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Properties of confined fibre-reinforced concrete under uniaxial compressive impact

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Abstract

The effect of confinement on plain and fibre-reinforced concrete (FRC) prisms subjected to uniaxial compressive impact was studied. It was found that the response of the material changed with the degree of confinement. Confined concrete exhibited more ductile behaviour, with both strength (f_c') and ultimate strain (ε_{ult}) increasing with the degree of confinement. However, the elastic modulus (E) of the confined specimens was found to be about the same as or slightly lower than those of unconfined prisms. In addition, the relationship between stress and stress rate (n value) was also determined. It was found that, with confinement, the material became more rate sensitive.

Keywords: Compressive strength; Elastic modulus; Impact; Mechanical properties

1. Introduction

Concrete is known to be a strain-rate-sensitive material; its properties change with changes in the rate of loading. Many studies [1–3] have shown that the apparent strength and the corresponding strain increase with increasing rate of loading. In most research studies, concrete specimens were subjected to simple loading conditions, such as uniaxial tension or compression or three-point bending. However, in practice, concrete may be subjected to much more complicated multiaxial loading. Many research studies have been carried out on concrete subjected to multiaxial loading, but mostly under only static loading conditions [4–10]. Therefore, our knowledge of the impact behaviour of concrete under confining stress is still far from complete. In this study, the compressive impact behaviour of plain and fibre-reinforced concrete (FRC) under confinement was examined, with a focus on the response of the material and its resulting mechanical properties.

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[1] This work was done while he was a PhD student at the University of British Columbia.

2. Experimental procedures

Concrete with mix proportions of 1.0:0.5:2.0:2.5 (cement:water:sand:coarse aggregate), providing an average compressive strength of 44.5 MPa for plain concrete and 45.1 MPa for FRC, was prepared in the form of rectangular prisms of dimensions $100 \times 100 \times 175$ mm. The concrete was mixed using a pan-type mixer, placed in oiled PVC forms in a single layer, roughly compacted with a shovel, and finally vibrated on a vibrating table before being covered with polyethylene sheets. After 24 h, the specimens were demoulded and transferred to storage in a lime-saturated water tank for 30 days. Hooked end steel fibres were used (Table 1) at volume fractions of 0.5% and 1.0%.

An instrumented, drop-weight impact apparatus, designed and constructed in the Department of Civil Engineering, University of British Columbia, with the capacity of dropping a 578-kg hammer from heights of up to 2500 mm on the target specimen, was used to carry out the impact tests (see Ref. [11] for details of the impact machine). A load cell, 100 mm in diameter, with strain gauges mounted on it, was rigidly connected to the impact hammer.

An instrumented confinement apparatus was used to apply the lateral confinement stresses (Fig. 1). This appa-

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Table 1
Geometry of fibre

Type	Shape	Length (mm)	Cross section	Diameter (mm)
Hooked end		30	circular	d = 0.50

ratus consisted of two 50-ton hydraulic jacks and two load cells instrumented with four strain gauges each, oriented in the x and y axis directions. The load cells were placed opposite to the jacks on each axis. Four heavy steel blocks, rigidly connected to a base plate to prevent horizontal displacement, were used to hold both the jacks and the load cells.

Two series of impact tests were carried out: (1) without confinement and (2) with confinement by steel platens. For both tests, the specimen was placed vertically on a 100 × 100-mm rigid steel base located at the center of the impact machine. The hammer was dropped from 250- and 500-mm heights to provide striking velocities of 2.21 and 3.13 m/s, with corresponding impact energies of 1417 and 2835 J, respectively. An accelerometer placed on the top of the hammer was used to determine the specimen deformation. For the confined tests, the confining stresses were varied from 0 to 1.25 MPa. Full details of the testing program are given in Table 2.

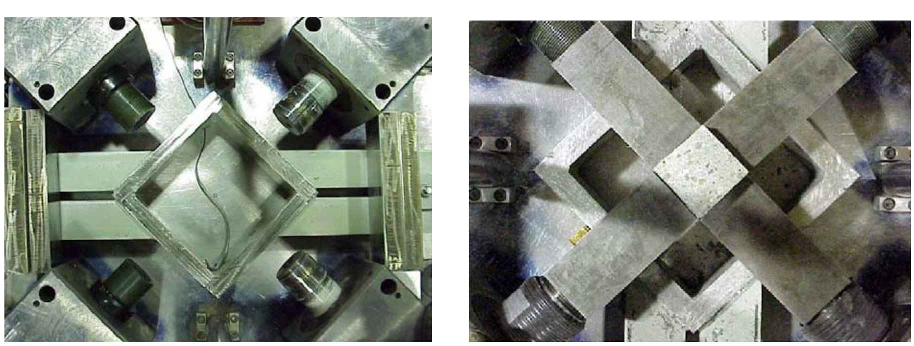
3. Results and discussion

3.1. Stress–strain response

The confinement stresses used in this study were completely unconfined, 0 (passive confinement), 0.625, and 1.25 MPa. For the latter three cases, since the specimens would all tend to expand laterally under compressive loading, the lateral confinement stresses would have increased somewhat during the impact event. Unfortunately, with the present test arrangement, it was not possible to measure these increases. They would, in any case, have varied along the length of the specimen during an impact event due to the reflections of the stress waves from the confined boundaries of the specimen. The typical responses of plain and FRC prisms are given in Figs. 2–4. The response of the confined concrete was quite similar to that of unconfined concrete; the prepeak response consisted of both linear and nonlinear portions, followed by a postpeak response (the descending branch). However, the confined specimens behaved in a more "ductile" manner with increasing confinement, as indicated by the increasing strain at peak load and toughness; the ultimate strength also increased. There was no direct relationship between the confinement stress and the elastic modulus. The responses of both plain concrete and FRC were quite similar, except that the toughness of

Table 2
Testing program

Designation	Description	Vf (%)	Drop height (mm)	Confinement stresses (MPa)
Unconfined tests				
CPL250	Plain	–	250	
CPL500	Plain	–	500	
C05HE250	FRC	0.5	250	
C05HE500	FRC	0.5	500	
C1HE250	FRC	1.0	250	
C1HE500	FRC	1.0	500	
Confined tests with steel platens				
CPL25B21.25S	Plain		250	1.25
CPL25B0.625S	Plain		250	0.625
CPL25B0S	Plain		250	0
CPL50B0.625S	Plain		500	0.625
CPL50B0S	Plain		500	0
C05H25B1.25S	FRC	0.5	250	1.25
C05H25B0.625S	FRC	0.5	250	0.625
C05H25B0S	FRC	0.5	250	0
C05H50B0.625S	FRC	0.5	500	0.625
C05H50B0S	FRC	0.5	500	0
C1H25B0.625S	FRC	1	250	0.625
C05H25B0S	FRC	1	250	0
C1H50B0.625S	FRC	1	500	0.625
C05H50B0S	FRC	1	500	0



(a) Top view (b) Test setup

Fig. 1. Instrumented confinement apparatus.