EXPERIMENTAL STUDY ON DYNAMIC COMPRESSIVE PROPERTIES OF MICROCONCRETE UNDER DIFFERENT STRAIN RATE

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ABSTRACT :

Shaking table test is more and more popular in research on seismic performance of high rise buildings. Microconcrete is normally used to construct the models for shaking table test. The mechanical performance of microconcrete is important for design of dynamic similitude relationship. Dynamic compressive strength test on prismy microconcrete specimens is carried out on static and dynamic testing machine named MTS. The relationship between constitutive relation, compressive strength, modulus, peak strain and failure type of microconcrete under compression and strain rate is studied. The constitutive relation and failure type of microconcrete under different strain rate is similar. The strain at peak value of stress is invariable under different strain rate. The microconcrete is depending on the strain rate. The compressive strength and modulus increase with the increase of the strain rate. The quantitative formulas are presented in this paper, which can be used in design of similitude relationship in shaking table test.

KEYWORDS: microconcrete，strain rate，compressive strength, Young’s modulus, failure type

1. INTRODUCTION

Dynamic loading normally is an important factor in the design of concrete structure. Some dynamic test on normal concrete has been carried out at home and abroad to study the mechanical properties of concrete. The strain rates of concrete are between 10^{-5}/s and 10^{-2}/s in earthquake [1]. Test on compressive strength of concrete under different strain rate are carried out and results showed that the compressive strength increases with the increase of the strain rate[2][3]. Concrete uniaxial constitutive relationship are established based on test results by several foreign scholars[4]. Test on concrete compressive strength under 7 kinds of strain rate are conducted [5]. And the results showed that stress-strain relationships of concrete under different strain rate are similar. The peak strain and stress of concrete increased slightly with the increase of the strain rate. The mechanism of dynamic strain rate effect on concrete was explained[6]. Dynamic test on compressive performance of concrete were done by force control method[7]. But the degrading part of stress-strain relationship were not got. The static and dynamic damage constitutive model was established[8]. The state of the art of dynamic performance of normal concrete was summarized[9]. Some research on concrete dynamic compressive properties has already been carried out.

Microconcrete is normally used to simulate concrete structure prototype in shaking table test[10]. The strength grade of microconcrete used in shaking table test is between MC2.5 and MC15.0 in order to satisfy the relationship. Test on stress-strain relationship under different strain rate of mortar whose mix ratio is 1:2:0.5 (cement: sand: water) was done[11]. The results showed that dynamic compressive strength increases with the increase of the strain rate. But this mortar can not be used to construct the shaking table test model for its strength is between 10 MPa and 18 MPa. The Young’s modulus and static compressive strength of concrete and microconcrete are similitude factors in shaking table test. That whether the ratio of dynamic strength to static strength of normal concrete and microconcrete is similar is not studied till now. The reduced model is normally used in shaking table test for limitation of its payload. And the similitude factor S_t of time *t* is $\sqrt{S_l / S_a}$. S_l

and S_l are the similitude factor of length l and acceleration a respectively. Normally the factor S_l is between 1/10 and 1/50 and S_l is between 1 and 3. So the factor S_t is between 0.0067 and 0.316. Strain rate of microconcrete improved by between 3 and 150 times.

More and more shaking table model tests will be done to study seismic performance of complex high rise buildings for there are many super complex high rise buildings will be constructed. The similitude relationship is fundament of design and result analysis of shaking table test. And microconcrete will be used to construct these models. It is necessary for us to study the dynamic compressive strength of microconcrete under different strain rate in shaking table test.

2. TEST PROGRAM

2.1. Test Setup

The MTS 322 testing system is used to study the dynamic and static performance of microconcrete. The test setup is shown in Figure 1.

Figure 1: Test set up

Figure2: Installment of specimen

The maximum loading of this system is 500KN. The LVDT transducer and high precision load cell are used to measure the displacement and loading, respectively. This system can be controlled by displacement, loading and strain. And the control mode can be switched between displacement, loading and strain. The frequency of this machine is between 0.01 and 15 Hz. The maximum velocity of the actuator is 70 mm/s. The maximum frequency of data acquisition is 50K Hz.

2.2. Test Specimens

The dimension of prismy specimens is 100mm×100mm×300mm. The design strength of microconcrete is MC7.5. The mix ratio of microconcrete is 1:6.60:1.37(cement: sand: water). The P.O.32.5 Portland cement is used. The maximum diameter of sand is 5 mm. The steel mold is used to construct these specimens.

The PUNDIT PLUS instrument for concrete non-destructive measuring is used to measure the wave velocity of specimens before test. The wave velocity deviation of specimens used for dynamic test is less than 3% in order to improve the accuracy of result. The specimen installed on the test system is shown in Figure 2.

2.3. Test Procedure

The test is aimed to study the dynamic compressive properties of microconcrete under different strain rate. The compressive strength of microconcrete under strain rate of 10^{-5}/s is considered as static compressive strength in test. The dynamic compressive strength of microconcrete under strain rate of 10^{-4}/s, 10^{-3}/s, 10^{-2}/s and 10^{-1}/s is studied in this paper.

10% of the ultimate compressive loading of microconcrete is applied on the specimen at first. Some adjustment is done to make sure the specimen is not eccentric according to the result form strain gauges glued on the two sides of the specimen. Then, loading is released to zero and a procedure is programmed by MPT793.10 Control Software of MTS to apply loading automatically.

2.4. Test Measurement

The data of loading and displacement are got by MTS data acquisition system and the strain is measured by DH5922 dynamic strain meter. The frequency of data acquisition is 10Hz, 100Hz, 1kHz, 10kHz and 50kHz when the strain rate is 10^{-5}/s, 10^{-4}/s, 10^{-3}/s, 10^{-2}/s and 10^{-1}/s, respectively. The concrete strain is measured by strain gauges glued at two sides of the specimen with 100 mm gauge length. The strain can also be got from the deformation of specimens tested by LVDT transducer. Results from these two transducers are compared to verify its validity.

3. TEST RESULT ANS ANALYSIS

3.1. Stress-strain relationship

The stress-strain relationship of microconcrete under different strain rate is shown in Figure 3. The falling segment of stress-strain relationship is got because displacement control mode is adopted.

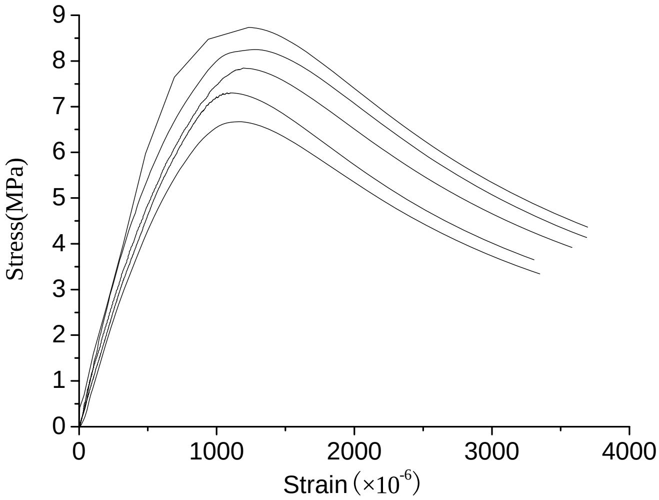

Figure 3: Stress-strain relationship of microconcrete under different strain rate

Note: the strain rate of the curves from top to bottom is 10^{-1}/s 、10^{-2}/s、10^{-3}/ s 、10^{-4}/s and 10^{-5}/s.

The shapes of stress-strain relationship of microconcrete under different strain rate are similar as shown in

Figure 3. The elastic modulus and peak strain of microconcrete under different strain rate are different.

3.2. Compressive Strength

The test result of dynamic compressive strength of microconcrete under different strain rate is shown in Table 1.

Table 1 Test result of dynamic compressive strength of microconcrete

No.	Strain rate	Compressive sterngth(MPa)			Average strength(MPa)
1	10^{-5}/s	6.85	6.37	6.78	6.67
2	10^{-4}/s	6.95	7.35	7.60	7.30
3	10^{-3}/s	7.84	7.98	7.70	7.84
4	10^{-2}/s	7.97	8.30	8.48	8.25
5	10^{-1}/s	8.57	8.65	8.97	8.73

As shown in Table 1, the ultimate compressive strength of microconcrete increases with the increase of strain rate ,obviously. Compared to static compressive strength of microconcrete, dynamic compressive strength increases by 9.4%, 17.5%, 23.6% and 30.8% when the strain rate is 10^{-4}/s, 10^{-3}/s, 10^{-2}/s and 10^{-1}/s, respectively. The test result is shown in Figure 4.

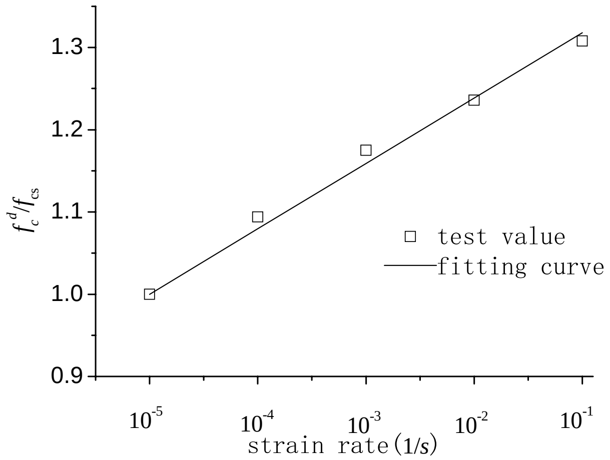

Figure 4: Compressive strength of microconcrete under different strain

As shown in Figure 4, the relationship between the ratio of the dynamic to static compressive strength of microconcrete and the logarithm of the strain rate is linear. So the increase of the dynamic compressive strength of microconcrete compared to static strength can be described as Eqn. 3.1.

$$f_c^d / f_{cs} = 1 + \alpha \lg(\dot{\varepsilon}_c / \varepsilon_{cs}) \tag{3.1}$$

Where:

f_c^d ——Ultimate compressive strength of microconcrete under current strain rate (MPa),

f_{cs} ——Ultimate static compressive strength of microconcrete (MPa),

$\dot{\varepsilon}_c$ ——Current strain rate (1/s),

α ——Material parameter, decided by fitting the experimental data.

By fitting test data, the result is as follows: α =0.0795 and $R^2 = 0.9901$. So there is an obvious linear relationship between the ratio of the dynamic to static compressive strength of microconcrete and the logarithm of the strain rate. The increase of the dynamic compressive strength of microconcrete can be expressed as Eqn. 3.2.

$$f_c^d / f_{cs} = 1 + 0.0795 \lg(\dot{\varepsilon}_c / \varepsilon_{cs}) \tag{3.2}$$

The effect of strain rate on the Young's modulus and strength of microconcrete shall be considered, when the similitude relationship is designed and adjusted. The design strength of microconcrete must be decreased correspondingly for the effect of strain rate.

3.3. Young's Modulus

Normally it is difficult to test the tangent modulus of microconcrete directly. So the secant modulus is adopted as the Young's modulus of microconcrete when the stress is 40%of the ultimate strength in the test,. The result is shown in Table 2.

Table 2 Modulus of microconcrete under different strain rate

No.	Strain rate	Young's modulus(MPa)			Average modulus(MPa)
1	10^{-5}/s	9228	9480	9276	9328
2	10^{-4}/s	10450	10034	9735	10073
3	10^{-3}/s	10700	11032	10647	10793
4	10^{-2}/s	12010	11362	12070	11814
5	10^{-1}/s	12230	13125	12634	12663

As shown in Table 2, the Young's modulus of microconcrete increases with the increase of strain rate ,obviously. Compared to that under static loading, Young's modulus of microconcrete under dynamic loading increases by 8.0%, 15.7%, 26.7% and 35.7% when the strain rate is 10^{-4}/s, 10^{-3}/s, 10^{-2}/s and 10^{-1}/s, respectively. The test result is shown in Figure 5.

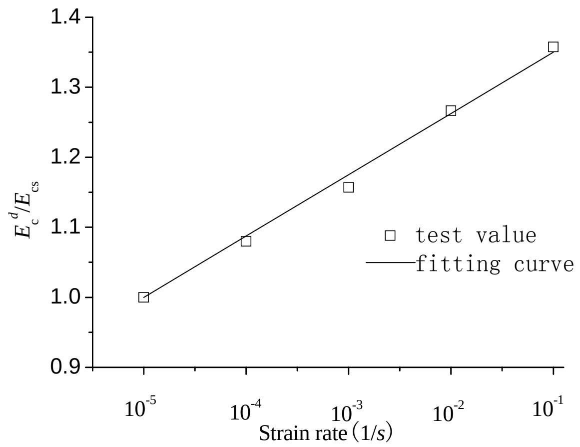

Figure 5: Modulus of microconcrete under different strain

As shown in Figure 5, the relationship between the ratio of Young's modulus of microconcrete under dynamic loading to that under static loading and the logarithm of the strain rate is linear. So the increase of Young's modulus of microconcrete under dynamic loading compared to that under static loading can be described as Eqn. 3.3.

$$E_c^d / E_{cs} = 1 + \beta \lg(\dot{\varepsilon}_c / \varepsilon_{cs}) \tag{3.3}$$

E_c^d ——Young's modulus of microconcrete under current strain rate (MPa),

E_{cs} ——Young's modulus of microconcrete under static loading(MPa),

β ——Material parameter, decided by fitting the experimental data.

By fitting test data, the result is as follows: β=0.0875 and $R^2 = 0.9945$. So there is an obvious linear relationship between the ratio of Young's modulus of microconcrete under dynamic loading to that under static loading and the logarithm of the strain rate. The increase of Young's modulus of microconcrete can be expressed as Eqn. 3.4.

$$E_c^d / E_{cs} = 1 + 0.0875 \lg(\dot{\varepsilon}_c / \varepsilon_{cs}) \tag{3.4}$$

By comparative analysis on Eqn. 3.2 with Eqn.3.4, it is found that the increase degree of compressive strength and Young's modulus of microconcrete is the same under the same strain rate. The dimension of Young's modulus and strength is same in designing similitude relationship, so the same similitude relationship is used. The result also shows that it is reasonable to simulate normal concrete with microconcrete in shaking table test.

3.4. Strain at Peak Value of Stress

Strain at peak value of stress of microconcrete under different strain rate is shown in Table 3.

Table 3 Strain at peak value of stress of microconcrete under different strain rate

No.	Strain rate	Strain at peak value of stress($\mu\varepsilon$)			Average strain($\mu\varepsilon$)
1	10^{-5}/s	1214	1183	1074	1157
2	10^{-4}/s	1187	1060	1059	1102
3	10^{-3}/s	1096	1214	1272	1194
4	10^{-2}/s	1190	1232	1394	1272
5	10^{-1}/s	1318	1140	1238	1232

As shown in table 3, it is found that strain at peak value of stress of microconcrete increases first and then decrease with the increase of the strain rate. The average strain at peak value of stress of microconcrete is 1191 $\mu\varepsilon$ under different strain rate. And the deviation of the minimum and maximum value of strain at peak value of stress of microconcrete from average strain is 7.5% and 3.5%, respectively. So it can be concluded that the strain at peak value of stress of microconcrete is invarialbe with increase of strain rate.

3.5. Failure Type

Failure type of specimens under static and dynamic loading is shown in Figure 6 and Figure 7. By comparative analysis on Figure 6 and Figure 7, it is found that failure type of microconcrete under different strain rate is similar. After test, the specimens are nearly like cones. And concrete falls off the sides. There are some crack occurs in the middle of specimens as well.

Figure 6: Failure type of specimens under static loading


Figure7: Failure type of specimens under dynamic loading

4. CONCLUSIONS

The following conclusions can be drawn from the experimental study and analysis.

(1)The dynamic compressive strength of microconcrete increases with the increase of the strain rate. The compressive strength increases by 9.4%, 17.5%, 23.6% and 30.8% compared with static compressive strength respectively，when the strain rate is 10^{-4}/s, 10^{-3}/s, 10^{-2}/s and 10^{-1}/s. There is an obvious linear relationship between

the ratio of dynamic compressive strength to static compressive strength of microconcrete and the logarithm of the strain rate. The quantitative formulas are presented in this paper, and it can be used in the design of similitude relationship.
(2)The Young's modulus of microconcrete increases with the increase of the strain rate. The Young's modulus of microconcrete under 40% ultimate loads increases by 8.0%, 15.7%, 26.6% and 35.8% compared with that under static loading respectively, when the strain rate is 10^{-4}/s, 10^{-3}/s, 10^{-2}/s and 10^{-1}/s. So there is an obvious linear relationship between the ratio of Young's modulus of microconcrete under dynamic loading to that under static loading and the logarithm of the strain rate. The quantitative formulas are presented in this paper, and it can be used in the design of similitude relationship.
(3) There is no obvious change of strain at peak value of stress of microconcrete with the increase of the strain rate.
(4) The constitutive relationship and failure type of microconcrete under different strain rate are similar.

The results of this paper can directly be used in design and adjustment of similitude relationship of microconcrete in shaking table test.

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