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Case study

Flexural behavior of lightweight concrete beams encompassing various dosages of macro synthetic fibers and steel ratios

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ABSTRACT

In this study, thirty-two lightweight concrete (LWC) beams were casted and tested as simply supported beams under four points' loading. The investigated parameters were the volume fraction (V_f) of discontinuous structural synthetic fiber (DSSF) and longitudinal steel reinforcement ratio (ρ). The modulus of rupture of structural LWC is low due to the weak lightweight aggregates used. Therefore, the feasibility of compensating for this shortcoming and providing post-cracking toughness characteristics using DSSF is of great interest. The behavior of each beam was evaluated in terms of cracking, failure mode, flexural strength, ultimate deflection, stiffness, toughness, and energy absorption. The results revealed measurable enhancements on majority of the aforementioned performance characteristics of LWC beams can be achieved when adding DSSF at V_f = 0.55% and 0.77%. The enhancements were attributed mainly to the effectiveness of the used DSSF in providing internal confinement/cracks arresting mechanism and toughness characteristics after cracking and even after reaching the peak strength. The experimental results of this study compared very well with predicted values using the ACI 318-14 in terms of cracking moment, service load deflection, and moment capacity.

1. Introduction

The use of fibers in concrete structures started in 1970s as a result of their ability to enhance the concrete mechanical properties. Nowadays, extensive investigations were carried out on the use of steel, glass, ceramics, and synthetic fibers for improving the mechanical properties of concrete structures. The fibers are typically added in an adequate amount to improve the ductility performance by controlling the macro and micro cracking in the concrete matrix, enhancing the tensile strength, and decreasing the concrete matrix brittle nature with very small enhancement of the compressive strength. In addition, the propagation and creation of cracks due to early age shrinkage can be significantly reduced using fibers. The improvements in the concrete ductility and flexural toughness depend on the type of fiber used, volume fraction, and aspect ratio [1,2].

Many studies investigated the effect of steel fibers on flexural performance of steel fibers reinforced concrete (SFRC) beams [3–13]. Abdui-Ahad and Aziz [3] investigated the effect of various amounts of steel fibers on the behavior of T-shaped normal weight reinforced concrete beams. They concluded that the ultimate load capacity of both over-reinforced and under-reinforced beams increased as the steel fibers content increased. Their numerical and experimental results both confirmed that the steel fibers can replace the steel reinforcement in the compression zone of over-reinforced concrete beams. Altun et al. [4] studied the behavior of reinforced concrete beams with steel fibers in terms of the flexural cracks initiation, propagation, and size. Their results indicated a major increase in flexural toughness and a minor increase in ultimate moment capacity as a result of the steel fibers. Campione and

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Mangiavillano [5] concluded that the presence of steel fibers enhanced the monotonic and cyclic behaviors of beams. Dancygier and Savir [6] studied the behavior of concrete beams with minimum amount of steel reinforcement and with steel fibers. Based on experimental results, the ductility of the tested beams was reduced due to the use of steel fibers. They proposed an equation for predicting the flexural capacity of concrete beams with steel fibers to accomplish a sufficient level of ductility. Henager and Doherty [7] reported that steel fibers enhance flexural performance by improving the post-cracking stiffness and ultimate load capacity and decreasing the cracks spacing and width. Qian and Patnaikuni [8] reported that steel fibers can improve the flexural stiffness and post-peak load resisting ability without any significant impact on the length and number of flexural cracks. Structural fibers are usually added to structural members to improve the behavior especially in terms of fracture toughness, ductility, and crack-width control. Toutanji et al. [14] utilized synthetic fibers to produce lightweight and high-performance concrete with improved ductility, fracture toughness and impact resistance. Nahhas [15] conducted an experimental investigation on the behavior of reinforced concrete beams made of LWC with different polypropylene fiber additions. It was found that the addition of polypropylene fiber increases the ductility, toughness capacity and the bearing strength of the reinforced concrete beams. Altoubat et al. [16] performed an experimental study on the flexural behavior of fiber-reinforced concrete slabs containing two steel fiber types and one synthetic fiber type. Their results demonstrated that both fibers increase the flexural capacity compared to plain concrete slabs. There are some other studies that evaluated other types of fibers in addition to steel fibers [17–21].

The center of attention of majority of previous studies was on the effect of steel fibers on the flexural behavior of normal weight reinforced concrete beams with a given amount of longitudinal reinforcement. Discontinuous structural synthetic fibers (DSSF) sometimes referred as macro synthetic fibers have good tensile, impact resistance, tensile strength, and flexural toughness. In addition, DSSF are not dangerous to workers, easily movable (low specific gravity), economically advantageous, no possibility of corrosion, and have high chemical resistance. Therefore, synthetic fibers have the potential nowadays to replace steel fibers if measurable benefits are achieved [19–28]. On the other hand, the influence of synthetic fibers on the behavior of LWC beams received miniature consideration, which is the direct motivation for this study. The flexural tensile strength of structural LWC is low compared with normal weight concrete as a result of the weak lightweight aggregates used. Evaluating the feasibility of compensating for this shortcoming of LWC using DSSF as well as adding post-cracking toughness characteristics is a major goal of this study.

2. Experimental program

2.1. Parameters of investigation

Thirty-two LWC beams were casted and tested as simply supported beams under four points' loading as shown in Fig. 1. The beams were 900 mm long with cross-sectional dimensions of 100 × 150 mm. The investigated parameters in this study are the volume fraction (V_f) of the discontinuous structural synthetic fiber (DSSF) and the longitudinal steel reinforcement ratio (ρ). The specimens were divided into four groups based on ρ: 1.26% (2ϕ10), 1.81% (2ϕ12), 2.46% (2ϕ14), and 3.22% (2ϕ16). Each group contains eight beams depending on the V_f: 0% (0 kg/m^3), 0.33% (3 kg/m^3), 0.55% (5 kg/m^3), and 0.77% (7 kg/m^3). Two identical beams having same V_f were tested as indicated in Table 1.

2.2. Preparation of specimens

The used concrete mixture is considered a structural LWC mixture since it has a unit weight of about 1800 kg/m^3, which meets the ASTM C330-05 classification for structural LWC [26,29]. The mixture ingredients include: ordinary Type I Portland cement, lightweight coarse aggregate of a maximum size of 9.5 mm and specific gravity of 1.05, and normal weight crushed limestone sand with a specific gravity of 2.41. The absorptions of the lightweight aggregate and sand were 10% and 4%, respectively. The proportions by weight of the mixture ingredients (water:cement:lightweight coarse aggregate:fine aggregate) were: 0.4:1.0:1.2:3.0. Superplasticizer was used as needed to improve the workability targeting a slump of approximately 75 mm. Fig. 1 shows the slump test results for the of plain and fibrous concrete mixtures. As shown in Fig. 1, the fibers were uniformly distributed within the mixture and the slump was comparable for the various fibers contents, which was ensured by just slightly increasing the superplasticizer content as the fibers content increases, and without additional water to avoid changing the strength properties. A tilting drum mixer with a capacity of

Fig. 1. Slump test for the plain and fibrous mixtures.