Experimental Study on Compressive Behavior of PVA Cementitious Composites with CNTs

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ABSTRACT

In order to control possible cracks in the TBM segment, attention is drawn to apply PVA-ECC which exhibits the strain-hardening behavior with multiple cracks. In addition, many researches tried to add CNTs on the mixture to increase the concrete compressive strength. In this study, the effect of CNTs on the compressive behavior of PVA-ECC was investigated through an experimental program. It was investigated that as the CNTs mix ratio increased, the compressive strength increased while the slump decreased.

1. INTRODUCTION

Recently many researches for the application of CNTs to the construction material have been conducted. Li (2005) confirmed that the compressive strength increased up to 19% when CNTs was mixed in concrete. In addition, CNTs were applied to PVA-ECC exhibiting the strain-hardening behavior with multiple cracks (Li 2001). Meanwhile, Chen (2009) and Xu (2019) showed that TBM segments required reinforcement to control cracks which cause collapse. For the crack control, many researchers (Plizzari 2006, Lee 2014) presented that fiber reinforced concrete could be effective and efficient on the crack control.

In this study, an experimental program is conducted to investigate the effect of CNTs mix ratio on the compressive behavior of PVA-ECC which exhibits excellent crack control with strain-hardening behavior.

2. MATERIALS

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[3)] Professor

In order to investigate the effect of CNTs on the compressive behavior of PVA-ECC, an experimental program was conducted. In the test, several CNTs mix ratios were considered which varied from 0 to 0.50 wt. % by weight of binding materials. For the PVA-ECC, the mix proportion was adopted as presented in Table. 1. In the mixture, ordinary portland cement (OPC), blast-furnace slag(BFS) and fly-ash (FA) were used as binding materials. The water/binder ratio (W/B) was fixed to 32.9%. Quartzite sand (grain size 0.1~1.7 mm) and hollow lightweight aggregate (CW) were used as fine aggregate while super plasticizer and shrinkage reducing admixture (SRA) were added to attain the ability for maintaining shape and workability. To attain ductile behavior with well-distributed cracks, polyvinyl alcohol (PVA) fibers were added in the mixture. The fiber volumetric ratio was fixed to 2.07% as the manufacturing company provided. The properties of the PVA fibers were summarized in Table. 2.

For the CNTs, multi-walled carbon nanotubes (MWCNTs) were used, which had an diameter of 10 nm and length of 1.5 μm. In order to keep good dispersibility of CNTs, 3% aqueous solution with CNTs were prepared. 5% polycarboxylate superplasticizer (PCE) was added to the CNTs aqueous solution (Li 2005) and sonicated since CNTs are easy to be bounded by van der Waals` force and generally regarded as insoluble in water (Isfahani 2016).

Table. 1 Mixing properties of PVA cementitious composites with CNTs

Specimen	CNT (wt. %)	Binder (kg/m^3)			Nonbinder (kg/m^3)				Water (kg/m^3)	W/B (%)	Fiber volume fraction (%)
		OPC	BFS	FA	Sand	Filler (CW)	Super plasticizer	SRA			
CNT-0.00	0.00	412	220	412	275	14	1.92	0.4	343	32.9	2.07
CNT-0.25	0.25	412	220	412	275	14	1.92	0.4	343	32.9	2.07
CNT-0.50	0.50	412	220	412	275	14	1.92	0.4	343	32.9	2.07

Table. 2 Properties of PVA fibers

Length (mm)	Diameter (mm)	Density (g/cm^3)	Tensile strength (MPa)	Young`s modulus (GPa)
12	0.039	1.3	1,600	25 ~ 40

3. EXPERIMENTAL PROGRAM

After cementitious composites were dry mixed, water, CNTs, and PVA fiber were mixed in the order as shown in Fig. 1. During the mixing, slump and slump flow were measured to investigate the effect of CNTs on workability. To experimentally investigate the compressive behavior of PVA-ECC with CNTs, five cylindrical specimens of 200 mm in height and 100 mm in diameter were fabricated for each mixture variable. The cylindrical specimens were cured for 28 days under the temperature of 20 ℃ and relative humidity of 70%.

After 28 days, the compression test was conducted as shown in Fig. 2. Two strain gauges with 60 mm length were attached on the side faces of the specimens so that the compressive strain could be measured during the compression test. The compression was applied through Universal Testing Machine(UTM) with the loading rate of 0.2 mm/min.

Fig. 1 Mixing CNT dispersed aqueous solution and PVA fibers

Fig. 2 Test set-up

4. TEST RESULTS

The slump and slump flow measured during mixing are presented in Table. 3 and Fig. 3. As shown in the table and figure, slump and slump flow considerably decreased as the CNTs mix ratio increased. This tendency is related to a high surface area of CNTs which are better able to hold water molecules (Rhee 2013). Therefore, the workability should be considered to determine the appropriate CNTs mix ratio.

Table. 3 and Fig. 4 present the test results including the compressive strength, the strain corresponding to the compressive strength, and the modulus of elasticity which were measured through the compression test on the age of 28 days. It is noted that the compression test results in the table and figure are the average of a total of five test results for each variable. As can be seen in Fig. 4, the compressive behavior of PVA-ECC was considerably affected by CNTs. When the CNTs mix ratio increased by 0.50 wt.%, the compressive strength increased by 32.1%, from 34.9 MPa to 46.1 MPa. As CNTs mix ratio increased, both strain at the compressive strength and the modulus of elasticity increased by 14.8% from 3.78×10^{-3} to 4.34×10^{-3} and 12.8% from 12.5 GPa to 14.1 GPa, respectively. These test results are consistent with Nochaiya (2008) which presented that CNTs enhanced the compressive behavior of cement paste since CNTs reinforced the matrix composite phase. Therefore, it can be concluded that CNTs could enhance the compressive behavior of PVA-ECC as well.

Table. 3 Summary of compressive test results on specimens

Specimen	Slump (cm)	Slump flow (cm)	Compressive strength (MPa)	Strain ($\times10^{-3}$)	Modulus of elasticity (GPa)
CNT-0.00	23.0	55.5	34.9	3.78	12.5
CNT-0.25	13.0	29.0	38.4	3.85	13.3
CNT-0.50	0.00	20.0	46.1	4.34	14.1

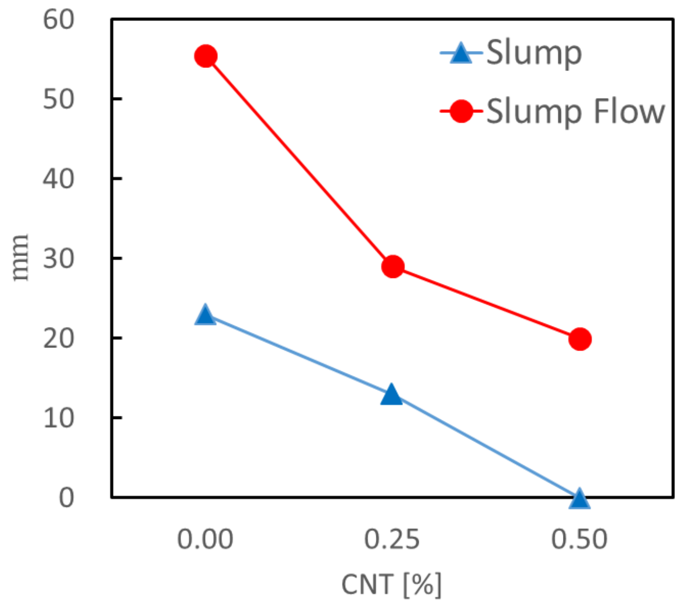
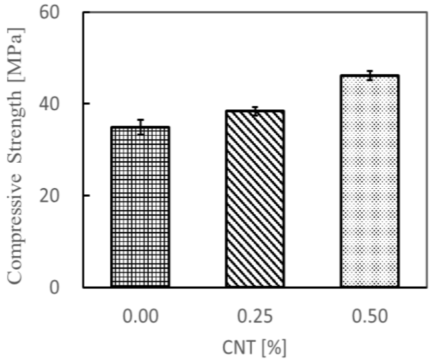
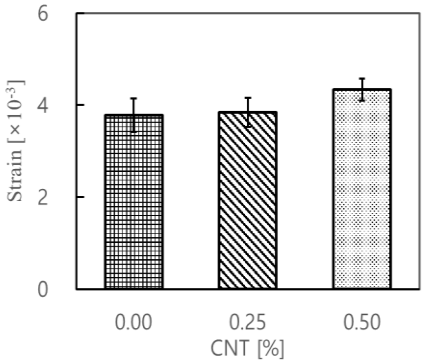


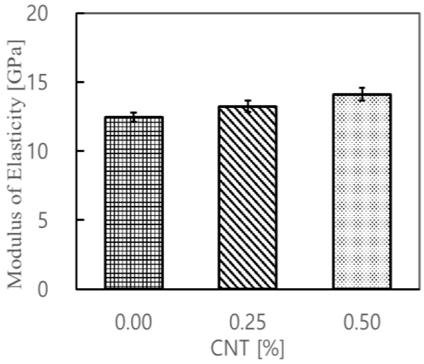
Fig. 3 Slump and slump flow



(a) Compressive strength



(b) strain



(c) Modulus of elasticity

Fig. 4 Compressive behavior graph of PVA cementitious composites with CNTs

5. CONCLUSIONS

This study investigated the compression behavior of CNTs mix ratio in PVA-ECC with CNTs. In addition, slump and slump flow were measured during the mixture in order to investigate the workability. The results investigated in this study are summarized as follow:

1) The test results for slump and slump showed that the flow decreased as the CNTs mix ratio increased. Therefore, it is required to properly determine the CNTs mix ratio in consideration of workability.

2) It was investigated through the compression test with cylindrical specimens that when the CNTs mix ratio increased up to 0.50 wt%, the compressive strength increased by 32.1%, the strain corresponding to the compressive strength increased by 14.8%, and the modulus of elasticity increased by 12.8%. It can be concluded, therefore, that the compressive behavior of PVA-ECC can be enhanced as the CNTs mix ratio increases.

3) Since fluidity can be considerably reduced when too much CNTs is mixed, workability as well as strength enhancing effect should be considered when selecting an appropriate CNTs mix ratio.

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