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

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SUMMARY:

The results of an experiment on the flexural performance of reinforced concrete beams with a polyethylene (PE) fiber reinforced strain-hardening cement-based composite (SHCC) layer in tension zone are presented in this paper. The goal of this research is to determine the effects of layer thickness (20 and 40mm) and expansive SHCC on the flexural performance and cracking behavior of SHCC-layered reinforced concrete beams. In a static four-point bending test, the concrete beams were monotonically loaded. For all specimens, the cross-section of a concrete beam was 1480130170mm. The experimental results show that the expansive SHCC-layered reinforced concrete beams have better flexural strength, crack width distribution, and flexural properties than conventional reinforced concrete beams.

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

I. GENERAL INSTRUCTIONS

In many industrialised countries, the load system of these buildings is seismically deficient. In order to recover the durability of the reinforced concrete structure and extend the life of the building from reduced durability due to environmental and physical factors, various repair•strengthen materials and construction techniques have been developed and commercialised. Current maintenance materials for reinforced concrete structures are insufficient for crack control, which can result in cracks caused by shrinkage and fatigue load, resulting in corrosion that compromises durability.

Recently, single fibre reinforced cement-based composites with excellent crack control performance have been developed by improving the problems that current cement repair•strengthen materials have. The new material concept is known as strain-hardening cement-based composite (SHCC). Because a single fibre in the cement matrix disperses fine cracks widely, it has excellent bending crack control, deformation, and energy dissipation capacity. As a result, many attempts have been made to use SHCC as a repair• strengthening material for concrete structures.

However, according to Li's team's research, shrinkage from rich mix increased by more than 160 percent in SHCC compared to general concrete. As a result, we decided to control shrinkage from a rich SHCC mix by replacing some of the cement with a calcium sulfo aluminate (CSA) expansive admixture (EXA).

In this study, we evaluated the mechanical properties of reinforced concrete beams flexural strengthened by expanding SHCC after the replacement of an expansive admixture of SHCC mixed with PE, as well as the bending and crack control performance of reinforced concrete beams flexural strengthened by expanding SHCC, to assess the feasibility of using it as a repair• strengthen material.

Reinforced cement concrete is one of the important component in the construction industry.

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Now a days, the use of concrete increased very much. In this paper an attempt is made for reduction of concrete and self-weight of the beam by replacing the concrete below neutral axis. However, concrete have low tensile strength and when a concrete member is subjected to flexure, the region under the neutral axis of the cross-section is considered ineffective when it is in tension at ultimate limit states.

II. OUTLINE OF EXPERIMENT

Test specimens

Table 1. Mix proportion of Concrete

	W/B (%)	EXA Replacement level (%)	Fiber volume fraction (%)	Water (kg/m^3)	Unit weight (kg/m^3)							
					C	EXA	S	G	Si1)	PE	SP2)	MC3)
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/m^3)	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/m^3)	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

The purpose of this study is to evaluate the bending and crack control performance of flexural reinforced concrete beams made of general SHCC and expansive SHCC with a 10% mix of CSA expansive admixture. To that end, it was planned to keep the construction standard compressive strength of flexural strengthened SHCC at 30MPa, and to make reinforced concrete beams flexural reinforced with 20mm and 40mm of SHCC reinforcement. The CSA expansive agent was used in the study, and its physical properties are described in Table 2. Polyethylene (PE) reinforced fibre is used in SHCC, and its mechanical properties and form are shown 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

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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 conditionon the surface. The curing was carried out for 14 days.

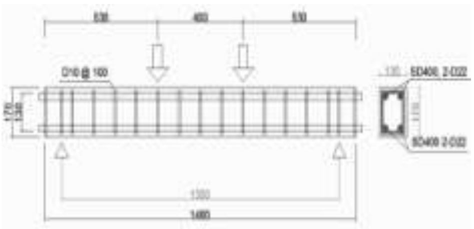

Figure 2. Reinforcement details of beam (unit: mm)

Figure 3. Test setting and four-point loading configuration

2.1 Testing method

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

III. EXPERIMENT RESULTS AND ANALYSIS

Crack and failure mode

Figure 4 depicts the ultimate failure mode of a concrete beam experiment object that has been flexural strengthened by SHCC. The diagonal crack was detected along with the transverse tension crack in the 30MPa general concrete beam in Fig. 4 (a), indicating a somewhat brittle failure pattern. In the case of the concrete beam flexural strengthened by 20mm of 30 MPa-level SHCC in Fig. 4 (b), an initial crack appeared on the SHCC strengthen, and a transverse tension crack from bending failure went through the concrete, causing ultimate failure. 40mm of expansive SHCC was used to reinforce the experiment object in Fig. 4 (c). As the thickness of the strengthen was doubled, multiple cracks appeared on the SHCC strengthen, and the cracks progressed into the substrate concrete, causing diagonal cracks on the concrete reinforcement increased tensile strength.

(a) CON30

(b) EXPE30_L20

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(c) EXPE30_L40

Figure 4. Failure mode of specimens

Flexural behaviour of beam

A loading-deflection relation curve of an experiment object flexural strengthened by expansive SHCC is shown in Table 4 and Fig. 5. The maximum flexural strength of an object reinforced by expansive SHCC increased by approximately 10% compared to CON30, a general concrete beam. Deformation capacity improved as the thickness of the strengthen increased from 20mm to 40mm, but maximum flexural strength decreased due to the diagonal crack. Because the increased strength thickness functioned as a bridge of SHCC reinforced fibre , 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

$$Rate\ of\ loading = \frac{EXPE - Concrete}{Concrete} \times 100$$

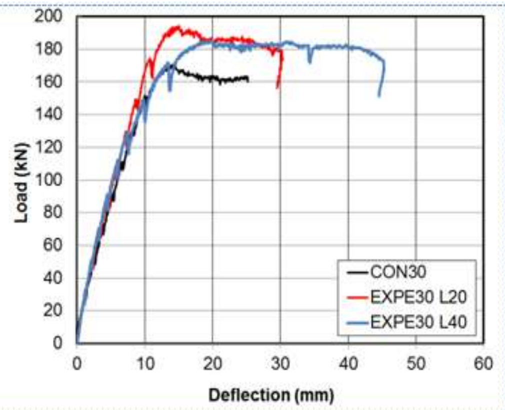

Figure 5. Load-deflection relationship curve

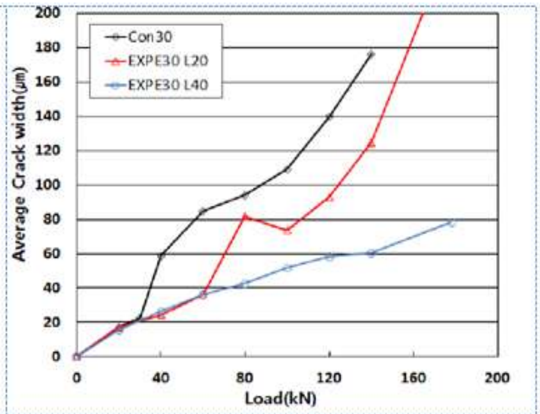

Figure 6. Average of crack width

Crack control characteristics

Figure 6 depicts the average crack width increase as loading on each object increases. As loading increased after the initial crack in a general concrete object of CON30, the crack became significantly wider. Meanwhile, the crack width on the object reinforced by expansive SHCC was narrower than CON30, and the average crack width decreased even when the load was heavier when the strengthen was thicker. The reason appears to be crack control performance as a result of SHCC strain hardening characteristics.

IV. 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 bendingreinforcement.

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