A Mechanical Model of Carbon Fiber Composite Materials based on Interfacial Effect

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Abstract: The carbon fiber cement has compression sensibility. In this paper, the compression sensitivity of carbon fiber concrete is analyzed based on shear-lag theory and single fiber pull-out testing on the basis of predecessors' researches. The results show that the change in interface resistance plays an important role on the change in resistance. The resistance increases with interfacial strain increasing. In the meanwhile, it is shown that the present research provides a comprehensive understanding on compression sensitivity of carbon fiber concrete.

Introduction

The chopped carbon fiber to be added uniformity in the cement structure material not only makes the material more strong, but also can improve its conductivity. Research at home and abroad has shown that certain ratio and process conditions of carbon fiber concrete specimen with strain-resistance effect. Many kinds of model is put forward by predecessors about the pressure sensitive mechanism of carbon fiber concrete, including the insert and pull out model of carbon fiber, conductive channel model, the tunneling effect model and series model. The resistance of the carbon fiber concrete is composed of three parts, which respectively are the resistance of carbon fiber, matrix and interface. Experiment and calculation show that when the specimen change deformation, the change of the resistance of carbon fiber and cement matrix is very small. The resistance change of sample is mainly caused by the interfacial interaction. On the basis of experimental analysis this paper compare the results of numerical simulation and set up a carbon fiber concrete mechanics model[1-2].

Experimental

A.Specimen Preparations

The sample making: the carbon fiber bundle (main technology parameter table1) is oxidized [3-4]. After drying out, draw out independent one monofil under the microscope from long carbon fiber bundle. Cement matrix coated directly on the side of rectangular strip of cardboard middle opening. The carbon fiber end is embedded in the cement matrix. Use the four-electrode resistance measurement in order to eliminate the contact resistance of the test results, shown in Figure 1.
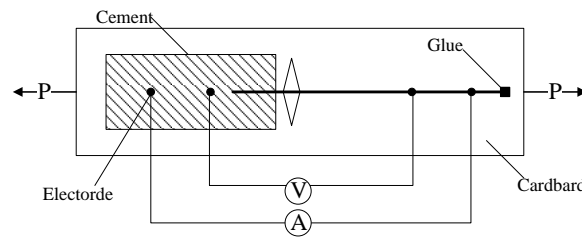
Fig1. Sample sketch

B. Carbon fiber monofilament puling out experiments

Under tensile load, Resistance rate formula the carbon fiber which is not embedded in concrete was derived and ohm's law is obeyed: $\Delta R / R = (1+\varepsilon)(1-2\upsilon_a\varepsilon)-1$ (υ_a is the Poisson's ratio of carbon fiber, $\upsilon_a = 0.27$). To compare calculation results with the experimental results, the impact of the change of carbon fiber resistance is caused by the change of the outside deformation is shown in table 1. Obviously, the change of resistance caused by the outside deformation of carbon fiber is very small, and the cement matrix changes of resistance can be ignored. Thus, in the process of the carbon fiber pulling out test, the change of resistance is mainly caused by the interface of carbon fiber cement matrix factors.

Table 1. the Influence coefficient

No.	P （mN）	Resistance rate of change $\triangle_1$（10^{-3}）	External Resistance rate of change $\triangle_2$（10^{-3}）	Influence coefficient $\triangle_2/\triangle_1$（%）
a	24.87	129	4.82	3.74
b	28.83	144	5.59	3.88
c	31.58	154	6.12	3.97
d	39.92	185	7.74	4.18

The mechanical model of CFRC

A.The micro unit mechanical model of CFRC

(1): The basic assumptions

Simplify the sample of carbon fiber pull out test for the axisymmetric concentric cylindrical model. Where L is the deepness of carbon fiber be buried, r_0 is the radius of carbon fiber radius, P is the tensiont. It is shown in figure 2.According to characteristics of its boundary, do the assumptions. (1) the carbon fiber and concrete substrate are the isotropic linear elastic material; (2) the interface between the carbon fiber and concrete substrate is ideal interface, which is only effected by the shear stress. On the interface the stress and displacement are all continuous; (3) the surface of the concrete substrate is free, regardless of the physical strength; (4) the load play on the top of the fiber and is parallel to the fiber without sliding friction at the bottom of the fibe; (5) because the carbon fiber is very thin and the stiffness is large, the radial displacement can be ignored. which w is the direction of displacement.
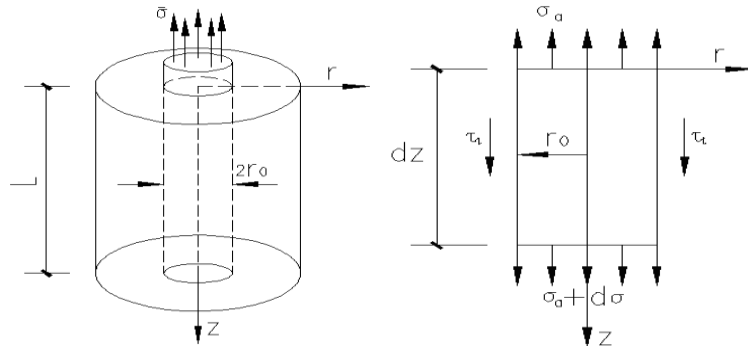
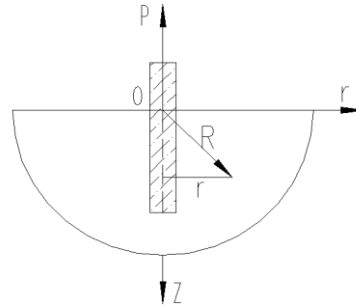Fig2. the micro carbon fiber concrete fiber monofilament drawing model

Fig3.the half space body with the concentrated tension

(2): The axial strain formula of interface eduction

According to this model, the stress and strain in the carbon fiber and matrix is all symmetry, using the cylindrical coordinates system (r, ϕ, z). All amount in the axisymmetric problem has nothing to do with coordinates ϕ. So the shear stress r_{zr} and the displacement of toroidal v are all zero. Remove the micro sectiong dz to analysis. Then remove the concrete and carbon fiber micro unit cell in the micro sectiong, which the radius is r, as shown in figure 3.

Consider the axial displacement of concrete matrix to $\tau_i = G_b \dfrac{\partial w}{\partial r}\Big|_{r=r_0}$

(1)

Where G_b is the shear modulus of concrete, τ_i is the shear stress of interface.

According to the hypothesis(2), there is $w\big|_{r=r_0} = w_i = w_0$.

Whih carbon fiber as the reasearch object, anslysis can get it, which is $\sigma_a = E_a \dfrac{dw_a}{dz} = E_a \dfrac{dw_i}{dz}$

(2)

According to the hypothesis(5), the axial stress σ_z of cement matrix near can be expressed, which is

$$\sigma_z = 2G_b(\frac{1-\upsilon_b}{1-2\upsilon_b})\varepsilon_z = 2G_b(\frac{1-\upsilon_b}{1-2\upsilon_b})\frac{dw}{dz} \qquad (3)$$

According to the shear-lag theory

$$\begin{cases} \dfrac{d^2 w_i}{dz^2} + \dfrac{2G_b}{r_0 E_a}\dfrac{\partial w}{\partial r}\Big|_{r=r_0} = 0 \\[3mm] \dfrac{d^2 w_i}{dz^2} + \dfrac{1-2\upsilon_b}{2(1-\upsilon_b)}\dfrac{1}{2}\dfrac{\partial}{\partial r}(r\dfrac{\partial w}{\partial r})\Big|_{r=r_0} = 0 \end{cases} \qquad (4)$$

According to the formula (4), We have the formula which is $w = A_2 ch\left[\sqrt{A_1}\,(L-z)\right]e^{-\frac{A_1}{K_1}r}$
(5)

Where they are $A_1 = \dfrac{K_1}{r_0} - K_1{}^2 K_2$, $K_1 = \dfrac{2G_b}{r_0 E_a}$, $K_2 = \dfrac{1-\upsilon_b}{1-2\upsilon_b}$.

Makeing $z = z$, $\sigma_a\big|_{r=r_0} = \overline{\sigma}$ and puting the faomula (5) into the formaula (3),

$$A_2 = -\frac{\overline{\sigma}}{E_a \sqrt{A_1}\, sh\left[\sqrt{A_1}\,(L-z_0)\right]}e^{\frac{A_1}{K_1}r_0} \tag{6}$$

In combination with the formula (5) and (6), we have the formula which is

$$w = -\frac{\overline{\sigma}}{E_a \sqrt{A_1}}\,\frac{ch\left[\sqrt{A_1}\,(L-z)\right]}{sh\left[\sqrt{A_1}\,(L-z_0)\right]}e^{\frac{A_1}{K_1}(r_0-r)} \tag{7}$$

Then puting the faomula (7) into the formaula (2), we have the calculationg fromulas of the interface shear stress and the axial tensile stress, which are

$$\tau_i = \overline{\sigma}\frac{G_b \sqrt{A_1}}{K_1 E_a}\,\frac{ch\left[\sqrt{A_1}\,(L-z)\right]}{sh\left[\sqrt{A_1}\,(L-z_0)\right]}, \sigma_a = \overline{\sigma}\frac{K_2 G_b}{E_a}\,\frac{sh\left[\sqrt{A_1}\,(L-z)\right]}{sh\left[\sqrt{A_1}\,(L-z_0)\right]}e^{\frac{A_1}{K_1}(r_0-r)} \tag{8}$$

According to the boundary condition of $z = 0$, the formaula does not meet this conditons of $\tau_{rz}\big|_{z=0} = 0$ and $\sigma_z\big|_{z=0} = 0$. Using the analysis method of the half space body with the concentrated tension (shown in figure 3) which can be obtained is

$$\tau_{rz}{}' = \frac{Bz^3}{(r^2+z^2)^{5\!/\!2}}, \sigma_z{}' = \frac{Drz^2}{(r^2+z^2)^{5\!/\!2}} \tag{9}$$ Assuming that when it is $z < z_0$ or $z > z_0$,

the faomula (9) or (8)is expressed the stress of the interface. When it is $z = z_0$, satisfy the following conditiongs.

$$\begin{cases} \tau_{rz}{}' = \tau_i \\ \sigma_z{}' = \sigma_b \end{cases} \tag{10}$$

we have the formula of z_0 which is $z_0 = \dfrac{r_0 K_1 K_2}{\sqrt{A_1}}\,th\left[\sqrt{A_1}\,(L-z_0)\right]$ (11)

Then puting the faomula (11) into the formaula (7) and combined with $\varepsilon_z = \dfrac{\partial w}{\partial z}$,We have the

formula which is $\varepsilon_z = \overline{\sigma}sh\left[\sqrt{A_1}\,(L-z)\right]e^{\frac{A_1}{K_1}(r_0-r)}\Big/ E_a sh\left[\sqrt{A_1}\,(L-z_0)\right]$
(12)

The formula of the axial strain in interface ($r = r_0$)is

$$\varepsilon_i = \overline{\sigma}sh\left[\sqrt{A_1}\,(L-z)\right]\Big/ E_a sh\left[\sqrt{A_1}\,(L-z_0)\right] \tag{13}$$

B. The theoretical model calculation contrast analysis

Based on results of calculating the interface strain, under the action of the force the interface shear strain gradually decreases along the axis direction. The significant change happen on where is Z=0.05mm~0.3mm, and ε_z sharply reduced by orders of magnitude. The figure 4

shows the interface strain distribution of the monofilament tensilet specimens under the action of 62.51 mN. The figure 5 shows the trend of strain curve under the condition of four kinds of tension(a,b,c,d). Obviously, that the trend curve is upward, which proved the strain of each point gradually increases as the tension increases.
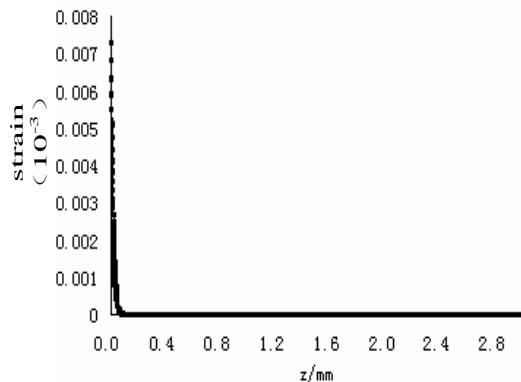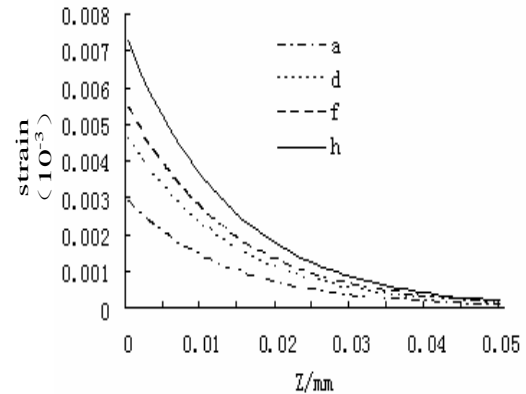

Fig4. the interface strain distribution tensions

Fig5. interface strain distribution under different

Conclusions

In monofilament drawing experiment, the overall resistance variation is made up of changes the resistance of the carbon fiber, cement matrix and interfacial resistance. The former occurs because carbon fiber and cement matrix geometric size change under external force. Under the action of external force of 50 mN, the change of the whole specimen geometry are extremely small. So the resistance change of carbon fiber and cement matrix can be neglected. The total resistance change of the carbon fiber reinforced concrete specimen under the effect of external force is mainly interface resistance changes, which have the direct relationship with the interface deformation. The total resistance change gradually increase along with the increase of interface strain.

Acknowledgements

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