Construction and Building Materials 37 (2012) 360–369

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Statistical and experimental analysis on the behavior of fiber reinforced concretes subjected to drop weight test

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HIGHLIGHTS

- Statistical and experimental analysis was carried out on impact resistance data.
- Cellulose fibers were investigated as a new reinforcing fiber under impact loads.
- Kruskal–Wallis test was used for drawing a distinction between fibers in impact test.

ARTICLE INFO

Article history:
Received 25 January 2012
Received in revised form 5 June 2012
Accepted 21 July 2012
Available online 5 September 2012

Keywords:
Statistical analysis
First crack strength
Failure strength
Fiber
Cellulose
Polypropylene
Steel

ABSTRACT

In this paper, the behavior of different fiber reinforced concretes subjected to drop weight test was statistically investigated. For this purpose, three different fiber types, including cellulose, polypropylene, and steel fibers were considered at volume fractions of 0.15%, 0.15%, and 0.5%, respectively. For each fiber type, a total of 32 specimens were tested in accordance with the drop weight test suggested by ACI Committee 544. The Kruskal–Wallis test indicated that the addition of cellulose and steel fibers significantly improve the first crack strength whereas in the case of increase in the number of post-first crack blows (INPB), polypropylene and steel fibers had a remarkable effect. Moreover, a general linear model (GLM) was developed for plain, cellulose, and polypropylene fiber reinforced concrete.

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1. Introduction

It is well known that concrete is a high strain rate sensitive material. Therefore, its statically determined properties cannot be used to evaluate the performance of concrete subjected to high strain rates encountered in impact, earthquake, and other forms of dynamic loads [1–3]. Results of the impact test appear to be good indicators of other concrete properties such as cavitation erosion resistance, fatigue, toughness, and strain capacity [4]. The incorporation of fibers in concrete greatly improves the resistance to impact and fracture toughness [5–8]. The effect of fibers in improving the mechanical properties of concrete is governed by both the load transfer process from the matrix to the fiber and the bridging effect across the cracks, thus leading to an increase in the toughness and energy absorption of the concrete [9].

Application of polypropylene fibers at 0.5% volume fraction increased the maximum bending load by 40% and the fracture energy was approximately doubled [10]. Concrete containing 0.5% volume fraction of hooked end steel fibers exhibited an increase of 2.4 times in the fracture energy compared to unreinforced concrete [11].

Nowadays, owing to the merits of natural fibers such as various geometries, nonhazardous nature, renewability, lower cost, and biodegradability, the utilization of these fibers is going to be noteworthy. However, further research is needed to study the performance of natural fibers as reinforcing materials in cementitious composites [12–18].

Different test methods have been proposed to estimate the impact resistance of concrete as a design parameter, either quantitatively or qualitatively [19]. According to ACI Committee 544, the response to impact is evaluated qualitatively by determining the number of blows necessary to cause prescribed levels of distress in the specimen [20]. The results of the drop weight impact test

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http://dx.doi.org/10.1016/j.conbuildmat.2012.07.068

are often noticeably scattered due to nature of the test and nonhomogeneous condition of the concrete. In addition to that, the parameters including the fiber type, specimen geometry, and concrete mixture could have a great effect on the variation of the results [4,21].

Prior studies have clearly shown the advantages of concrete containing metallic and synthetic fibers such as steel and polypropylene fibers under impact loads, and in some cases, the impact test results were subjected to statistical analysis [21–24]. However, much less is known about the impact behavior of cellulose fiber reinforced concrete and its comparison with commonly available fibers used in order to reinforcing concrete. The objective of this study was to investigate statistically the effect of different fibers on concrete impact resistance under drop weight tests. For this purpose, steel, polypropylene and cellulose fibers as the three most common and popular types of fiber from three categories of metallic, synthetic and natural fibers were chosen and a comprehensive statistical analysis was carried out to evaluate the variation of the results. Moreover, by using the regression technique, linear relationships between the first crack and failure strengths were proposed.

2. Experimental program

2.1. Material

Normal Portland cement (ASTM type II) was used for concrete mixtures. Natural river sand with a specific gravity of 2.62 and fineness modulus of 3.31 was used as the fine aggregate while crushed natural stone of specific gravity 2.66 was used as coarse aggregate. A polycarboxylate based superplasticizer was added at 0.1% by weight of cement to obtain the desirable workability. The cement, sand, gravel and mixing water contents were 400, 957, 783, and 160 kg/m^3, respectively. The fibers used in this study were cellulose, polypropylene, and hooked steel (Fig. 1). Cellulose fibers were in the form of 5 × 6 mm chips which readily dispersed into individual fibers when mixed with concrete.

The properties and volume fractions of these fibers are presented in Tables 1 and 2. The average compressive strengths of the nonfibrous and fiber reinforced concretes at 28 days are also given in Table 2.

Table 1
Properties of different fibers used.

Property	Cellulose	Polypropylene	Steel
Length (mm)	2.1	12	35
Diameter (mm)	0.018	0.022	0.55
Aspect ratio (l/d)	117	545	64
Specific gravity	1.1	0.91	8
Tensile strength (MPa)	760	300–400	1100
Geometry	5 × 6 mm Chip	Fibrillated	Hooked

Table 2
Fiber dosage and compressive strength results of concrete mixtures.

Mixture	Fiber type	Fiber volume fraction (%)	Fiber dosage (kg/m^3)	Compressive strength (MPa)
Plain	–	–	–	41.8
CFRC	Cellulose	0.15	1.7	42.5
PFRC	Polypropylene	0.15	1.4	42.3
SFRC	Steel	0.5	39	43.2

2.2. Mixing and samples preparation

The procedures for mixing the fiber reinforced concrete were as following: firstly, the coarse aggregate, sand, and cement were mixed dry in a pan mixer for a period of 2 min. Then, the mixing liquids (water–superplasticizer mixture) were added and mixed for 1 min. This was followed by 2 min of rest and then 1 min of mixing. After which, the fibers were dispersed by hand to avoid fiber balling. Mixing was continued for 2 min to achieve a uniform distribution throughout the concrete.

For each fiber type, eight 150 × 300 mm cylinders were cast. After 24 h, the specimens were demolded and cured in water at 23 ± 1 °C for 28 days. Then, each cylindrical specimen was cut into four discs of 150 mm diameter and 64 mm thickness for the drop weight impact testing.

2.3. Test procedure

The impact test was carried out in accordance with ACI Committee 544 drop weight impact test. The test simply consisted of repeatedly dropping a hammer weighing 44.7 N from a height of 457 mm on a 63.5 mm diameter steel ball which was located at the center of the top surface of the specimen. The number of blows to cause the first visible crack was recorded as the first crack strength, while the failure strength was defined as the number of blows to spread the cracks sufficiently so that the pieces of concrete touched three of the steel lugs.

3. Results and discussion

3.1. Failure patterns under impact

Fig. 2 shows the failure pattern of the specimens with and without fibers. As expected, all the plain specimens were observed to fail suddenly through the aggregates and in a brittle manner. For the cellulose fiber reinforced concrete (CFRC), the failure was mainly breakage into three pieces without crushing, implying the relatively brittle behavior of the CRFC specimens. The most common failure pattern of the polypropylene fiber reinforced concrete (PFRC) specimens occurred by breaking into two and three pieces, usually accompanied by narrow cracks, small bits of debris, and dust. For the steel fiber reinforced concrete (SFRC), the failure was characterized by multiple cracking, excessive separation of the aggregates from the matrix, and fiber pull out, while still retaining their integrity [25].

3.2. Statistical analysis

The impact resistance results of the plain and fiber reinforced concretes (FRC) are given in Tables 3–6. The statistical analysis for the first crack strength, failure strength, and increase in the number of post-first crack blows (INPB) of the specimens is shown

Fig. 1. Fibers types: (a) cellulose, (b) polypropylene, and (c) steel.

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