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Research Article

Study on the Dynamic Performance of Polypropylene Fiber Reinforced Concrete

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Abstract: The dynamic performance of polypropylene fiber reinforced concrete is studied with the SHPB experiment. The relationship of the strain-stress curves are all obtained in the experiment. The crack characteristics of polypropylene reinforced concrete and plain concrete are also investigated. Analyzed the relation between the character on the crack surface of concrete and material properties and the impact pressure. Also the multi-fractal characteristics are given on the crack surface of concrete. The crack distributions of plain concrete and polypropylene concrete are investigated. The crack resistance effects of polypropylene fiber are analyzed from the degree of closeness and uniformity.

Keywords: Concrete, crack, dynamic, fractal model, polypropylene fiber

INTRODUCTION

Concrete is important material used in thin structures, nuclear power plants and defensive facilities which may experience impact loads. But the concrete is a brittle material. Concrete should be designed to resist and to absorb the energy of manmade and natural forces such as explosion and earthquake (Lam *et al*., 1998). It is well known that the using of small amount of polypropylene fibers into concrete will enhance the tensile and fatigue resistance and toughness of concrete. Although the mechanical properties of Polypropylene Fiber Reinforced Concrete (PFRC) have been investigated intensively and widely used in engineering, most of these investigations and applications were only limited to the static case. Tang (2004), Jacques and Cete (2004), Bonneau *et al*. (1996) and Richard and Cheyrezy (1995). Toughness is a measure of the ability of the material to absorb energy during deformation estimated using the area under the stress-strain curve. Karahan and Atis (2011), while studying the properties of polypropylene fiber reinforced fly ash concrete, reported that adding a volume fraction of 0, 0.05 and 0.10%, respectively polypropylene fiber seemed to slightly increase or maintain the strength, but when 0.20% of polypropylene fiber was added, the strength reduced. In this study, the dynamic properties of PFRC were studied experimentally by using the SHPB method whose diameter is 74 mm. The crack characteristics of polypropylene fiber reinforced concrete investigated in the SHPB test by the multi-fractal method.

MATERIALS AND SHPB EXPERIMENT

Four types of cementitious materials are used in study: Portland Cement (PC), Silica Fume (SF), Ultra Fine Fly Ash (UFFA) and Ultra Fine Slag (UFSL). The natural river sand with max size 3 mm is used to replace the ultra fine quartz sand. The super-plasticizer with the water reducing ratio of 30% produced by jingwei company in Guangzhou is used. Steel fibers are manufactured by Guo Mao Steel fiber Company in jiang Xi province, PR china. The matric is designed with C30. The specimens are circular cylinders 40 mm in diameter. Specimens with same length (20 mm) are used. The strain rates achieved ranged from 30 to 100s-1.

A 74 mm diameter SHPB was used for this program and the set-up is outlined in Fig. 1. The SHPB consists of four basic parts: a striker bar (projectile), input bar, output bar and a short specimen placed between input and output bar. The projectile from the gas gun is forced under pressure out of a barrel to impinge the input bar and the impact at the free end of the input bar develops a compressive longitudinal incident wave ε_i (t). Once this wave reaches the interface of input bar and specimen, a part of it, ε_r (t), is reflected, whereas another part goes through the specimen and develops in the output bar the transmitted wave ε_t (t). These three waves are recorded by strain gauges attached at the middle of the input and output bars. There are two fundamental postulates for SHPB test:

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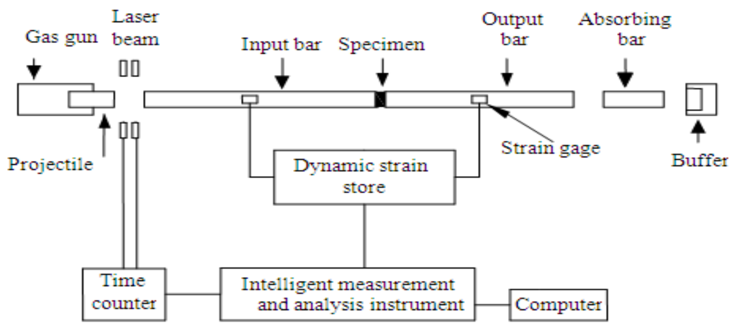
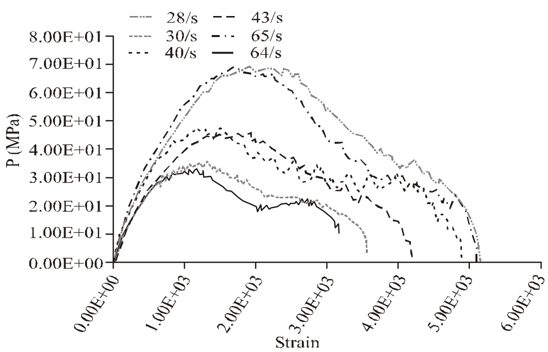
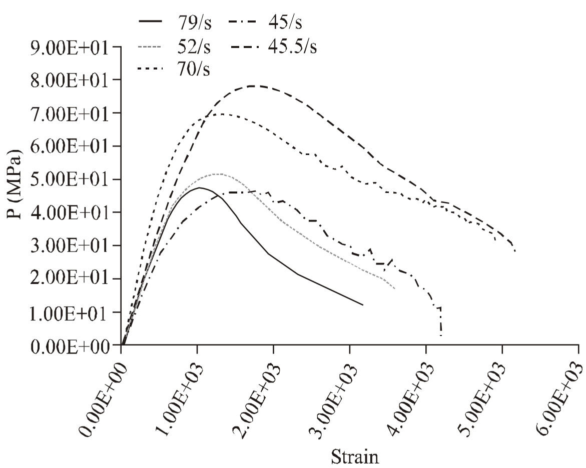


Fig. 1: Typical SHPB experimental device



(a) Plain concrete



(b) PFRC with the 6 Kg/m^3

Fig. 2: The stress-strain relationship curves of the concrete

- One-dimensional elastic stress wave theory is valid in pressure bars.
- Stress and strain states within the specimen are uniaxial and uniform.

Base on these assumptions, the stress, strain and strain rate of the specimen in the SHPB can be represented respectively as:

$$\sigma (t) = (A_e E_e / 2A_s) [\varepsilon_i (t) + \varepsilon_r (t) + \varepsilon_t (t)] \quad (1)$$

$$\varepsilon (t) = (C_e/L_s) \int_0^t [\varepsilon_i (t) - \varepsilon_r (t) - \varepsilon_t (t)] \, dt \quad (2)$$

$$\dot{\varepsilon} = (C_e/L_s) [\varepsilon_i (t) - \varepsilon_r (t) - \varepsilon_t (t)] \quad (3)$$

where

E_e, C_e & A_e : The elastic modulus, longitudinal wave velocity and cross-sectional area of the input or output bars respectively

A_s & L_s : The cross-sectional area and length of the specimen, respectively

Compressive strain is taken as positive. From the above information, the dynamic stress-strain relationship for a specific strain rate may be ascertained.

An absorbing bar is positioned at the far end and in contact with the output bar during the test, This serves to absorb the stress wave that travels along the output bar, thus avoiding reflection back into the output bar. A buffer is mounted on the platform to attenuate the impact of the absorbing bar.

A pair of laser beams is used to measure the velocity of projectile and the velocity of projectile raises when the pressure of gas increases, then the strain rate of specimen increases. But velocities of projectile were slightly different at same gas pressure and the strain rate of specimen may be not a specified value and only controlled to a range about the specified value.

With the Eq. (1), (2) and (3), the stress-strain relationship curves of the concrete are all obtained (Fig. 2).

Fractal characteristics of the SHPB experiments: The multi-fractal method is used to study the fractal characteristics of the concretes in SHPB experiments (Fig. 3). Grid of each pixel (i, j) calculated belonging to the crack, which divided by the total grids of the pixels $\sum n_{ij}$. The probability of each square P_{ij} can be obtained. The concrete cracked in the experiment is presented in Fig. 4:

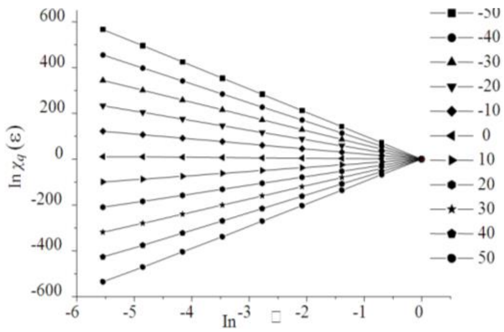
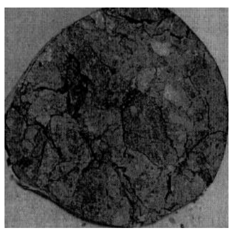


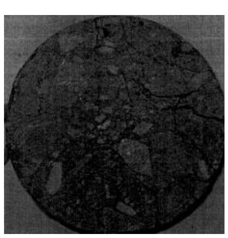
Fig. 3: In χ_q (ε) ~ in ε curves



(a) C30 plain concrete (0.5 Mpa)

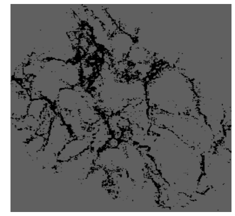
(b) C30 plain concrete (0.45 Mpa)

(c) C30 polypropylene concrete (0.5 Mpa)

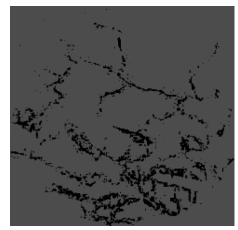


(d) C30 polypropylene concrete (0.45 Mpa)

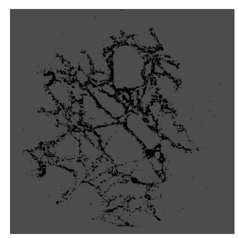
Fig. 4: The concrete cracked in the experiment



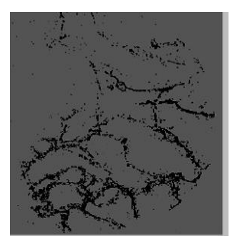
(a) C30 plain concrete (0.5 Mpa)



(b) C30 plain concrete (0.45 Mpa)



(c) C30 polypropylene concrete (0.5 Mpa)



(d) C30 polypropylene concrete (0.45 Mpa)

Fig. 5: Black-white bitmap of concrete

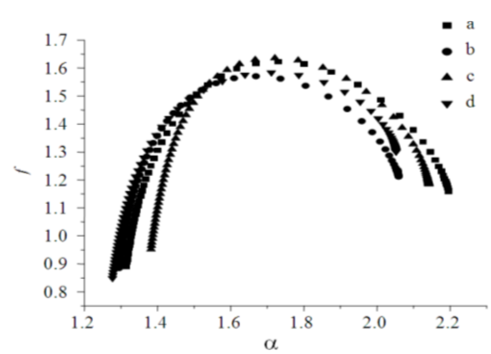


Fig. 6: Concrete multi-fractal spectrum curves

Table 1: The main parameters of multi-fractal spectrum in Fig. 5

	α_{min}	α_{max}	$\Delta\alpha$	$f(\alpha_{min})$	$f(\alpha_{max})$	Δf
a	1.31	2.20	0.880	0.896	1.159	0.60
b	1.29	2.06	0.760	0.884	1.212	0.50
c	1.38	2.14	0.760	0.950	1.180	0.56
d	1.28	2.05	0.758	0.848	1.300	0.50

$$p_{ij} = \frac{n_{ij}}{\sum n_{ij}} \tag{4}$$

Suppose N is the number of singular existence interval box, f (α) is defined as a singularity α of the grid geometry of the Hausdorff dimension:

$$N(\alpha) \propto \alpha^{-f(\alpha)} \tag{5}$$

From the multi-fractal method:

$$\begin{cases} \alpha(q) = \dfrac{\mathrm{d}\,\tau(q)}{\mathrm{d}\,q} \\ f(\alpha(q)) = \alpha(q)q - \tau(q) \end{cases} \tag{6}$$

where
$X_q(\varepsilon)$: The partition function
τ (q) : The quality index

Using a cylindrical block, the polypropylene fiber reinforced concrete and plain concrete test of the crack have the following image (Fig. 5a, b, c and d).

The Morphological comparison of concrete damage converted to the Black-white bitmap of concrete.

The multi-fractal method is used to study the fractal characteristics of the concretes in SHPB experiments. The results are obtained (Fig. 6). The parameters of the C30 are all gotten in Table 1.

RESULTS AND DISCUSSION

In Table 1 we can obtain the following results:

- For the same kinds of concrete at different chamber pressure, the pressure increase, $f(\alpha)_{max}$ are also on the rise, that the proportion of cracks in concrete on the rise.
- Δα increasing with the increasing of the pressure which indicated the more uniform distribution of crack the more smaller of the pressure.

As an example, The C30 concrete (0.5 Mpa) images calculated by the log-log curves. It can be seen from the calculated results basically remains a straight line, which indicating that the scale-free and the concrete surface crack with multi-fractal characteristics.

CONCLUSION

A mechanistic model for unsaturated flow in frature hard rocks based on the method using the specific fractal to describe a fractured rock. The resulting water content expression is used to estimate the unsaturated hydraulic conductivity of the fractured medium based on the well-known model of Burdine. It is found that for large enough ranges of fracture apertures the new constitutive model converges to the empirical Brooks-Corey model.

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