Tensile Stress-Strain Relationship of High-Performance Fiber Reinforced Cement Composites

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ABSTRACT :

This research is conducted to investigate the tensile stress-strain relationship of High-Performance Fiber Reinforced Cement Composites (HPFRCC) using the finite element method (FEM). The bending tests of beam members with and without fiber were conducted to clarify the relationship of bending moment-displacement. The dimension of the beam specimens is 100 × 100 × 750mm (width x depth x length). The bending failure was occurred to the all beam specimens. FEM is used to verify the tensile stress-strain relationship of HPFRCC members in comparison with the experimental results of the beam specimens. The analytical results using of the proposed tensile stress-strain relationship is good agreement with the experimental results of HPFRCC beams.

KEYWORDS: HPFRCC, Tensile stress-strain, FEM, Beam, Bending test

1. INTRODUCTION

High-Performance Fiber Reinforced Cement Composites (HPFRCC), which show a strain hardening branch and multiple cracking under uniaxial tensile stress, have been developed. Additionally, technological advancements are required which make it possible to control damage and deterioration caused by external loadings such as a large-scale earthquake during the service life of buildings.

At present, the mechanical characteristic of the tension zone of HPFRCC is making clear, but the tensile stress-strain relationship of the pure tension experiment is different from the relationship observed under calculated from the experiment results of HPFRCC column or beam tests [1]. As well-known the tension behavior of HPFRCC is an important factor to decided the strength and the ductility of RC columns and beams.

This paper conducts bending test of the beam and analyzes the experimental values. The purpose of this paper is introduced the tensile property of HPFRCC.

2. BENDING TEST OF THE BEAM MEMBER OF HPFRCC

2.1. Materials and Specimens

The outline of the test specimen is shown Table 1.The 9 series of HPFRCC specimens were mixed by adding the PVA fibers is 2% of a volume ratio. In addition, the synthetic fiber which used in this study in PVA fiber (polyvinyl alcohol fiber, KURALON K Ⅱ REC) is tensile strength, 1600N/mm^2 and young modulus, 40000N/mm^2. Configuration of the test specimen and the bar arrangement is shown in Figure 1. Table 2 and Table3 show the material strength of the concrete and steel, respectively.

2.2. Measuring Method

The pressing method used 1000kN universal tester and bending test by 4 point loading was executed to conform mechanical properties of HPFRCC. The measuring method is observed by displacement gauge set up under the specimen and load meter built-in tester. The strain of the main bar was measured from the strain gauge put on the center above and below in 2 bottom reinforcement. In the loading, yield strength, maximum strength, crack patterns and fracture behavior were observed by the specimen.

Table 1 Outline of test specimen

Test Specimen	Cross section b×D (mm)	Main bar	Stirrup	Stirrup ratio (%)	Sand:Cement ratio
A1	100×100	2-D6	2-ϕ2.5@40	0.25	1:2
A2					1:1
A3		3-D6			1:2
A4					1:1
B1,B2		2-D10			1:1
B3,B4,B5		3-D10			

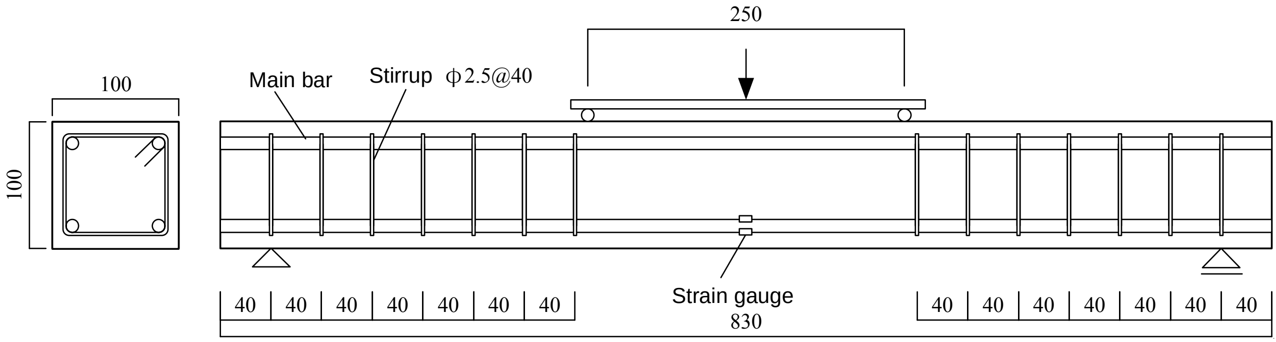


Figure 1 Bar arrangement

Table 2 Material strength of HPFRCC

Concrete	Compression strength(MPa)	Elastic modulus(GPa)
A series	35	92.3
B series	40.5	172

Table 3 Material strength of steel

Steel	Yield strength (Mpa)	Elastic modulus (GPa)	Yield strain (μ)
D6	490	178.6	2800
D10	350.9	121.8	2880
φ2.5	423.4	39.5	12300

2.3. Experimental Result

Figure 2 shows the failure pattern after loading. Table 4 shows the experimental results. The design strength of the flexural yield strength and shear strength is calculated as follows;

i) Flexural Yield Strength

$$M_y = a_t \cdot \sigma_y \cdot j + 0.45 \cdot J^2 \cdot \sigma_t \quad (\mathrm{N \cdot mm})$$

$$P_y = M_y / 125 \ (\mathrm{N})$$

Where,

M_y : yield moment a_t : cross section area of main bar σ_y : yield strength of main bar $j = 7/8 \cdot d$
J=j+(D-d) D : depth of member d=effective depth σ_t : tensile stress of HPFRCC P_y : yield strength
The stress distribution of HPFRCC is assumed as shown in Figure 3.

ii) Shear Strength[1]

$$V_{su} = b \cdot j_t \left(p_w \sigma_{wy} + \sigma_t\right) \cot\phi + \tan\theta (1-\beta) b D \nu \sigma_B / 2$$

Where, $$\beta = \left\{\left(1+\cot^2\phi\right) \cdot p_w \sigma_{wy} + \cot^2\phi \cdot \sigma_t\right\} / \nu \sigma_B$$

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

A1

A2

A3

A4

B1

B2

B3

B4

B5

Figure 2 Failure pattern after loading

Table 4 Experimental results

Test specimen	Yield strength (kN)	Maximum strength (kN)	Design strength (kN)	
			Yield strength (kN)	Shear strength (kN)
A1	22.9	25.6	18.7	53.1
A2	21.64	25.2		
A3	31.89	36.6	28.0	
A4	32.09	35.9		
B1	34.5	40	28.8	
B2	31.4	38		
B3	44.2	50.48	43.1	
B4	47.3	54.3		
B5	47.36	54.25		

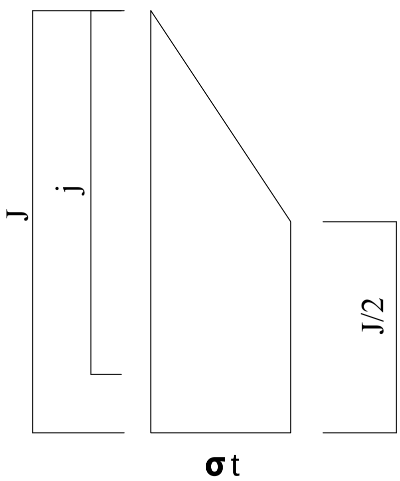


Figure 3 Assumed stress distribution

V_{su} : shear strength b : width of member j_t: distance between compression and tension bars
p_w : stirrup ratio σ_{wy} : yield strength of stirrup σ_t : tensile stress of HPFRCC L : clear span length
ν : effective coefficient of compressive strength of HPFRCC D : depth of member
σ_B : compressive strength of HPFRCC However, $p_w \sigma_{wy} \leq (\nu \sigma_B - \sigma_t)/2$

The flexural failure was occurred to the all beams. The ratio between sand : cement was changed but the yield and maximum strength was same values.

A1 and A2 occur to the first crack in 7.85kN. They are looked like the same crack patterns. A3 found the first crack in 4.91kN and A4 the first crack in 14.5kN. The crack width of A3 was bigger than A4. The crack width of B1 was bigger than B2. B3 and B4 are looked like the same crack patterns. At B5 cracks occurred at the over all length of the beam.

3. CROSS SECTION ANALYSIS OF THE BEAM MEMBER OF HPFRCC

3.1. Outline of Analytical Works

The experimental strengths are compared with the analytical results in this chapter. The compression zone of the HPFRCC are assumed from the result of test pieces [Figure 4]. This shows the major typical stress-strain relationship. The tensile zone of the main bar draws upon the tension test [Figure 5]. The tensile zone of the HPFRCC are assumed the yield and maximum strength of experimental values and the reference [1] [Figure6]. Figure 7 shows the sections of the analytical model. The moment-curvature relationship is introduced from the cross section analysis, and the yield and maximum strength of the beam are decided with the use of it.

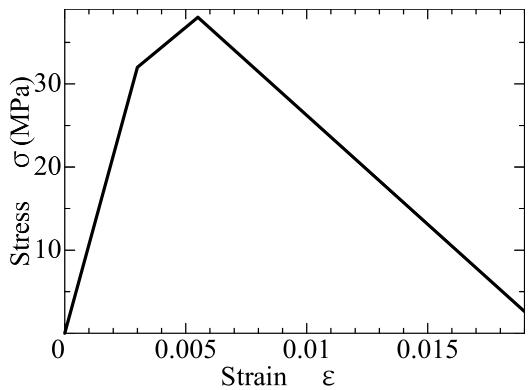


Figure 4 Compression zone of HPFRCC

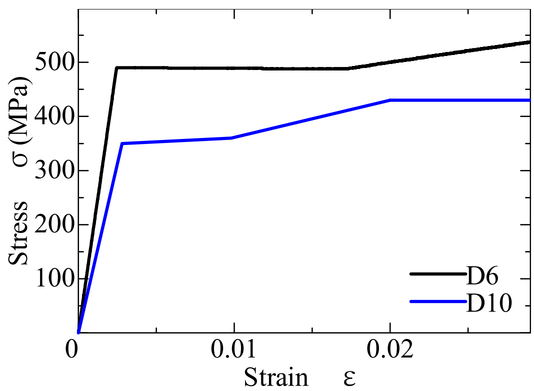


Figure 5 Stress-strain relationship (main bar)

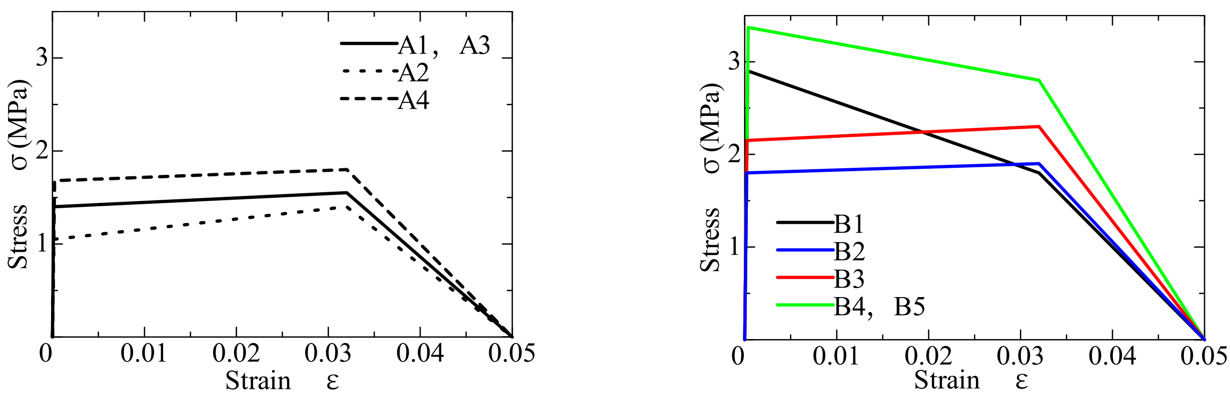


Figure 6 Tensile property of HPFRCC

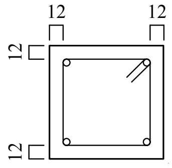
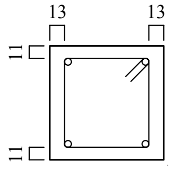
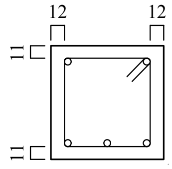
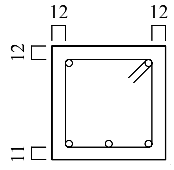
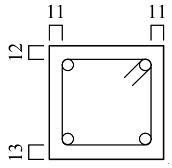
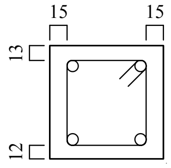
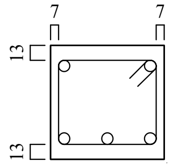
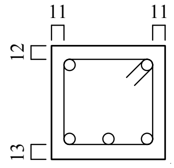
Section				
Test specimen	A1	A2	A3	A4
Main bar	2-D6	2-D6	3-D6	3-D6
Section				
Test specimen	B1	B2	B3	B4，B5
Main bar	2-D10	2-D10	3-D10	3-D10

Figure 7 Section

3.2. Analytical Result

Table 5 shows the experimental and analytical results.

The experimental values are compared with the analytical values. The yield and maximum of the analysis values are good agreement with the experimental one. The maximum values of the analysis of A series are a little greater than the experimental values.

Table 5 Experimental and analytical results

	Yield strength（kN）		Maximum strength（kN）	
Test specimen	Experimental value	Cross section ayalysis	Experimental value	Cross section ayalysis
A1	22.90	22.88	25.60	27.04
A2	21.64	21.84	25.20	26.88
A3	31.89	31.84	36.60	37.84
A4	32.09	32.00	35.90	38.16
B1	34.50	34.00	40.00	40.32
B2	31.40	31.20	38.00	38.80
B3	44.20	44.16	50.48	52.80
B4	47.30	47.28	54.30	54.32
B5	47.36	47.28	54.25	54.32

4. FEM ANALYSIS OF THE BEAM MEMBER OF HPFRCC

4.1. Outline of Analytical Works

FEM was used to verify the tensile stress-strain relationship of HPFRCC members in comparison with the experimental results of the beam specimens. The analytical model is idealized the half of beam using the bilaterally-symmetrical test specimen. Figure 7 shows the sections of the analytical model. In the analysis, the beam specimens are assumed to consist of three kinds of elements that are the concrete as two dimensional

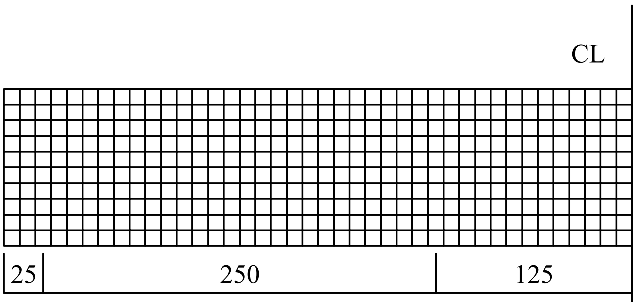


Figure 8 Concrete factor

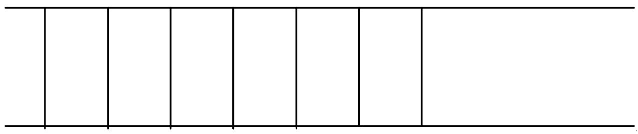


Figure 9 Steel factor

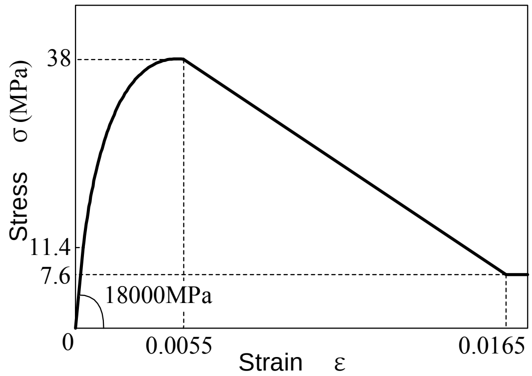


Figure 10 Compression property of HPFRCC

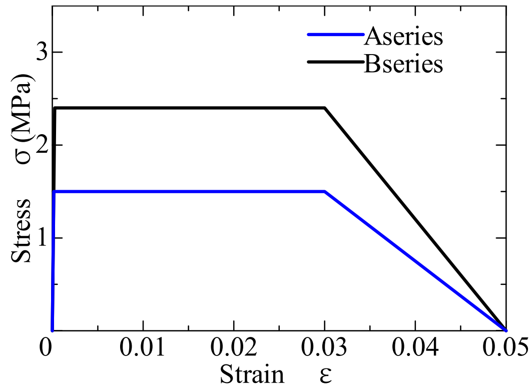


Figure 11 Tensile stress-strain relationship

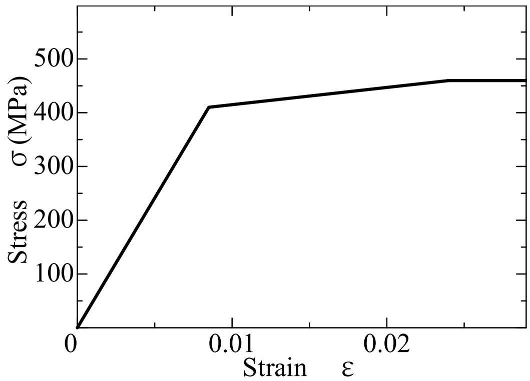


Figure 12 Stress-strain relationship (Stirrup)

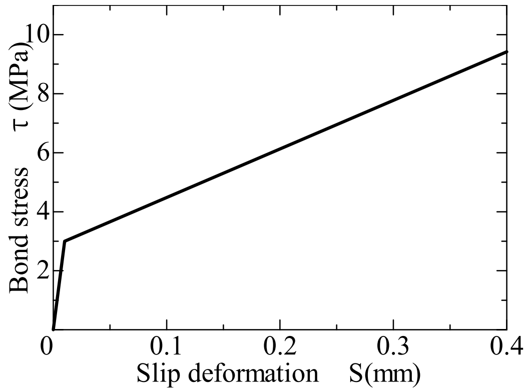


Figure 13 Bond property

Table 6 Comparison of Experimental and Analytical results

	Yield strength (kN)			Maximum strength (kN)		
Test specimen	Experimental value	Cross section ayalysis	FEM analysis	Experimental value	Cross section ayalysis	FEM analysis
A1	22.90	22.88	22.95	25.60	27.04	27.22
A2	21.64	21.84	23.22	25.20	26.88	27.34
A3	31.89	31.84	32.03	36.60	37.84	37.23
A4	32.09	32.00	31.82	35.90	38.16	37.13
B1	34.50	34.00	33.11	40.00	40.32	37.74
B2	31.40	31.20	32.82	38.00	38.80	36.22
B3	44.20	44.16	44.16	50.48	52.80	50.78
B4	47.30	47.28	44.32	54.30	54.32	51.00
B5	47.36	47.28	44.32	54.25	54.32	51.00

quadrilateral elements [Figure 8], the steel as one dimensional element[Figure 9], and the bond link between the concrete and the steel as springs. The main bar model is shown in Figure 5

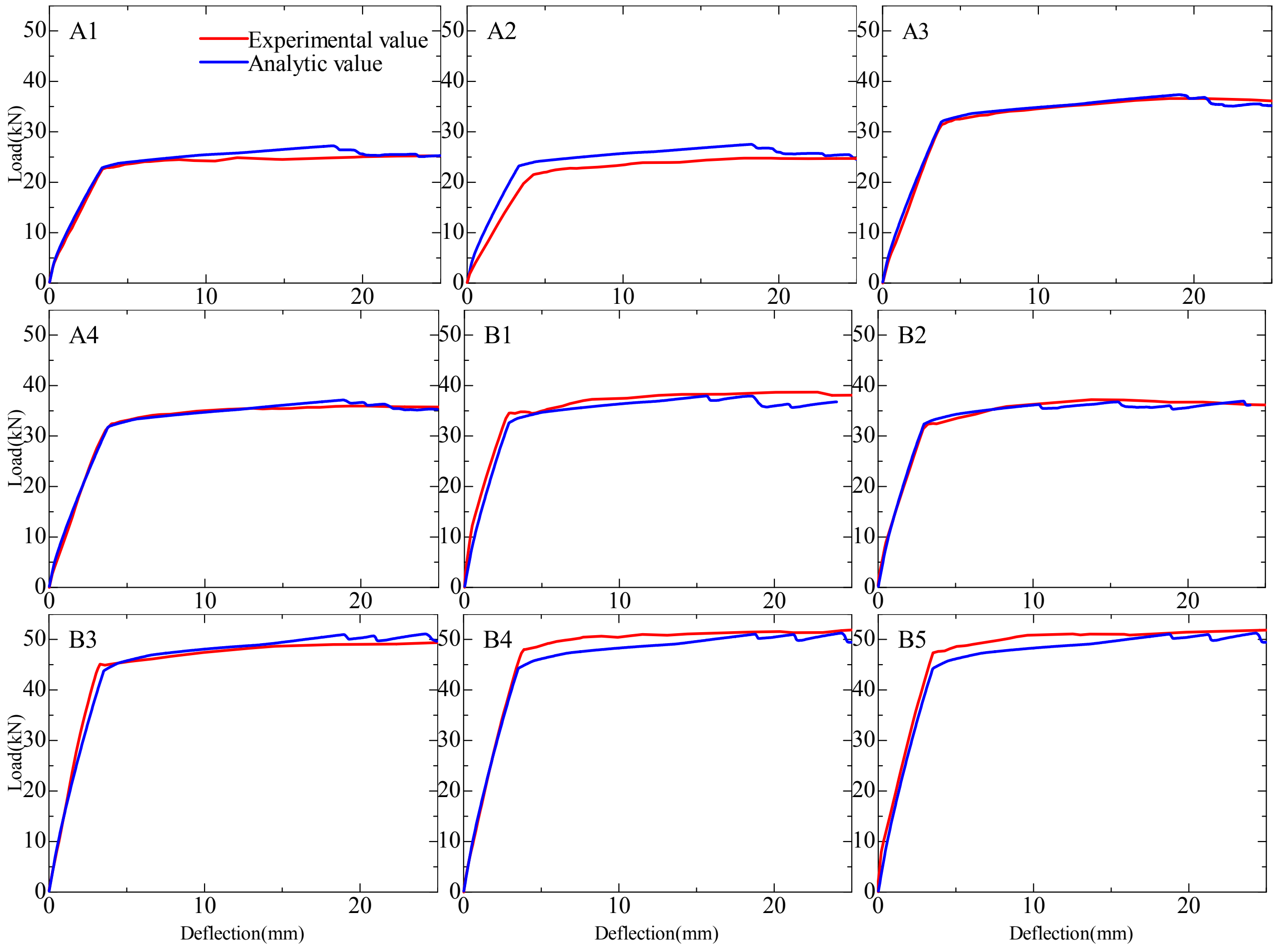


Figure 14 Loading-Deflection curves

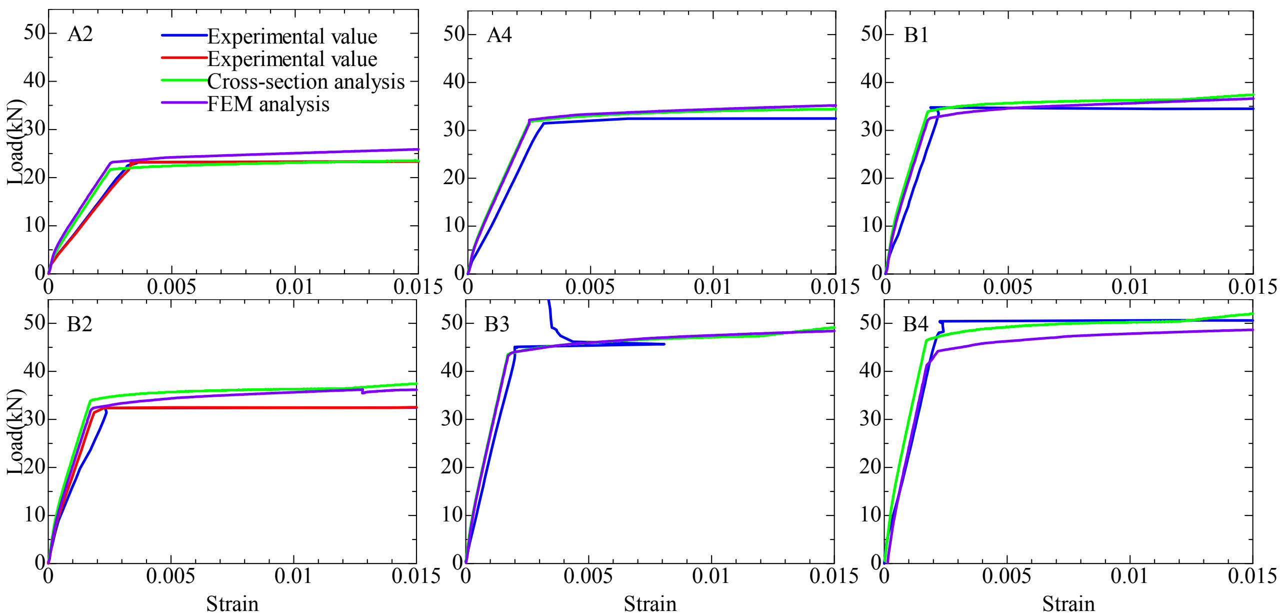


Figure 15 Loading-Strain relationship

On the basis of the experimental results the stress-strain relationship of concrete in the uniaxial state was idealized by the parabolic curve in the compression field [Figure 10]. In the tension field of the concrete the stress-strain curve was idealized by the tri-linear relationship proposed in this paper [Figure 11]. The reason that tensile strengths make a difference about D6 and D10 would appear that each bond stiffness and the main bar strength are different in this analysis. D6 and D10 differs from the shape of deformed bar. The D6 was small the asperity. The stress-strain relationship of the steel was assumed as a muti-linear curve and the breakage of the steel was not considered. Figure 12 shows the stress-strain relationship of the stirrup. The spring for the bond link was idealized by a bi-linear curve based on the previous bond tests [Figure 12] [2]-[5].

4.2. Analytical Result

Table 6 is shown the comparison with the experimental and analytical results.

When the experimental values compare the analytical values, all test specimens showed the good agreement with one.

Figure 14 is shown the loading-Deflection curves.

All test specimens showed the good agreement. In addition, all graphs are unstable the final curve because of the concrete entered the negative inclination region on the tension field in this analysis.

Figure 15 is shown the loading-strain relationship.

All test specimens showed the good agreement. All strain of the main bar of the experience was plastic state.

5. CONCLUSIONS

From the investigation reported in this paper, the following conclusions can be drawn.

1. The tensile stress-strain relationship of HPFRCC is make clear through the experiment of the beam and the analysis of the cross section and FEM.
2. HPFRCC are keeping the crack occurred stress until 3% strain and releasing the it's stress from 3% to 5% strain.
3. Using the introduced tensile stress-strain relationship of HPFRCC, the analytical results are good agreement with the experimental results.
4. D6 of the tensile stress-strain relationship is compared with D10's one, D6 shows more lower value than D10. It would because the bond stiffness and the main bar strength are different.

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