Construction and Building Materials 187 (2018) 584–595

Contents lists available at ScienceDirect

Construction and Building Materials

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

Research on compressive impact dynamic behavior and constitutive model of polypropylene fiber reinforced concrete

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HIGHLIGHTS

- The dynamic behavior of PFRC under impact loading are studied by SHPB device.
- The effects of w/c ratio, fiber content and strain rate on PFRC are studied.
- The dynamic performance of PFRC is significantly affected by strain rate.
- Suitable amount of fiber can improve the impact toughness and strength of concrete.
- A damage dynamic compressive constitutive model is derived for PFRC.

ARTICLE INFO

Article history:
Received 11 April 2018
Received in revised form 2 July 2018
Accepted 22 July 2018

Keywords:
PFRC
SHPB
High strain rate
Dynamic mechanical properties
ZWT constitutive model

ABSTRACT

The latest experimental studies indicate that polypropylene fiber is able to remarkably enhance the ability of concrete to resist impact loading and crack. This paper further studies the dynamic behavior and constitutive model of polypropylene fiber reinforced concrete (PFRC) at high strain rate. PFRC specimens with various polypropylene fiber content (0, 0.8, 1.2, 1.6, 2.0, 5.0 kg/m^3) are tested by utilizing the Split Hopkinson Pressure Bar (SHPB). Both the quasi-static tests and the SHPB tests were performed to study the effect of fiber content, strain rate and water-cement (w/c) ratio on the dynamic mechanical properties of PFRC. Test results indicate that the dynamic mechanical properties of PFRC such as dynamic strength, dynamic increase factor, peak and ultimate strain, peak and ultimate toughness, are positively affected by strain rate. Polypropylene fiber can improve the impact toughness and crack resistance of concrete and it is more suitable for concrete material with a higher w/c ratio. Finally, the experimental stress-strain curves obtained in SHPB test were fitted by a damage dynamic constitutive model of PFRC on the basis of ZWT constitutive model. The great fitting results prove that the modified model can well describe the dynamic behavior of PFRC.

1. Introduction

Fiber reinforced concrete (FRC) is a kind of multiphase heterogeneous cementitious material with fibrous materials as the reinforcement and cement paste, mortar or concrete as the matrix [1]. It has been a significant substitution for concrete nowadays. Among the commonly used fibrous materials, such as steel, glass, carbon and polypropylene [2], polypropylene fiber is considered as secondary reinforcement of concrete [3] and PFRC has been extensively used in many infrastructure construction and protection projects in the world. The great interest in PFRC is from its low price, light weight and the obvious improvement of concrete performance [4–6].

Many research works on the physical and quasi-static mechanical properties of PFRC have been carried out and the relevant theories become more perfect. Studies have proved that not only will the tensile and bending capacity of concrete, added the appropriate amount of polypropylene fiber, increase remarkably [3–5], but also the plastic shrinkage and crack propagation will be restrained obviously [7,8]. Moreover, the durability of PFRC is remarkably enhanced by polypropylene fiber compared to plain concrete. For instance, experiments have shown that PFRC has higher impermeability [9] and abrasion resistance [10] in comparison with plain concrete. Many researchers have discussed the relationship between polypropylene fiber content and the compressive strength but got different results and conclusions. Here, early test results [11–17] about it are plotted together in Fig. 1. It can be seen that the overall effect is slightly positive in many cases with the appropriate fiber content (about 0.5–1.4 kg/m^3). In practical

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https://doi.org/10.1016/j.conbuildmat.2018.07.164

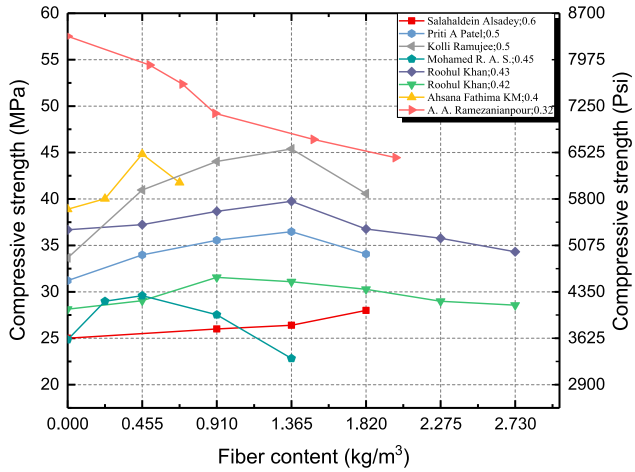

Fig. 1. Early investigations of compressive strength of PFRC.

applications, concrete structures have to inevitably withstand various dynamic loads and this requires a higher impact resistance of concrete. Fig. 2 gives the strain rate in different loading cases [18,19]. Therefore, a further study of the dynamic behavior of PFRC subjected to impact loading is necessary for its design and application. The investigation of the strain rate effect of concrete traces back to 1917 when Abrams found that the loading rate could significantly enhance the strength of concrete [20]. Since then, studies have shown that FRC has an obvious strain rate effect [21–23]. Some experiments show that the dynamic compressive strength and the anti-impact properties of PFRC ($\leq$2 kg/m^3) are obviously improved [24–26]. But the above researches only focused on a few aspects of the dynamic properties and did not investigate the constitutive model of PFRC. Lee SF [27], investigating from a microscopic perspective, concluded the improvement of ductility and strength of FRC was as a result of the stress transfer and redistribution from matrix to fiber through the adhesive contact between them.

SHPB apparatus has been broadly employed in the dynamic response test for concrete at high strain rate (e.g., 10^1–10^4/s) since it was established in 1949. With a 75 mm SHPB device, Sun et al. [28] investigated the dynamic properties of steel fiber reinforced concrete (SFRC) and discovered that the dynamic strength, peak and ultimate strain and toughness of concrete were obviously affected by the steel fiber content and strain rate. Zhang et al. [22] used a 74 mm variable cross-section SHPB to study the dynamic response of basalt fiber reinforced concrete (BFRC) and used a modified constitutive model to fit the experimental stress-strain curves. By making use of computational simulation, Dong et al. [29] established two different simulation models of SHPB device to estimate the SHPB approach and investigated several influential factors that affect the dynamic behavior of both mortar and concrete at high strain rate. At present, due to the imperfect theoretical methods and different experimental conditions, references related to the dynamic behavior of PFRC, especially tests under impact loading, are very scarce. And the majority of related researches focused on a low fiber content (about 0.5–2.0 kg/m^3).

This paper aims at providing a further research on the dynamic behavior of PFRC subjected to compressive impact loading. A series of quasi-static tests and SHPB tests on PFRC were performed. Through the experimental data, we observed the effect of the fiber content and strain rate on the mechanical properties of PFRC with different w/c ratios. At last, a damage dynamic constitutive model considering the damage within concrete was derived for PFRC material. The stress-strain curves obtained in SHPB test were fitted and analyzed subsequently.

2. Experiment program

2.1. Preparation of PFRC specimens

This experiment considered three different w/c ratios, namely 0.4, 0.5 and 0.6. Six polypropylene fiber contents (0, 0.8, 1.2, 1.6, 2.0, 5.0 kg/m^3) were selected. The impact pressure of SHPB system controlled the value of the strain rate, which were 0.4, 0.5 and 0.6 MPa in this study. The proportions of the mixture are shown in Table 1. Coarse aggregates were detritus and the particle size ranged from 5 mm to 10 mm. Fine aggregates were river sand whose maximum size was 3 mm after sieving. According to China National Standard GB 175-2009, the 42.5 Portland cement was used as cementitious material. Fig. 3 is the chopped polypropylene fiber and its physical and chemical characteristics are listed in Table 2.

Table 1
Mix Proportion for Concrete.

w/c ratio	Concrete compositions (kg/m^3)			
	Water	Cement	Sand	Detritus
0.4	220	550	620	1120
0.5	220	440	620	1120
0.6	220	367	620	1120

Fig. 3. 18 mm chopped polypropylene fiber.

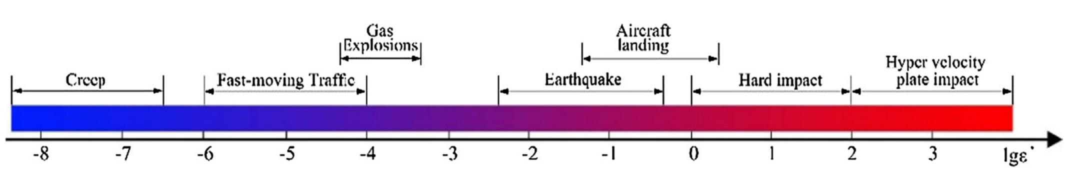

Fig. 2. Magnitude of strain rate in different loading cases.