Full Length Research Paper

Study on the mechanical behavior of steel reinforced high strength concrete subjected to impact loading

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Accepted 26 May, 2011

In this paper, the impact experiments of steel fiber reinforced concrete with same impact velocity and different steel fiber contents are processed by one-stage light gas gun. Through the manganin gauges embedded in the target, the voltage-time signals are recorded. Lagrangian method is used to analyze the flow field, then the particle velocity (u), specific energy, specific volume with time are obtained. Moreover, it was observed from the measured pressure-time curves that the decay factor is smaller in the steel reinforced high strength concrete. The dynamic response is analyzed.

Key words: Concrete, relationship, steel fiber.

INTRODUCTION

Ultra-high performance cementitious composite is a type of building material with very high strength and durability. With high strength and ductility, it is suitable for bridge decks, thin shell structures, nuclear power plants and defensive facilities that may experience impact loads (Tang, 2004; Jacques and Cete, 2004; Bonneau et al., 1996; Richard and Cheyrezy, 1995). But the higher the strength of the concrete, the higher the brittle. So it necessary to add the steel fiber to the high strength to increase its mechanical property. Also, to design and analyze these structures better, it is imperative to investigate the mechanical characteristics and constitutive model of steel fiber reinforced high strength concrete. A great number of tests have been conducted to find the effect of strain rate on the dynamic strength of concretes. A few methods, such as direct impact test, split Hopkinson pressure bar (SHPB) test, plate impact test and the light gas gun test, are commonly used to determine the dynamic material properties (Tang, 2004; Jacques and Cete, 2004; Bonneau et al., 1996; Richard and Cheyrezy, 1995; Hao and Tarasov, 2008). The split Hopkinson pressure bar (SHPB) is an effective method to obtain the dynamic stress–strain curves of materials.

The strain rate of concrete in SHPB test is usually $10^2/s$ and below. Using a long barrel, the strain rate of concrete can reach $10^3$ to $10^4/s$. It is commonly understood that dynamic material properties are different from the corresponding static material properties. For example, the recent dynamic compressive tests of masonry material properties (clay brick and mortar) indicated that the material yield and ultimate strength, yield and ultimate strain, elastic modulus and Poisson’s ratio all change with the strain rate (Hao and Tarasov, 2008). It was found that the strength of the mortar and clay brick increase by two to three times at strain rate of about $100/s$. Other tests on concrete materials (Grote et al., 2001) and rock material (Li et al., 2004) also indicated a similar increase of compressive strength. Substantially more significant increase in concrete material tensile strength was also observed by many researchers (Schuler et al., 2006). This phenomenon of material strength increase at high strain rate is termed strain rate effect. Understanding the strain rate effect is very important in assessing the structural capacity in resisting impact and blast loads.

THE EXPERIMENTS

Materials preparation

The strength grade of cement is P·II 52.5 according to the
Figure 1. Schematic diagram of the experiment. (1) Projectile assembly, (2) light chamber, (3) flyer, (4) target, (5) base board, (6) managanin gauges, (7) recycle bin, (8) specimen.

relevant China standard. The maximum particle size of natural sand is 2.5 mm with a fineness modulus of 2.6. The equivalent diameter, length and tensile strength of the steel fiber are 0.2 mm, 13 mm and 1800 MPa respectively. The mix proportion is adopted C100 by the China standard. The volumetric steel fiber concentration 0 and 5% are used which called C100V0 and C100V5. The static strength of which are 158.3 and 164.6 MPa respectively.

Specimens have a diameter of 92 mm and a length of 8 mm. There are four specimens assembled. The flyer has the same diameter and 10 mm length. Considering contact, this length is rather small and it due to the dynamic loading conditions. The analysis of the test is based on the assumption of no lateral effect, therefore long specimens compared with the diameter must be avoided.

A second point after striking, a stress wave propagates in the flyer and the specimens. When it arrives at the head face of the flyer, a sparsity reflection stress wave is produced. To avoid the reflection wave from catching up with the specimens, the length of flyer must be long compared with the diameter.

The design of the experiments

The one-stage light gas gun has been one of the main experimental setups for testing concrete and reinforced concrete specimens. The experiments are carried out in the Earthquake Research Center laboratory of Guangzhou University in China. The diameter and length of the gun is 100 mm and 13 m, respectively. The range of impact velocities is from 200 to 800 m/s the error of which is less than 5% and the level of impact is less than $10^{-3}$ rad. The responses of strain rates range from $10^3$ to $10^4$/s. The one-stage light gas gun apparatus is shown in Figure 1.

Upon impact, the flyer is placed on the projectile assembly. The high pressure gases are suddenly released to propel the projectile assembly to move along the gun chamber. When the projectile assembly with a high velocity collides with target, high pressure pulses are produced. These voltage-time signals will be recorded by the three H gauges (Figure 2). The details of the H gauges (50 Ω) are described in Cai et al. (2010) and Ma et al. (2006). The signals can be obtained by the oscilloscopes and can be changed to the pressure by using the following formula:

$$\sigma = (0.3252 \pm 0.069) + (40.2733 \pm 0.4164)(\frac{\Delta R}{R})$$

$$\sigma = (0.0014 \pm 0.0055) + (51.469 \pm 0.2773)(\frac{\Delta R}{R})$$

Where $\sigma$ is the pressure, $\Delta R$ is the change of the resistance, $R_0$ is the initial resistance.

From the formula the pressure-time curves are obtained (Figures 3 and 4).

LAGRANGIAN METHOD

The record of 1-D Lagrangian method is used to calculate the flow field distributed in the tested materials. The experimental temporal curves are used to calculate
Figure 2. H type gauges.

Figure 3. The C100V0 stress-strain curves experimented.

Figure 4. The C100V5 stress-strain curves experimented.
the value-time relations of particle velocity, relative specific volume and internal energy per unit volume on every Lagrangian position. The relationship of experiment, academic model and the numerical simulation is established by the Lagrangian method. Conservation equations in one-dimension are as follows (Cotsovos and Pavlović, 2007):

\[ u - u_i = v_0 \int_{t_1}^{t_2} \left( \frac{\partial p}{\partial t} \right)_h, dt \]  
(2)

\[ v - v_i = \int_{t_i}^t \left( \frac{\partial u}{\partial h} \right), dt \]  
(3)

\[ e - e_i = v_0 \int_{t_1}^{t_2} \left( \frac{\partial u}{\partial h} \right), dt \]  
(4)

Where \( \rho_0 \) is the density, \( u \) is particle velocity, \( u_i \) is particle velocity of shock front, \( v \) is relatively specific volume, \( v_i \) is relatively specific volume of shock front, \( E \) is internal energy per unit volume, \( E_i \) is internal energy per unit volume of shock front, and \( t_1, t_2 \) is start time and end time, respectively. \( h \) is Lagrangian position.

The path lines and particle lines are adopted to prevent the useful information lost in integral along the isochrones lines. The analogical points (Huan et al., 1989) (the characteristic points on the waves such as the end point of elastic wave, the peak point of plastic wave etc.) in the pressure-time curves are connected to establish the path lines. The particle lines are the curves of the parameters varied with the time recorded by the Lagrangian gauges. The integral along isochrone lines can be changed along the path lines and particle lines:

\[ \left( \frac{\partial p}{\partial h} \right)_h, = \left( \frac{\partial p}{\partial h} \right)_h, \left( \frac{\partial t}{\partial h} \right)_h, \]

\[ \left( \frac{\partial u}{\partial h} \right)_h, = \left( \frac{\partial u}{\partial h} \right)_h, \left( \frac{\partial t}{\partial h} \right)_h, \]

So, the Equations 2, 3, 4 can be written as follows:

\[ u = u_i - \frac{1}{\rho_0} \int_{t_i}^{t_2} \left[ \left( \frac{\partial p}{\partial h} \right)_h, - \left( \frac{\partial p}{\partial t} \right)_h, \left( \frac{\partial t}{\partial h} \right)_h, \right], dt \]  
(7)

\[ v = v_i + \int_{t_i}^{t_2} \left[ \left( \frac{\partial u}{\partial h} \right)_h, - \left( \frac{\partial u}{\partial t} \right)_h, \left( \frac{\partial t}{\partial h} \right)_h, \right], dt \]  
(8)

\[ E = E_i - \int_{t_i}^{t_2} P(t) \left( \frac{\partial v}{\partial t} \right)_h, dt \]  
(9)

Steel reinforced effect

The problem in dynamic material testing is the lateral inertial confinement. Some researchers argued that the increase in material strength observed during dynamic test is caused, at least partially, by inertial confinement (Zhou and Hao, 2008a, b; Tang et al., 1992). In this research, from Figure 5 the stress peak value-Lagrangian position curves (Figure 6) is obtained. It can be observed that at the first Lagrangian position the pressure between the two type concrete are nearly the same. But the steel reinforced high strength concrete weakens more slowly than the high strength concrete. The steel reinforced the mechanical behavior of the high strength concrete. The mechanism of reinforced effect can be resolved from Figure 7(a). Steel girds are perpendicular to loading direction and increase the intensity of the concrete, so the load-carrying capacities of steel reinforced high strength increase too.

Conclusions

The shock properties of C100 concrete is investigated by gas gun planar impact technique. The manganin pressure gauge is used to measure the pressure-time curves of the samples. The physical quantities are all obtained by the Lagrange method. The steel reinforced effect has been analyzed. Moreover, it is observed from the measured pressure-time curves that the rate-sensitivity of dynamic response for C100 concrete is not negligible, showing marked stress relaxation and dissipation.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support from National Natural Science Foundation of China (Project 51078094 and 50708022).
Figure 5. The stress-strain curves at different position.

Figure 6. The stress peak value-position curves.
Inertia forces

Figure 7. (a) Lateral inertial confinement under uniaxial compression; (b) under uniaxial tension.

REFERENCES