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MICROSTRUCTURE MODEL OF STEEL FIBER REINFORCED CONCRETE

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1. INTRODUCTION

This study presents the microstructure model of steel fiber reinforced concrete(SFRC) as a brittle-plastic heterogeneous material subjected to multiaxial loading. The constitutive properties are characterized separately on planes of various orientations within the material, called the microplanes. The state of each microplane is characterized by normal deviatoric and volumetric strains and shear strain. The behavior of fiber and concrete on each microplane is modeled and the material parameters are determined from experimental data. From the simulation for numerous test data, it is confirmed that the present model is suitable to express the behavior of SFRC in multiaxial loading.

2. MODELING OF FIBERS IN CONCRETE

Fibers inside concrete is modeled by composite material consideration[1], and based on following assumptions.

(1)All fibers are bonded inside concrete at initial loading state.

(2)Direction of fibers are normal to microplanes [see Fig.1(a)]. The relationship of the microstrain and combined bond stress of several fibers in one microplane is modeled as shown in Fig.1(b).

Then, the microscopic stress and strain relationships for fibers are as follows :

$$\sigma_V^f = C_V^f(\epsilon_V)\epsilon_V \;;\quad \sigma_D^f = C_D^f(\epsilon_D)\epsilon_D \quad \cdots\cdots \quad (1\text{-a})$$

$$\text{where } C_V^f = C_{V0}^f \, exp\left[-\frac{\epsilon_V}{a_1^f}\right]^{p_1^f} \;;\quad C_D^f = C_{D0}^f \, exp\left[-\frac{\epsilon_D}{a_1^f}\right]^{p_1^f} \quad \cdots\cdots \quad (1\text{-b})$$

and those for concrete matrix are

$$\sigma_V^m = C_V^m(\epsilon_V)\epsilon_V \;;\; \sigma_D^m = C_D^m(\epsilon_D)\epsilon_D \;;\; \sigma_T = C_T(\epsilon_T)\epsilon_T \quad \cdots\cdots \quad (2\text{-a})$$

$$\text{where } C_V^m = C_{V0}^m \, exp\left[-\frac{\epsilon_V}{a_1^m}\right]^{p_1^m} \;;\; C_D^m = C_{D0}^m \, exp\left[-\frac{\epsilon_D}{a_1^m}\right]^{p_1^m} \;;\; C_T = C_{T0} \, exp\left[-\frac{\epsilon_T}{a_3}\right]^{p_3} \quad \cdots \quad (2\text{-b})$$

where C_{V0}^f,C_{D0}^f and C_V^f,C_D^f are the initial elastic and secant moduli for fiber, C_{V0}^m,C_{D0}^m and C_V^m,C_D^m and C_T are the initial elastic and secant moduli for concrete matrix. a_1^m,a_1^f,p_1^m, p_1^f,a_3 and p_3 are material parameters. For SFRC which is considered as a composite material, the secant moduli become

$$C_V = C_V^m(1 - V_f) + C_V^f V_f \;;\; C_D = C_D^m(1 - V_f) + C_D^f V_f \quad \cdots\cdots \quad (3)$$

where V_f is the volume fraction of fiber.

3. INCREMENTAL MACROSCOPIC STRESS-STRAIN RELATION

Using the principle of virtual work to approximately enforce the equivalence of forces on the microscale and macroscale, finally the macroscopic stress-strain relation can be obtained and written in the form[2]

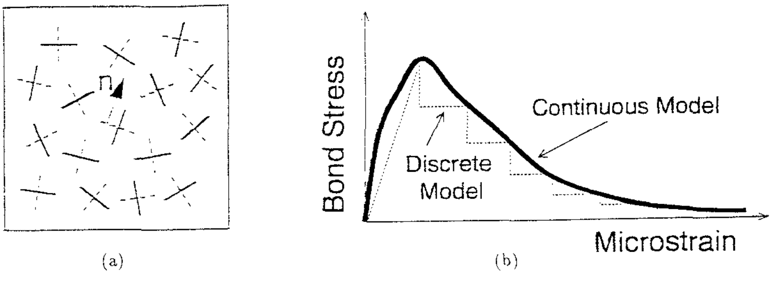

Figure 1 Modeling of fibers in concrete

(a) Fibers in microplanes ; (b) Bond stress-strain relation

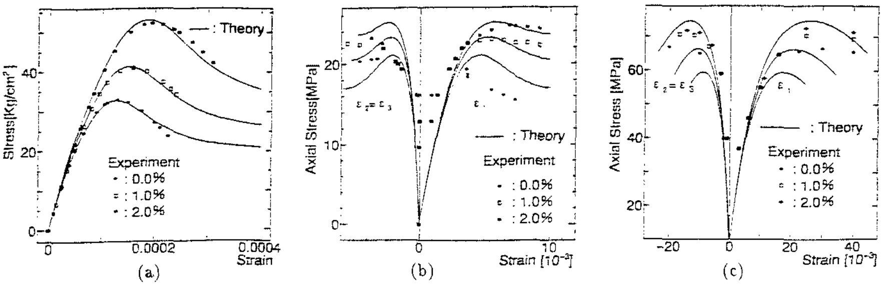

Figure 2 Comparison with experimental data

(a)Uniaxial tension ; (b)Uniaxial Compression ; (c)Triaxial Compression(p=10MPa)

$$d\sigma_{ij} = C_{ijkm} d\epsilon_{km} - d\sigma''_{ij} \quad \cdots\cdots (4)$$

where C_{ijkm} denotes the incremental stiffness tensor (elastic modulus tensor):

$$C_{ijkm} = \frac{3}{2\pi}\int_S [(C_D^t - C_T^t)n_i n_j n_k n_m + \frac{1}{3}(C_V^t - C_D^t)n_i n_j \delta_{km} + \frac{1}{4}C_T^t(n_i n_k \delta_{jm} + n_i n_m \delta_{jk} + n_j n_k \delta_{im} + n_j n_m \delta_{ik})]\ f(n)\ dS \quad \cdots\cdots (5)$$

and $d\sigma''_{ij}$ denotes the inelastic stress increments:

$$d\sigma''_{ij} = \frac{3}{2\pi}\int_S \left[n_i n_j d\sigma''_N + \frac{1}{2}(n_i\delta_{rj} + n_j\delta_{ri} - 2n_i n_j n_r)d\sigma''_{T_r}\right] f(n)\ dS \quad \cdots\cdots (6)$$

where C_V^t,C_D^t and C_T^t are the incremental elastic moduli for the current loading step for microplane and n_i is the microplane direction cosine, $d\sigma''_N$ and $d\sigma''_{T_r}$ are the inelastic normal and shear stress increments, S is the surface of a unit hemisphere and $f(n)$ is a weighting function of the normal direction n.

4. VERIFICATION WITH EXPERIMENTAL RESULTS

SFRC uni- and tri-axial compression test data are from the literature [3]. In this test, straight carbon-steel fibers with an aspect ratio of 44 were used. Specimens were made with steel fiber contents of 0(i.e.,plain concrete),1,and 2 percent in volume. For SFRC uniaxial tension test, data is from the literature [4] with the same percentages of fiber. The optimum values of the material parameters corresponding to each of these fits [see Fig.2] are listed in Table 1.

Table 1 Optimum values of material parameters

Test data	V_f	$a_1^m = a_1^p$	$p_1^m = p_1^f$	a_3	p_3
Uniaxial Tension	0%	$0.3\text{x}10^{-4}$	0.8	0.5	1.5
	1%	$0.33\text{x}10^{-4}$			
	2%	$0.378\text{x}10^{-4}$			
	V_f	$(2.97 + 39V_f)10^{-5}$			
Uniaxial Compression	0%	$4.0\text{x}10^{-4}$	0.5	1.8	
	1%	$40\text{x}10^{-4}$	0.4		
	2%	$400\text{x}10^{-4}$	0.3		
	V_f	$4\times10^{**}(100V_f)$	$0.5 - 10V_f$		
Triaxial Compression	V_f	$4.0\text{x}10^{-4}$	0.5		

5. CONCLUSION

This present model is suitable to express the behavior of SFRC in tension and compression under multiaxial loading. The experimental data can be fitted easily. Several empirical material parameters can be fixed and considered the same for all SFRC.

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