Flexural Performance of Reinforced Concrete Beams with a Layer of Expansive Strain-hardening Cement -based Composite(SHCC)

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SUMMARY:
This paper presents an experimental results on the flexural performance of reinforced concrete beams with a polyethylene (PE) fiber reinforced strain-hardening cement-based composite (SHCC) layer in tension zone. The objective of this study is to evaluate effects of the layer thickness (20 and 40mm) and expansive SHCC on the flexural performance and cracking behavior of SHCC-layered reinforced concrete beams. The concrete beams were monotonic loaded in static four-point bending test of specimens. A cross-section of concrete beam was 1480×130×170mm for all specimens. The experimental results show that the flexural strength, distribution of crack width, and flexural properties of the expansive SHCC-layered reinforced concrete beams are better than the conventional reinforced concrete beams.

Keywords: Flexural strengthening, Expansive admixture (EXA), Strain-hardening cement-based composite (SHCC), Stress redistribution

1. GENERAL INSTRUCTIONS

In many industrialized countries are seismically deficient the load system of these buildings for recovery of durability of reinforced concrete structure and long life of building from reduced durability due to environmental and physical reasons, various repair·strengthen materials and construction techniques have been developed and commercialized. Current maintenance materials for reinforced concrete structure are not enough in crack control, which can cause cracks from shrinkage and fatigue load, leading to corrosion that undermines durability.

Recently, single fiber reinforced cement based composites have been developed with excellent performance in crack control by improving the problems that current cement repair·strengthen materials have. The new concept of material is called strain-hardening cement-based composite (SHCC). Single fiber in the cement matrix widely disperses fine cracks, which makes its bending crack control, deformation, and energy dissipation capacity outstanding. As a result, there are many attempts to use SHCC as a repair· strengthen material for concrete structure.

However, according to research conducted by Li's team, it is reported that shrinkage from rich mix soared more than 160% in SHCC compared to general concrete. Thereby, we decided to control shrinkage from rich mix of SHCC by replacing some of cement mixed in SHCC by calcium sulfo aluminate (CSA) expansive admixture (EXA).

In this study, we evaluated mechanical characteristics after the replacement of expansive admixture of SHCC mixed with PE, and bending and crack control performance of reinforced concrete beam flexural strengthened by expanding SHCC, to review feasibility of using it as a repair· strengthen material.

2. OUTLINE OF EXPERIMENT

2.1 Test specimens

Table 1. Mix proportion of Concrete

	W/B (%)	EXA Replacement level (%)	Fiber volume fraction (%)	Water (kg/m³)	Unit weight (kg/m³)							
					C	EXA	S	G	Si[1)]	PE	SP[2)]	MC[3)]
Concrete	50	-	-	175	350	-	770	981	-	-	-	-
EXPE30	45	10	1.5	489	968	107	-	-	430	14	9.6	0.5

1)Si : Silica sand, 2)SP : Super plasticizer, 3)MC : Methyl cellulose

Table 2. Mechanical properties of EXA

Type	Specific gravity (kg/m³)	Fineness (㎠/g)	Setting time		Expansion	
			Initial set (min)	Final set (hour)	7 days (%)	28 days (%)
CSA	2.8～3.0	3,350	184	5.5	0.072	0.01

Table 3. Mechanical properties of fiber

Fiber	Specific gravity (kg/m³)	Length (mm)	Diameter (μm)	Aspect ratio (ℓ/d)	Tensile strength (MPa)	Elastic modulus (GPa)
PE	0.97	12	12	1,000	2,500	75

Figure 1. Shape of fiber

This study is to evaluate bending and crack control performance of flexural strengthened concrete beam by using general SHCC and expansive SHCC with 10% mix of CSA expansive admixture. To this end, it was planned to maintain 30MPa for construction standard compressive strength of flexural strengthened SHCC, and make reinforced concrete beam be flexural strengthened by 20mm and 40mm of SHCC reinforcement. Expansive admixture used in the study was CSA expansive agent, and its physical characteristics are described in Table 2. Reinforced fiber used in SHCC is polyethylene (PE), and its mechanical characteristics and form are in Table 3 and Fig 1. Also, steel bar laid in reinforced concrete beam was SD400-level deformed bar with nominal diameter of 22mm, and reinforced bar of shear was made of steel with its nominal diameter of 10mm. The detailed layout is shown in Fig. 2.
To evaluate bending performance of expansive SHCC reinforcement, 150mm and 130mm depth of 30MPa concrete was poured 24 hours before pouring SHCC, then 20mm and 40mm depth of 30MPa expansive SHCC was additionally poured, and finally 1,460×170×130mm concrete beam was constructed. Water was sprinkled for curing, to prevent drying shrinkage and maintain wet condition on the surface. The curing was carried out for 14 days.

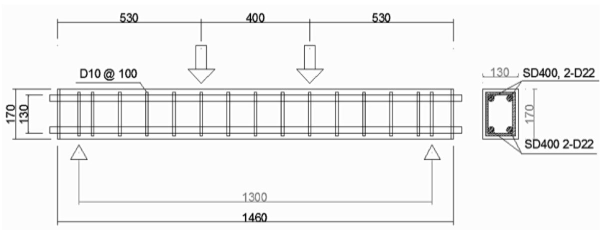


Figure 2. Reinforcement details of beam (unit: mm)

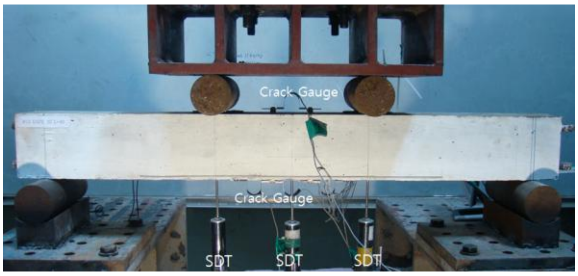


Figure 3. Test setting and four-point loading configuration

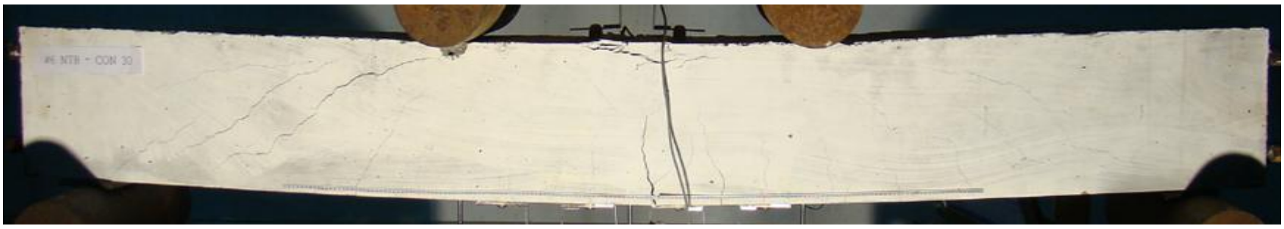
2.1 Testing method

To evaluate bending performance of beam with flexural-strengthened expansive SHCC, experiment objects were installed as shown in Fig. 3 Three SDTs were installed in the middle to measure deflection of the beam, and three crack gauges were attached to lower part of beam while one was to upper part to measure crack width. In addition, 2-axis gauge and concrete gauge were attached to boundary surface between SHCC strengthen and concrete to measure deflection of SHCC strengthen and concrete interface, while a gauge was installed on tensile and compression side reinforcement bar of beam to measure deformation rate of the bar. Monotonic 4 point loading was carried out by using deformation control method with 500 kN actuator to measure loading of the beam.

3. EXPERIMENT RESULTS AND ANALYSIS

3.1 Crack and failure mode

Fig. 4 indicates ultimate failure mode of concrete beam experiment object flexural strengthened by SHCC. In the 30MPa general concrete beam in Fig. 4 (a), diagonal crack was detected along with transverse tension crack, showing somewhat brittle failure pattern. In case of the concrete beam flexural strengthened by 20mm of 30 MPa-level SHCC in Fig. 4 (b), there was initial crack on SHCC strengthen, and transverse tension crack from bending failure went through concrete, causing ultimate failure. The experiment object in Fig. 4 (c) was reinforced by 40mm of expansive SHCC. As the thickness of strengthen was doubled, there were multiple cracks on SHCC strengthen, and the cracks progressed into substrate concrete, causing diagonal crack on the concrete, leading to ultimate failure. It is considered that the diagonal crack was created on the substrate concrete as SHCC reinforcement increased tensile strength.



(a) CON30

(b) EXPE30_L20

(c) EXPE30_L40

Figure 4. Failure mode of specimens

3.2 Flexural behaviour of beam

Table 4 and Fig. 5 is a loading-deflection relation curve of experiment object flexural strengthened by expansive SHCC. It was revealed that maximum flexural strength of object reinforced by expansive SHCC increased by approximately 10%, compared to CON30, which is a general concrete beam. As the thickness of strengthen increased from 20mm to 40mm, deformation capacity also improved, but maximum flexural strength somewhat decreased due to diagonal crack. Since the increase in strengthen thickness worked as a bridge of SHCC reinforced fiber, doubled strengthen thickness seemed to increase strain volume.

Table 4. Flexural strength of reinforced beam

Specimens	Flexural strength (kN)	Rate of loading (%)	Deflection (mm)
CON30	169.0	-	22.6
EXPE30 L20	191.5	13.3	29.9
EXPE30 L40	183.5	8.6	44.8
$Rate\ of\ loading = \frac{EXPE - Concrete}{Concrete} \times 100$			

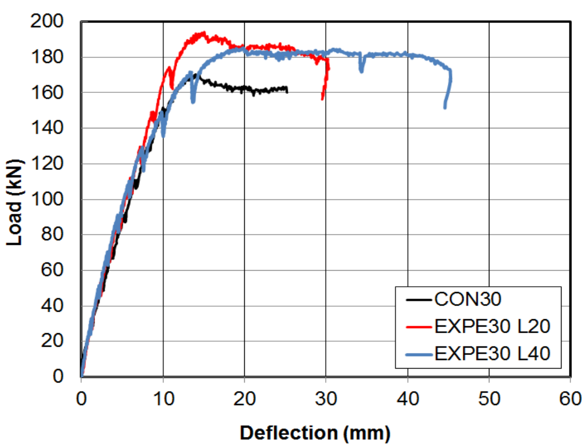


Figure 5. Load-deflection relationship curve

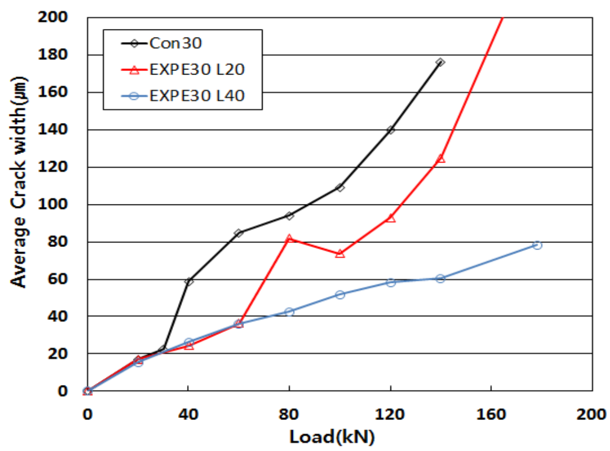


Figure 6. Average of crack width

3.3 Crack control characteristics

Fig. 6 shows average crack width rise according to increased loading on each object. In a general concrete object of CON30, as loading increased after initial crack, the crack became drastically widen. In the meantime, the crack width on the object reinforced by expansive SHCC was narrower than CON30, and average crack width decreased even with heavier load when strengthen was thicker. The reason seems to be crack control performance resulted from strain hardening characteristics of SHCC.

4. CONCLUSIONS

The column-tree type and the WUF-B type weak-axis steel moment connection specimens were tested cyclically to study the seismic performance of two different types of connection. The following conclusions can be made for the specimens:

1) The concrete beam flexural strengthened by expansive SHCC showed excellent bending performance with 20% improvement in strain and 10% in flexural strength, compared to a general concrete beam.

2) The concrete beam flexural strengthened by expansive SHCC showed better crack dispersion performance due to strain hardening characteristics of SHCC as well as ductile behavior according to crack damage control.

3) Strengthening of expansive SHCC thickened from 20mm to 40mm, excellent mechanical characteristics of SHCC enhanced deformation capacity of beam.

4) Additional shear reinforcement is required, considering failure from diagonal crack of concrete beam flexural strengthened by expansive SHCC. It is considered that this can guarantee better bending reinforcement.

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REFERENCES

Minoru Kunieda, Keitetsu Rokugo.(2006) “Recent Progress on HPFRCC in Japan Required Performance and Applications” Journal of Advance Concrete Technology, Vol **4**, pp. 19～33

Mo Li, Victor C Li.(2006)."Behavior of ECC/Concrete Layer Repair System Under Drying Shrinkage Conditions" , Restoration of Buildings and Monuments, Vol. **12**, no. 2, pp. 143～160

Jun Zhang, Christopher K.Y. Leung, Yin Nee Cheung.(2006). “Flexural performance of layered ECC-concrete composite beam”, Composites Science and Technology **66**, pp. 1501～1512

Toshiro Kamada, Victor C. Li.(2000) “The effects of surface preparation on the fracture behavior of ECC/concrete repair system”, Cement & Concrete Composites **22**, pp. 423～431

K Rokugo, M Kunieda, S. C. Lim.(2005) “Patching repair with ECC on cracked concrete surface”, CONMAT,

Lim, Y. M., Li, V. C.(1997). “Durable repair of aged infrastructures using trapping mechanism of engineered cementitious composites” Journal of Cement and Concrete Composites, Elsevier **19(4**), pp. 373～385.