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Effect of Superabsorbent Polymer (SAP) on the Performance of Polyvinyl Alcohol (PVA) Fiber-Reinforced Strain-Hardening Cement Composites

Kyung-Lim Ahn, Seok-Joon Jang, Dae-Hyun Kang and Hyun-Do Yun*

Department of Architectural Engineering
Chungnam National University, Daejeon, 305764, South Korea
*Corresponding author

Abstract

This paper reports the effect of superabsorbent polymer (SAP), a promising chemical admixture for multifunction cement composites, on the fresh and hardened properties of polyvinyl alcohol (PVA) fiber-reinforced strain-hardening cement composite (PVA-SHCC). Two types of PVA-SHCC mixtures were prepared and investigated to evaluate the effect of SAP introduction. The PVA fiber volume content was fixed at 2.0% and content of SAP was 1.0% by the binder mass. It was found that the SAP particles lead to the deterioration in the slump. It is also confirmed that the addition of SAP within 1% into cement composite improves the hardened properties, such as compressive, flexural and direct tensile performances, of PVA-SHCC due to internal curing in the cement matrix.

Keywords: Superabsorbent polymer (SAP), Slump, Compressive strength, Direct tensile strength, Flexural strength, Strain-hardening cement composite (SHCC)

1 Introduction

The control of water in concrete is important and also closely related to shrinkage, internal curing and crack healing. In several decades, new chemical additives have been developed to improve mechanical properties of fresh and hardened concrete with the control of water in concrete. These examples are superplasticizer and water-reducing additive.

In recent study [1], superabsorbent polymer (SAP) as a new component for the production of cement composites shows a number of potential possibilities to achieve efficiently the water control in concrete. A purposeful water control, absorption and release, in the fresh or hardened concrete can be promoted by the introduction of SAP materials. As a result, SAP can be applied for improving the workability, durability and mechanical properties in the cement composites as reported in the literature [2].

SAP is polymeric material that the ability to absorb a large amount of liquid from the surroundings and retain it within its structure. SAP can have a water uptake of 500 times its own weight [3]. Generally, SAP absorbs the mixing water and in dry period, the water is released to the cement matrix. The released water in hardened cement matrix decreases the autogenous shrinkage and accelerates the internal curing of cement composites.

Meanwhile, cracks in concrete, which is most popular construction material, are unavoidable defects, damages and deterioration causes of reinforced concrete (RC) structures. Therefore, repairing or healing the cracks occurred in the RC infrastructures exposed to natural environments are required to maintain the performance and elongate the service life. It is known that cracked cement composites have been healed autogenously when cracks are immersed in the water [4, 5]. The self-healing of cracks in RC members is highly dependent on the crack width, matrix component and exposed condition. In particular, it is not practical to expose the cracked RC members to wet or saturated environment.

Recently, SAP's water release in dry condition and swelling in wet condition have been used for sealing and healing cracks in the cement composites such as concrete and fiber-reinforced cement composites [6].

This study is a part of research which develops the active self-healing strain-hardening cement composite. In this paper, the effect of SAP addition on the fresh and hardened performances of polyvinyl alcohol (PVA) fiber-reinforced strain-hardening cement composite (PVA-SHCC) developed in previous study [5] is investigated.

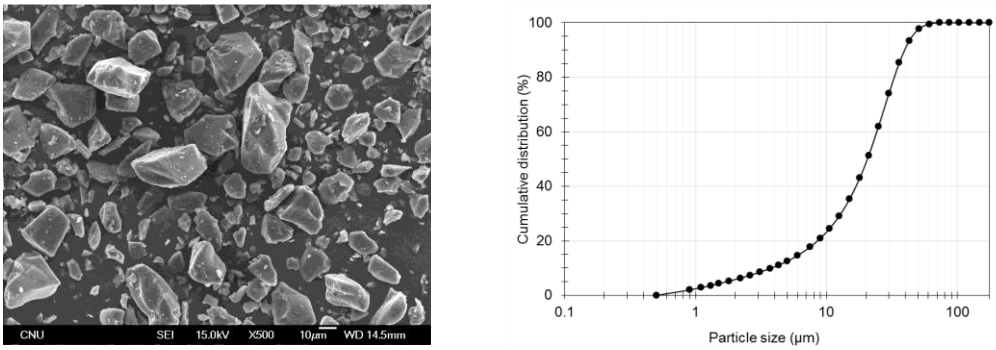
2 Experimental Program

Materials

Components of conventional PVA-SHCC mixed in the study consist of ordinary Portland cement (OPC), fly ash, silica sand and PVA fibers. The chemical compositions of OPC, fly ash and silica sand were provided in reference [5]. The fly ash was supplied from Boryeong power plant in the west of South Korea. PVA fibers with a length 8 mm and a diameter of 39 μm were incorporated to redistribute the tensile stress and control the cracks in the cementitious matrix.

The SAP used in the experiments was a gel polymerized type and a product supplied by LG chemical company, South Korea. The shape of SAP is shown in

Figure 1(a). Gel polymerized SAP is typically crushed from larger pieces and has an irregular shape. The particle size distribution of the SAP used in the study is provided in Figure 1(b). The SAP is white powder form with particle size ranging from several μm to about 100 μm shown in Figure 1(b).



(a) Shape of SAP (b) Particle size distribution of SAP

Figure 1. Particle shape and size distribution of SAP used in this test

Mixture proportions and mixing procedure

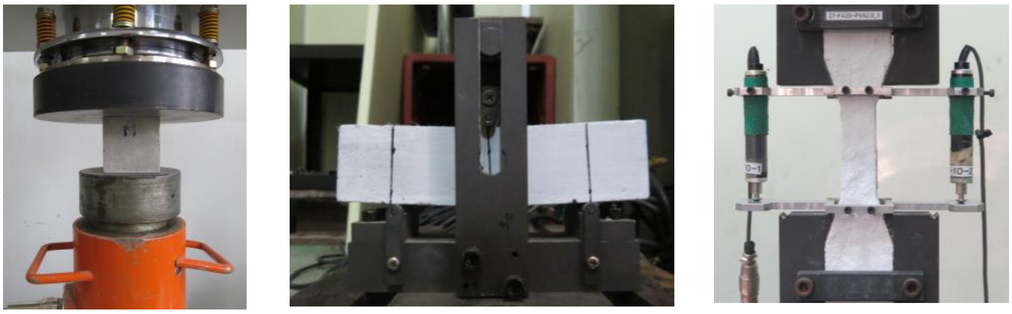
The mixture proportions of two PVA-SHCCs with and without SAP are provided in Table 1. The PVA-SHCC mixtures used for investigating the effect of SAP addition on the fresh and hardened properties contained ordinary Portland cement (OPC), silica sand, water, SAP and additional water to compensate for the loss in workability. The mixture proportions of PVA-SHCC are based on the SHCC 40 mixture shown in reference [5].
All mixtures were mixed with the same procedure found in reference [5]. The sustainable SHCCs were prepared with a pan mixer with 60L capacity. Dry mixing of all solid constitutes including cement, fly ash, silica sand and SAP powder was first performed for 3 minutes.

Table 1. Mixture proportions of PVA-SHCC

Mix designation	*w/cm* (%)	SAP (%)	Unit weight (kg/m^3)			
			Cement	Total water	Fly ash	Silica sand
SHCC40-0	49	0.0	833	511	208	416
SHCC40-1	49	1.0	833	511	208	416

Specimen preparation and testing procedure

To evaluate the workability of the fresh SHCCs investigated in this study, flow values for each SHCC mixture were estimated. To examine the hardened properties of PVA-SHCC mixture, cubic specimen, prismatic specimen and dumbbell-shaped specimen were manufactured for compressive, flexural and direct tensile tests, respectively. The cubic specimen of size 50 x 50 x 50 mm was used for evaluating the compressive performance of PVA-SHCCs. They were cured in the air or water-immersed condition for 7 and 28 days after casting the specimens. Flexural performance tests of PVA-SHCCs were performed on 40 x 40 x 160 mm prismatic specimens at the same curing age and conditions as the cubic specimens for compressive tests. To characterize the direct uniaxial tensile performance of PVA-SHCCs, direct tensile tests were conducted on dumbbell-shaped specimens with 100mm in measuring length, 30 mm in width and 30 mm in depth as described in reference [5]. The compressive and flexural tests were conducted in accordance with Korean industrial Standard KS F 5105 and KS F 2477, respectively. These testing rig and setup for PVA-SHCCs are shown in Figure 2.



(a) Compression (b) Flexure (c) Direct tension

Figure 2. Testing rig for evaluating compressive, flexural and tensile performance

3 Experimental Results and Discussions

The fresh and hardened properties of PVA-SHCCs were summarized in Table 2. The test results in Table 2 are the average and standard deviation of three specimens.

Fresh properties

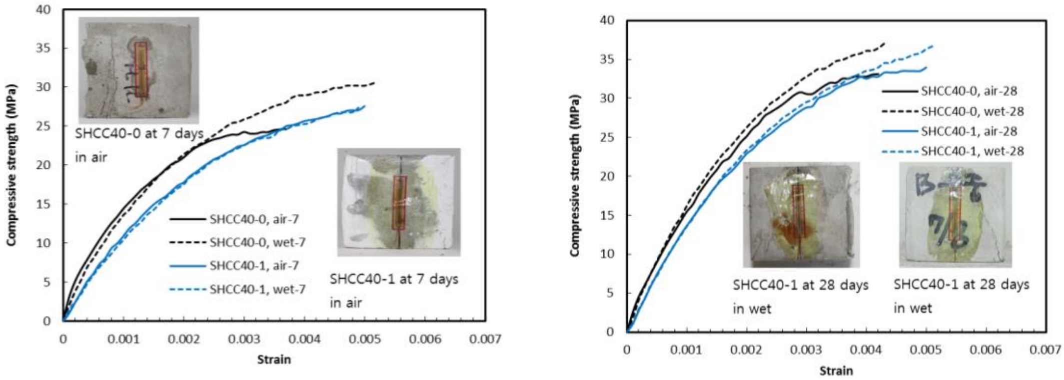
The effect of SAP addition on the fresh properties of PVA-SHCC was investigated by using the slump test. The slump value was measured by mini slump cones according to KS F 2402 (similar to ASTM C 1437). As shown in Table 2, SHCC40-0 mixture without SAP showed better workability than SHCC40-1 containing 1% SAP related to the mass of cement. As Jensen and Hansen [6] mention that the addition of SAP will lead to a lowering of free water in the cement composites, the decreasing of free water in the SHCC40-1 caused a decrease in the slump. It is noted that at adding SAP to SHCC mixtures, extra water should be added for compensating the workability and internal curing.

Compressive properties

Table 2 and Figure 3 show the test results of cubic specimens of PVA-SHCC mixtures under compression and typical compressive stress versus strain curves of PVA-SHCC mixtures at curing ages of 7 and 28 days, respectively. Table 2 indicates that the addition of 1% SAP has little effect on the compressive strength of PVA-SHCC cubic specimen while the elastic modulus of SHCC40-1 mixtures ranges from 63% to 96% of SHCC40-0 mixtures' elastic modulus with accordance with the curing age and curing condition of cubic specimens.

Table 2. Summaries of test results

	Age (days)	Curing condition	SHCC-40-0	SHCC40-1
Slump (mm)			202 ± 5.8	185 ± 4.5
Compressive strength (MPa)	7	Air	25.3 ± 0.81	27.4 ± 0.53
		Wet	29.8 ± 1.82	27.8 ± 1.48
	28	Air	33.7 ± 0.61	34.3 ± 1.27
		Wet	37.3 ± 0.91	37.5 ± 1.43
Elastic modulus (GPa)	7	Air	12.3 ± 0.93	11.7 ± 3.26
		Wet	12.8 ± 0.78	10.3 ± 1.60
	28	Air	15.0 ± 0.79	13.9 ± 3.19
		Wet	16.2 ± 1.19	13.3 ± 0.95
Flexural strength (MPa)	7	Air	13.1 ± 1.46	12.0 ± 1.03
		Wet	12.7 ± 2.27	12.4 ± 1.89
	28	Air	13.2 ± 1.12	13.5 ± 1.31
		Wet	13.6 ± 1.20	13.1 ± 1.03
Direct tensile strength (MPa)	7	Air	2.90 ± 0.76	2.82 ± 0.57
		Wet	3.44 ± 0.26	3.53 ± 0.46
	28	Air	3.74 ± 0.13	3.73 ± 0.30
		Wet	3.90 ± 0.03	3.90 ± 0.17
Direct tensile strain (%)	7	Air	1.68 ± 0.14	0.73 ± 0.40
		Wet	1.38 ± 0.29	1.26 ± 0.35
	28	Air	0.96 ± 0.35	0.78 ± 0.26
		Wet	0.85 ± 0.04	1.22 ± 0.42



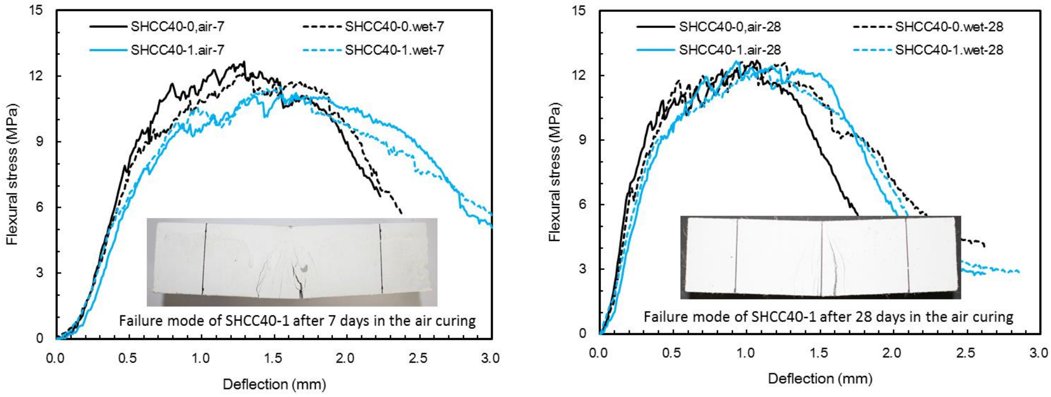
(a) Curing age of 7 days (b) Curing age of 28 days

Figure 3. Typical compressive behaviors of PVA-SHCC mixtures

For ultra-high-strength concrete mixture with w/c = 0.25 and 0.4% SAP tested by Mechtcherine et al [1], it was reported that the use of SAP led to some decrease in compressive strength measured on cubic specimens and halves of small beam. Paiva et al [7] used 0.2%, 0.35% and 0.5% of SAP as water retaining agent (introduced SAP without extra water) and showed that the presence of SAP decreased compressive strength. Larianovsky [8] investigated the effect of SAP on the mechanical properties of high-strength concrete with w/c = 0.25 and 0.33. The test results indicated that the compressive strength of concrete without extra water at the 1 day was reduced by SAP addition whereas the strength at 7 and 28 days slightly increased. It is concluded from this study and existing studies that the incorporation of SAP without extra water into high-strength cementitious composite decreased early compressive strength while as curing age increases, compressive strength in improved due to internal curing.

Flexural properties

Typical flexural stress versus deflection curves of the beams with the cross-section of 40 x 40 mm and net span of 100mm are shown in Figures 4(a) and (b). Average flexural strengths of SHCC40-0 and SHCC40-1 beams with different curing age and condition are summarized in Table 2. The curing conditions, such as air and wet curing, have little effect on the flexural behavior and strength of the medium-strength SHCC beams while the addition of 1% SAP reduced the flexural stiffness and early flexural strength of the PVA-SHCC beams. However, at curing age of 28 days, the flexural strength of SHCC40-1 with 1% SAP is equivalent to that of conventional SHCC beams. As curing age increases, the flexural stiffness and strength increases slightly. As shown in Figure 4, multiple cracking behaviors of prismatic beams under flexural loading were more remarkable in the PVA-SHCC beams at a curing age of 7 day than at 28 days. From high-strength cementitious composites tested by Mechtcherine et al [1], it can be noted that flexural strength showed similar trends with compressive strength of high-strength cementitious composites.



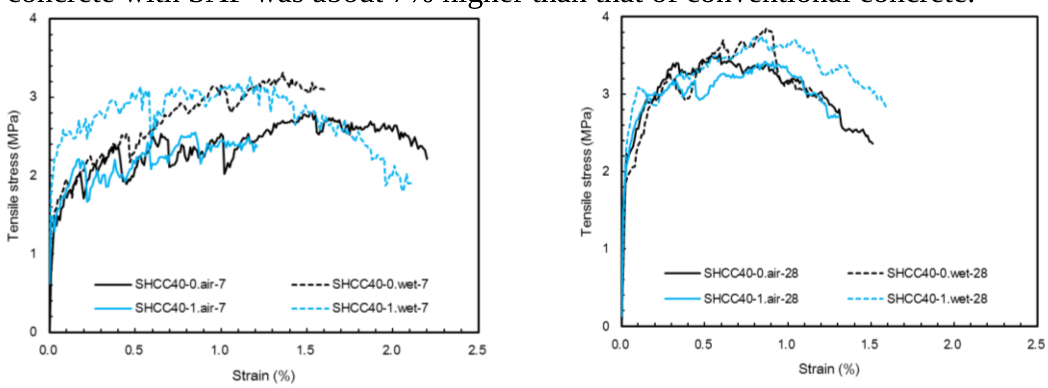
(a) Curing age of 7 days (b) Curing age of 28 days

Figure 4. Typical flexural behaviors of PVA-SHCC mixtures

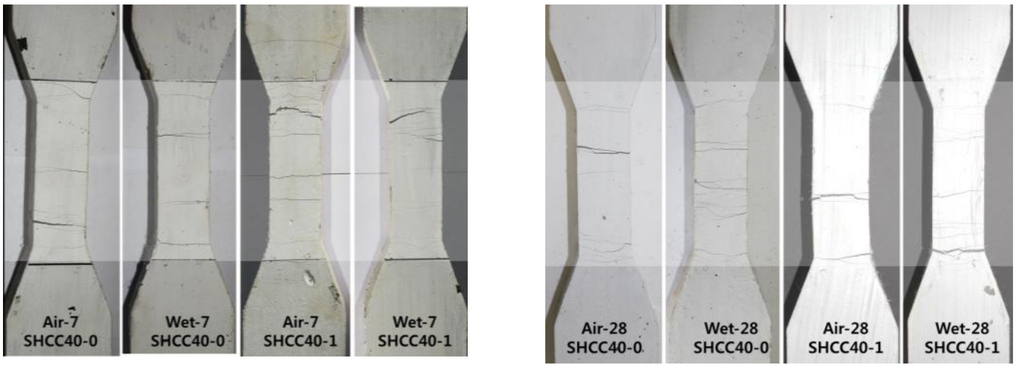
Direct tensile properties

Figures 5(a) and (b) shows direct tensile stress versus strain behaviors of three dumbbell-shaped SHCC specimens cured in different conditions at curing ages of 7 and 28 days. Average tensile strength and strain capacity of three tensile specimens were summarized in Table 2. At early ages, curing condition has a significant effect on the direct tensile behavior of PVA-SHCC mixtures. Specially, curing condition at an early curing age is more important for PVA-SHCC including SAP. At a curing age of 28 days, direct tensile strength and strain capacity of SHCC40-0 specimens were similar to those of SHCC40-1 specimens. Direct tensile properties of medium-strength PVA-SHCC showed similar trends in compressive and flexural performance. Figures 5(c) and (d) present the typical failure modes of dumbbell-shaped specimens in direct tension. Curing condition and SAP inclusion have little effect on failure modes. However, as curing age increases, multiple cracking properties were deteriorated.

Under standard curing condition for 28 days, direct tensile strength of high-strength concrete (w/c = 0.25) dog-bone specimen with 0.4% of SAP [1] showed about 19% less than that of conventional concrete specimens. However, under oven stored curing condition for 2 days, tensile strength of high-strength concrete with SAP was about 7% higher than that of conventional concrete.



(a) Tensile behavior at 7 days (b) Tensile behavior at 28 days



(c) Crack patterns at 7 days (d) Crack patterns at 28 days

Figure 5. Typical tensile behaviors and failure modes of PVA-SHCC mixtures

4 Conclusions

The addition of SAP into PVA-SHCC mixture with medium-strength of 40 MPa resulted in the reduction of compressive, flexural and direct tensile strength at early ages. However, at a curing age of 28 days, these strengths were equivalent to or exceeded that of conventional PVA-SHCC mixture without SAP. The enhancement of the strengths is due to the internal curing. Curing condition has an effect on the mechanical properties of PVA-SHCC mixtures at early ages.

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