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Evaluation of crack width in steel reinforced DFRCC members

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ABSTRACT

In order to evaluate crack width in steel reinforced Ductile Fiber-Reinforced Cementitious Composites (DFRCC) members, uniaxial tension test was conducted for specimens with one deformed steel rebar arranged. Polyvinyl Alcohol (PVA) fibers are used in DFRCC. The experimental parameters are cross-sectional area and fiber volume fraction. According to the test result, larger tension stiffening effect is observed in specimens which have larger cross-sectional area and larger fiber volume fraction. Crack width tends to widen in specimens which have larger cross-sectional area and smaller fiber volume fraction.

1. INTRODUCTION

Ductile Fiber-Reinforced Cementitious Composite (DFRCC) is cementitious material reinforced with short discrete fibers. DFRCC shows high ductility under tensile and bending stress condition by bridging of fibers at crack. The previous studies have reported that structural members using DFRCC shows less damages and crack opening compared with conventional concrete members (Sano et al. 2015, Kanakubo and Hosoya 2015). DFRCC can make it possible to improve durability and sustainable use of structures. However, it is difficult to evaluate tensile characteristic of DFRCC and there are only a few examples using DFRCC in structural members as actual applications.

In order to use DFRCC in structural members and make the use of its high ductility, it is needed to evaluate crack width precisely. At the level of DFRCC members, bridging laws (tensile stress – crack width relationships) are used to evaluate crack width (Kanakubo et al. 2016). On the other hand, it is generally considered to use DFRCC with steel reinforcing bars in structural members as steel reinforced DFRCC members. In the case of evaluating crack width in steel reinforced DFRCC members, not only bridging laws but also bond behavior between DFRCC and steel rebar should

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be considered.

The objective of this study is to evaluate crack width in steel reinforced DFRCC members. Uniaxial tension test is carried out for specimens using DFRCC by considering the influence of bridging effect and bond behavior between DFRCC and steel rebar.

2. OUTLINE OF UNIAXIAL TENSION TEST

2.1 Specimen

Fig. 1 shows the dimension of specimens and Table 1 shows the specimens list. The total length of the specimen is 800mm. One steel deformed rebar D16 (SD490) was arranged in the center of square cross-section along the axial direction. PVA fibers were used for DFRCC. The experimental parameters are cross-sectional area (A series:100mm×100mm and B series:150mm×150mm) and fiber volume fraction (1%, 2% and no fiber). Three specimens were loaded for each parameter and 18 specimens were tested in total.

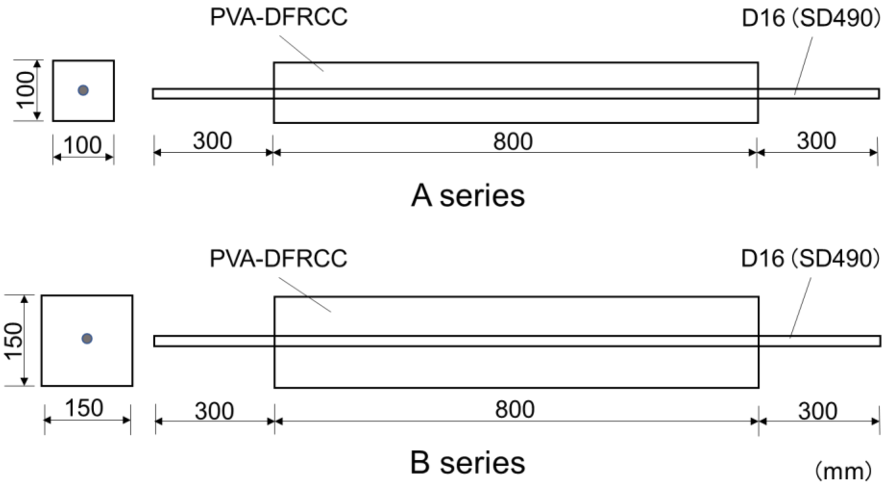


Fig. 1 Specimen dimensions

Table 1 Specimen list

Type	ID	Common factor	Cross-sectional area	Fiber volume fraction
No Fiber-A	1~3	Length: 800mm Steel rebar: D16 (SD490) Fiber: PVA	100mm×100mm	—
PVA1%-A	1~3			1.0%
PVA2%-A	1~3			2.0%
No Fiber-B	1~3		150mm×150mm	—
PVA1%-B	1~3			1.0%
PVA2%-B	1~3			2.0%

2.2 Materials

The mechanical properties of PVA fibers used in DFRCC are listed in Table 2 and the visual appearance is shown in Fig. 2. The mix proportion of DFRCC is shown in Table 3. DFRCC is filled into the mold by pouring from one end of the mold to control the fiber orientation.

Table 4 shows the mechanical properties of DFRCC at loading age of uniaxial tension test. The results of tension test for reinforcing bar are shown in Table 5.

Table 2 Mechanical properties of fiber

Fiber	Length (mm)	Diameter (mm)	Tensile strength (MPa)	Elastic modulus (GPa)
PVA	12	0.10	1200	28

Fig. 2 Visual appearance of fiber

Table 3 Mix proportion of DFRCC (kg/m^3)

Type	Water	Cement	Sand	Fly ash	PVA fiber
No Fiber					0
PVA1%	380	678	484	291	13
PVA2%					26

Table 4 Mechanical properties of DFRCC

Type	Compressive strength (MPa)	Elastic modulus (GPa)
No Fiber	47.2	17.0
PVA1%	47.4	16.8
PVA2%	44.1	15.9

Table 5 Test results of tension test for reinforcing bar

Type	Diameter	Yield strength (MPa)	Elastic modulus (GPa)	Yield strain (μ)	Tensile strength (MPa)
SD490	D16 (16mm)	491	188	2610	561

2.3 Loading and measurements

Uniaxial tension test was carried out by universal testing machine as shown in Fig. 3. Total deformation was measured by 2 LVDTs. Crack widths were measured by Pi-type LVDTs spaced at 100mm on both side of the specimens.

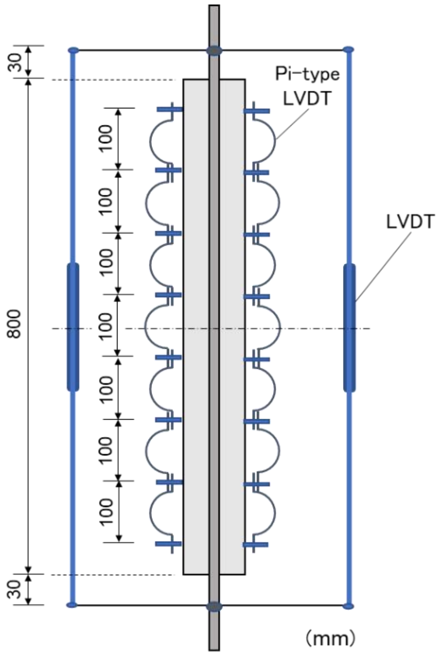


Fig. 3 Test setup

3. TEST RESULTS AND DISCUSSIONS

3.1 Load – total deformation relationships

Fig. 4 shows the load – total deformation relationships measured from the loading test. Since the deformation measured by LVDTs includes the elongation of steel rebar at both ends of specimens (60mm), the deformation of the specimens in 800mm was obtained by excluding the elongation of steel rebar in 60mm region. The elastic modulus obtained from tension test of reinforcing bars was used to calculate the elongation of steel rebar. The dotted line in Fig. 4 shows the load – deformation relationships of steel bare rebar in 800mm length. The yielding strengths of all No Fiber-A specimens and one of No Fiber-B specimens are lower than those of other specimens because some steel rebars showed lower yielding strength than specified value.

In general, tensile load of steel reinforced concrete member is larger than that of steel bare rebar at same deformation. This phenomenon is called tension-stiffening effect. Tension-stiffening effect is brought by tensile load carrying in surrounding concrete being transmitted via bond between the rebar and concrete. In case of DFRCC, tension-stiffening is caused not only by bond behavior between DFRCC and steel rebar but also by bridging of fibers at cracks.

According to the test results, tension-stiffening effect is small in No Fiber specimens without bridging. By comparing PVA1% specimens to PVA2% specimens in the same series of cross-sectional area, tension-stiffening effect is larger in PVA2% specimens. By comparing A series (100mm×100mm) to B series (150mm×150mm) in the same fiber-volume fraction, tension-stiffening effect is larger in B series specimens. However, in No Fiber specimens, there is a few differences between A series and B series. Therefore, tension-stiffening effect is mostly influenced by bridging of fibers.

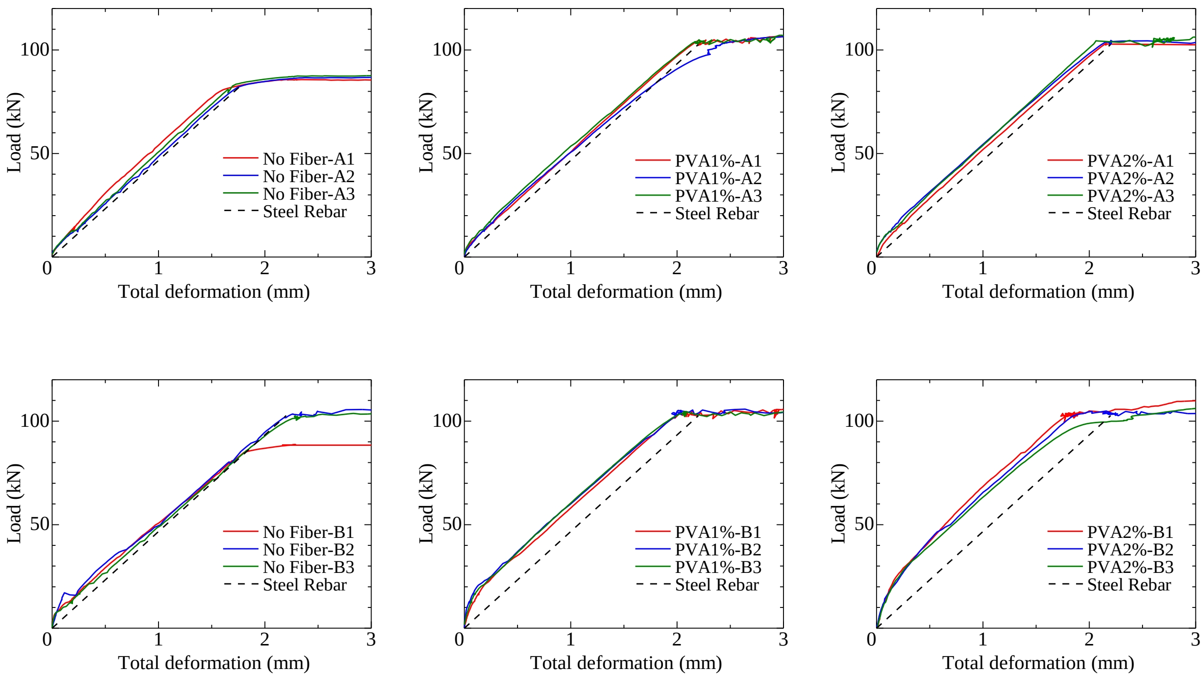
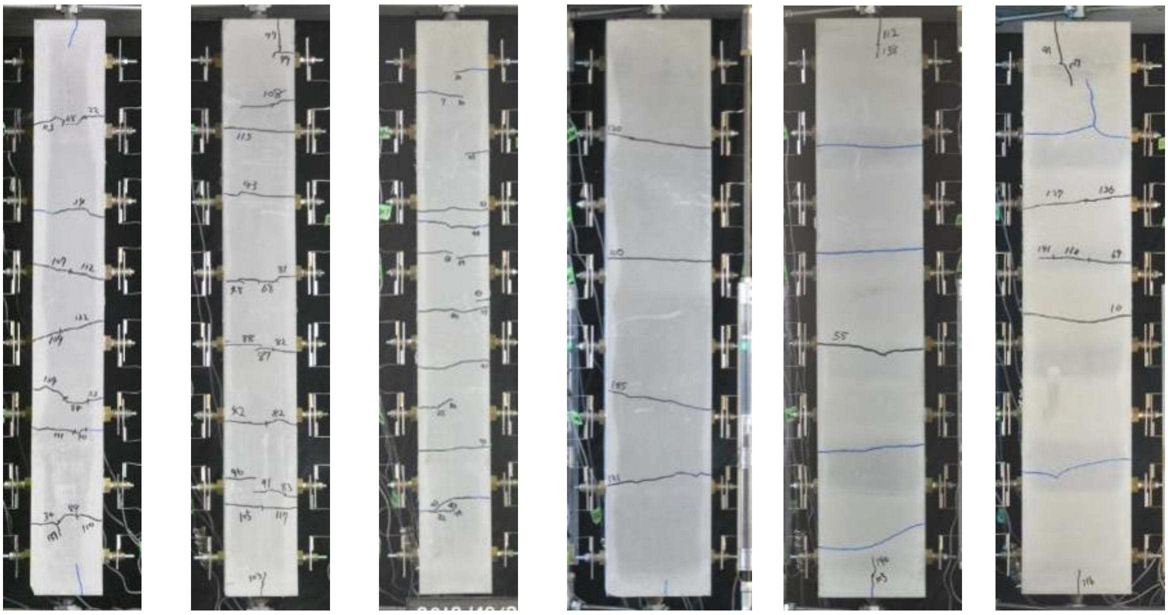


Fig. 4 Load – total deformation relationship

3.2 Crack patterns

Fig. 5 shows the examples of crack patterns at steel rebar yielding. The specimens with least axial cracks are picked up from each type of specimens. Table 6 shows the number of cracks in each specimen shown in Fig. 5.

Comparing with the number of cracks in A series (100mm×100mm), increasing fiber volume fraction increased the number of cracks. However, in B series (150mm×150mm), there was few differences among No Fiber, PVA1% and PVA2%. This tendency is also observed in the other two specimens for each type.



No Fiber-A PVA1%-A PVA2%-A No Fiber-B PVA1%-B PVA2%-B

Fig. 5 Examples of crack patterns at steel rebar yielding

Table 6 Number of cracks

Type	No Fiber-A	PVA1%-A	PVA2%-A	No Fiber-B	PVA1%-B	PVA2%-B
Number	7	10	13	4	5	5

3.3 Crack width

In each LVDT measurement section with one crack, crack width is calculated by averaging two values measured by both sides of LVDTs. The number and occurrence of cracks are checked by visual observation and measurement values of LVDT. The section which has axial cracks, two or more cracks, and cracks taking place on the boundary of sections or across two sections are excluded from the evaluation.

Fig. 6 shows steel strain – crack width relationship. The test results of each section in the same type of specimens are shown in the same graph. Tension load is converted to steel strain by using the elastic modulus obtained from the tension test of reinforcing bars. The dotted line in Fig. 6 shows the average of test results in each type of specimens. The test results of each section are evaluated by the least square method to obtain slopes and Y-intercepts. The dotted line is determined by average values of them in the same type of specimens.

According to the test results, by comparing A series (100mm×100mm) to B series (150mm×150mm) in the same fiber volume fraction, the slope of average line is smaller in specimens which have larger cross-section. Crack width tends to widen with increasing of cross-sectional area. Since the number of cracks becoming fewer in larger specimens, crack width of each crack also becomes to widen at the same value of steel strain. On the other hand, by comparing PVA1%, PVA2% to No Fiber specimens in the same cross-sectional area, the slope of average line is larger in specimens which have larger fiber volume fraction. Crack width tends to narrow with increasing of fiber volume fraction. That is because the bridging force of fibers increases with cross-sectional area.

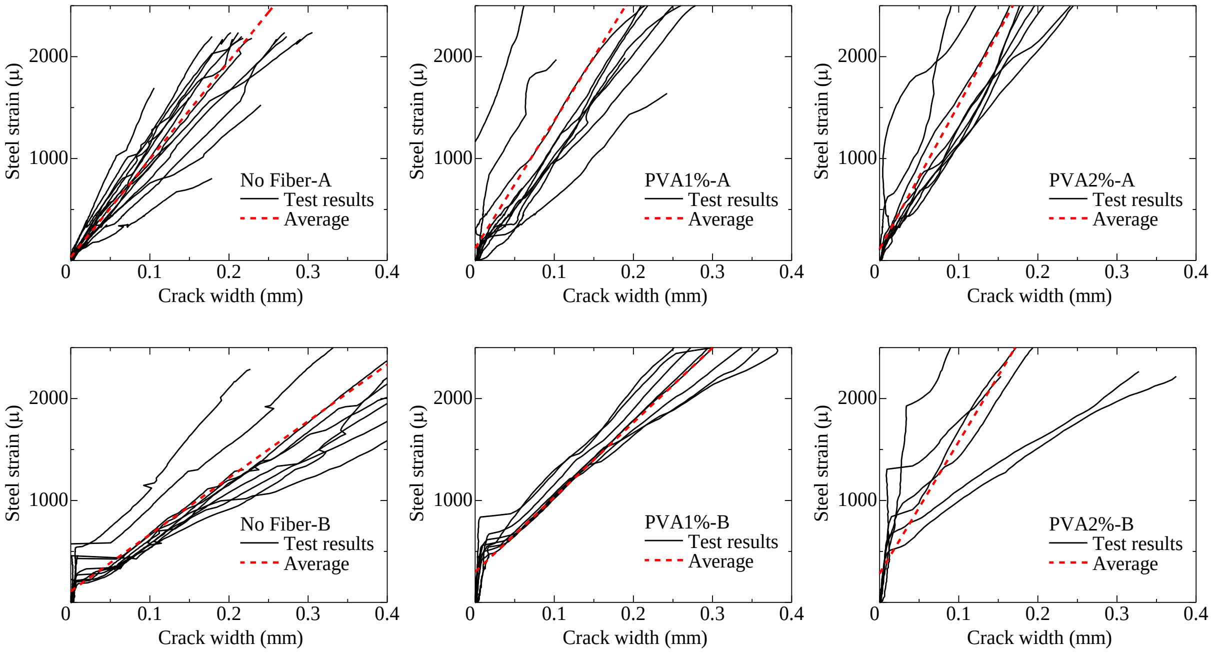


Fig. 6 Steel strain – crack width relationship

4. CONCLUSIONS

In this study, to evaluate crack width in steel reinforced DFRCC members, uniaxial tension test is carried out for specimens with one steel deformed rebar arranged. Polyvinyl alcohol (PVA) fiber is used in DFRCC. The experimental parameters are cross-sectional area and fiber volume fraction. The test results are concluded as follows;

(1) Larger tension stiffening effect is observed in specimens which has larger cross section and larger fiber volume fraction.
(2) Crack width tends to widen in specimens which have larger cross section and smaller fiber volume fraction.

5. ACKNOWLEDGMENT

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6. REFERENCES

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