SHEAR BEHAVIOR OF PVA-ECC BEAMS

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Abstract

In this research, uniaxial tensile test for PVA-ECC (ECC with Polyvinyl alcohol fiber) and bending shear test of PVA-ECC beams is conducted to obtain fundamental properties of PVA-ECC members. Parameters are ratio of lateral reinforcement and volume percentage of PVA fiber. From the results of beam tests, shear strength increases as volume percentage of PVA fiber increases. In the uniaxial tensile test of PVA-ECC, it can be recognized that difference of fiber volume percentage influences maximum stress and ultimate strain. Predicting method for shear strength of beams is proposed based on the tensile strength obtained from uniaxial tensile test of PVA-ECC. Shear strength of PVA-ECC beams can be evaluated well by this calculation method.

1. INTRODUCTION

ECC (Engineered Cementitious Composites) [1], which is grouped in one of the fiber reinforced cementitious composites, shows pseudostrain hardening behavior with several percent tensile strain. To use fiber reinforced cementitious composites such as ECC as structural elements, ECC members have been experimented by several research institutes. Most of those specimens are flexural yielding type, because of utilizing as energy absorbing elements for structural control, upgrading materials for flexural members, and so on. It is important that shear behavior is comprehended for the purpose of structural performance design as same as flexural behavior. In the present, back data is insufficient to build shear strength of members. Additionally, it is significantly important that tensile behavior of ECC is appropriately evaluated, and structural performance of ECC members can be predicted and designed tensile behavior evaluation.

In this reseach, uniaxial tensile test for PVA-ECC (ECC with Polyvinyl alcohol fiber) and bending shear test of PVA-ECC beams is conducted to obtain fundamental properties of PVA-ECC members. Parameters are ratio of lateral reinforcement and volume percentage of

PVA fiber. Predicting method for shear strength of beams is considered based on the tensile stress - strain model obtained by uniaxial tensile test of PVA-ECC.

2. BENDING SHEAR TEST OF BEAMS

2.1 Specimens and test methods

Fiber of ECC is polyvinyl alcohol (PVA) fiber. Mechanical properties of PVA fiber are shown in Table 1. These values are given by manufacturer.

Table 1: Properties of PVA fiber

Fiber type	Length of fiber (mm)	Diameter (mm)	Tensile strength (MPa)	Elastic modulus (GPa)
PVA	12	0.04	1600	40

The dimensions and reinforcing bar arrangements of the beam specimens are shown in Figure 1 and list of specimens are shown in Table 2. Specimens have the 180 x 280mm size rectangular section, and shear span ratio is 1.5. Specimens of reinforced beam are made with D13 main bar and D4 or D6 stirrup. Parameters are ratio of stirrup and volume percentage of PVA fiber. Volume percentage of PVA fiber (V_f) is set to 1.0, 1.5, 2.0%. Mortal (MT) beams, which is beam specimen without PVA fiber, are planned for the comparison to PVA-ECC one. Beam specimens named by F are designed to have flexural yielding before failure. Other specimens are designed to show shear failure before flexural yielding.

Loading is carried out by Ohno method under anti-symmentrical moment with monotoric manner. LVDTs are set to measure relative displacement between the stubs, partial deformations of each zone (A-C) shown in Figure 1. Strain guages are set to measure main bar and stirrup strain.

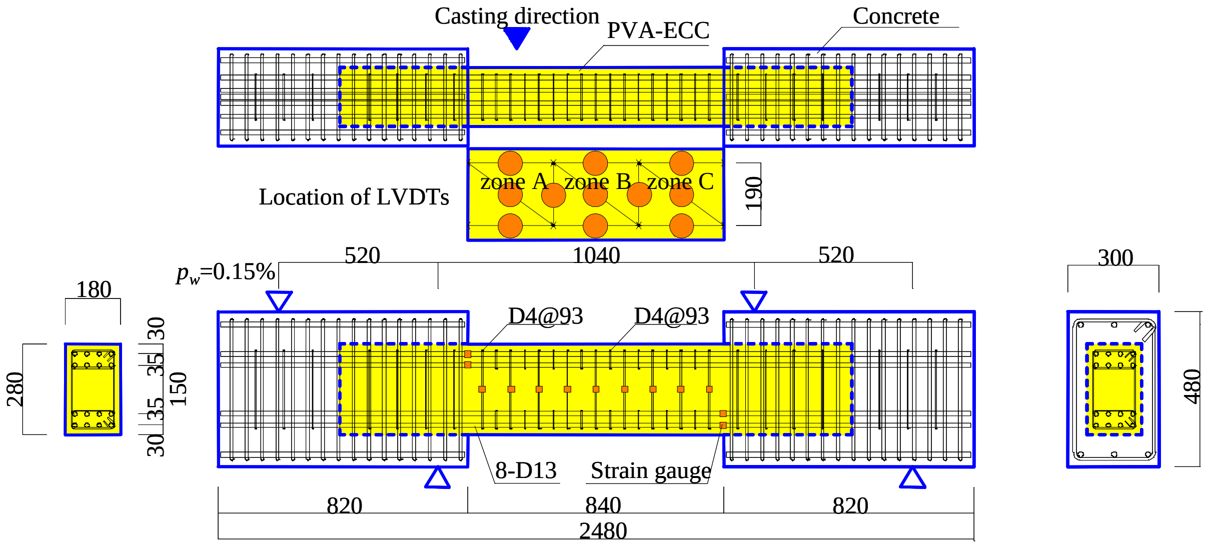

Figure 1: Dimension and bar arrangement of beam specimen

Table 2: List of beam specimens

Specimen	Fiber volume percentage	Main bar		Stirrup	
		Arrange -ment	Type	Arrange -ment	Reinforce -ment ratio
PVA10-00	1.0%	8-D13 p_t=2.43%	SD685	-	0.00%
PVA10-15				2-D4@93	0.15%
PVA10-30				2-D4@47	0.30%
PVA10-60				2-D6@59	0.60%
PVA10-89				2-D6@40	0.89%
PVA10-89F			SD390	2-D6@40	0.89%
PVA15-00	1.5%		SD685	-	0.00%
PVA15-15				2-D4@93	0.15%
PVA15-30				2-D4@47	0.30%
PVA15-60				2-D6@59	0.60%
PVA15-89				2-D6@40	0.89%
PVA15-89F			SD390	2-D6@40	0.89%
PVA20-00	2.0%		SD685	-	0.00%
PVA20-15				2-D4@93	0.15%
PVA20-30				2-D4@47	0.30%
PVA20-60				2-D6@59	0.60%
PVA20-89				2-D6@40	0.89%
PVA20-89F			SD390	2-D6@40	0.89%
MT-30	0.0% (Mortal)		SD685	2-D4@47	0.30%
MT-60				2-D6@59	0.60%
MT-89				2-D6@40	0.89%

Results of compression test using 100ϕ - 200mm cylinder test pieces and tensile test results of reinforcing steel are summarized in Table 3. Beam specimens type of shear failure are

Table 3: List of material properties

Specimen	Compression test			Yield strength	
	σ_B (MPa)	ε_B (%)	E (GPa)	Main bar (MPa)	Stirrup (MPa)
PVA10-00, 15, 30	37.3	0.35	17.8	720	295
PVA10-60, 89	49.9	0.39	20.2	711	334
PVA10-89F				438	
PVA15-00, 15, 30	35.7	0.35	16.3	720	295
PVA15-60, 89	50.3	0.39	19.4	711	334
PVA15-89F				438	
PVA20-00, 15, 30	39.1	0.36	19.5	720	295
PVA20-60, 89	45.8	0.37	19.5	711	334
PVA20-89F				438	
MT-30	61.0	0.33	28.6	711	358
MT-60, 89					334

made with main bar of yield stress 700MPa class (SD685), type of flexural yielding are made with main bar of yield stress 400MPa class (SD390).

2.2 Test results

Results of beam tests are shown in Table 4. Bending and shear crack are observed at 0.0025rad.. In PVA-ECC beams, multiple cracks and effect of crack opening repression can be observed. In beam specimens of shear failure type, when load becomes around the maximum value, deformation is concentrated on a certain one shear crack. Another crack width is decreased due to localize deformation. In series F specimens, shear load is in process of increasing when translational angle becomes 0.05rad.. Shear load - translational angle curve is shown in Figure 2. Maximum strength and translational angle at maximum load increase as volume percentage of PVA fiber increases and reinforcement ratio increases.

Table 4: Results of beam tests

Specimen	Shear force at first crack (kN)		At maximum load		Ultimate translational angle*1 ($\times 10^{-3}$rad)	Failure mode*2
	Bending crack	Shear crack	Shear force (kN)	Translational angle ($\times 10^{-3}$rad)		
PVA10-00	26.1	66.7	123.9	6.4	7.6	S
PVA10-15	20.4	55.3	144.8	8.1	16.4	S
PVA10-30	18.8	60.5	171.5	11.8	16.4	S
PVA10-60	18.1	128.9	262.7	14.8	44.0	S
PVA10-89	25.1	130.2	317.9	19.0	47.5	S
PVA10-89F	26.1	94.9	259.0*3	50.7*3	>50	F
PVA15-00	31.1	66.6	142.8	9.1	10.4	S
PVA15-15	42.4	63.7	169.7	11.0	17.9	S
PVA15-30	27.9	123.7	182.9	11.6	14.3	S
PVA15-60	22.4	150.7	295.5	16.9	31.5	S
PVA15-89	39.5	143.9	343.9	23.3	>50	S
PVA15-89F	31.0	166.7	269.7*3	49.9*3	>50	F
PVA20-00	17.0	36.3	182.7	10.9	12.6	S
PVA20-15	20.8	33.0	205.8	13.8	15.2	S
PVA20-30	19.8	90.6	208.6	12.6	22.6	S
PVA20-60	15.0	146.5	310.2	18.8	23.9	S
PVA20-89	19.1	163.4	341.2	19.2	43.1	S
PVA20-89F	24.7	178.1	272.4*3	50.1*3	>50	F
MT-30	9.7	96.3	177.7	13.7	>50	S
MT-60	23.4	67.8	230.7	15.5	>50	S
MT-89	50.2	70.3	277.1	18.3	>50	S

*1 Translational angle when load comes down 80 percentage of maximum load
*2 S = Shear failure, F = flexural yeild
*3 At 0.05rad., when unloading started

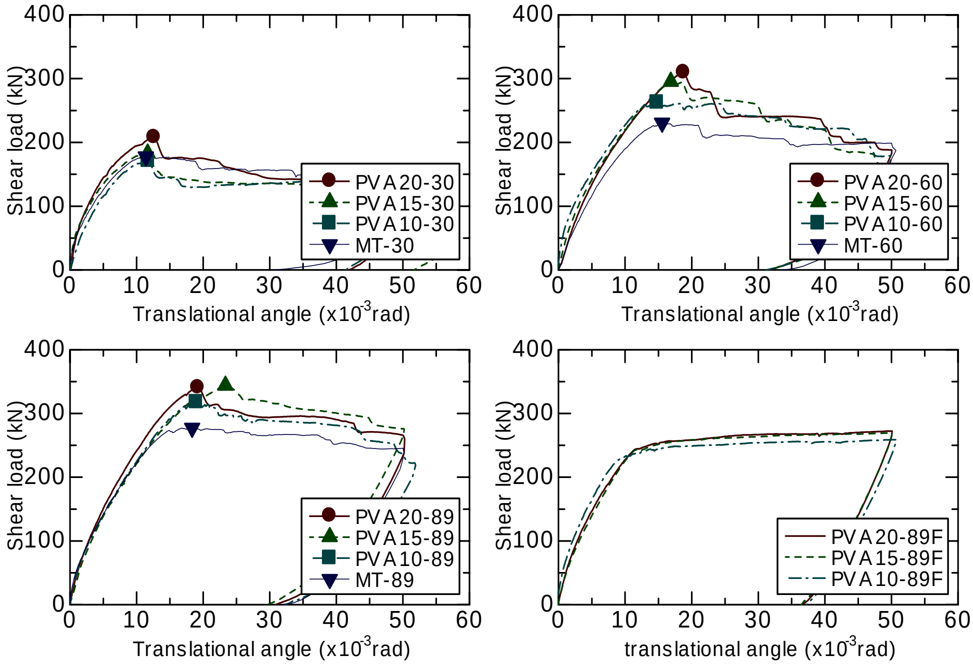

Figure 2: Relationship between shear load and translation angle

3. SHEAR CAPACITY EVALUATION OF PVA-ECC BEAMS

3.1 Uniaxial tensile test

Uniaxial tensile test is conducted to obtain tensile properties of PVA-ECC. Uniaxial test specimens are made with same batch PVA-ECC with beam specimens. Figure 3 shows the outline of uniaxial tensile test. This tensile specimen is use to minimize the influence of fiber orientation and secondary bending effect and was expected to reproduce a more precise tensile performance of ECC in structural elements [2].

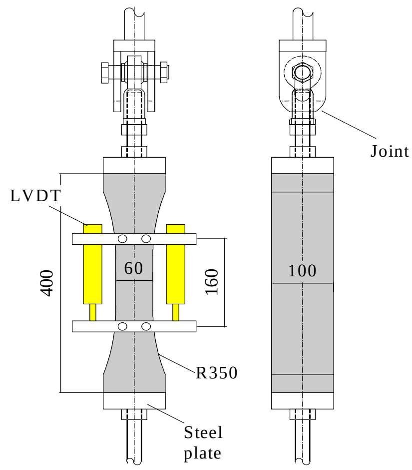

Figure 3: Uniaxial tensile test

Sectional dimension in test region of this specimen is 100 x 60mm. The monotonic tensile load is applied to specimens through pin-support of one end of specimen and fixed condition of the other end. The head speed of loading machine is set to 0.5mm/min. Two LVDTs are set to measure axial deformation with gauge length of 160mm.

Tensile stress and tensile strain relationships are shown in Figure 4. The tensile strain is obtained by LVDT's deformation divided by contact length as average strain. Results of PVA-ECC that volume percentage of PVA fiber is 1.5 and 2.0% clearly indicated the pseudostrain hardening characteristics, where stress increased after first crack.

Test results are summarized in Table 5. The ultimate strain is defined as the point at which stress becomes smaller than half of maximum stress after maximum stress. It can be recognized that difference of fiber volume percentage influences maximum stress and ultimate strain.

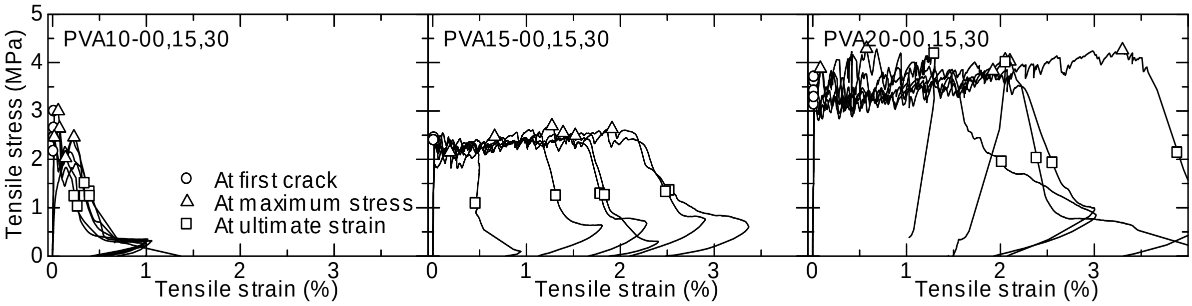

Figure 4: Tensile stress – strain relationships obtained by uniaxial tensile test

Table 5: Uniaxial tensile test results

Specimen	At first crack		At maximum stress		At ultimate strain*	
	Tensile stress (MPa)	Tensile strain (%)	Tensile stress (MPa)	Tensile strain (%)	Tensile stress (MPa)	Tensile strain (%)
PVA10-00, 15, 30	2.54	0.017	2.52	0.10	(1.26)	0.33
PVA10-60, 89, 89F	1.47	0.014	2.09	0.21	(1.05)	0.32
PVA15-00, 15, 30	2.41	0.018	2.50	1.16	(1.25)	1.74
PVA15-60, 89, 89F	1.98	0.015	2.99	0.58	(1.50)	0.71
PVA20-00, 15, 30	3.41	0.018	4.06	1.67	(2.03)	2.37
PVA20-60, 89, 89F	2.45	0.019	3.76	0.90	(1.88)	0.90

*When stress becomes smaller than half of maximum stress after maximum stress

3.2 Proposal of shear capacity evaluation

At present, the research of shear transmittance capacity of ECC on cracks has been conducted [3]. There have bean many unclear points in relationship between stress and strain at ultimate state (i.e., failure completing curve concerning stress and strain under multi-axial stress). In literature [3], for example, it was reported that shear strength is almost equal to uniaxial tensile strength, even this depends on stress path of normal and shear stress.

In order to design simply, predicting method for shear strength of beams is proposed using truss - arch method. Assuming that stress of PVA-ECC in beam specimens is influenced by shear stress on crack, shear strength which is same value as uniaxial tensile strength is added to method A of AIJ [4]. Shear strength of ECC beam is expressed by following Eq.(1). Following Eq.(5) is used for calculating effective coefficient of concrete compressive strength.

$$V_u = b \cdot j_t \left(p_w \cdot \sigma_{wy} \cdot \cot\phi + \sigma_{max}^{ECC} \right) + \tan\theta (1-\beta) b \cdot D \cdot \nu \cdot \sigma_B / 2 \quad (1)$$

$$\tan\theta = \sqrt{(L/D)^2 + 1} - L/D \quad (2)$$

$$\beta = \frac{(1+\cot^2\phi)(p_w \cdot \sigma_{wy} + \sigma_{max}^{ECC} / \cot\phi)}{\nu \cdot \sigma_B} \leq 1 \quad (3)$$

$$\cot\phi = \min\{2,\ j_t / (D \tan\theta)\} \quad (4)$$

where,

b : width of member

D : depth of member
L : clear span length
j_t : distance between tensile and compressive main bars
p_w : reinforcement ratio
σ_{wy} : yield strength of stirrup
σ_{max}^{ECC} : tensile strength of PVA-ECC
σ_B : compressive strength
ν : effective coefficient of concrete compressive strength

$$\nu = 3.68\sigma_B^{-0.333} \quad \text{(unit of } \sigma_B \text{ is kgf/cm}^2\text{)} \tag{5}$$

Because stress of PVA-ECC is superposition to yield strength of stirrup, it is necessary that stirrups are yielded at maximum load of PVA-ECC beams in order to adopt above formulas. In PVA-ECC of PVA10-00, PVA10-15, and PVA10-30 specimen, since average strain at tensile strength is 0.10%, which is not more than yeild strain of stirrup, 2.23MPa is used for calculation as tensile stress at yield strain of stirrup.

Predicting method for bending strength of ECC beams is used section analysis by fiber models. Perfect elastic - prastic model is selected to represent tensile stress - strain curve. Parabola model is chosen for compressive stress - strain relation.

Figure 5 shows validation of shear capacity evaluation. Arrowheads shows the results of series F specimens, which maximum loads are obtained at the unloading point. The actual capacities are assumed to be not less than plotted marks. Shear strength of PVA-ECC beams can be evaluated well by this calculation method.

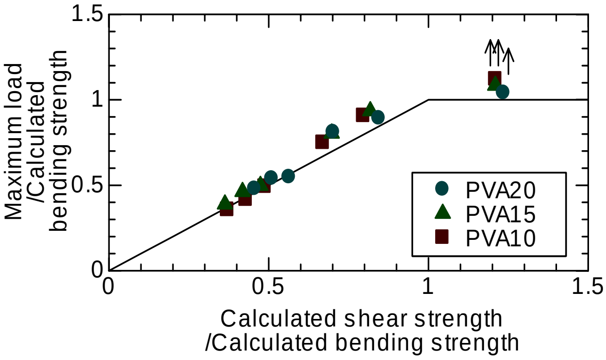

Figure 5: Validation of structural performance evaluation

4. CONCLUSIONS

- In the beam test, maximum strength increases as volume percentage of PVA fiber increases and reinforcement ratio increases.
- In the uniaxial tensile test of PVA-ECC, it can be recognized that difference of fiber volume percentage influences maximum stress and ultimate strain.

- Predicting method for shear strength of beams is proposed based on the tensile strength obtained from uniaxial tensile test of PVA-ECC. Calculated shear strength of PVA-ECC beams shows good agreement with experimental strength.

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