

ポスター発表 | 第V部門

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補修・補強 (材料) / 短繊維補強コンクリート (材料)

座長：審良 郁夫 (オリエンタルコンサルタンツ)

[12PM2-Oe-02] Bridging Model of Aramid Monofilament in Fiber-Reinforced Cementitious Composite

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キーワード：FRCC、アラミド繊維、単糸、一軸引張試験、架橋則、断面解析

著者らはアラミド単糸に着目し、単引抜き試験の代替としてアラミドFRCCの一軸引張試験を実施している。引張試験の結果と合致させるように単繊維の架橋モデルを決定した。架橋モデルを用いて計算によって架橋則を求め、一軸引張試験の結果を再現することができた。架橋則の計算結果を用いて、アラミドFRCCの引張応力-ひずみ関係を仮定し、断面解析を行った。解析結果は、アラミドFRCCの4点曲げ試験の結果と良好に一致した。

The authors have focused on aramid monofilament and conducted the uniaxial tension test of aramid FRCC as an alternative to single-fiber pullout test. A bridging model for the single fiber is identified to match the tensile test results. The calculation of the bridging law is able to reproduce the uniaxial tension test results. Using the bridging law calculation results, the tensile stress-strain relationship of aramid FRCC is assumed, and a section analysis is performed. The analysis results showed good agreement with the test results of four-point bending test of aramid FRCC.

Bridging Model of Aramid Monofilament in Fiber-Reinforced Cementitious Composite

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1. INTRODUCTION

The authors have proposed an evaluation method for bridging law to assess the tensile characteristics of fiber-reinforced cementitious composites (FRCC). This method considers the pullout behavior of the single-fiber bridging model and combines the pullout forces to derive the tensile stress-crack width relationship of FRCC. The proposed approach requires a bridging model that represents the pullout behavior of a single fiber, which can be obtained through pullout tests. However, conducting such tests becomes challenging when dealing with fine fibers with diameters in the range of a few micrometers. The authors have focused on aramid monofilament with a diameter of 0.012 mm and conducted the uniaxial tension test as an alternative to single-fiber pullout test [1]. In this report, a bridging model calibrated to match the result of uniaxial tension test is reported, along with a comparison between the calculated bridging law using this model and the results of bending test of aramid-FRCC.

2. UNIAXIAL TENSION TEST OF FRCC [1]

The mixture proportion of FRCC is shown in Table 1. Aramid monofilament shown in Table 2 is used with the volume fraction of 0.5%. The compressive strength of FRCC obtained by ϕ 100-200 mm cylinder test pieces at the loading age of the uniaxial tension test is 45.4 MPa. Fig. 1 shows the dimensions of the uniaxial tension test specimen. The test section is 30 mm long with a cross-sectional area of 5 mm \times 5 mm. Total of 10 specimens was tested. The loading was carried out using an electronic system universal testing machine with a capacity of 200 N (Fig. 1) and a loading speed of 1 mm/min. Fig. 2 and Fig. 3 present the specimens after loading and tensile stress – head displacement curves, respectively.

Table 1 Mixture proportion

Series	W/B	FA/B	Unite weight (kg/m ³)			
			W	C	FA	S
Aramid-0.5%	0.39	0.30	380	678	291	484

W: water, C: high early strength Portland cement,
 FA: fly ash type II, S: silica sand

Table 2 Mechanical properties of fiber

Type	Length (mm)	Diameter (μ m)	Tensile strength (MPa)	Elastic modulus (GPa)
Aramid	12	12	3432	73

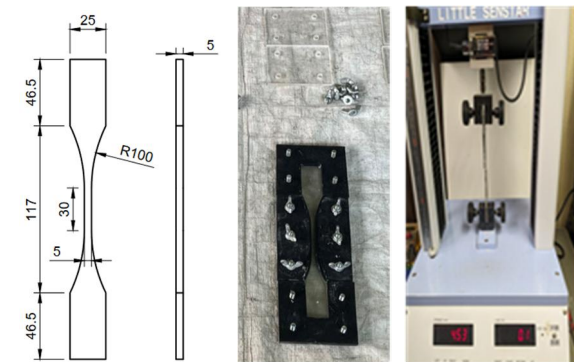


Fig. 1 Uniaxial tension test specimen (unit: mm)

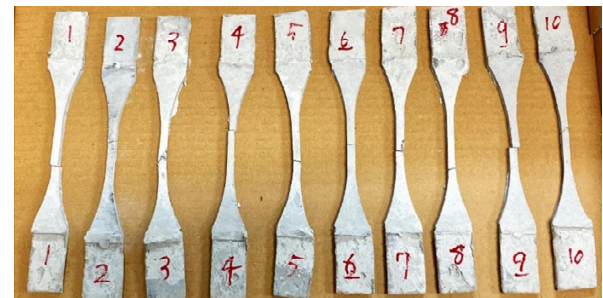


Fig. 2 Specimens after loading

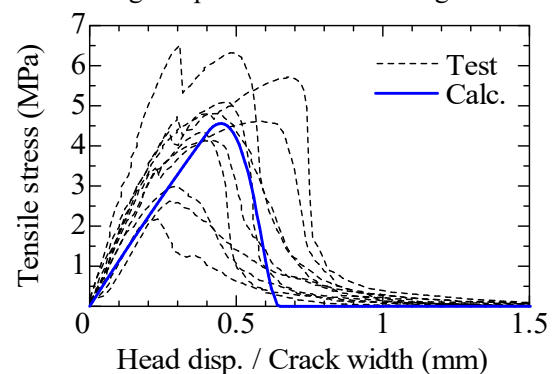


Fig. 3 Tension test result

Keywords FRCC, Aramid fiber, Monofilament, Uniaxial tension test, Bridging law, Section analysis

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3. FIBER BRIDGING MODEL

The bridging law (tensile stress – crack width relationship) is calculated by the summation of forces carried by single-bridging fibers. Assuming a bilinear model for the single fiber pullout model as shown in Fig. 4, the maximum pullout force (P_{max}) and the corresponding crack width (δ_{max}) were identified to match the tension test results. Other parameters for calculation [2] are listed in Table 3. As a result, the values of $P_{max} = 0.4\text{N}$ and $\delta_{max} = 1\text{mm}$ are obtained. The calculated bridging law is shown in Fig. 3. The maximum stress and the crack width at the maximum are 4.56MPa and 0.45mm , respectively.

4. BENDING TEST AND SECTION ANALYSIS

In accordance with ISO 21914, a four-point bending test was conducted on aramid-FRCC, and the moment-curvature curves were obtained. The number of the specimens is four. An example of the specimen after loading is shown in Fig. 6. After the elastic behavior, a decrease in stiffness was observed, accompanied by the propagation of crack. On the fracture surface, no pulled-out fibers were observed. Fig. 7 shows the bending moment – curvature curves. The average of the maximum bending moment was $1.55\text{kN}\cdot\text{m}$, and the corresponding curvature was 0.082m^{-1} .

As shown in Fig. 5, a bilinear model is applied to the tension side and a parabolic model to the compression side to express the stress-strain relationship of FRCC, and a section analysis is conducted. The maximum tensile stress (σ_t) is set to 4.56MPa , as calculated from the bridging law, and the corresponding strain is set to 0.0045 , derived by dividing the crack width by the pure bending span of 100mm . The ultimate strain (ϵ_{tu}) is set to 0.018 . The characteristic values for the compression side are based on the results of the compression test. The analytical bending moment – curvature curve is also shown in Fig. 7. This shows a good agreement with the test results. The analytical maximum bending moment is $1.59\text{kN}\cdot\text{m}$, and the corresponding curvature is 0.083m^{-1} .

5. CONCLUSIONS

1) A bridging model for the single fiber was identified to match the tensile test results. The calculation of the bridging law was able to reproduce the test results.

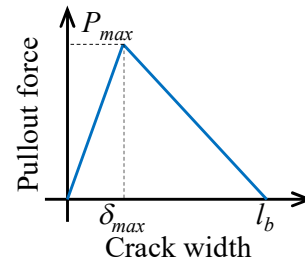


Fig. 4 Bridging model

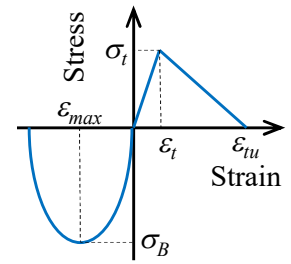


Fig. 5 $\sigma - \epsilon$ model

Table 3 Bridging model and bridging law calculation

Bridging model	P_{max} (N)		δ_{max} (mm)	
	0.4		1	
Parameters for bridging law calc.	Fiber strength (MPa)	Strength reduction factor	Orientation intensity x-y, z-x	Snubbing coefficient
	2300	0.3	6.5	0.5
Calc. result	Max. stress (MPa)		Crack width at max. (mm)	
	4.56		0.45	

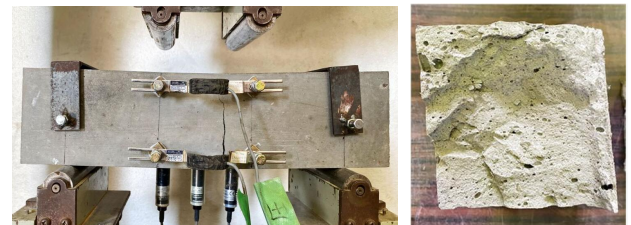


Fig. 6 Specimen after loading

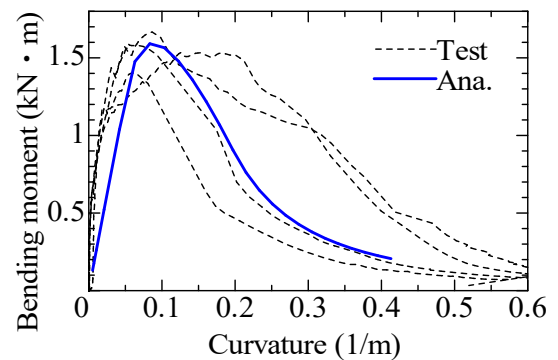


Fig. 7 Bending moment – curvature curve

- 2) Using the bridging law calculation results, the tensile stress-strain relationship of FRCC was assumed, and a section analysis was performed. The analysis results showed good agreement with the test results.

REFERENCES

- [1] Biao, C., Zhang, H., Kanakubo, T., Study on Bridging Law and Uniaxial Tension Test of Aramid Fiber-Reinforced Cementitious Composite, JSCE 2024 Annual Meeting, V-383, 2024.
 [2] Kanakubo, T., Miyaguchi, M., Asano, K., Influence of Fiber Orientation on Bridging Performance of Polyvinyl Alcohol Fiber-Reinforced Cementitious Composite, ACI Materials Journal, Vol.113, No.2, 131-141, 2016