

# Workability and Mechanical Properties of Hybrid Fiber Reinforced Concrete Using Amorphous Steel Fiber and Polyamide Fiber

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Many studies have been performed on hybrid fiber reinforced concrete for years, which is to improve some of the weak material properties of concrete. Studies on characteristics of hybrid fiber reinforced concrete using amorphous steel fiber and polyamide fiber, however, yet remain to be done. The purpose of this experimental research is to evaluate the workability and mechanical properties of hybrid fiber reinforced concrete using amorphous steel fiber and polyamide fiber. For this purpose, the hybrid fiber reinforced concrete containing amorphous steel fiber (ASF) and polyamide fiber (PAF) were made according to their total volume fraction of 0.5 % for water-binder ratio of 33 %, and then the mechanical properties such as the compressive strength, direct tensile strength, flexural strength, and flexural toughness of those were estimated. It was observed from the test results that the compressive strength was slightly decreased with increasing ASF and decreasing PAF and the effect of fiber combination on the flexural strength was not much but the flexural toughness was relatively largely increased with decreasing ASF and increasing PAF.

**Keywords :** Hybrid fiber reinforced concrete, Amorphous steel fiber, Polyamide fiber, Compressive strength, Direct tensile strength, Flexural strength, Flexural toughness index.

## 1. INTRODUCTION

Due to the continuous increase in demand for high-strength and high-performance construction materials, many studies have been performed on fiber reinforced concrete for years, which is to improve some of the weak material properties of concrete (Cho et al. 2011; Jeon et al. 2014; Karl et al. 2011; Kim et al. 2012; Kim et al. 2008). Also, studies on amorphous steel fiber reinforced concrete have been conducting to further improve the flexural toughness and strength than the conventional steel fiber reinforced concrete (Choi et al. 2015; Hameed et al. 2010; Kim et al. 2016). Recently, many studies are focusing on hybrid fibers such as combination of steel fiber and organic fiber that materials properties differ from each other and combination of macro fiber with large dimension and diameter

and micro fiber with small dimension and diameter (Lawer et al. 2000; Qian and Stroevenb 2000; Song 2011; Yang 2010; Yao et al. 2003). Studies on characteristics of hybrid fiber reinforced concrete using amorphous steel fiber and polyamide fiber, however, yet remain to be done. Thus, the purpose of this experimental research is to evaluate the workability and mechanical properties of hybrid fiber reinforced concrete using amorphous steel fiber and polyamide fiber. For this purpose, the hybrid fiber reinforced concrete containing amorphous steel fiber (ASF) and polyamide fiber (PAF) were made according to their total volume fraction of 0.5% for water-binder ratio of 33%, and then the characteristics such as the workability, compressive strength, direct tensile strength, flexural strength, and flexural toughness of those were estimated.

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## 2. EXPERIMENTAL WORK

### 2.1 Materials and mix proportions

Ordinary Portland cement(KS L 5201, Type 1, 2010) was used in this study and its physical properties are given in Table 1. For fine aggregate and coarse aggregate, river sand and crushed stone with maximum size of 25mm were used, respectively and their physical properties are given in Table 2. To control fluidity of hybrid fiber reinforced concrete(HFRC) mixture, high-range water reducing agent of polycarbonic acid was used as a kind of superplasticizer(SP), as shown in Table 3. Table 4 shows the detail properties for several kinds of fibers used in this study. Table 5 shows the mix proportions of HFRC using ASF and PAF according to their total volume fraction of 0.5%. Water-binder(W/B) ratio is 33% and the target slump and air content are  $180 \pm 25$ mm,  $3.5 \pm 1.5\%$ , respectively.

### 2.2 HFRC specimens

According to the KS F 2403(2014), KS F 2566(2014), concrete cylinders( $\varnothing$  100x200mm) and concrete prisms(100x100x400mm) were made to measure the compressive strength and flexural performance of HFRC.

On the other hand, mortar specimens of dumbbell shape were made to estimate direct tensile strength of HFRC(Fig. 1).

After casting, all the mortar and concrete specimens were demoulded after 24 hours and were cured in the water of  $20 \pm 3^\circ\text{C}$  until test began.



Fig. 1. Detail of the specimens for direct tensile test

### 2.3 Evaluation of mechanical properties of HFRC

#### 2.3.1 Compressive strength test

In order to evaluate the compressive strength properties of HFRC, the compressive strength tests of concrete cylinders were carried out at 28 days according to KS F 2405(2010).

Table 1. Physical properties of cement

Specific gravity	Setting(mm)		Blaine ( $\text{m}^2/\text{kg}$ )	Compressive strength(MPa)		
	Initial	Final		3 Days	7 Days	28 Days
3.15	225	305	341	26.8	38.6	56.0

Table 2. Physical properties of aggregates

Type	Maximum size of coarse aggregate(mm)	Density ( $\text{g}/\text{cm}^3$ )	Absorption (%)	Unit mass ( $\text{kg}/\text{m}^3$ )	Amount of passing 0.08mm sieve(%)	Fineness modulus
River sand	-	2.54	2.15	1,660	2.25	2.72
Crushed stone	25	2.65	1.22	1,648	-	7.27

Table 3. Properties of chemical admixtures

Type	Specific gravity	pH	Solid content(%)	Quantity(%) (by mass of cement)	Main component
Superplasticizer	1.05	3~4	18	0.5~2.5	Polycarbonin acid admixture

**Table 4. Properties of fibers**

Type	Length (mm)	Diameter (mm)	Density (g/cm <sup>3</sup> )	Tensile strength (MPa)	Remark
SF(Steel fiber)	30	0.3	7.85	1,100	For comparison
ASF	30	-	7.16	1,400	
PAF	30	0.5	1.14	600	Polyamide fiber

**Table 5. Mix proportions of HFRC**

Specimens	Fiber volume fraction(%)			Target slump (mm)	W/B(%)	Unit mass(kg/m <sup>3</sup> )				SP (B×%)
	ASF	PAF	SF			W	C	S	G	
A(Plain)	-	-	-	180±25	33	190	580	765	783	1.5
B(SF)	-	-	0.5							
C	0.2	0.3	-							
D	0.3	0.2	-							
E	0.4	0.1	-							

**2.3.2 Direct tensile strength test**

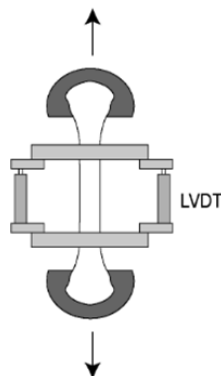
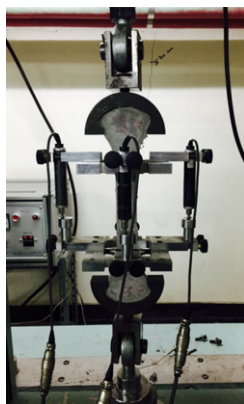
In order to evaluate the tensile strength properties of HFRC, the direct tensile test was carried out by using the test apparatus, as shown in Fig. 2.

**2.3.3 Flexural performance test**

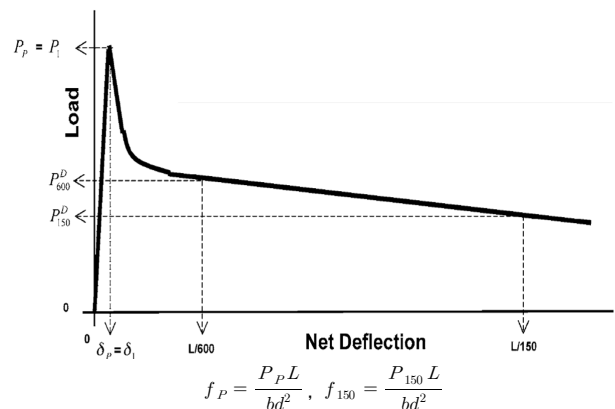
In order to estimate the flexural performance of HFRC, the flexural performance test was carried out by the method of third–point loading according to ASTM C 1609(2013). Deflection with loading was measured at the third point of the span by using displacement gauge, as shown in Fig. 3. The flexural toughness index of HFRC was calculated by T<sub>150</sub> of ASTM C 1609(Fig. 4, Table 6).



**Fig. 3. Evaluation of flexural performance for HFRC**



**Fig. 2. Direct tensile test of HFRC**



**Fig. 4. Evaluation method of flexural toughness index(ASTM C 1609)**

### 3. RESULTS AND DISCUSSION

#### 3.1 Workability of HFRC

As shown in Fig. 5, it was revealed that the workability of HFRC was slightly decreased than plain concrete but was similar to steel fiber reinforced concrete(SFRC). It could be concluded that the workability of HFRC is satisfactory because slumps of all the HFRCs satisfied the target value( $180 \pm 25$ mm) and their fiber clumps were not found.

#### 3.2 Compressive strength of HFRC

Fig. 6 shows the compressive strengths of HFRC at 7 and 28 days. It was found that those of HFRC decreased with increasing ASF and decreasing PAF irrespective of age. It was thought that the compressive strength of HFRC was not almost improved because the compressive strength of HFRC was slightly smaller than plain concrete and was similar to SFRC,

#### 3.3 Direct tensile strength of HFRC

Fig. 7 shows the direct tensile strength of HFRC at 28 days. It was observed that the direct tensile strength of all the HFRCs was larger than SFRC and the direct tensile strength of Mix B was smallest, that of Mix D(ASF 0,3%+PAF 0,2%) was largest of all the concrete mixtures,

It was found that the direct tensile strength of HFRC was more or less improved than plain concrete or SFRC and the proper combinations of ASF and PAF largely influenced the

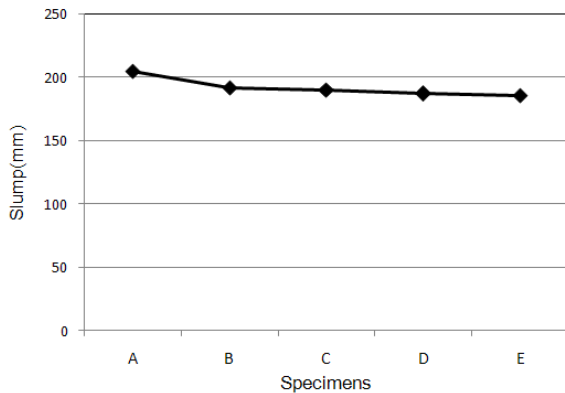


Fig. 5. Slump of HFRC

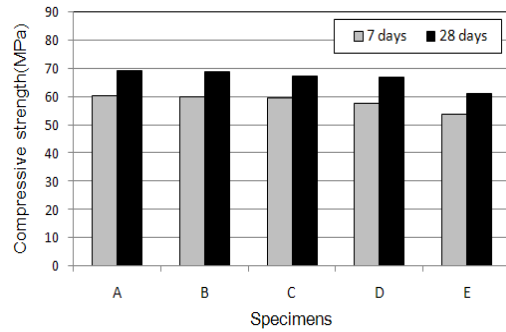


Fig. 6. Compressive strength of HFRC

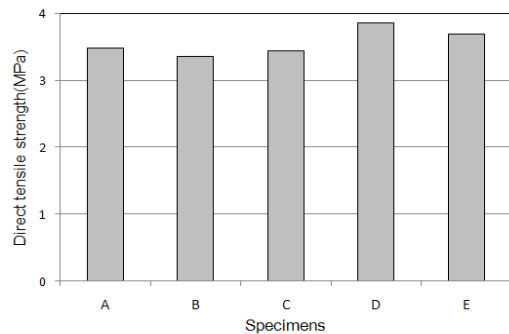


Fig. 7. Direct tensile strength of HFRC

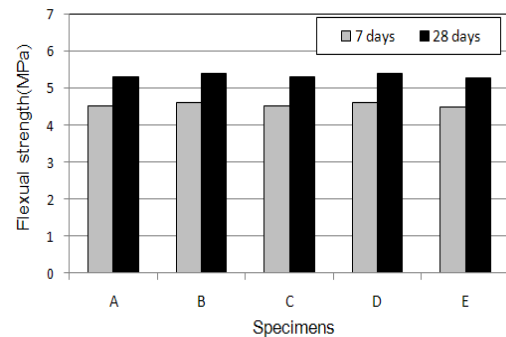


Fig. 8. Flexural strength of HFRC

direct tensile strength of HFRC.

#### 3.4 Flexural performance of HFRC

Fig. 8 shows the flexural strength of HFRC at 7 and 28 days. It was revealed that the effect of combinations of fibers on the flexural strength of HFRC was not so much, because the flexural strength of all the concrete mixtures are almost similar. Fig. 9 shows load–deflection curve of HFRC under the flexural

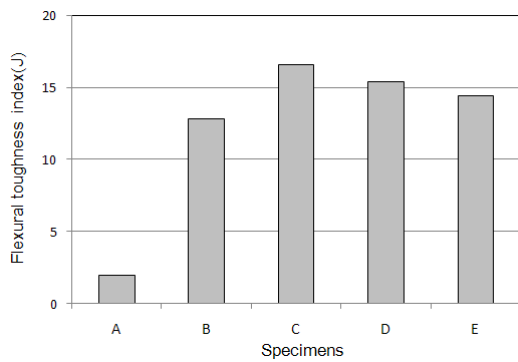


Fig. 10. Flexural toughness index of HFRC

strength test and Table 6 shows the flexural test results of HFRC obtained according to the ASTM C 1609. Fig. 10 shows the flexural toughness index of HFRC, it was observed that the flexural toughness of HFRC was larger than SFRC and was increased with increasing PAF and decreasing ASF. It was revealed that Mix C(ASF 0,2 % + PAF 0,3 %) is most favorable for improvement of flexural toughness and PAF more influenced improvement of flexural toughness than ASF.

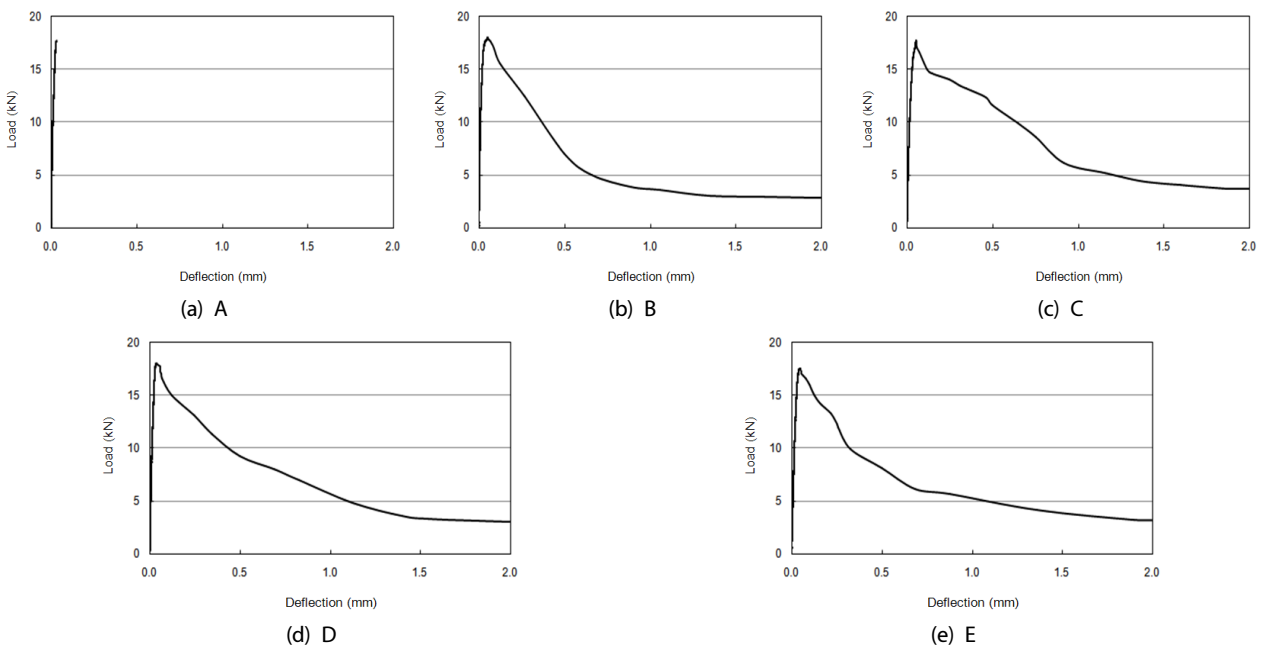


Fig. 9. Load-deflection curve of HFRC

Table 6. Flexural test results of HFRC

Specimens	$P_p^a$ (kN)	$F_p^b$ (MPa)	$P_{600}^c$ (kN)	$F_{600}^d$ (MPa)	$P_{150}^e$ (kN)	$F_{150}^f$ (kN)	$T_{150}^g$ (J)
A	17.73	5.32	-	-	-	-	2.32
B	18.03	5.41	7.03	2.11	2.88	0.86	12.82
C	17.73	5.32	11.56	3.47	3.65	1.09	16.58
D	18.03	5.41	9.24	2.77	3.02	0.91	15.36
E	17.57	5.27	8.12	2.44	3.21	0.96	14.41

a: Peak load

b: Peak strength

c: Residual load at net deflection of 1/600 of the span length

d: Residual strength at net deflection of 1/600 of the span length

e: Residual load at net deflection of 1/150 of the span length

f: Residual strength at net deflection of 1/150 of the span length

g: Area under the load vs. net deflection curve 0 to 1/150 of the span length

## 4. CONCLUSIONS

The following conclusions can be drawn from the estimation of the workability and mechanical properties of hybrid fiber reinforced concrete containing ASF and PAF when the total contents of fibers are fixed as the total volume fraction of 0.5%.

1. It was observed that the workability of HFRC was satisfactory because slumps of all the HFRCs satisfied the target value ( $180 \pm 25$ mm) and their fiber clumps were not found.
2. It was revealed that the compressive strength of HFRC was not almost improved because the compressive strength of HFRC was slightly smaller than plain concrete and was similar to SFRC.
3. It was found that the direct tensile strength of HFRC was more or less improved than plain concrete or SFRC and the proper combinations of ASF and PAF largely influenced the direct tensile strength of HFRC.
4. It was revealed that the effect of combinations of fibers on the flexural strength of HFRC was not so much. But it was observed that the flexural toughness index of HFRC was larger than SFRC and was increased with increasing PAF and decreasing ASF. It could be concluded that PAF more influenced improvement of flexural toughness than ASF.

## Acknowledgements

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