Analysis for Flexural Failure Behavior of PET Fiber Reinforced Cementitious Composites by Means of 3-D Meso-scale Analysis

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1. Introduction

Fiber reinforced cementitious composites, having potential for facilitating increased ductility and crack resistance, have been anticipated as a material able to realize sustainable structures. While diversification of fiber types has been advanced, a variety of material design methods have proposed to achieve the required mechanical performance. However, there have been few material design methods in which fiber distribution can be considered or fracture mechanism can be predicted. Therefore, the authors proposed that 3-D meso-scale analysis based on a rigid-body spring model (RBSM) [1]. This paper presents flexural analysis of PET fiber reinforced concrete using the proposed model to verify the reinforcement mechanisms.

2. Outline of the Proposed Model

Fig. 1 shows an example of a pair of Voronoi cells composing the element stiffness matrix in the 3-D RBSM. These Voronoi cells were assumed to be rigid bodies, while setting 6 degrees of freedom for each cell. Six springs were placed on each boundary plane of each cell, in the normal and tangential to the boundaries and rotational directions. As shown in Fig. 2, a zero-size spring was placed on a point where a fiber crosses a boundary of two Voronoi cells, and the bridging stress of the fiber acted on the spring. The embedment length, l, and the angle to normal, ϕ, were calculated for each fiber. The stress transfer by fibers across a crack was calculated using the steps shown in Fig. 3. The slip distribution of a fiber and the bond stress-slip relation are necessary at this stage. These are identified through analysis of single fiber pullout testing [2].

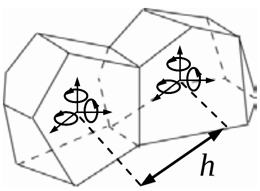

Fig. 1: Voronoi cells

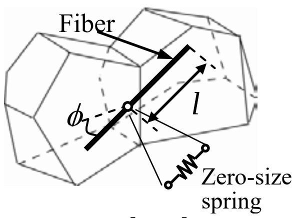

Fig. 2: Fiber location and zero-size spring

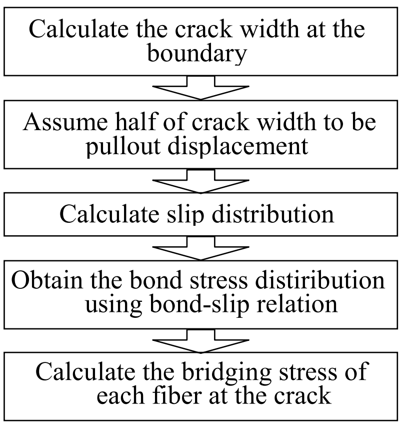

Fig. 3: Procedure for calculation of fiber bridging stress

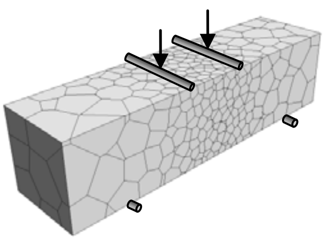

Fig. 4: 3D RBSM Voronoi diagram for simulation

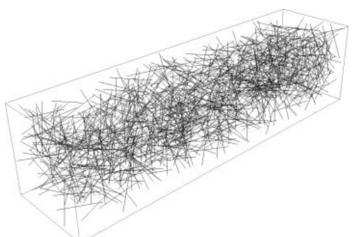

Fig. 5: Discretized fiber distribution

3. Flexural Analysis of PET Fiber Reinforced Concrete

The analysis model is shown in Fig. 4. Dependence of the mesh size and shape was minimized by adopting Voronoi discretization. Fibers were modeled by dispersing using random numbers, as shown in Fig. 5. Table 1 gives the physical properties for the analysis. Values identified by the single fiber

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Table 1: Input material poroperties

Fiber	Volume fraction (%)	0.5
	Length L_f (mm)	45
	Diameter d_f (mm)	0.7
	Elastic modulus E_f (GPa)	20
	Strength σ_{fu} (MPa)	350
Matrix	Tensile Strength σ_{mu} (MPa)	4.2
	Elastic modulus E_m (GPa)	39.6
	Fracture energy G_{ft} (N/m)	100
Interface (bond)	Frictional bond strength τ_i (MPa)	4.0
	Chemical bond strength τ_s (MPa)	7.0
	Stiffness G (MPa/mm)	95

pullout bond testing [2] were used for properties of the fiber-matrix interface. Fig. 6(a) shows the load-displacement relations obtained by analysis, as well as experimental results. The analysis results adequately expressed the experimental results. Fig. 7 shows the cracks at the times of 3mm in displacement.

In order to confirm the effect of fiber length on flexural toughness, analysis was conducted by changing the fiber length to 15 and 30mm. Fig. 6(b) shows the load-displacement relations, and Fig. 8(a) shows the ratio of fiber rupture to the number of fibers across a crack in the matrix (hereafter referred to as “ratio of fiber rupture”). This figure reveals that the influence of differences in fiber length on load-displacement is small, but that the ratio of fiber rupture differs greatly in each case. When fiber length is 30 and 45mm, 30 ~ 40 percent of bridging fibers are ruptured, thereby causing load decrease. It follows from these results that there is room for achieving improvement of flexural toughness, if fiber strength can be further enhanced. Therefore, analysis was conducted when the fiber strength was assumed to be 700MPa. Fig. 6(c) shows the load-displacement relations, and Fig. 8(b) shows the ratio of fiber rupture. The increase in flexural toughness with fiber length of 45mm is observed. This is because fiber rupture did not occur by enhancement of fiber strength.

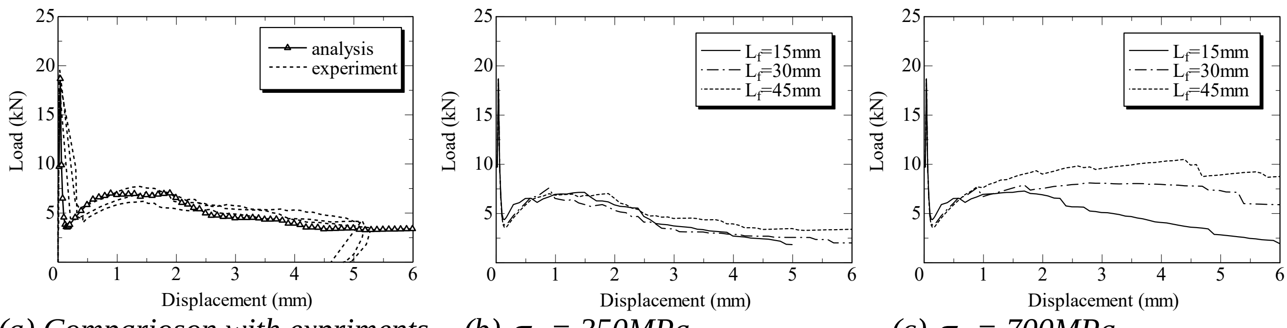
4. Conclusions

In this study, flexural analysis of PET fiber reinforced concrete was conducted using the proposed model. The findings obtained include the following: 1) This model can well simulate load-displacement relations obtained from experiments. 2) In the case of fiber length of 30mm and 45mm, 30 ~ 40 percent of fibers across a crack were ruptured, and it causes load decrease.

5. Reference

[1] Kawai, T., “New Discrete Models and Their Application to Seismic Response Analysis of Structures”, *Nuclear Engineering Design*, Vol.48, 1978, pp. 207-229.

[2] Fukuoka, M., et al., “Study on the Mechanical Characteristics and the Applicability of Short Fibers of Recycled Polyethylene Terephthalate (PET) for Protection and Lining”, *Proceeding of the Symposium of Rock Mechanics*, Vol. 34, 2005, pp.507-512 (in Japanese).



(a) Comparioson with expriments *(b) σ_{fu} = 350MPa* *(c) σ_{fu} = 700MPa*

Fig. 6: Load-displacement relations

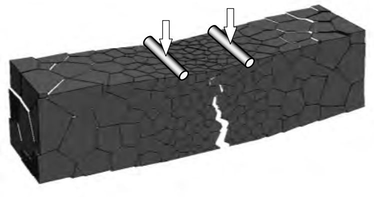
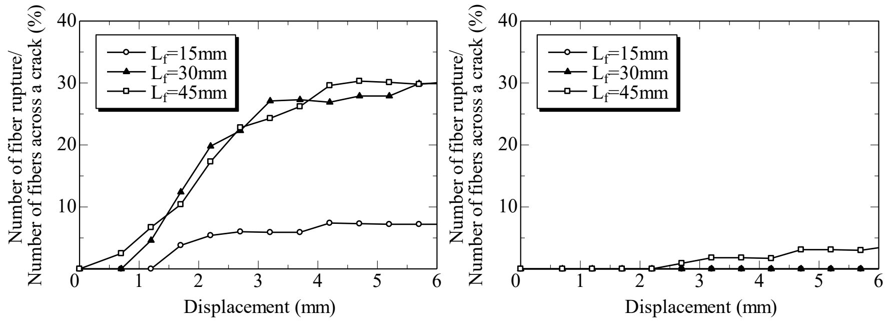


Fig. 7: Deformation at failure



(a) σ_{fu} = 350MPa *(b) σ_{fu} = 700MPa*

Fig. 8: Ratio of fiber rupture