Construction and Building Materials 95 (2015) 143–151

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental investigation of the behavior of aramid fiber reinforced polymer confined concrete subjected to high strain-rate compression

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HIGHLIGHTS

- A series of quasi-static and SHPB tests were conducted on AFRP-confined concrete.
- AFRP-confined concrete outperformed unconfined concrete significantly under impact.
- An abnormal increase of dynamic strength was found in AFRP-confined concrete.
- Influence of strain rate effect was quantized by empirical formulae.
- The enhancement mechanism of AFRP during dynamic tests was illustrated.

ARTICLE INFO

Article history:
Received 23 October 2014
Received in revised form 24 April 2015
Accepted 12 July 2015
Available online 20 July 2015

Keywords:
Aramid fiber reinforced polymer (AFRP)
Split Hopkinson pressure bar (SHPB)
High strain rate
Dynamic strength
Ultimate strain
Energy absorption density

ABSTRACT

This study investigated the behavior of aramid fiber reinforced polymer (AFRP) confined concrete subjected to high strain-rate compression. A total of 71 specimens were tested under quasi-static and high strain-rate axial compression using a hydraulically-driven testing system and a 100-mm-diameter split Hopkinson pressure bar apparatus, respectively. Influence of the loading rate was examined with strain rates ranging from 80 to 170 s^{-1}. The influence of lateral confinement level was also examined by varying the number of AFRP layers and imposing different strain rates. The experimental results indicate that the dynamic strength, ultimate strain and energy absorption density are sensitive to strain rate, and that the external AFRP confinement significantly improves these properties. In addition, this paper discusses the strengthening and toughening mechanisms of AFRP jackets.

1. Introduction

Validity of the enhancement of concrete column structures by means of external wrapping fiber reinforcement polymer (FRP) has been well established over the last three decades. Numerous studies, starting with the study by Fardis and Kahalili [1] who conducted axial compressive tests on fiberglass tubes, have verified that the lateral confinement provided by FRP jackets places lateral dilated core concrete into a three-dimensional stress state, which significantly improves the axial compression and dilation behavior [2–10].

As a result, most of the current investigations about the axial behavior of FRP-confined concrete are focused on their bearing capacity. However, with the increasing use of FRP in structure retrofitting, more attention should be paid to its resistance against high strain-rate compression, since it is likely to encounter such kind of load during its service life. As generally acknowledged, when subjected to strong impacts (or blasts), concrete often cracks quickly for consuming a large amount of impact energy, and the ability of absorbing energy will be more important in such situations [11]. Since the reinforced structure with an increased toughness offers the possibility to raise the resistance to dynamic loading [12], FRP with high tensile strength and elastic modulus should be applicable for impact protection.

Aramid fiber reinforce polymer (AFRP) is a synthetic fibrous composite material, light in weight, high in tensile strength and low in thermal expansion coefficient, which has widely utilized in fields of aerospace, national defense and military. According to a recent crucial database built by Ozbakkalouglu and Lim [13], the type of FRP have an important influence on the behavior of FRP-confined concrete. Compared to the FRPs made of inorganic fibers such as carbon fibers and glass fibers, AFRP have higher elongation at break which leads to an even better impact resistance [14]. Moreover, aramid fibers are high polymer compound whose impact damage mechanism is distinctly different from those of

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http://dx.doi.org/10.1016/j.conbuildmat.2015.07.084
0950-0618/

inorganic fibers [15], thus this investigation becomes more meaningful.

In this paper, a hydraulic testing system and a 100-mm-diameter split Hopkinson pressure bar apparatus were adopted to experimentally investigate the mechanical properties of AFRP-confined concrete in both quasi-static and dynamic states. Meanwhile, an instantaneous radial stress formula was proposed by introducing inertia effect, and the mechanics of strengthening and toughening of AFRP-confined concrete were also discussed.

2. Experimental details

2.1. Materials preparation

Experimental materials used for the tests are described as follows: Qinling® P.O 42.5R cement, river sand (fineness modulus = 2.78, bulk density = 1.50 kg/L), limestone rubble (of which 15% with a diameter of 5–10 mm and 85% with a diameter of 10–20 mm), tap water. Silica fume (with an average grain diameter of 0.15–0.2 μm, and 97.44% of SiO_2 content) was utilized to improve mechanical properties as suggested by reference [16]. Naphthalene-based super-plasticizer (NS) was adopted to improve workability. The mix proportions of concrete are stated in Table 1. Kevlar CAS-415 AFRP composite, manufactured by Beijing Carbon Institute of Engineering Technology, China, was chosen for external retrofitting (see Fig. 1). Physical and mechanical properties of AFRP and epoxy resin adhesive are stated in Tables 2 and 3 respectively.

2.2. Specimens preparation

A total of 71 cylindrical specimens were prepared for tests, among which 16 specimens were prepared for quasi-static tests and 55 specimens for SHPB tests. To minimize the effect of friction, specimens for the SHPB tests were designed in size of Ø 97 mm × 48 mm [17]. Specimens for the quasi-static tests had the same diameter as those used for dynamic tests, but with a length to diameter ratio of 2.0 to satisfy “GB/T 50081-2002” [18]. The mixture was first cast into plastic molds for 24 h then cured at a temperature of 20 ± 2 °C with a relative humidity of >95% for 28 days.

The manual wet lay-up procedure adopted for preparing the specimens is described in the following. First, the lateral surface of each specimen was polished, and a layer of epoxy resin adhesive was applied to fill the perforations and microdefects. The AFRPs were then glued to the specimens’ lateral surface using the epoxy resin adhesive, where a 150 mm overlap was left to prevent premature debonding failure. After the lay-up procedure was done, another layer of epoxy resin adhesive was applied on the external surface of AFRPs to permeate through the AFRP layers. All AFRP-confined concrete specimens were cured at ambient temperature for 7 days before tests to harden the epoxy resin adhesive. Typical specimens available for tests are shown in Fig. 2.

2.3. Testing

2.3.1. Quasi-static tests

A hydraulic testing system, which comprises a hydraulic testing machine and a data acquisition system, was adopted to test the static mechanical properties of specimens. The loading rate which controlled by the data acquisition system was set as 2.5 kN/s. During tests, load and displacement records on the loading plate were collected in real time via the data acquisition system and then used in the calculation of average axial strain and stress along the height of the specimens. In addition, two unidirectional strain gauges, with a gauge length of 20 mm, were instrumented at the mid-height of the specimen to measure axial strains, which were used to ventilate acquired data at the early stages of loading (see Fig. 3).

2.3.2. SHPB tests

A 100-mm diameter SHPB was utilized to test the axial dynamic mechanical properties of the 55 AFRP-confined concrete specimens. As shown in Fig. 4, this apparatus comprises an energy source, a projectile, an incident bar, a transmission bar, a shock absorber and a data acquisition system. In this study, the incident bar, transmission bar and projectile are all composed of 48CrMoA with a density of 7850 kg/m^3, an elastic modulus of 210 GPa and a wave velocity of 5172 m/s.

Table 1
Mix proportions of concrete (kg/m^3).

Cement	Water	Sand	Limestone rubble	NS	Silica fume	Slump (mm)
556	225	476	1037	3.09	62	110

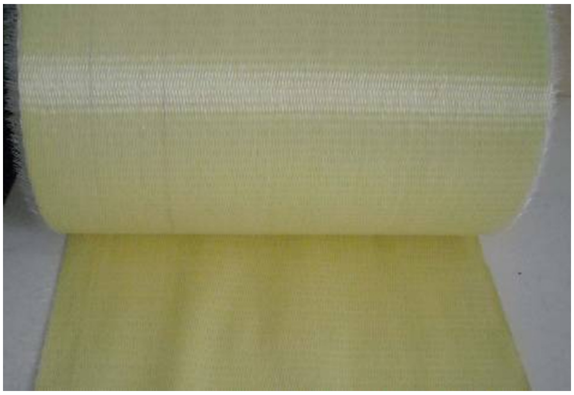

Fig. 1. Aramid fiber-reinforced polymer.

Table 2
Physical and mechanical property of FRP.

Fiber type	Density ($g\,m^{-2}$)	Thickness (mm)	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation (%)
Aramid fiber	415	0.286	2206	131	2.1

Table 3
Physical and mechanical property of epoxy resin adhesive.

Adhesive	Density ($g\,cm^{-3}$)	Operable time (min)	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation (%)
CASRA/B	1.05–1.25	45	42	2924	1.8

Fig. 2a. Typical specimen for quasi-static test.