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Dynamic Constitutive Model of Steel Fiber Concrete

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Abstract. The paper studies the dynamic compressive strength of steel fiber reinforced concrete. ZWT constitutive model was choose as the basic framework, and the introduction of forms of damage factor Weibull function optimization, combined with M-6 and M-10 groups the experimental data determined parameters, and with the experimental obtained stress-strain curves were compared. The constitutive equation can more accurately reflect the constitutive relation of steel fiber reinforced concrete under three strain rate, and in the form of a shape parameter and scale parameter to distinguish different types of content and steel fiber concrete area, relatively simple parameters, to be close and convenient.

Introduction

At present, the dynamic performance of steel fiber reinforced concrete material focused on the dynamic tension and compression and the relevant constitutive model and numerical simulation studies [1-8]. For steel fiber type research on mechanical properties of steel fiber reinforced concrete dynamic much. Through the research on the dynamic compressive strength of flat-shaped, pressure-angled, arcuate and corrugated steel fiber reinforced concrete and comprehensive analysis of the four types of steel fibers incorporated into the dynamic properties of concrete, and further analysis of orthogonal test to find the optimal ratio of steel fiber reinforced concrete.

Sample Preparation

In this paper, steel fiber concrete material component mainly including cement, aggregate thickness, water, steel fiber and water reducing agent.

According to the requirements of the test, a total of two types of mold. SHPB test specimen using two Φ73.5mm × 36.5mm (each can be made six samples) homemade molds. Wash the mold before each use, and evenly coated with a layer of mineral oil in the mold.

After curing the specimen, the need for SHPB shock compression test using cylindrical specimens were polished to reduce the impact of error when. In this paper, China University of Mining and the Faculty of Science SHM-200-type double-end machine millstone polished specimen.

Test Programs and Processes

SFRC Mix Design

SFRC mix design principles and orthogonal pilot program, the "absolute volume method" to determine the amount of material each group 1m3 steel fiber reinforced concrete, the amount of material in each group SFRC as shown in Table 1

Dynamic Impact Test

SHPB rock dynamics test system used in this paper by the power loading unit, speed timing device, signal acquisition device, information processing and visualization system components, the material obtained in the higher strain range stress - strain relations, and control over their failure criterion failure process, the basic structure shown in Figure 3.

Test Results and Data

In this paper, a total of 21 groups of steel fiber reinforced concrete specimens points 0.3MPa, 0.35MPa and 0.4MPa pressure three kinds of the dynamic mechanical properties test. Test measured the speed of a bullet, the average strain rate, maximum strain rate, stress and peak power increase coefficients are shown in Table 3.

Table 1. Steel fiber reinforced concrete of different types of steel fibers in detail with the group M(kg/m^3).

Test No.	water	cement	sand	Coarse aggregate	Steel fiber content	Superplasticizer
M-1	170	587	540	1098	59	10
M-2	170	587	573	1065	98	10
M-3	170	587	606	1032	138	10
M-4	170	587	638	999	177	10
M-5	171	533	562	1143	98	10
M-6	171	533	597	1110	59	10
M-7	171	533	631	1075	177	10
M-8	171	533	664	1040	138	10
M-9	171	489	580	1179	138	10
M-10	171	489	615	1143	177	10
M-11	171	489	650	1108	59	10
M-12	171	489	685	1072	98	10
M-13	172	440	594	1208	177	10
M-14	172	440	630	1171	138	10
M-15	172	440	666	1135	98	10
M-16	172	440	702	1098	59	10

Establish Constitutive Model

When you create a dynamic constitutive model of SFRC, fully and rationally also own characteristics of raw materials. As described in the SFRC under impact loading viscoelastic behavior, this paper introduces Z-W-T constitutive equation can be simplified and amended.

In the form of its constitutive equation is:

$$\begin{aligned}\sigma &= \sigma_e + \sigma_{m1} + \sigma_{m2} \\ &= E_0\varepsilon + \alpha\varepsilon^2 + \beta\varepsilon^3 + E_1\int_0^t \dot{\varepsilon}\, exp\left(-\frac{t-\tau}{\varphi_1}\right)d\tau + E_2\int_0^t \dot{\varepsilon}\, exp\left(-\frac{t-\tau}{\varphi_2}\right)d\tau\end{aligned} \tag{1}$$

$\sigma_e = E_0\varepsilon + \alpha\varepsilon^2 + \beta\varepsilon^3$ represents the equilibrium state of stress and strain rate independent, there are three that describe the nonlinear elastic material, taking into account the relatively small amount of deformation of steel fiber reinforced concrete, and in the second chapter of the quasi-static compression tests, the stress - strain curve is almost linear, so you can just take the stress equilibrium first, the elastic portion is considered to be linear. $\dot{\varepsilon}$ is the average strain rate of each group, $\dot{\varepsilon} = const$, $\varepsilon = \dot{\varepsilon}t$.

$$\sigma = E_0\varepsilon + \varphi_1 E_1\dot{\varepsilon}\left[1 - exp\left(-\frac{\varepsilon}{\dot{\varepsilon}\varphi_1}\right)\right] + \varphi_2 E_2\dot{\varepsilon}\left[1 - exp\left(-\frac{\varepsilon}{\dot{\varepsilon}\varphi_2}\right)\right] \tag{2}$$

In order to complex the effect of Comprehensive Test of steel fiber content and type brings, we use Weibull function to describe the damage factor of concrete:

$$D = 1 - exp\left(\frac{\varepsilon}{F}\right)^m + D_0 \tag{3}$$

D_0 is the initial amount of damage. The steel fiber content as a controllable parameter, as the scale parameter F and shape parameter m describe the type of steel fiber brings difference, as the (4) and (5)

$$m = \left(1 + av_f\right)\left(1 + bln\,\dot{\varepsilon}\right) \tag{4}$$

$$F = \left(1 + kv_f\right)\left(1 + nln\,\dot{\varepsilon}\right) \tag{5}$$

Taking into account the steel fiber reinforced concrete initial damage is small, and the impact of the initial crack propagation process under load as the main injury. To simplify the equation, ignore the initial injury, $D_0 = 0$.

The fitting equation (3) in damage factor D formula into the formula (2), the paper used for the final:

$$\begin{aligned}\sigma &= \left(1-D\right)\left\{E_0\varepsilon + \varphi_1 E_1\dot{\varepsilon}\left[1-exp\left(-\frac{\varepsilon}{\dot{\varepsilon}\varphi_1}\right)\right] + \varphi_2 E_2\dot{\varepsilon}\left[1-exp\left(-\frac{\varepsilon}{\dot{\varepsilon}\varphi_2}\right)\right]\right\} \\ &= exp\left(\frac{\varepsilon}{F}\right)^m\left\{E_0\varepsilon + \varphi_1 E_1\dot{\varepsilon}\left[1-exp\left(-\frac{\varepsilon}{\dot{\varepsilon}\varphi_1}\right)\right] + \varphi_2 E_2\dot{\varepsilon}\left[1-exp\left(-\frac{\varepsilon}{\dot{\varepsilon}\varphi_2}\right)\right]\right\}\end{aligned} \tag{6}$$

Limited to the length of the article, this article orthogonal experimental group M-6 and M-10 steel fiber concrete set at three strain rate test data before peak stress as a case, Using Matlab software in accordance with the formula (6) fitting parameters obtained as shown in Table 2 and Table 3, all the other groups in the same test method can achieve better fitting effect.

Table 2. M-6 set of constitutive equations fit parameters table.

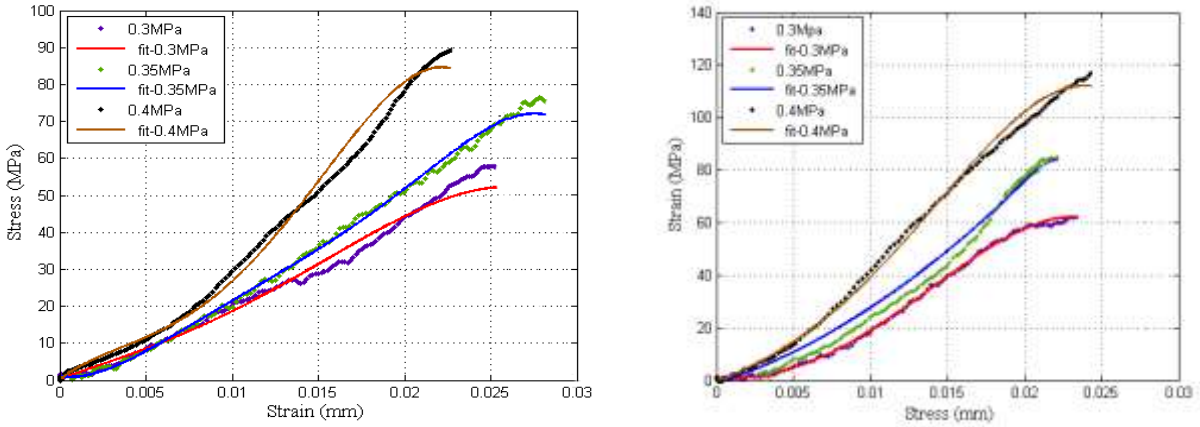
Barometric pressure(MPa)	a	b	k	n	E_0(GPa)	E_1(GPa)	φ_1(s)	E_2(GPa)	φ_2(s)
0.3	0.03645	0.9035	0.2137	0.5387	6.758	6.752	1.003E-5	6.741	6.636E-6
0.35	0.02979	0.8731	0.2114	0.5071	8.435	8.43	7.492E-6	8.428	1.858E-5
0.4	0.03209	0.8850	0.2137	0.5191	11.38	11.36	2.129E-5	11.37	3.617E-5

Table 3. M-10 group, the constitutive equation fitting parameter table.

Barometric pressure(MPa)	a	b	k	n	E_0(GPa)	E_1(GPa)	φ_1(s)	E_2(GPa)	φ_2(s)
0.3	0.03209	1.1032	0.2137	0.5788	13.48	13.45	8.71E-6	7.28	2.34E-6
0.35	0.03409	0.8852	0.2137	0.5191	13.54	13.53	5.10E-5	13.51	1.19E-5
0.4	0.02809	0.8879	0.2137	0.5191	16.06	15.94	4.32E-6	15.98	4.32E-6

From the fitting parameters, the characterization of the elastic modulus of the three parameters increase with the strain rate increasing trend, reflecting the strain rate effect of steel fiber reinforced concrete, and the shape parameter and scale parameter characterizing the impact of steel fiber type is not changed great, but also to further illustrate the type of steel fiber on the mechanical properties of concrete dynamics of weak.

Fitting results shown in Figure 1:



(a) M-6 series of tests and fitting stress-strain curve (b) M-10 group test and stress-strain curve fitting

Figure 1. Test and stress-strain curve fitting.

As can be seen from Fig.1, Z-W-T improved constitutive model can describe the dynamic mechanical properties of steel fiber reinforced concrete, test curve and fitting curve in good agreement. On the other hand, since the establishment of the fitting equation, ignoring the nonlinear elastic term damage factor of the initial damage and Z-W-T model is simplified, but also makes the calculation results with the experimental values of a certain bias.

Conclusion

This selection ZWT constitutive model as the basic framework, and the introduction of forms of damage factor Weibull function optimization, combined with M-6 and M-10 to obtain two sets of experimental data fitting parameters, and with the experimentally obtained stress - strain curves were compared analysis. The constitutive equation can more accurately reflect the constitutive relation of steel fiber reinforced concrete under three strain rate, and in the form of a shape parameter and scale parameter to distinguish different types of content and steel fiber concrete area, relatively simple parameters, to be close and convenient.

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