第V部門

2024年9月5日(木) 11:10 ~ 12:30 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）(2)

座長：佐々木 亘（三井住友建設）

12:00 ~ 12:10

[V-389] Uniaxial Tension Test for Fiber-Reinforced Cementitious Composite with Thin Fiber

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キーワード：FRCC、PVA、単軸引張試験、架橋則

本研究では,繊維配向の影響を除いた繊維補強セメント複合材料 (FRCC)の引張特性を評価するために,細径短繊維を用いたFRCCの単軸引張試験を行い,実験結果をトリリニア架橋モデルによる計算結果と比較した。実験結果は,繊維破断の可能性を考慮した計算結果に良く適合することを示した。

Uniaxial Tension Test for Fiber-Reinforced Cementitious Composite with Thin Fiber

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1. INTRODUCTION

Fiber-reinforced cementitious composite (FRCC) is a cement-based composite material incorporating short fibers to enhance its tensile property. To clarify the pullout behavior of fibers, it is necessary to perform a direct pullout test on single fiber embedded in the matrix [1]. However, conducting direct pullout tests on micro-diameter fibers can be challenging due to handling difficulties. Therefore, in this research, a uniaxial tension test was conducted on FRCC to evaluate the pullout behavior of thin fiber, while excluding the influence of fiber orientation.

2. EXPERIMENT OVERVIEW

Ten specimens were prepared following the mixture proportion of PVA-FRCC presented in Table 1. The dimension of specimens, as shown in Fig. 1, has a length of 30 mm and a cross-sectional area of 5 mm × 5 mm at the target test region. The employed specimen dimension design method ensures approximately consistent fiber orientation within the specimen, which excluding the influence of fiber orientation on tensile property. The uniaxial tension test was conducted using an electronic system universal testing machine with a capacity of 200 N and a load speed of 1 mm/min. Additionally, a compression test with ϕ 100 mm × 200 mm cylinder test pieces was conducted.

3. TEST RESULTS

3.1 Compression test

The compressive strength experimental result is presented in Table 2. The average compressive strength is 49.1 N/mm^2, and the average elastic modulus is 19.2 kN/mm^2.

3.2 Uniaxial tension test

Ten specimens were prepared for testing. Three specimens were excluded due to fractures during demolding, and two specimens developed cracks before loading. During testing, specimen 1, 2, and 3 showed one crack, while specimen 6 and 7 showed two cracks. The tensile load-head displacement relationship obtained from the uniaxial tension test is shown in Fig. 2, excluding specimen 4 and 5, which showed cracks before the experiment. According to the figure, specimen 3 and specimen 6 show better experimental results compared to the others. Therefore, for the following comparison with the calculation, the experimental data of specimen 3 and specimen 6 were used.

Table 3 gives the tensile properties of the specimens obtained from the experiment. The table shows that the maximum tensile loads of specimen 3 and specimen 6 are 114.56 N and 107.79 N, respectively, and the average tensile strength of the experiment is 2.54 N/mm^2. From this table, it is evident that the experimental data have large discrepancies, which may be attributed to the small size of the experimental section.

Table 1 Mixture proportion of PVA-FRCC (V_f = 2%)

Series	W/B	FA/B	Unit weight (kg/m^3)			
			W	C	FA	S
Fc36-2%	0.39	0.30	380	678	291	484

V_f: fiber volume fraction; C: high early strength Portland cement; FA: fly ash type II; S: silica sand; W: water;
Fiber: polyvinyl alcohol (PVA), diameter 0.1mm, length 12mm

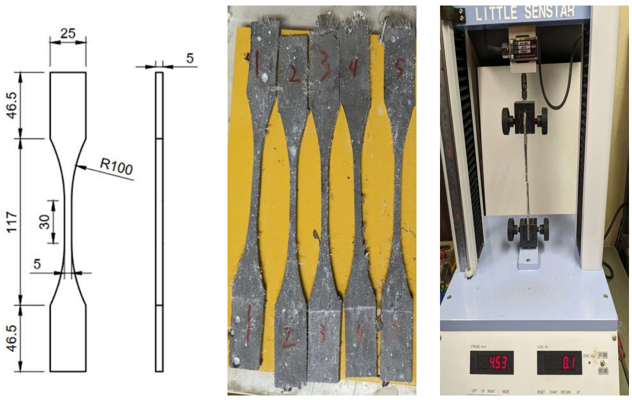

Fig. 1 Dimension of specimens (Unit: mm)

Table 2 Compressive strength test result

Series	Average compressive strength (N/mm^2)	Average elastic modulus (kN/mm^2)
Fc36-2%	49.1	19.2

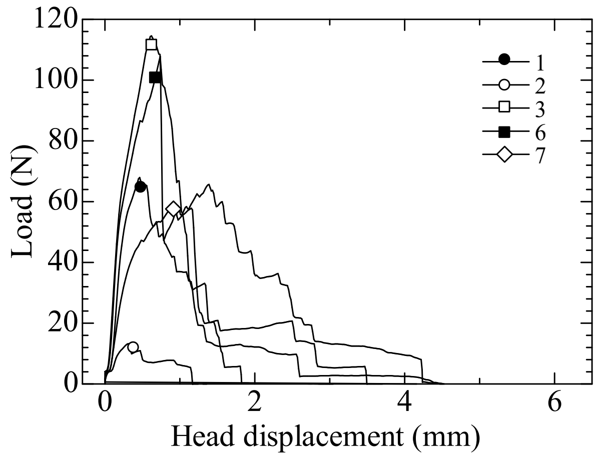

Fig. 2 Tensile load-head displacement relationship

Keywords　FRCC, PVA, Uniaxial tension test, Bridging law
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4. CALCULATION OF BRIDGING LAW

4.1 Method of calculation

In this research, the only factor affecting the fiber pullout behavior is the embedded length of individual fiber since the influence of fiber orientation has been eliminated, as shown in Fig. 3. Therefore, the calculated bridging force can be obtained using Equation (1) with the trilinear bridging model shown in Fig. 4 [2] and fiber rupture. The fiber rupture probability (P_r) is a function of n. In this research, n is set to be 1000 and P_r is assumed to be 0.006.

$$F_{bridge} = \sum_{l_b \leq l_f/2} \begin{cases} F_i(l_b) & (P > P_r) \\ 0 & (P \leq P_r) \end{cases} \qquad (1)$$

$$P_r = f(n)$$

F_{bridge}: bridging force; $F_i(l_b)$: pullout force of single fiber
P_r: fiber rupture probability; l_b: embedded length
l_f: fiber length; n: assumed number for calculation

4.2 Monte Carlo simulation

In this calculation method, the results vary depending on which fibers with different embedded lengths rupture. Therefore, Monte Carlo simulation (MCS) was used to analyze the dispersion. A total of 600 trials were conducted, as shown in Fig. 5. The x-axis represents the number of trials, and the y-axis represents the bridging strength (=maximum bridging force) of each calculation trial. The bridging force-crack width relationships for the cases of maximum, minimum, and average strength are shown in Fig. 6. The maximum bridging strength is 119.98 N, the minimum is 103.66 N and the average is 112.59 N in this MCS, with a standard deviation (SD) of 2.87 N.

Fig. 7 shows the comparison of experimental results with calculated results. The red line in Fig. 7 represents the average relationship of 600 trials which is the same line as in Fig. 6. The figure shows that the calculated result is in good agreement with the experimental results.

5. CONCLUSION

A uniaxial tension test was conducted on FRCC to evaluate the pullout behavior of thin fiber excluding the influence of fiber orientation. The calculated results were compared to the experimental results, and it was determined that the trilinear bridging model provided a better fit to the experimental data, taking into consideration of the fiber rupture probability.

ACKNOWLEDGEMENTS

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REFERENCES

[1] 浅野浩平，金久保利之：高性能繊維補強セメント複合材料における短繊維の付着性状に関する研究：その1:PVA 単繊維の付着実験，AIJ 大会梗概集，821-822，2010.

[2] Toshiyuki Kanakubo, et al.: Influence of Fiber Orientation on Bridging Performance of Polyvinyl Alcohol Fiber-Reinforced Cementitious Composite, Materials Journal, 113(2), 131-141, 2016.

Table 3 Tensile properties

No.	Maximum load (N)	Cross-sectional area (mm^2)	Tensile strength (N/mm^2)	HD at max load (mm)	Average tensile strength (N/mm^2)
1	67.94	27.96	2.43	0.464	2.54
2	13.26	26.26	0.50	0.309	
3	114.56	28.34	4.04	0.621	
6	107.79	29.92	3.60	0.738	
7	59.53	28.08	2.12	0.930	

HD: head displacement

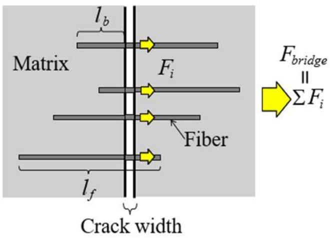

Fig. 3 Calculation model

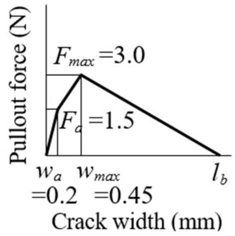

Fig. 4 Bridging model[2]

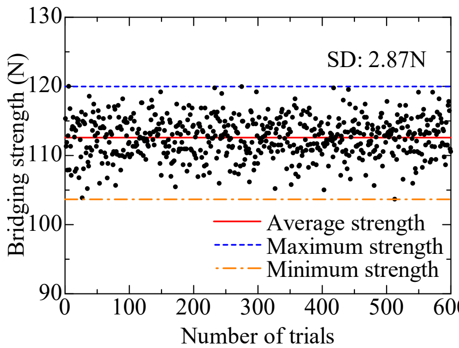

Fig. 5 Calculation results in MCS

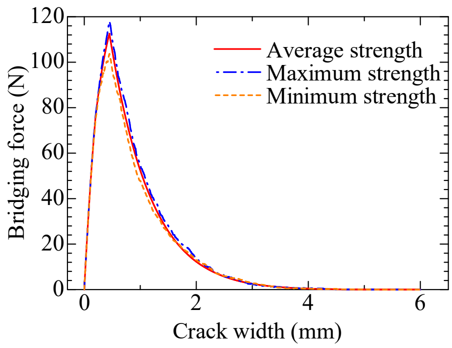

Fig. 6 Bridging force-crack width relationship

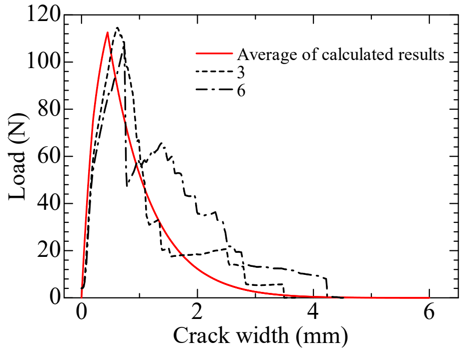

Fig. 7 Comparison of experiment and calculation