Composites: Part B 42 (2011) 1285–1290

Contents lists available at ScienceDirect

Composites: Part B

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

On the strength and toughness properties of SFRC under static-dynamic compression

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ARTICLE INFO

Article history:
Received 14 October 2010
Received in revised form 5 December 2010
Accepted 23 January 2011
Available online 1 February 2011

Keywords:
B. Strength
B. Impact behavior
D. Mechanical testing
Steel fiber-reinforced concrete

ABSTRACT

The addition of steel fibers into concrete mix can significantly improve the engineering properties of concrete. This paper experimentally studies the mechanical behaviors of steel fiber-reinforced concrete (SFRC) through both static and dynamic compression tests. Cylindrical specimens with three different percentages of short and fine fibers 0%, 1.5% and 3% by volume of concrete are firstly fabricated. These specimens are then tested by MTS for static compression and split Hopkinson pressure bar (SHPB) for dynamic impact. It is revealed that the failure mode of concrete considerably changes from fragile to ductile with the increase of steel fibers. The plain concrete may fail under low strain-rate single impact whereas the fibrous concrete can resist high strain-rate repeated impact. Stain-rate exerts great influence on concrete strength. Besides, toughness energy is proportional to the fiber content in both static and dynamic compressions.

1. Introduction

Steel fiber-reinforced concrete has become a practical alternative construction material in various structures. The steel fibers can be used externally to improve the compressive strength, flexure and shear capacities of beams, slabs and wall made by conventional concrete effectively. Also, it can be used internally as reinforcement replacing common steel reinforcing bars in structures due to its advantages [1,2]. These randomly distributed fibers may bridge microcracks and restrain their widening, thus delaying the cracks further propagation. Such reinforcements may largely improve the post-peak ductility and energy absorption capacity of concrete [3].

Well designed members should be able to avoid catastrophic failure of a structure [4]. Concrete structures are usually exposed to various load environments in their service periods. A key design issue is to fully understand the responses of these structures to both static and dynamic loads. In conventional concrete members, crack widths are restrained by the use of steel reinforcing bars. However, the thicker steel bar has different heat expansion compared to the surrounding concrete. This may produce microcracks on the interface between bar and concrete. How to maintain the concrete structure with less or no propagation of microcracks is a notable issue. Numerous publications can be found in both experimental studies and in situ applications of steel fibers in concrete frame buildings [5–8].

Strength and toughness have been recognized as two important characteristics of steel fiber-reinforced concrete [8,9]. In general, toughness or energy absorption capacity (*hereafter called toughness energy*) is determined from the area encompassed by the stress–strain curve in compression. This expresses the total energy absorbed by the specimen prior to its complete damage or failure. The additional load-bearing capacity is in direct proportion to the toughness that the steel fibers impart to the concrete. The improvement of residual strength of concrete also reflects the capability to carry more loads even after cracking [10].

Over the past several decades, several attempts have been made in both numerical and experimental methods to understand the mechanical responses of SFRC. Test methods like servo-controlled material testing system (MTS) [11], drop-weight tester [8] and split Hopkinson pressure bar (SHPB) technique [12] have been adopted so far. The MTS device is typically used for quasi-static tests. For a higher strain-rate like dozens, even hundreds per second, drop-weight tester or pneumatic SHPB are usually employed. In particular, the SHPB is a very popular experimental apparatus for the study of the dynamic responses of materials. It has been used by numerous investigators to elucidate the dynamic mechanical properties of solid media [2,13].

This study will experimentally investigate the mechanical responses of the concrete cylindrical specimens by using MTS and SHPB techniques. The emphasis is on the comparison of strength and toughness properties between the plain concrete and the steel

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1359-8368/$ - see front matter
doi:10.1016/j.compositesb.2011.01.027

fiber-reinforced concrete with volume fractions of 1.5% and 3.0%, respectively. The mechanical responses of these specimens are evaluated in terms of strain-rate effect, the fiber content by volume and the failure patterns of the tested specimens.

2. Experiment program

2.1. Materials

Ordinary Portland cement was used as the cementitious material. Dry non-compacted silica fume was provided by *Zhongxing* Technology Company of China. The coarse aggregate was crushed limestone with a maximum size of 10 mm. The fine aggregate was river sand with a fineness modulus of 2.6. Short and straight steel fibers were added in concrete mixes at different volume fractions. The super plasticizer (SP) is a liquor of phenolic aldehyde which was added to the mix with 1.5% dosage of the cement volume. Fiber shapes are shown in Fig. 1, and their specifications are listed in Table 1. The fibers were added to each series of mixes at 0.0%, 1.5% and 3.0%, by volume of concrete. These values correspond to the steel fiber weight of 0, 117 and 234 kg per cubic meter of concrete. Their volume fraction is denoted by a symbol V_f.

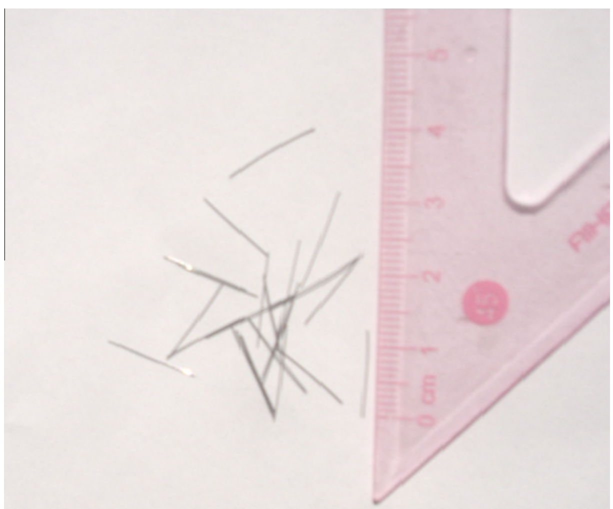

Fig. 1. Photograph of steel fibers tested.

2.2. Specimen preparation

The ingredients of concrete mixes are presented in Table 2. In the process of specimen-making, steel fibers, cement, crushed stone, sand, and silica fume were firstly mixed for about 5 min. Water and super plasticizer were then added. The mixture was mixed until uniform concrete was obtained. From each mix, two sizes of cylinders (Φ70 mm × 35 mm and Φ50 mm × 100 mm) were cast in steel moulds. The moulds were oiled and placed on a vibration table vibrating at low speed to ensure good compaction while the concrete was poured. The cylindrical specimens were demoulded 24 h later and cured in lime-saturated water for 28 days at room temperature. The ends of all cylinders are carefully ground in order to assure the parallelism of the end surfaces.

2.3. Experimental set-up

Quasi-static compression was performed in closed-loop servo-controlled material testing machine (MTS) with a capacity of 1000 kN. A complete uniaxial stress–strain response can be obtained through its measurement system. This experimental process used displacement control. Two loading rates ($\dot{\varepsilon} = 10^{-5}$ and 10^{-2}) were tested. An inbuilt electronic data acquisition system was used to record the axial displacements and corresponding loads. This data acquisition can measure the total axial displacement over

Table 1
Properties of steel fibers tested.

Type	Density (kg/m^3)	Length (mm)	Diameter (mm)	Tensile strength (MPa)	Appearance
WSF1	7800.0	13.0	0.2	2500.0	Bright/straight

Table 2
Mix proportions (kg/m^3).

V_f	w/(c + sf)	Cement	Water	Silica fume	Coarse aggregate	River sand	Steel fiber
0.0%	0.35	440	171.5	50	850	900	0
1.5%	0.35	440	171.5	50	811	900	117
3.0%	0.35	440	171.5	50	770	900	234

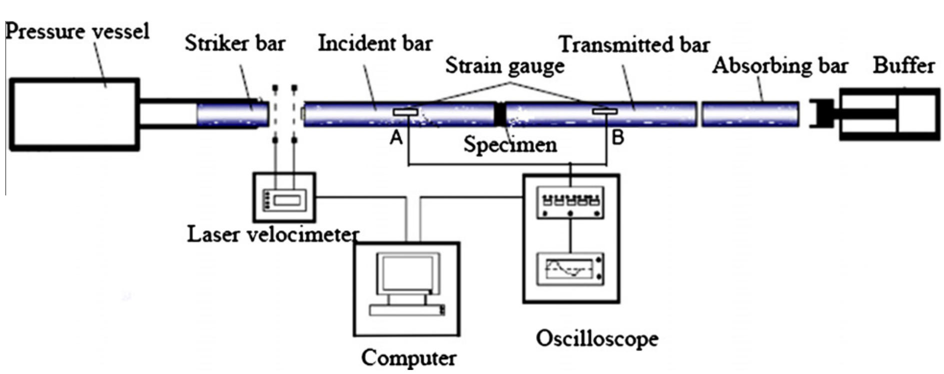

Fig. 2. Split Hopkinson pressure bar device.