Construction and Building Materials 183 (2018) 493–501

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

An experimental study on strength and toughness of steel fiber reinforced expanded-shale lightweight concrete

Minglei Zhao [a,b,*], Mingshuang Zhao [b], Meihua Chen [b], Jie Li [a], David Law [a]

[a] School of Engineering, RMIT University, Melbourne, VIC 3003, Australia

[b] International Joint Research Lab for Eco-building Materials and Engineering of Henan, North China University of Water Resources and Electric Power, No. 36 Beihuan Road, 450045 Zhengzhou, China

HIGHLIGHTS

- A steel fiber reinforced expanded-shale lightweight concrete (SFRELC) is developed.
- Strength and toughness of SFRELC under compression and flexure are studied.
- Flexural strength and toughness of SFRELC are studied.
- Toughness of SFRELC is markedly improved by increasing amount of steel fiber.
- Elasto-plastic characteristics of SFRELC display with large amount of steel fiber.

ARTICLE INFO

Article history:
Received 19 March 2018
Received in revised form 12 June 2018
Accepted 21 June 2018

Keywords:
Steel fiber reinforced expanded-shale lightweight aggregate concrete (SFRELC)
Strength
Toughness
Volume fraction of steel fiber
Cement strength
Water-binder ratio

ABSTRACT

A steel fiber reinforced expanded-shale lightweight aggregate concrete (SFRELC) was developed by using sintered expanded shales as coarse and fine aggregates. This paper presents the experimental investigations of the fundamental mechanical properties of SFRELC under compression and flexure. The cement strength, water-binder ratio and volume fraction of steel fiber were considered as test parameters. Effects of these parameters on the compressive and flexural strengths, modulus of elasticity, compression toughness and flexural toughness are analyzed based on the experimental results. The results manifest that the superiority of steel fibers is to enhance the deformation sustainability of SFRELC after peak-load, thus the toughness is clearly enhanced.

1. Introduction

Compared to sanded lightweight-aggregate concrete (sLAC), all-lightweight-aggregate concrete (aLAC) is an even lighter weight concrete in which both the fine and coarse aggregates are lightweight [1–3]. Under the premise of a further lightened density, determining the effects influencing the mechanical properties is the key to ensure the successful utilization of aLAC in structural engineering. This led to a series of studies investigating the effects of steel fibers in steel fiber reinforced all-lightweight-aggregate concrete (SFRaLAC). For the purpose of utilizing the local raw materials, local fine and coarse sintered expanded shales and steel fibers, which are available in the marketplace as raw materials are employed. Utilizing these materials, steel fiber reinforced expanded-shale lightweight concrete (SFRELC) was developed [4]. The volume fraction of steel fiber was up to 2.0%, and the fresh concrete had a high-performance with good flowability [5–8]. The results demonstrated that the addition of steel fiber improved the fundamental mechanical properties of aLAC, especially the tensile strength. The failure patterns of aLAC were also modified from brittle to ductile, with multi cracks observed. In addition, with an increasing volume fraction of steel fiber, the cracking resistance at the early age was enhanced, the rate of the development of drying shrinkage was reduced [8], and the carbonation depth of aLAC decreased over time. These results indicate that it might be feasible to develop an economical, high-performance steel fiber reinforced aLAC (SFRELC) that can be successfully applied in the construction process.

* Corresponding author at: School of Engineering, RMIT University, Melbourne, VIC 3003, Australia.

E-mail address: coffeyha@aliyun.com (M. Zhao).

https://doi.org/10.1016/j.conbuildmat.2018.06.178
0950-0618/

For the structural application, the ductility of SFRELC structure members should meet the level of those with conventional concrete. However, there is lack of the studies on the compression toughness and flexural toughness of SFRELC. Düzgün et al. [2] discovered that the addition of steel fiber to aLAC with pumice aggregate increased the strain at peak stress, modulus of elasticity and deformation capacity. The slope of the descending portion of compressive stress-strain curves decreased with the increase of fiber content. Both strength and ductility of SFRaLAC consistently increased with the volume fraction of steel fiber up to 1.5%. Kayali et al. [9] reported that by adding steel fiber with a 1.7% volume fraction, the sudden failure of aLAC with sintered fly-ash aggregate could be prevented. It was also noted that the deformation could be very large before total uncontrollable collapse. The compressive toughness evaluated by the strain energy density of SFRaLAC is approximately doubled compared with that of the aLAC. Choi et al [10] developed a kind of aLAC with fine and coarse artificial lightweight-aggregates, adding steel fiber with a 1.2% volume fraction which could improve the flexural strength and the splitting tensile strength. Moreover, the fracture toughness of aLAC increased effectively more than twelve times. In addition, the residual strength of SFRaLAC increased proportionally to the amount of steel fiber.

Other studies on the compressive and flexural properties of steel fiber reinforced sLAC (SFRsLAC) can be referenced for the studies of SFRELC [11–19]. The types of coarse lightweight aggregate included pumice [11,12], expanded clay [12–14], sintered pulverized fuel ash [15], cold bonded fly ash [16], expanded shale [17] and oil palm shell [18,19]. The steel fibers in the form of hooked-ends [11,12,16,19], crimped [13], rectangular/straight with or without indentation [14], round/straight [15], round/straight with slightly enlarged ends [17] were applied. Some studies with added steel fiber ranged from 0 to 2.0% in volume fraction [12,14,17]. Generally, in spite of the differences of coarse lightweight aggregate, steel fiber and mix proportion, the bond of steel fibers with sLAC matrix provides homogenous stress distribution and prevents crack growth, which provides some beneficial effects at different levels on the strength and toughness of SFRsLAC. The most notable modification is to the descending part of compressive load-deformation curve [2,11,12,18] and the flexural load-deflection curve [11,12,14,15,17,19], which leads to a significant enhancement of the ductility of SFRsLAC.

Based on above developments and in correspondence with the new state strategic plan of green building and building industrialization of China, this study was carried out to meet the urgent demand for economical high-performance SFRELC. Local commercial sintered expanded shales were used as the coarse and fine lightweight aggregate. In order to select a proper strength grade of cement and volume fraction of steel fiber for the mix design of SFRELC, different strength grades of cement, and a volume fraction of steel fiber ranged from 0 to 2.0% were used. To simulate different situations of precast and/or cast-in-situ structural members, a wide range of slump of fresh SFRELC with different water-binder ratio was designed. Based on the test results, the strength and toughness of SFRELC under compression and flexure are analyzed.

2. Experimental study

2.1. Materials properties

Fig. 1 illustrates the raw materials used in this study. Coarse aggregate was high-strength sintered expanded shale in continuous gradation with a maximum size of 20 mm. The particle density, bulk density, 1-hour water absorption, mud content and cylinder compressive strength were 1262 kg/m^3, 827 kg/m^3, 9.1%, 0.7% and 7.4 MPa, respectively. Fine aggregate was sintered expanded shale sand of continuous gradation in the range of 1.6–5 mm and fineness modulus of 3.6. The particle density, bulk density, 1-hour water absorption and mud content were 1350 kg/m^3, 850 kg/m^3, 9.0% and 0.11%, respectively. All the properties of lightweight aggregates met the requirements of the Chinese national standard GB/T 17431-2010 [20,21]. Crimped cut-sheet type steel fiber was used in this study, with the length of 36.68 mm, and 1.35 mm equivalent diameter. It was commercially available and met the specification of the Chinese standard for Steel Fiber Reinforced Concrete [22–24].

Ordinary Portland cement and the class-II fly ash were used in this study. The basic properties of cement are listed in Table 1, which met the requirements of Chinese standard GB175 [25]. The apparent density, water demand ratio, fineness modulus passing 0.045 mm sieve and water content of class-II fly ash were 2049 kg/m^3, 104.2%, 26.4% and 0.4%, respectively, which met the requirements of Chinese standard GB/T 51003 [26]. Tap water and Polycarboxylic acid superplasticizer with a water-reducing ratio of 19% were used in the experiment.

2.2. Mix proportions and specimens

Based on previous experimental studies [5–8], a reference water-binder ratio (w/b) of 0.30 was selected, and the volume fraction of steel fiber (V_f) ranged between 0 and 2.0%. A w/b = 0.25, 0.35 and V_f = 0.8% were selected to investigate the effect of water-binder ratio on the workability in the fresh state and the hardened mechanical properties of SFRELC. Table 2 presents the principal data of the mix which was calculated by using the absolute volume method [22]. The dosages of cement and fly ash were kept constant as 440 kg/m^3 and 110 kg/m^3, respectively. The content of water reducer was 1.0% of binder mass in all mixtures. The pre-wet water was determined based on the 1-hour water absorption of the lightweight aggregates. As the previous studies of this research displayed some beneficial effects of pre-wetting lightweight aggregates on the fundamental properties, especially on the reduction of shrinkage of SFRELC [5–8], the same method for pre-wetting lightweight aggregates was adopted in the test.

All mixing and preparation of specimens were carried out in the laboratory. Lightweight aggregates were wet-processed for one hour in a horizontal spindle forced-mixer. Then the cement, fly ash, mix water and water reducer were successively added, and mixed uniformly in the mixer. Then, the steel fiber was added, and uniformly mixed. The workability of fresh concrete was evaluated in accordance with Chines code JG/T 472 [22]. The flowability of fresh concrete was measured by the slump cone method. The tested slumps of all mixtures are presented in Table 2. Generally, all mixtures had good workability in flowability, consistency and water retention. The slump of SFRELC reduced with an increasing volume fraction of steel fiber and a decreasing water-binder ratio. In the same mix proportion, fresh SFRELC with 52.5 cement had lower flowability than those with 42.5 cement. This is due to the larger fineness of 52.5 cement particles, which increased the physical absorption to mix water. For the SFRELC, 52.5 cement, w/b = 0.30, the slump was in the range 205 mm–170 mm when V_f = 0–1.2%, while the slump was between 100 mm and 55 mm when V_f = 1.6%–2.0%; when V_f = 0.8%, the slump was 35 mm–50 mm for the w/b = 0.25, and 190 mm–220 mm for the w/b = 0.35.

After completing the workability tests, the following specimens were cast for each mix: