Effects of fiber addition and evaluation of engineering performance on fiber reinforced concretes

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ABSTRACT: Effect of add of PVA fiber and carbon fiber on the mechanical properties of the fiber reinforced cement has been studied. The experimental variations were fiber length (3, 6, 9mm) and fiber weight fraction (0.25, 0.5, 0.75, 1.0 wt %). The compressive, tensile and flexural strength of the PFRC (PVA Fiber Reinforced Cement) and CFRC (Carbon Fiber Reinforced Cement) tend to increase with add of the fiber. The compressive strength of PFRC was the highest when the length of PVA fiber was 3mm, and that of CFRC was the highest when the length of carbon fiber was 6mm. The tensile and flexural strength of PFRC and CFRC were increased with increase of the fiber length and fiber content.

1 INTRODUCTION

Fiber Reinforced Concrete (FRC) is the construction material which mixed with cement and reinforcement fibers. The general concrete product of not using reinforcements has lower tensile strength and brittle fracture tendency by high strength addition (Zhang and Wu 2001). However, FRC shows the decrease of crack growing by thermal energy and the increase of impact strength due to stiffness increase through crack control effects of reinforcement fibers addition (Fatih and Tefaruk 2003). Since 1970 years, steel fibers and alkali-resistant glass fibers were used as the representative reinforcement fibers and now high strength PVA (polyvinyl alcohol), polyacrylonitrile, carbon, aramid fibers and high strength and high modulus polyethylene fibers are used as usual. Among these fibers, PVA fibers have high crystallinity and bonding effect and show high alkali-resistance with almost no damage under severe alkaline condition, over pH 12. PVA fibers have no more cohesiveness among fibers because of lots of hydrophilic groups on the fiber surface. Also, PVA fibers show the excellent reinforcement properties due to the convex and concave surface structure to increase the specific bonding areas between concrete and reinforcement fibers. In this study, PVA and PAN (polyacrylonitrile) based carbon fibers were used to increase the reinforcement effects. These reinforcement effects were examined through comparison of mechanical properties between PVA and carbon fibers with fiber length and fiber addition content.

2 EXPERIMENTAL

2.1 *Preparation of samples*

Table 1 shows the specifications of reinforcement fibers in this study.

Table 1. Specifications of reinforcement fibers

Fiber	Length (mm)	Diameter (㎛)	Specific Gravity (g/cm^3)	Strength (GPa)	Elongation (%)
PVA	3	25	1.3	1.14	15.8
PVA	6	15	1.3	1.47	7.2
PVA	9	15	1.3	1.47	7.2
Carbon	3	6	1.8	4.5	1.0~2.0
Carbon	6	6	1.8	4.5	1.0~2.0
Carbon	9	6	1.8	4.5	1.0~2.0

Density of cement to be used in this study is 3.15 and a kind of typical 1 grade Portland cement. Gravity and absorbance of aggregate used to make

concrete are 2.48 and 1.78%, respectively. Mixing specification of reinforcement fibers is shown in Table 2.

Table 2. Mixing specification of reinforcement fibers

Fiber	Length(mm)	Content wt(%)
PVA	3 6 9	0.25 0.5 0.75 1.0
Carbon	3 6 9	0.25 0.5 0.75 1.0

Design strength of FRC was determined as 350kg/cm^2 in accordance with Korea Construction Standard Guide which high strength concretes have more over 300kg/cm^2. For strength test of mortar, only cement, aggregate, water was used and the mixing ratio of this is 1:1:0.4. The numbers of specimens for compressive and tensile strength tests is 144 and those for bending strength test are 72. Concrete curing was done during 28 days in the ambient temperature after filling mixed concrete to cylindrical molder.

2.2 *Tests of mechanical properties of FRC*

Compressive strength of FRC was evaluated in accordance with KS F 2405(; Standard test method for concrete compressive strength evaluation). Size of test specimen is cylindrical type, 10cm×20cm and numbers of test specimens are minimum over 3 pieces under the same test condition. Tensile strength test of FRC was examined in accordance with KS F 2423(; Standard test method for concrete tensile strength test. Size and numbers of test specimen is as same as compressive strength test as explained before. Bending strength test was evaluated in accordance with KS F 2408(; Standard test method for concrete bending strength evaluation). Size of test specimen is rectangular type 10cm×10cm×40cm and numbers of specimen is also same as compressive and tensile strength tests. Finally, alkali-resistance test for PVA and carbon fibers was done under the similar alkaline condition, pH 12 solution. Tensile strength change of these reinforcement fibers was examined after 10 hours immersion.

3 RESULTS AND DISCUSSION

3.1 *Compression properties*

Fig. 1 and 2 show the compressive strength change with reinforcement fiber length and addition content, respectively. In here, compressive strength rage of PFRC (PVA fiber reinforced concrete) is 400~500kgf/cm^2 and that of CFRC (carbon fiber reinforced concrete) is 400~600kgf/cm^2 respectively. Both PFRC and CFRC show higher compressive strength than the referred specimen without reinforcement fiber and compressive strength development is caused by reinforcement fiber addition to concrete. Also, it is seen that compressive strength of CFRC is higher than PFRC.

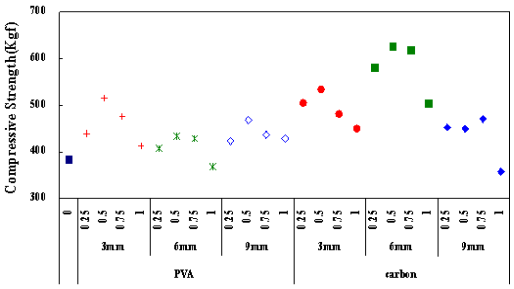

Figure 1. Compressive strength variation of FRC with fiber length change.

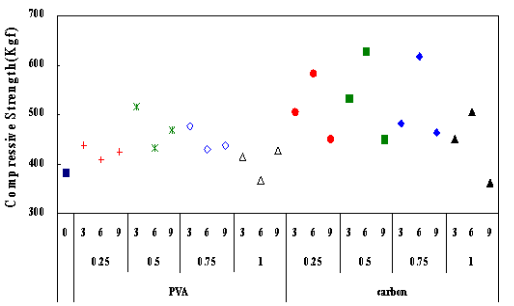

Figure 2. Compressive strength variation of FRC with fiber content change.

Fig. 3 shows the compressive strength of PFRC with fiber length and addition content. The case of 3mm PVA fiber added PFRC showed the highest compressive strength. Compressive strength decreased with longer fiber length and this is due to the strong bonding effect of PVA fibers to concrete. PVA fibers showed the best compressive strength for 0.5wt% fiber addition content but reinforcement effect decreases over this content. This means that over optimum addition of PVA fibers would be cause of reinforcement effect decrease by non-uniform mixing. Fig. 4 shows the compressive strength of CFRC with fiber length and addition content. Compressive strength for carbon fiber length 3mm addition increased as 1.5~2.0 times higher than no carbon fiber addition. However, the

maximum compressive strength is in carbon fiber length 6mm addition and then rapidly decreased in carbon fiber length 9mm addition. It is seen that bonding between carbon fibers and concrete is relatively weaker than PVA fiber. From this, longer fiber length of carbon fiber could have better reinforcement effect and decrease of this effect for over 9mm would be occurred by increase of fiber aggregation.

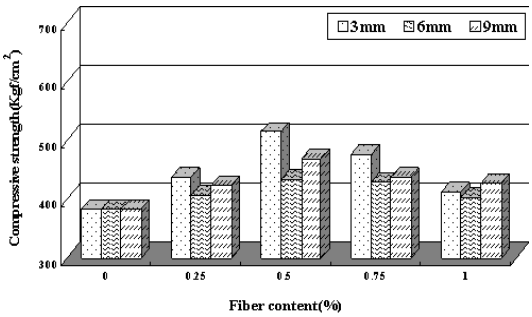

Figure 3. Effect of fiber content variation on the compressive strengths of PVA fibers reinforced cement.

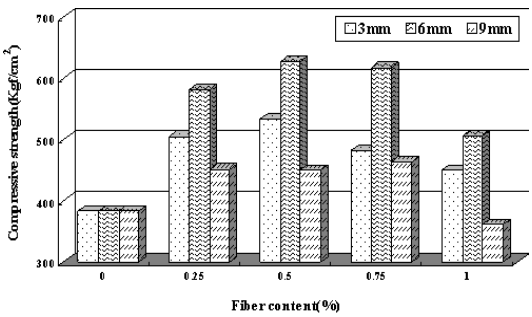

Figure 4. Effect of fiber content variation on the compressive strengths of carbon fibers reinforced cement

Fig. 5 shows the fractured features of FRC after compressive strength test to be compared the referred specimen without reinforcement fiber. It is seen that PFRC and CFRC keep the test specimen shape together in spite of crack existence but referred specimen without reinforcement fiber showed the crack induced failure.

(a) PFRC (b) CFRC (c) Referred

Figure 5. Fractured feature of FRC with reinforcement fibers.

The reinforcement effect of PVA and carbon fibers as bridging action within concrete is also confirmed through these phenomena.

3.2 *Tensile properties*

Fig. 6 and 7 show the tensile strength change of FRC with fiber length and fiber addition content, respectively. Tensile strength of PFRC is larger than CFRC with fiber length and fiber addition content. Fig. 8 shows the tensile strength of PFRC with fiber length and fiber addition content. In here, it is seen that longer fiber length showed higher tensile strength. Fig. 9 shows the tensile strength of PFRC with fiber length and fiber addition content but no significant change is not observed.

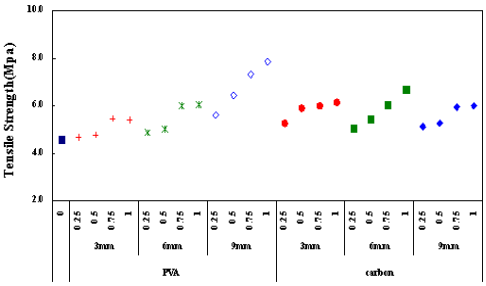

Figure 6. Tensile strength variation of FRC with fiber length change.

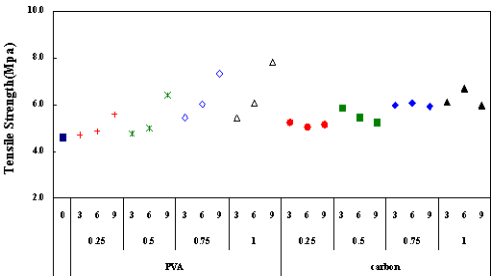

Figure 7. Tensile strength variation of FRC with fiber content change.

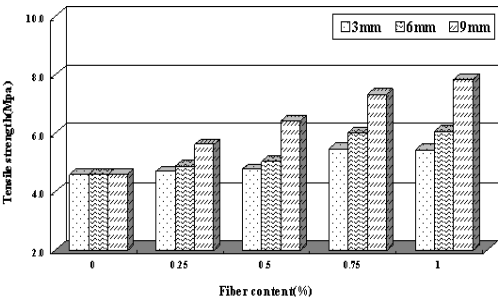

Figure 8. Effect of fiber content variation on the tensile strengths of PVA fibers reinforced cement.

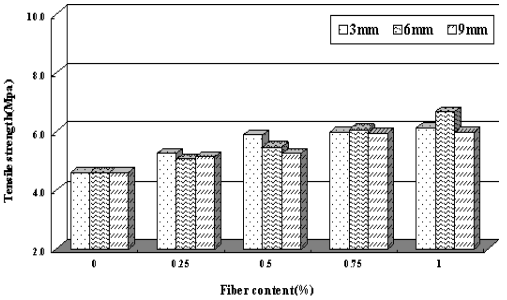

Figure 9. Effect of fiber content variation on the tensile strengths of carbon fiber reinforced cement.

3.3 *Flexural properties*

Fig. 10 and 11 show the flexural strength change of FRC with fiber length and fiber addition content, respectively. PFRC and CFRC showed similar tendency and higher flexural strength with regardless to fiber length and fiber addition content than referred specimen. For both FRC, flexural strength increased with fiber length and fiber addition content. Fig. 12 shows the flexural strength of PFRC with fiber length and fiber addition content. The longer fiber length showed higher flexural strength. Fig. 13 shows the flexural strength of CFRC with fiber length and fiber addition content. Flexural strength of CFRC is increased with the longer fiber length and fiber addition content 0.25% but there is no clear tendency with fiber length and fiber addition content.

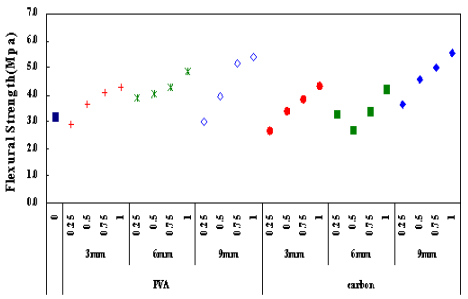

Figure 10. Flexural strength variation of FRC with fiber length change.

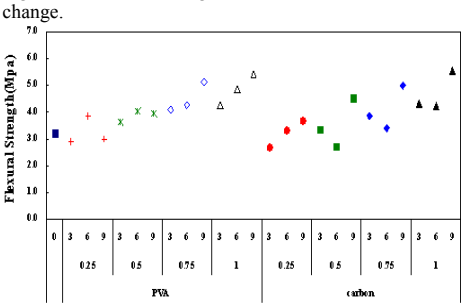

Figure 11. Flexural strength variation of FRC with fiber content change.

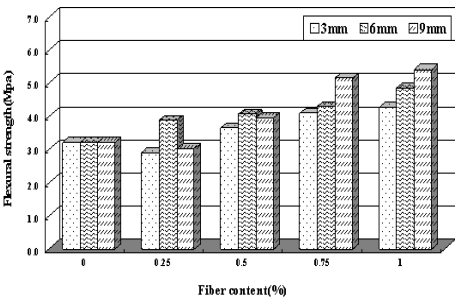

Figure 12. Effect of fiber content variation on the flexural strengths of PVA fiber reinforced cement.

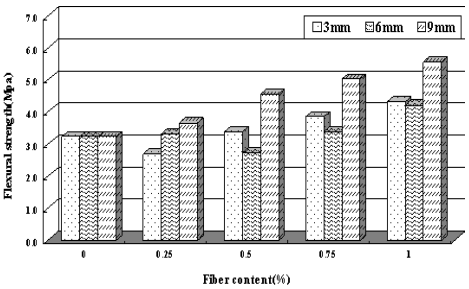

Figure 13. Effect of fiber content variation on the flexural strengths of carbon fiber reinforced cement

3.4 *Resistance to alkaline solution*

For both PFRC and CFRC, it is seen that no change of breakage strength and strain is observed under pH condition of cement mortar.

4 CONCLUSION

Through the mechanical property tests of PFRC and CFRC with fiber length and fiber addition content, it is concluded as following. PVA and carbon fiber reinforcement concretes showed the improvement of engineering performance e.g., compressive, tensile, flexural properties than referred test specimen without reinforcement fibers. Compressive strength of PFRC increased with shorter fiber length and CFRC showed the maximum compressive strength for 6mm fiber length. Both PFRC and CFRC showed the increase of tensile and flexural strength with longer fiber length and larger fiber addition content. Finally, PFRC showed the better reinforcement effect than CFRC through overall experimental data.

ACKNOWLEDGEMENT

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