties, including workability, density and compressive strength were investigated. Additionally, the microstructure of SFLWC was also observed by using scanning electron microscope (SEM). A slight change was made for Deng's proposed toughness index which could reflect the degree to which the fiber improves the post-cracking toughness of plain concrete. A simple and practical method for evaluating the flexural toughness of fiber reinforced concrete was recommended by JG/T 472-2015 standard, which solved many problems in the existing methods. This method makes full use of pre-peak and post-peak information which can reflect the influence of fiber on the pre-peak and post-peak behaviors. The results revealed that SF had a negative impact on the workability and density of lightweight aggregate concrete (LWC). However, the addition of SF could improve the compressive strength of LWC to some extent. The optimal SF content of 2.0% was proposed based on the degree to which the fiber improved the toughness of plain LWC. SF addition could significantly enhance the equivalent initial flexural strength and the equivalent residual flexural strength of LWC. The effectiveness of SF on pre-peak behavior was superior to that on the post-peak behavior. The interfacial transition zone between aggregates and paste was not the weakest link in SFLWC.

1. Introduction

Since lightweight aggregate concrete (LWC) has many excellent properties over normal weight concrete, including reduced density, better fire resistance, superior seismic resistance, and etc. [1–4], much attention has been paid to the development of lightweight aggregate concrete (LWC) [5]. Nevertheless, some defects in LWCs such as low tension-compression ratio, low shear and tensile strength [6,7] have prevented it being widely used in construction industry [8,9]. As is well known to us, the addition of fibers in the concrete can mitigate these negative effects and dramatically improve the strength and ductility of LWCs [10,11].

Flexural toughness is a major indication which can reflect the toughening effects of fibers and inner structural performance of matrices. Plenty of experimental and theoretical researches were made in order to investigate the flexural toughness property on fiber reinforced concrete. Yu et al. [12] evaluated the flexural

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toughness of ultra-high performance fiber reinforced concrete (UHPFRC) according to ASTM C1018 [13] and JSCE SF-4 [14] methods. They pointed out that hooked fibers performed better than short straight fibers on improving flexural toughness of UHPFRC. Lin et al. [15] investigated the influence of fiber types on flexural behavior of self-compacting fiber reinforced cementitious composites and observed that fibers types had little effect on pre-cracking behavior and the first crack strength of specimens. However, the post-cracking behavior and the deflection types (deflection-hardening or deflection-softening type) were significantly affected by fiber characteristics. Wu et al. [16] studied the effects of steel fiber (SF) content and shape on the flexural property of ultra-high performance concrete (UHPC). It was observed that SF content had little influence on the first crack strength and corresponding deflection of UHPC, but affected the peak load tremendously. The results derived from Deng et al. [17] indicated that the post-cracking behavior of fiber reinforced concrete (FRC) was significantly enhanced with the increase of fiber length, fiber content and concrete strength.

However, there has be no consistent and recognized flexural toughness evaluation method for FRCs. Generally, the flexural toughness evaluation methods can be divided into two categories according to the first crack point: the first crack-dependent including ASTM C1018 method and CECS 13:2009 [18] and the other including ASTM C1609 [19], JSCE SF-4 and etc. Some comparisons of these evaluation methods could be easily found in the previous literatures. For instance, Nataraja [20] stated that the location of the first crack was crucial and one of the main problems with ASTM C1018 method, which was not a concern with the JSCE SF-4 method. Besides, the JSCE SF-4 method was very simple and independent of the type of the deflection measuring technique. No sophisticated instrumentation was required to determine the toughness factor. Sukontasukkul [21] pointed out that JSCE SF-4 method could easily reflect the flexural toughness performance of SF reinforced concrete (SFRC), which was consistent with the conclusion derived from Yu et al. [12]. However, JSCE SF-4 method seemed to be insufficient to reflect the true flexural toughness of polypropylene fiber reinforced concrete (PFRC). According to Ref. [21], the ASTM C1018 method seemed to perform well on reflecting the true flexural toughness behaviors of PFRC at different deflections. Kim [22] considered that there were difficulties in applying ASTM C 1609 standard to deflection-hardening materials. Hence, they suggested that the first crack point specified in ASTM C 1018 could be used to instead of the first peak point. Besides, they suggested that one additional point (L/100) should be added to fully differentiate behaviors between different fibers. Banthia and Trottier [23] reported that there were several limitations in both ASTM C 1018 and JSEC SF-4 standards for FRCC toughness behavior. Hence, among the various methods of characterizing flexural toughness of FRC, it made sense to compare different evaluation methods and clarify which one was the most suitable method for determination of flexural toughness of FRC.

According to the published literatures, in most cases, these evaluation methods mentioned above were directly used to estimate the toughness of fiber reinforced LWC. In this research, at the first stage, the effects of SF content on the basic properties of LWC including slump, density and compressive strength were investigated. The principal concerns were focused on the effect of SF content on the flexural properties of LWC. Flexural toughness behavior of SFLWCs was evaluated by using ASTM C 1018, ASTM C1609, JSCE SF-4 and JG/T 472-2015 [24] methods, respectively. Additionally, optimal SF content in LWC was proposed and the microstructure of aggregates-paste interface and fiber-paste interface was observed by using scanning electron microscope (SEM).

2. Experimental program

2.1. Materials

In this study, P·O 42.5R Portland cement (Chinese national standard GB175-2007 [25]), was used. The physical and mechanical properties of this cement are given in Table 1. The fine aggregate was river middle sand with fineness modulus of 2.9 and bulk density of 1547 kg/m^3. The coarse aggregate was lytag (Fig. 1) with a round shape, obtained from Jingzheng Building Materials Co.,Ltd (Baotou, China). The properties of the coarse aggregate are shown in Table 2. The SF with crimped shape (Fig. 2) was employed as basic reinforcement material. The characteristics of SF are shown in Table 3. A poly-carboxylic type superplasticizer (SP) with a water reducing ratio of 20% was used in this study.

2.2. Mixture proportions and production

The mixture proportions are given in Table 4. Before mixing, the coarse aggregates were soaked in enough water for 1 h according to Ref. [26], then processed into a saturated surface dry (SSD) condition with absorbent towels. To ensure adequate workability of the fresh mixture and reduce the balling (or clumping) effect of fibers [27], the superplasticizer (SP = 0.7% of cement) was utilized in all mixtures.

The mixing procedure was performed according to Ref. [26]. During the mixing, SFs were gradually fed into the mixer by hand

Fig. 1. Coarse aggregate.

Table 1
Physical and mechanical properties of cement.

80 μm sieve residue (%)	Specific surface area (m^2/kg)	Water requirement of normal consistency (%)	Setting time (min)		Flexural strength (MPa)		Compressive strength (MPa)	
			Initial	Final	3d	28d	3d	28d
1.08	350	27	115	255	5.8	9.4	24.7	47.8