Flexural Performance of Expansive SHCC beams according to Shrinkage and Hydration heat

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SUMMARY:

Strain Hardening Cement-based Composite (SHCC) has high performance representing by great tensile strain capacity. This type of composites is concerned about shrinkage and hydration heat from low water-binder ratio. Therefore, test to reduce the shrinkage an
d hydration heat of SHCC using expansive admixture were conducted. This study was investigated the flexural performance of SHCC beams with expansive admixture according to shrinkage and hydration heat. The beams carried out four-point loading test. Test results indicated that EX-PE30 compared with PE30 initial cracking load, the stiffness, the yield was higher. This result is due to reduction in shrinkage and hydration heat.

Keywords: Strain Hardening Cement-based Composite (SHCC), Expansive admixture, Shrinkage, Hydration heat

1. INSTRUCTIONS

Concrete is relatively vulnerable to tensile strength considering its compressive strength, and subject to brittle fracture. Strain-hardening cement-based composite (SHCC), recently researched in various studies, is a new material with about 2% of reinforced fibres to improve tensile strength and ductility. But SHCC does not use thick aggregate for better fibres dispersion. Instead, it uses many sands and binders, which generate considerable shrinkage and heat of hydration. Since they cause crack formation in the cement-based matrix, it is required to come up with solution to address the issue.
A recently conducted study showed that the alternative use of expansive admixture for cement mixture in SHCC stimulated creation of needle-shaped ettringite, which reduced shrinkage in the cement-based composite. However, while expansive admixture is sensitive to temperature, there has not been enough study on heat of hydration. SHCC requires more cement than concrete does, generating more heat of hydration. The heat causes temperature gap between inside and outside of construction material, leading to crack formation. However, it is expected that the replacement of some cement by expanding cement can be effective in reducing the heat.
This study is to find out how much the expansive admixture can affect the performance of SHCC, by making 30MPa SHCC beam and measuring shrinkage and heat of hydration as well as conducting bending test, with expansive admixture as a variable.

2. EXPERIMENTS

2.1. Experimental plan

In this study, 30 MPa of compressive strength was planned for concrete and SHCC. 1.5% volume of polyethylene (PE) fibers was mixed in the SHCC. Aggregate was composed of adhesive Silica (specific gravity 2.61, diameter of 105~120 ㎛). The expansive admixture was from K-type calcium sulfo Aluminate CSA), and its planned cement replacement rate was 0 and 10%. Three types of experiment specimen were planned. The mix condition of concrete and SHCC is table 1 and table 2.

Table 1. Mix proportion of concrete

Mix type	f_{ck} (MPa)	W/C (%)	S/A (%)	Water (kg/m^3)	Cement	Sand	Aggregate
Con30	30	50	45	175	350	770	981

Table 2. Mix proportion of SHCC

Mix type	W/B	EXA Replace ment Level (%)	Fiber Volume fraction (%)	Water (kg/m^3)	Unit weight				
					Cement	EXA	Si	PE	SP
PE30	45	-	1.5	484	1075	-	430	14	9.6
EX-PE30	45	10	1.5	489	968	107	430	14	9.6

1)EXA : Expansive admixture, 2)Si : Silica sand, 3) SP : Super plasticizer

2.2. Design of specimen

Figure 1 shows the experiment specimen. The specimen for bending performance test was measured 130×170×1460mm, and its clear span was 1300mm. To make the specimen, substrate concrete was casted first, and then SHCC was casted one day later. Also, upper and lower part of steel reinforcement were welded with steel sheet laid on the edge of the beams to fix the steel as shown in Figure 2.

After sprinklign water water, the surface was covered for curing of concrete to prevent drying shrinkage and maintain wet condition.

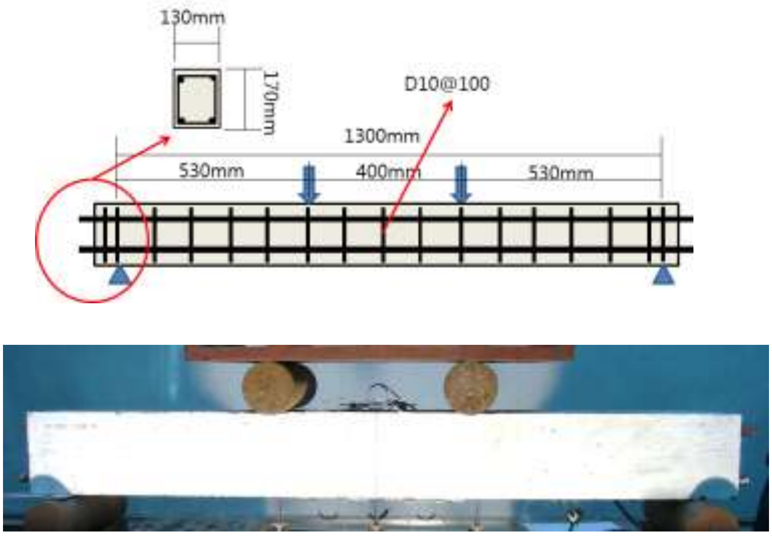


Figure 1. Test setting and four-point loading configuration

Figure 2. End of beams

2.3. Measurements

(1) Shrinkage test

In this study, shrinkage test was conducted to measure shrinkage of SHCC after mixing of expansive admixture. For the shrinkage test, shrinkage was measured in constant temperature and humidity room at 20±1℃ of temperature and 60±1% of humidity for 28days from the casting of concrete, with a shrinkage a shrinkage gauge installed at the center of 100×100×400mm experiment specimens.

(2) Hydration heat measurement test

For hydration heat test, full scale beams 130×170×1460mm was built and a temperautre gauge was installed at the center of the expriment specimen. The temperature at the center could be measured though the specimen from the casting of concrete. Outdoor temperature was measured as well.

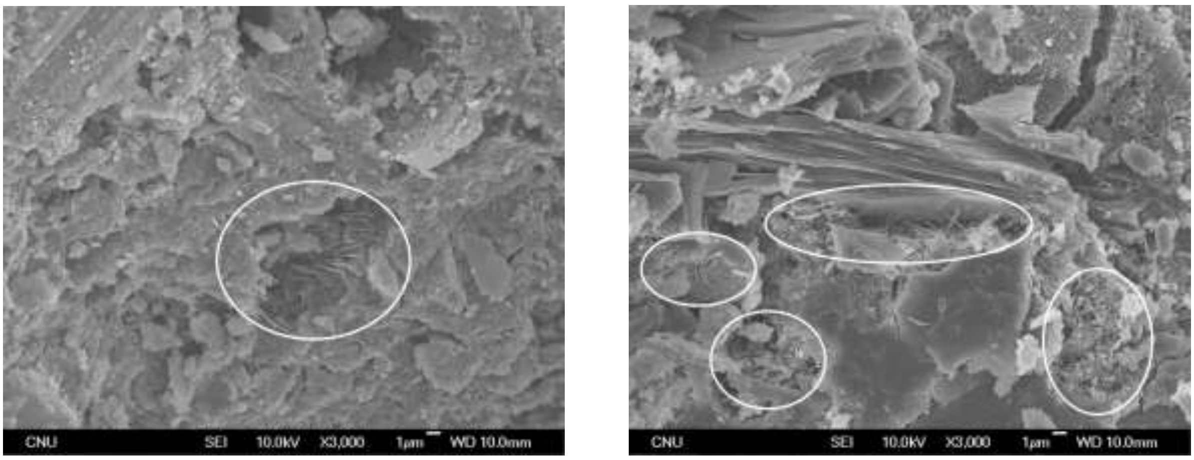
(3) Flexural test of beams

For flexural test, 500kN actuator was used with displacement control system, and deflection was measured by strain displacement transducer (SDT) installed at the center of the specimen. In addition, a pi-shaped(Ω) gauge was installed in the upper and lower part of specimen to measure curvature, and micro scope was used to measure crack formed on the specimen.

3. TEST RESULTS

3.1. SEM analysis

Scanning electron microscope (SEM) analysis was conducted in this study to see how much ettringite was generated depending on the use of expansive admixture. SEM analysis was done at 1㎛ magnification for specimen ground after 28 days. In this study, the CSA expansive admixture contained calcium (3CaO), sulphuric acid ($CaSO_4$), aluminium ($3Al_2O_3$), plaster ($CaSO_4$) and calcium oxide(CaO). They are known to respond to water to create ettringite and mainly affect expansion. Figure 3 shows SEM analysis results. White circles highlight ettringites. Ettringite was observed in both PE30 and EX-PE30 specimen. In case of EX-PE30, in particular, a multiple number of ettringites were generated throughout specimen depending on the use of expansive admixture.

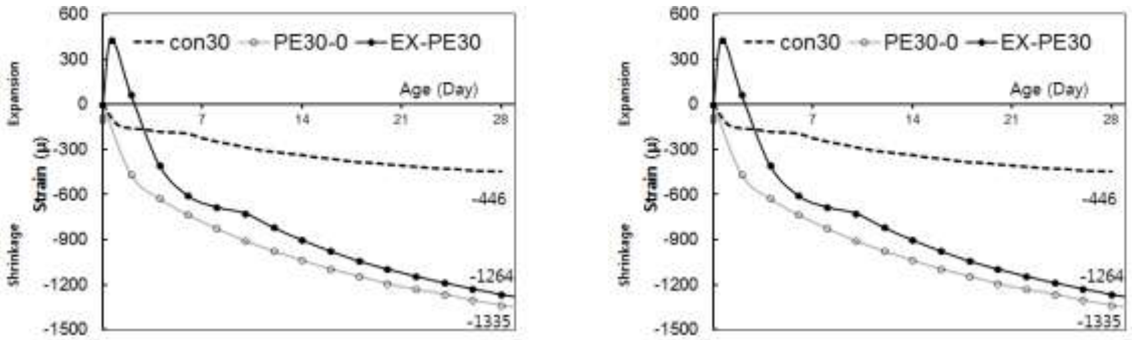


(a) PE30 (b)EX-PE30

Figure 3. SEM image of ettringite

3.2. Shrinkage test

Shrinkage of each specimen was measured for 28 days after casting of concrete, and the results are shown in Figure 4. In case of concrete specimen, the final shrinkage was 446㎛ while that in PE30 was 1335㎛, which shows that SHCC tends to have larger shrinkage. EX-PE30 had maximum shrinkage of 429㎛, 15 hours after casting of concrete with final shrinkage. Therefore, the replacement of expansive admixture could reduce 5% of final shrinkage.



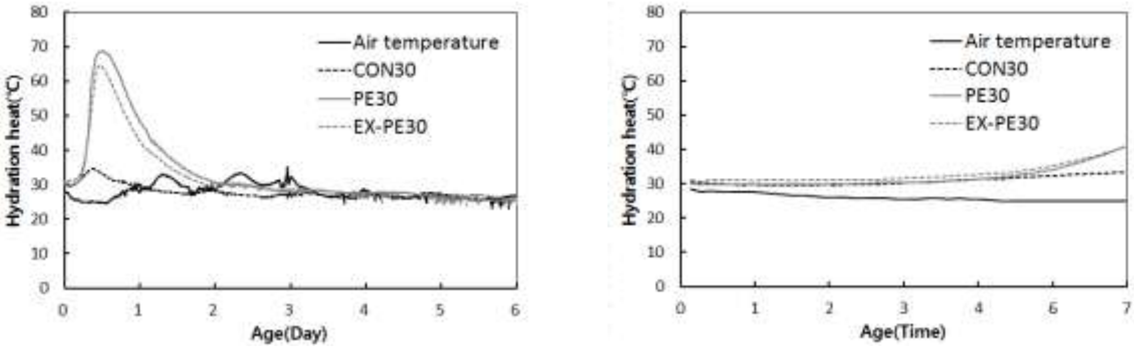
(a) Shrinkage during 24 hours

(b) Shrinkage during 28 days

Figure 4. Results of shrinkage test

3.3. Hydration heat test

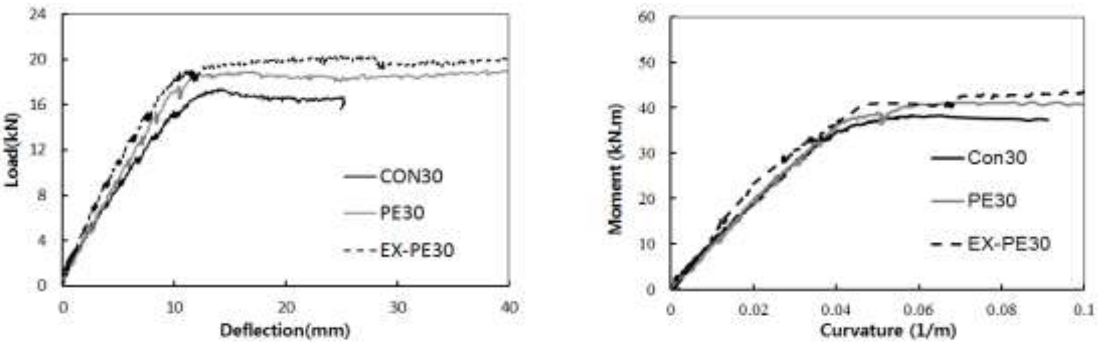
Figure 5 is a graph that measured heat of hydration from the casting of concrete. Average outdoor temperature was 26℃. All had similar hydration heat for the first four hours after the pouring, but later temperature at the center increased. The maximum temperature of concrete was 36℃, measured 8 hours after the pouring, but that of PE30 was 67℃ 11 hours after the pouring. This shows the mix of SHCC uses a large amount of cement, generating large hydration heat. In case of EX-PE30, temperature at the center was 63℃ after 12 hours. Therefore, the replacement of expansive admixture could reduce 7% of hydration heat.



(a) Temperature during 6 days

(b) Temperature during 7 hours

Figure 5. Results of four-point flexural test

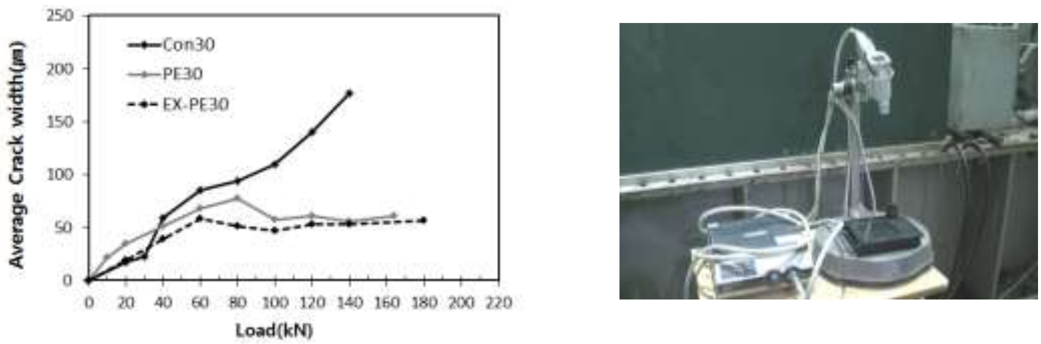


(a) Load-deflection relationship curve (b) Moment-Curvature relationship curve

Figure 6. Results of four-point bending test

3.4. Flexural behaviour of beams

A load-deflection relationship curve indicating the test result is in Figure 6(a). The initial cracking load of Con30 was 16kN, while it was 18.2kN in PE30. EX-PE30 had the highest initial cracking load of 18.7kN. EX-PE30 also showed higher initial rigidity value than Con30 and PE30, and displayed excellent bending performance even after yield.
Figure 6(b) is a moment-curvature curve measured by a pi-shaped gauge installed in specimens. PE30 showed a similar curvature as a concrete specimen did at first, but it reached a high moment after yield. In addition, it was observed that EX-PE30 was affected by largest moment in the same curvature.



(a) Average crack width according to loading step (b) microscope

Figure 7. Crack width of specimens

3.5. Crack behaviour of reinforced cement composite beams

Cracks on reinforced concrete construction due to shrinkage, temperature, and loading have a huge impact on durability. Therefore, cracks should be avoided in practical and aesthetic reasons. Crack control is required to rather replace one wide crack with more than one narrow crack. Figure 6 is the result of measuring maximum crack width at each loading step up to yield in each experiment object. As a result of measurement, concrete had the widest crack, while crack width in PE30 was drastically reduced. EX-PE30 ended up with the narrowest crack. In particular, the maximum crack of concrete was 176, but it was reduced to 50㎛ in EX-PE30, which proves expansive SHCC is effective in controlling cracks.

(a) Con30 Yield strength

(b) Con30 Fracture strength

(b) PE30 Yield strength

(c) PE30 Fracture strength

(d) EX-PE30 Yield strength

(e) EX-PE30 Fracture strength

Figure 8. Comparison of crack pattern

Cracks on reinforced concrete beam can be categorized into transverse tension crack, flexure shear crack, and diagonal crack. In this study, we compared cracks on each experiment object at yield and ultimate failure steps to evaluate crack control performance of expansive SHCC. The results are described in Table 3. At ultimate failure step, there was no difference between PE30 and EX-PE30. However, EX-PE30 had more cracks than PE30 at yield step. Therefore, it is considered that a multiple number of cracks could reduce the crack width on EX-PE30.

4. CONCLUSIONS

In this study, we constructed actual-size 30 MPa SHCC and concrete beams for experiment by using expansive admixture replacement rate as a variable to test shrinkage, heat of hydration, and bending performance. The conclusions are as follows:

1. Compared to Con30, PE30 had more than doubled shrinkage and hydration heat, but when expansive admixture was added, shrinkage decreased by 5% while hydration heat did by 7%.
2. Compared to PE30, EX-PE30 had higher initial cracking load, rigidity, and load after yield. In addition, EX-PE30 showed higher moment in the same curvature. The reason seems to be improved bending performance in EX-PE30 after the replacement of expansive admixture.
3. Compared to PE30, the maximum crack width of EX-PE30 was measured much smaller. This leads to the conclusion that expansive admixture is effective in controlling crack width.

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