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MICROSTRUCTURAL SHEAR MODEL FOR STEEL FIBER REINFORCED CONCRETE

Yokohama National University Student Member Sunaryo SUMITRO
Yokohama National University Member Tatsuya TSUBAKI

1. INTRODUCTION

A mathematical model is presented in this study for the deformational behavior of a steel fiber on a crack surface of steel fiber reinforced concrete(SFRC) under shear loading. The effect of the inclining angle between a steel fiber and a crack surface is taken into account. In the present model it is assumed that debonding of fiber is completed once shear load is applied and the load is sustained by frictional resistance.

2. MICROSTRUCTURAL SHEAR MODEL

For a steel fiber subject to a shear force f_t, local failure occurs in the matrix under the fiber near the crack plane. Due to the local failure the axial force P which pulls out the fiber is produced by the applied shear force (see Fig. 1). Therefore, the longitudinal fiber pullout model can be used for a fiber loaded transversely by a shear force as in the present case.

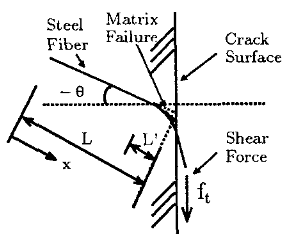

Fig. 1 Failure Condition under Shear

Table 1 Size of Matrix Failure Domain

θ (deg)	Prepeak Stage	Postpeak Stage
0	Small	Small
−45	Small	Large
+45	Medium	Medium

An elastic fiber with elastic modulus E_f and diameter d is embedded in a stiff matrix and is pulled by an axial force P at its end $x = L$ where L is the embedded length and x is the coordinate measured from the embedded end of the fiber. Considering the failure condition of mortar matrix as shown in Table 1, the size of the local failure of the mortar matrix L' in the prepeak stage can generally be neglected. For inclining angle $\theta = +45°$, however, the failure size is medium. Therefore, it needs extra parameters (δ_1, δ_2) to express the local failure in the prepeak stage (see Table 2).

The slippage $s(x)$, axial strain $\epsilon(x)$, and axial force $F(x)$ of the fiber at an arbitrary point x can be governed by the following equations [1].

$$s(x) = s(0) + \int_0^x \epsilon(x')\,dx'; \quad \epsilon(x) = \frac{4}{\pi E_f d^2} F(x); \quad F(x) = \int_0^x \pi\tau d\,[1 + \epsilon(x')]dx' \quad \cdots\cdots (1)$$

where the constant frictional bond along the embedded length of the fiber $\tau = \frac{P}{\pi d L}$.

Subsituting $\epsilon(x)$ into $F(x)$, the following differential equation is obtained.

$$\frac{dF}{dx} - \frac{4\tau}{E_f d} F = \pi\tau d \quad \cdots\cdots (2)$$

Assuming that $s(0) = 0$, the above equations may be solved to obtain the peak load P^*, the displacement of the loaded end at peak load δ^* and the axial strain $\epsilon(x)$ as

$$P^* = F(L) = \frac{1}{4}\pi E_f d^2 \left[\exp\left(\frac{4\tau L}{E_f d}\right) - 1\right]; \quad \delta^* = \delta(L) = \frac{E_f d}{4\tau}\left[\exp\left(\frac{4\tau L}{E_f d}\right) - 1\right] - L \quad \cdots (3)$$

$$\epsilon(x) = \exp\left(\frac{4\tau L}{E_f d}\frac{x}{L}\right) - 1 \quad \cdots\cdots (4)$$

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79-5 Tokiwadai, Hodogaya-Ku, Yokohama 240 TEL 045-339-4043 FAX 045-331-1707

Table 2 Optimum Values of Material Parameters of Shear Model

Test Data	θ (deg)	a_e	p_e	a_p	P^* (N)	δ_1 (mm)	δ_2 (mm)
SH−64−0	0	4.29		0.40	162	–	–
SH−64−45	−45	3.96	0.006	0.20	188	–	–
SH−64+45	+45	4.80		0.42	125	0.6	5.0

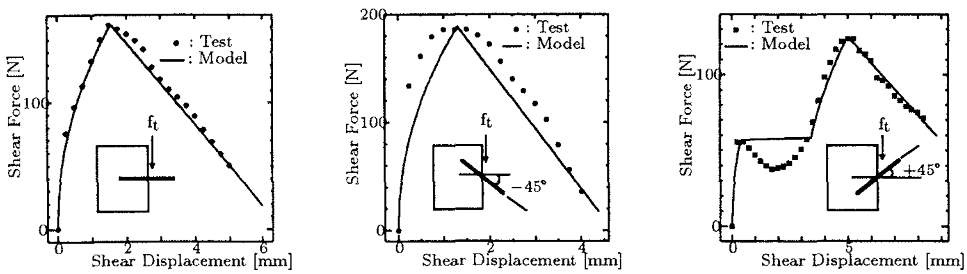

Fig. 2 Relationship between Shear Force and Shear Displacement

For $(L/d)/(E_f/\tau) \ll 1$, the axial strain may be linearized and the load P and displacement δ can be related through the following equation.

$$P(\delta) = \pi\sqrt{\frac{E_f d^3 \tau \delta}{2}} \qquad (\delta \leq \delta_0) \quad \cdots (5)$$

The force-dependent elastic modulus of fiber is modeled as

$$E_f = E_{f0} \exp\left[-a_e \left(\frac{P(\delta)}{P^*}\right)^{p_e}\right] \quad \cdots (6)$$

where E_{f0} is the initial elastic modulus. $\delta_0 \equiv 2L^2\tau/E_f d$ corresponds to the displacement δ at which the load P reaches its maximum value.

After reaching its peak without rupture, fiber pullout continues and the pullout load decreases. Assuming frictional bond and ignoring the elastic elongation of the fiber, the pullout force can be related to the load point displacement δ through the following equation.

$$P(\delta) = \pi\tau L d\left[1 - \frac{(\delta - \delta_0)}{L_p}\right] \qquad (\delta_0 < \delta \leq L) \quad \cdots (7)$$

where L_p is the frictional length between fiber and matrix and is expressed as follows.

$$L_p = a_p L \quad \cdots (8)$$

3. VERIFICATION WITH EXPERIMENTAL RESULTS

A set of SFRC shear tests [2] have been done to investigate the shear force - shear displacement relationship. In those shear tests the fiber inclination effect under shear load is examined with fiber inclining angle $\theta = 0°, -45°, +45°$. To simulate the experimental results, the following parameters are used: $E_{f0} = 2.0\text{x}10^5\text{N/mm}^2$, $L = 12.5$mm and $d = 0.55$mm. The optimum values of other material parameters are listed in Table 2 and the data fits are shown in Fig. 2.

4. CONCLUSION

A shear model taking into account the microscopic shear behavior is proposed for SFRC. Comparing with the experimental results, it is confirmed that the present model is suitable to express the mechanical behavior of SFRC after cracking under shear loading.

REFERENCES

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