Effects of Fiber Types on Seismic Behavior of Strain Hardening Cement Composite (SHCC) Precast Infill Wall

Su-Won Kang, June-Su Kim & Seung-Ju Han
Chung-nam National University, Republic of Korea

Hyun-do Yun
Chung-nam National University, Republic of Korea

SUMMARY:
Earthquake resistance of structure is so important in the seismic region that much heavier reinforcement details are needed for new building construction. However, there exist many structures that do not satisfy the current seismic provision. In terms of the preservation of natural resources and CO2 emissions in their new construction, these structures are suggested to be retrofitted rather than to be removed and newly built. This paper presents experimental results of 1/3 scaled precast infill walls under lateral load were carried out to investigate the influence of reinforced fiber types on strain-hardening cement-based composites (SHCC) matrix. Three cyclic loading tests were conducted on a conventional concrete infill wall and two types of SHCC infill wall. The two types SHCC contain both polyethylene fiber (PE) and polyvinyl alcohol (PVA) with different volume fraction. The total fiber volume content of SHCC was 1.5 vol.% which composed of 0.2 vol.% and 0.75 vol.% of PE and 1.3 vol.% and 0.75 vol.% of PVA respectively. Test results indicated that SHCC infill wall developed in this study showed high deformation capacity due to multiple cracks and pseudo strain hardening properties compared to concrete infill wall. Therefore it could be confirmed that SHCC has a sufficiently high seismic resistance performance to qualify as a retrofit member.

Keywords: Precast infill wall, Seismic retrofit, SHCC, Fiber type

1. INTRODUCTION

As a great number of earthquakes are occurring around the world, earthquake-resistant structures have been become more important recently. Accordingly, domestic reinforces the criterion about earthquake-resistant design. However, before the revision of the domestic regulation, to meet required performance for established building structure, it is required to adopt strengthening method, using reinforcement material, which is properly reinforced, rather than breakup and building again. Consequently, many researches about strengthening method have been interested by many architects. Especially, among the strengthening methods, the method to reinforce the structure by using precast Infill Walls have been known as controlled by strength characteristic of Infill Walls's reinforce and framework. There is the problem when structured by concrete Infill Wall. Since it is difficult to reflect the enough reinforcement effect by Infill Walls itself, destroying conjunction between frames works from too strong strength of characteristic. In this study, SHCC, representing the Strain Hardening and excellent multiple cracking, was adapted to Infill Walls for increasing ductility of member and Energy Dissipation Capacity. Besides, SHCC causes the damage in Infill Wall by putting the notch at the left and right side of Infill Walls and decreasing center aspects.

2. EXPERIMENTAL PROGRAM

2.1. Test specimens

Three specimens were tested, as listed in Table 2.1. The reinforcing fibers used in the experimental program were listed in Table 2.2. It was noted that several parameters were selectively investigated:

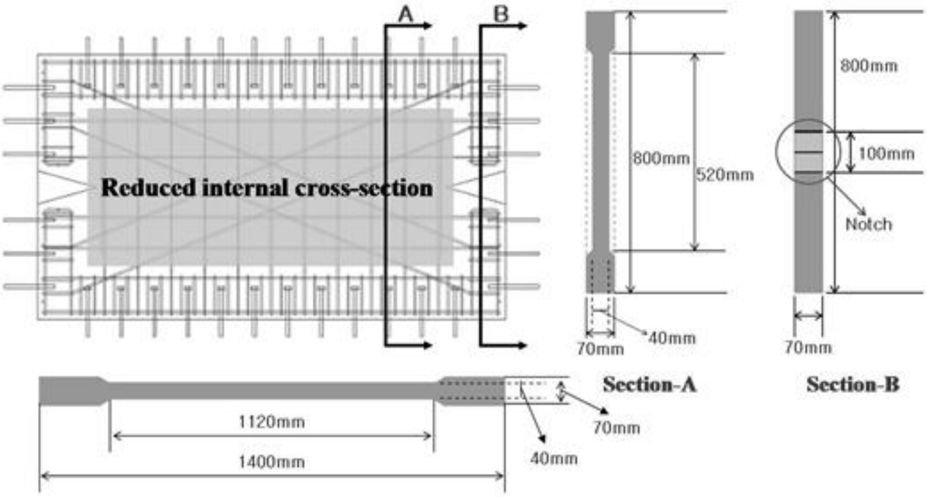


Figure 1. Details of Reinforcement

Table 2.1. Description of Specimens

Specimen	f_{ck} (MPa)	Reinforcing fibers	lw x hw x tw (mm)	Reinforcing Method	Notch	ρ_h (%)	ρ_v (%)
PW-C	50	-	1,400x800x70 (outside) 1,120x520x40 (inside)	Diagonal	Yes	1.1	0.9
PW-V		PVA1.3+PE0.2					
PW-E		PVA0.75+PE0.75					

Table 2.2. Physical properties of Reinforcing fibers

Fiber type	Density (g/cm^3)	Length (mm)	Diamater (μm)	Aspect Ratio	Tensile strength (MPa)	Elastic Modulus (GPa)
PE	0.97	15	12	1250	2500	75
PVA	1.30	12	39	307	1600	40

two different fibers (PVA and PE), two different matrices (concrete and SHCC). A regular concrete matrix was used in specimens PW-C, and SHCC was used in specimens PW-V and PW-E, respectively. The infill wall specimens were scaled to about 1/3, which was 1,400 mm wide and 800 mm high for specimens with of an aspect ratio of hw / lw=0.57. The depth of a notch was 250 mm, which is about 18 % of total midsection length. A 70 mm thick panel was needed to allow reinforcing D6 rebar as horizontal, vertical, and diagonal reinforcement. Figure.1 shows the reinforcement details of the specimens.

2.2. Material Properties

The SHCC matrix used in this study utilized hybrid 1.3% or 0.75% ultra-high molecular weight PVA and 0.2% or 0.75% PE fibers, cement, fine aggregates (grain sizes ranging from 105 to 120 μm), and methyl cellulous-based viscosity modifying admixture (VMA) 0.2 % at cement weight fractions. The total fiber content of the SHCC matrix was 1.5%. In the concrete, coarse aggregates (maximum grain size 18 mm), cement, and water were used. A high range water-reducing admixture was also added to enhance the fresh properties of the mixture. The mixture proportions on each matrix used in this study were listed in Table 2.3.

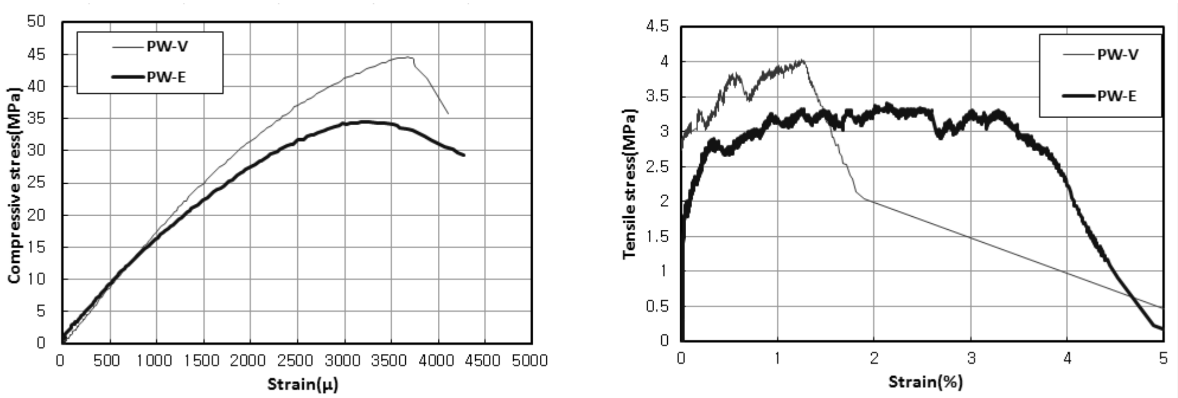
All specimens had been stored at 23℃ and 95-100% relative humidity (RH) for about 1 day,

Table 2.3. Mixture proportion of Cement composites

Spcimen type	W/C (%)	Fiber contents, V_f(%)		Unit weight (kg/m^3)						
		PVA	PE	C	W	S	G	PVA	PE	MC
Concrete	0.35	-	-	165	471	737	932	-	-	-
PW-V	0.45	1.3	0.2	1,075	484	312	-	16.9	1.94	0.523
PW-E		0.75	0.75					9.75	7.26	

Table 2.4. Summary of Material test results of Cement composites

Cement composite	Maximum load		Tensile test	
	fcu (MPa)	Ecu (x10^{-6})	ft (MPa)	εt (%)
PW-C	62.2	2,460	-	-
PW-V	42.3	3,680	4.7	1.3
PW-E	34.8	3,268	3.4	2.1



(a) Compressive (b) Tensile

Figure 2. Stress-strain curve of cement composites

whereupon they were demolded, and then all specimens had been cured in water at 23±2℃ for 28days.

As a steel reinforcement, only a D6 deformed bar was used as the vertical, horizontal and diagonal reinforcement. Tensile tests were performed on five steel samples of rebar. D6 showed a yielding strength of 291 MPa at 0.19% strain and an ultimate strength of 375 MPa at 0.58% strain.

The monotonic compressive tests were carried out on the cylindrical specimens, which were 100 in diameter and 200 mm in height, according to KS F 2405. All of the compressive testing was performed at a strain rate of 0.30% per minute. Direct tensile tests were monotonically performed on the dumbbell-shaped specimens to examine the effect of reinforcing fibers on the tensile capacity of SHCCs. The results of the compressive and direct tensile tests are showed in Table 2.4 and Figure 1(a), and each test result presented is the average of each of the five specimens.

As shown in Figure 2(a), The concrete specimen showed 62.2 MPa in compressive strength and 2,460 strain. And The SHCCs with PVA1.3% and PE 0.2%, showed 42.3 MPa in compressive strength and 3,680 strain. And The SHCCs with PVA0.75 and PE 0.75, showed 34.8 MPa in compressive strength and 3,268 strain. In the tensile behavior, as shown in Figure 2(b), PVA1.3%+PE0.2% specimen showed higher tensile strength and PVA0.75+PE0.75 specimen showed higher strain capacity.

2.3. Testing method

As shown in Figure 3, the experimental setup was designed to simulate a rectangular frame structure with four pin joints under lateral reversal cyclic loading. The loading frame composes two steel frame columns pin-connected with a lateral loading beam and reaction floor. The capacity of the loading actuation is 1,000 kN. The test specimens were instrumented to monitor the applied loads and displacements at the top of the wall specimen. Displacement transducers were used to measure the drift and shear deformation of the wall. The figure 4 showed the displacement routine used for reversed cyclic loading.

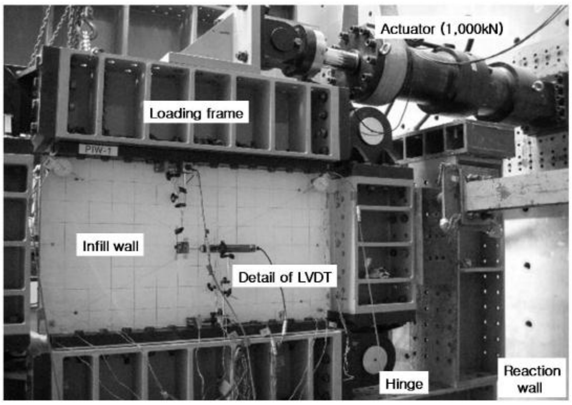


Figure 3. Setup of test specimen

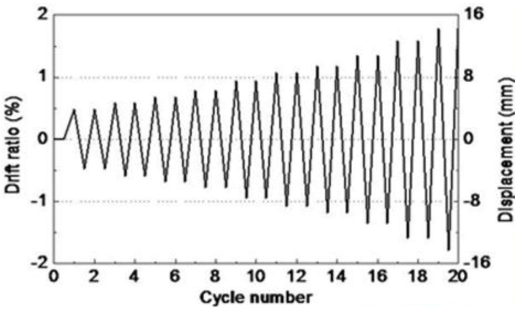
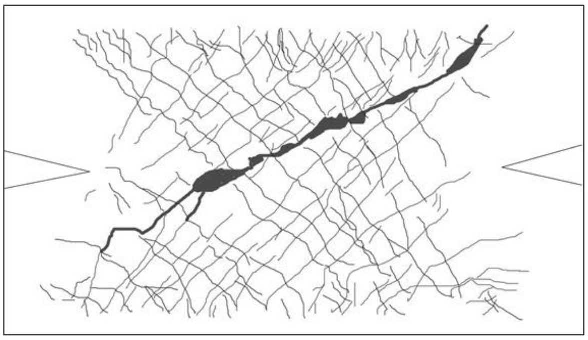
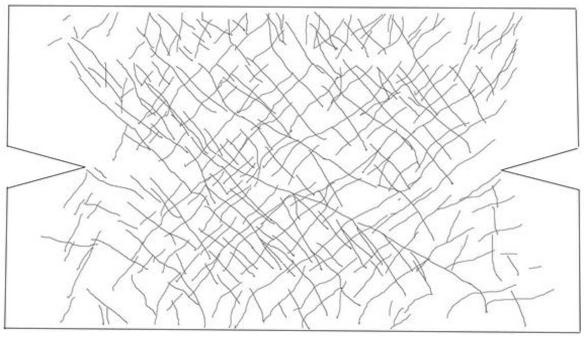


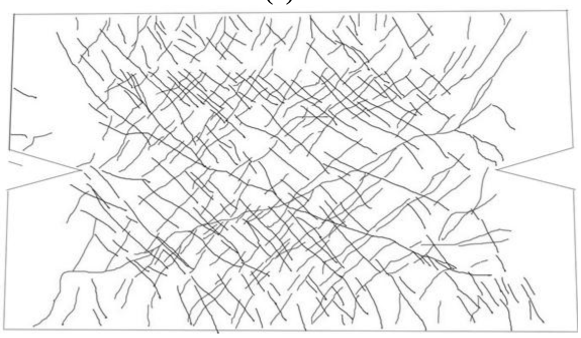
Figure 4. Displacement routine



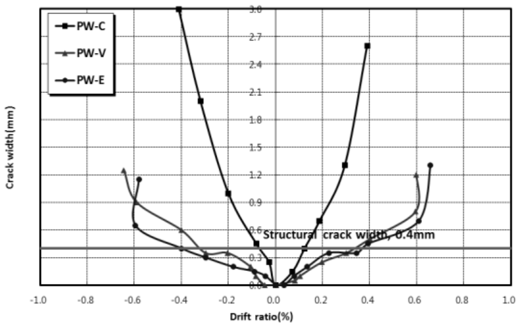
(a) PW-C



(b) PW-V



(c) PW-E



(d) Crack width – Drift ratio curve

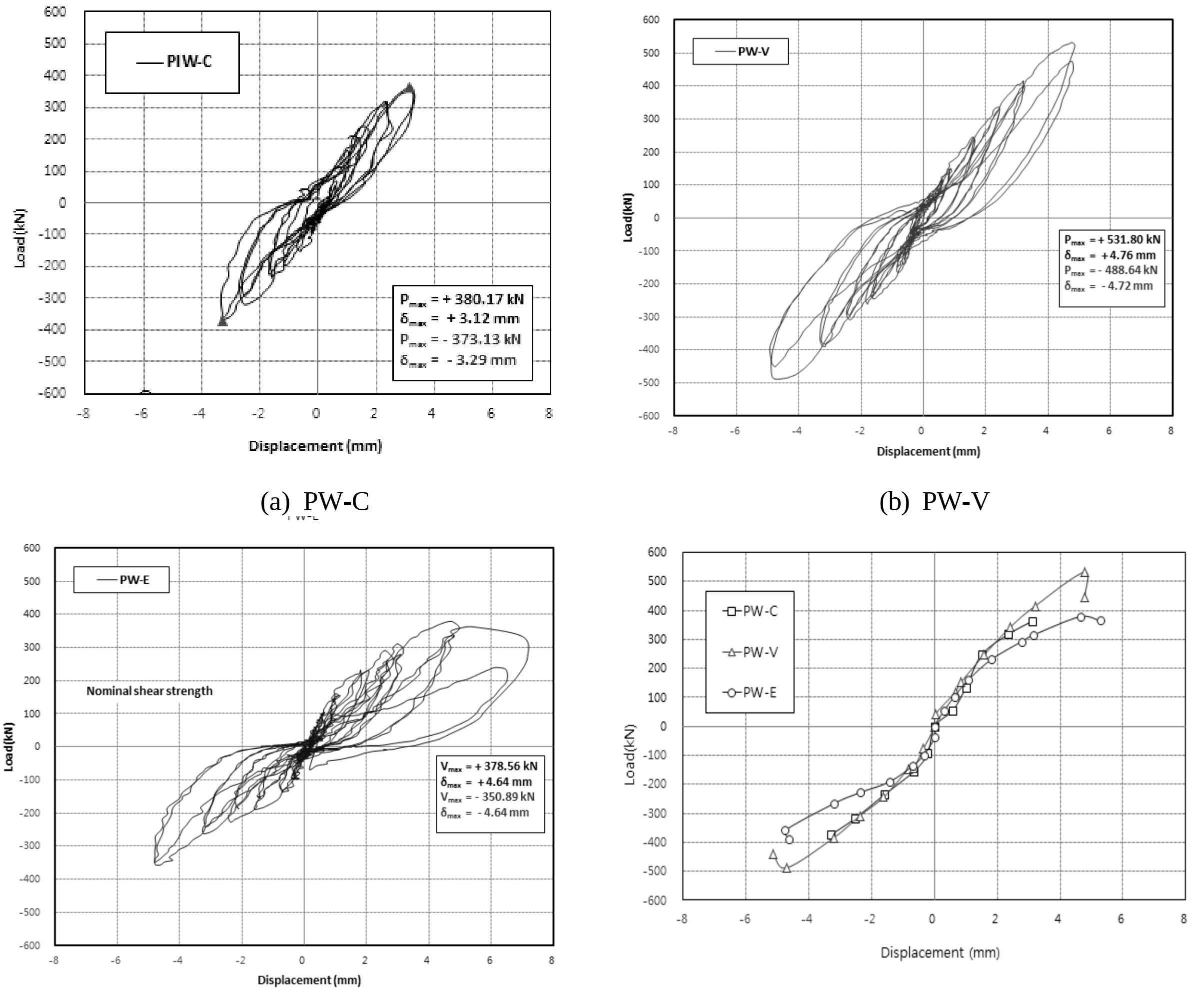
Figure 5. Cracking pattern and failure mode of specimens

3. EXPERIMENTAL RESULTS

3.1. Crack pattern and general failure mode

Figure 5 showed the final cracking patterns of the infill wall specimens. In specimen PW-C, which was a conventionally reinforced concrete wall, At a 0.12% drift, an inclined crack propagated from the top to the bottom of specimen. Finally, shell concrete at the surface of specimen fell off and the shear capacity of the wall decreased.

In specimen PW-V, which was a reinforced with PVA1.2%+PE0.3%, the first inclined crack was observed at the middle of the wall at 0.08% drift. And many flexural cracks appeared. As the drift increased, many hair cracks appeared near the inclined cracks. Before 0.3% drift the width of the occurring inclined cracks on increased, and there was no occurrence of new cracks. At 0.4% drift, width of a previously developed shear crack increased rapidly. And the wall was completely failed by yielding of diagonal reinforcing bar.



(a) PW-C (b) PW-V

(c) PW-E (d) Envelops of Load versus drift

Figure 6. Load versus displacement response

Table 3.1. Summary of Test results

Specimen	Compressive test (kN)		Drift capacity (%)	
	(+)	(-)	(+)	(-)
PW-C	380.2	-373.1	0.39	-0.41
PW-V	531.8	-488.6	0.60	-0.59
PW-E	378.6	-350.9	0.58	-0.58

In specimen PW-E, which was a reinforced with PVA0.75%+PE0.75%, the first inclined crack was observed at the middle of the wall at 0.07% drift. And many flexural cracks appeared. After 0.4% drift, increased crack width was appeared. At 0.6% drift, the wall was completely failed by yielding of diagonal reinforcing bar.

3.2. Load-displacement relationship

Figure 6. shows the load versus displacement response. The drift in the figure was defined as the ratio of the relative displacement from the data recorded by the displacement transducers mounted along the middle of the infill wall specimen. The conventionally reinforced concrete infill wall, specimen PW-C showed stable hysteretic behaviour up to 0.39% drift. It showed considerable loss of stiffness at 3.12% drift and unstable, degrading hysteresis beyond 3.12% drift. In the specimen PWC, the capacities attained in the positive and negative directions were 380.2 kN and 373.1 kN, respectively. The drift capacities of specimen at maximum load were averagely 51% higher than that of PW-C specimen. Also, as shown in Figure 7. The stiffness of SHCC walls degraded relatively slowly while PW-C specimen showed steep degradation characteristic. The envelope of the load vs. displacement is shown in Figure 6(d).

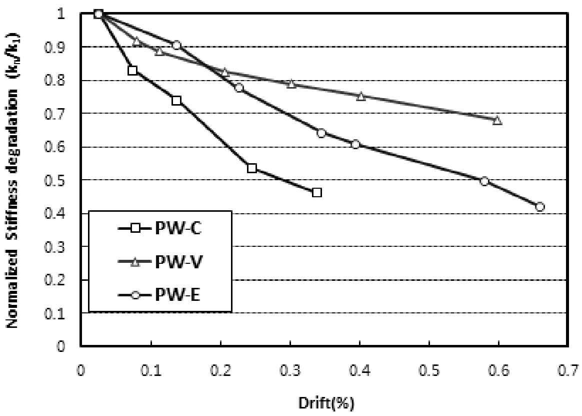


Figure 7. Cyclic stiffness degradation

3. CONCLUSION

This study conducted to evaluate the Effects of Fiber Types on Seismic behavior of Stain Hardening Cement Composite (SHCC) Precast Infill Wall. Results obtained are as follows:

1) SHCC of specimens appeared a great number of micro cracks all over the wall, and these cracks did not developed locally until final failure, while PW-C specimen, which was conventional concrete specimen, failed due to loss of strength as a result of only a few large shear cracks and increasing of the crack width.

2) SHCC specimens showed more ductile behavior. So, SHCC can be used for material of seismic retrofit members

ACKNOWLEDGEMENT

This research was financially supported by the Ministry of Education, Science Technology (MEST) and National Research Foundation of Korea (NRF) through the Human Resource Training Project for Regional Innovation (2011-0429) and the Brain Korea 21

REFERENCES

Canbolat B. Afsin, Parra-Montesinos Gustavo J., and Wight James K. (2004). Behavior of precast high-performance fiber reinforced cement composite oupling beams under large displacement reversals. 13th world conference on earthquake engineering

FEMA-273 (1999) "NEHRP Guidelines for Seismic Retrofit of Buildings," Federal Emergency Management Agency, Washington, D.C.

Keith E. KESNER, Sarah L. BILLINGTON. Behavior of precast infill panels made with ductile fiber-reinforced concrete.

Kesner, K.E., Billington, S.L. and Douglas, K.S. (200x) "Cyclic Response of Highly Ductile Fiber-Reinforced Cement-Based Composites," Accepted for Publication in ACI Materials Journal, November 2002.

Marwan T.Shedid, Wael W. El-Dakhakhni, Robert G. Drysdale.(2009). Behavior of fully grouted reinforced concrete masonry shear walls failing in flexure: Analysis. Enginneering Structures 31 (2009) 2032-2044.