第V部門

2024年9月5日(木) 9:30 ~ 10:50 C306(川内北キャンパス講義棟Ｃ棟)

短繊維補強コンクリート（材料）(1)

座長：岩下 健太郎（名城大学）

10:20 ~ 10:30

[V-382] Sensitivity Analysis of Fiber Dimensions on Bridging Performance of PVA-FRCC

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キーワード：PVA fiber、PVA-FRCC、fiber dimension、bridging law calculation、bridging performance

In this research, the effect of fiber dimensions (diameter and length) of PVA fiber on the bridging performance of PVA-FRCC was studied. 11 different fiber diameters and 9 different fiber lengths were considered to study the effect. Single fiber pullout model was developed for all fiber diameters and bridging law calculation was performed. The bridging performance is highly affected by fiber diameter whereas the fiber length has an insignificant effect on it. The bridging stress increases as the fiber diameter decreases. The smaller fiber diameter shows a sudden rupture of fibers while there is no ruptured fiber for fibers with a diameter greater than 0.2mm.

Sensitivity Analysis of Fiber Dimensions on Bridging Performance of PVA-FRCC

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1. INTRODUCTION

Polyvinyl alcohol (PVA) fibers are high-performance reinforcement fibers used in mortar and concrete that have high modulus of elasticity, high tensile strength, and superior crack-bridging capabilities.

Bridging law is expressed by tensile stress-crack width relationship, which measures the fibers' ability to bridge at the crack. The property of the matrix, fiber, and fiber-matrix interface define the bridging performance of FRCC [1]. This study investigates the effect of fiber dimensions (diameter and length) of PVA fibers on the bridging performance of PVA-FRCC.

2. BRIDGING LAW CALCULATION

Bridging law is calculated by summations of pullout load of every single fiber bridging the crack surface [1]. Several researchers have identified that the bond behavior of PVA fibers consists of two stages: the chemical bond stage and the friction stage. As shown in Fig. 1, PVA fibers' pullout load-crack width relationship commonly exhibits the first peak in the debonding process of the chemical bond and slip hardening and softening.

2.1 Bridging law calculation considering fiber diameter

The authors have developed single fiber pullout models for 0.1mm diameter PVA fiber. Based on this model, the single fiber pullout models for other diameters are assumed using the following concept. Since the first peak load, P_a, results from the debonding of the chemical bond and the materials have the same chemical composition, the first peak load is considered to show the proportional relations with fiber perimeter. The debonding of the chemical bond is assumed to cause at the same slip from the matrix, and the same crack width at first peak load, w_a, is considered for all fiber diameters. The maximum pullout load, P_{max}, is determined using the fundamental bond equilibrium conditions that Asano et.al. developed based on the relationship between the bond strength and bond fracture energy as shown in Eq. (1). [2]

$$P_{max} = \sqrt{2G_f E_f a_f \phi_f} \qquad (1)$$

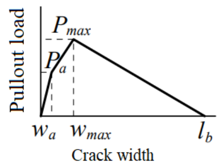

Fig. 1 Single fiber pullout model

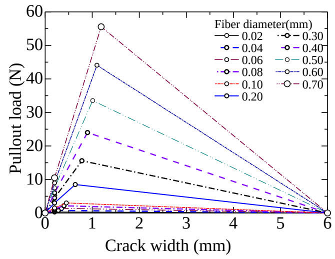

Fig. 2 Single fiber pullout model considering fiber diameter

Table 1. Parameters for bridging law calculation

Fiber diameter (mm)	First peak load, P_a(N)	Crack width at P_a, w_a (mm)	Maximum load, P_{max} (N)	Crack width at P_{max}, w_{max} (mm)
0.02	0.3	0.2	0.30	0.20
0.04	0.6	0.2	0.76	0.28
0.06	0.9	0.2	1.39	0.35
0.08	1.2	0.2	2.15	0.40
0.1	1.5	0.2	3.00	0.45
0.2	3.0	0.2	8.49	0.64
0.3	4.5	0.2	15.59	0.78
0.4	6.0	0.2	24.00	0.90
0.5	7.5	0.2	33.54	1.01
0.6	9.0	0.2	44.09	1.10
0.7	10.5	0.2	55.56	1.19

Snubbing coefficient $f = 0.5$
Fiber strength reduction factor $f' = 0.3$
Fiber orientation intensity, $k = 1$
Fiber strength, $\sigma_{fu} = 774$MPa
Elastic modulus, $E_f = 28$GPa
Bond fracture energy, $G_f = 0.00651$N/mm
Fiber volume fraction, V_f=2% and Length, l_f= 12mm

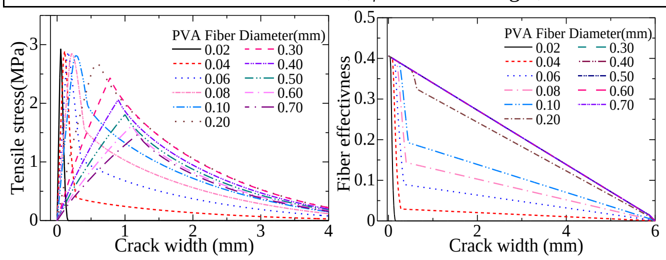

Fig. 3 Calculated bridging law and fiber effectiveness considering fiber diameter

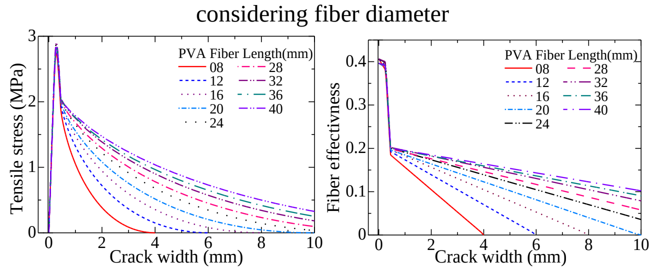

Fig. 4 Calculated bridging law and fiber effectiveness considering fiber length

Where G_f is bond fracture energy of fiber which is calculated from the value of the 0.1mm diameter fiber. E_f, a_f and ϕ_f are the elastic modulus, cross-sectional area, and perimeter of

Keywords　PVA fiber, PVA-FRCC, fiber dimension, bridging law calculation, bridging performance
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fiber respectively. From a rigid-plastic model of the bond stress-slip relationship, it is assumed that the maximum crack width, w_{max} has a proportional relation to the square root of fiber diameter. The parameters for single fiber pullout model considering fiber diameter and parameters for bridging law calculation are shown in Table 1, and the models are illustrated in Fig.2.

2.2 Bridging law calculation considering fiber length

The bridging law calculation for 8mm, 12mm, 16mm, 20mm, 24mm, 28mm, 32mm, 36mm, and 40mm fiber lengths are conducted using the single fiber pullout model for 0.1mm diameter fiber, keeping the other parameters the same as shown in Table 1.

3. BRIDGING LAW CALCULATION RESULT

The result of the bridging law calculations considering fiber diameter and fiber length are shown in Fig. 3 and Fig. 4. The left figures show tensile stress-crack width curves, and the right figures show fiber effectiveness (the ratio of numbers of bridging fibers to total fibers) -crack width curves. As Fig. 3 shows, when the diameter of the fiber increases the maximum bridging stress decreases. The smaller diameter fibers have high slope of softening curves due to the sudden rupture of the fibers. In contrast, the larger diameter fibers have low slope of softening curve. The inflection stress increases as the diameter increases up to 0.2mm fiber diameter and then decreases for greater fiber diameters due to the gradual slipping out of the fibers. For diameters greater than 0.2mm, the maximum tensile stress and the inflection stress are equal which shows that all the fibers are slipped out. This phenomenon is also shown in terms of fiber effectiveness. As shown in Fig. 4 the maximum tensile stress is almost the same for all fiber lengths and shows the same characteristics until the inflection stress. After the inflection stress it has different softening slope due to the gradual slipping out of the fiber.

Based on these results, a trilinear model is proposed to represent the relationship between tensile stress and crack width in the FRCC, as illustrated in Fig. 5. The first stage shows fiber slip out, the second stage shows sudden fiber rupture of some of the fibers, and the final stage shows gradual slip out the fibers. The maximum tensile stress, σ_{max}, crack width at maximum stress, δ_{max}, inflection stress, σ_2,

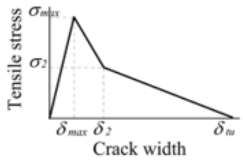

Fig. 5 Tri-linear model for bridging law

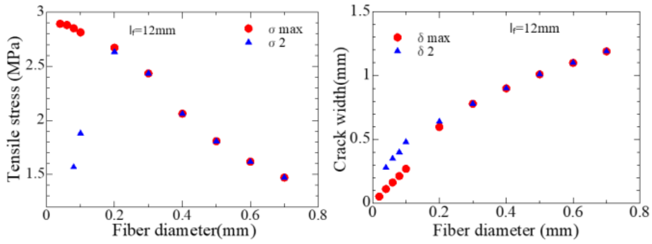

Fig. 6 Stress and crack width parameters for tri-linear model considering fiber diameter

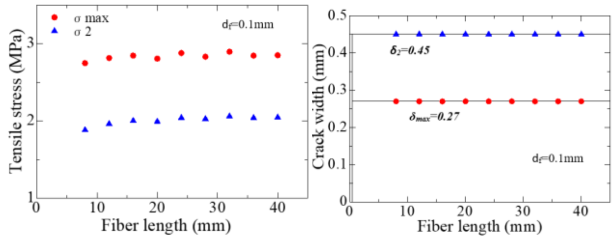

Fig. 7 Stress and crack width parameters for tri-linear model considering fiber length

and crack width at inflection stress, δ_2, are determined from the bridging law calculation. The relationship between PVA fiber dimensions (diameter and length) and the stress and crack width parameters for the tri-linear model are shown in Fig. 6 and Fig. 7. The inflection stress, σ_2, is the stress where the rupture of some of the fibers ends and the gradual slip out of the rest of fibers starts. The crack width at this stress is the same as the crack width from the single fiber pullout model where the slip hardening stage ends, and the slip softening stage starts ($\delta_2=w_{max}$)

CONCLUSION

1. The bridging performance is highly affected by the fiber diameter, whereas the fiber length has an insignificant effect on it. The bridging stress increases as the fiber diameter decreases.
2. The smaller diameter fibers show sudden rupture of the fibers but there are no ruptured fibers for fibers that have a diameter greater than 0.2mm.

REFERENCE

[1] Kanakubo T., Miyaguchi M., and Asano K. 2016. "Influence of Fiber Orientation on Bridging Performance of PVA-FRCC" *ACI Materials Journal* 113 (2): 131-141.

[2] Asano K, Yasojima A, and Kanakubo T, 2008. "Study on Bond Splitting Behavior of RC Members" AIJ, Vol. 73, N. 626, 641-646