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Flowing Ability and Mechanical Properties of Polypropylene Fiber Reinforced High Performance Concrete

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Abstract

This study was performed to examine the flowing ability and filling ability of polypropylene fiber reinforced high performance concrete. The slump flow was decreased with increasing the polypropylene fiber content, rapidly. At the box-type filling ability, the difference of box height was increased with increasing the fiber content and the box-type passing ability was closed in fiber content 1%. The final flowing distance of L-type was decreased with increasing the fiber content. Also, it was decreased above 0.75% of polypropylene fiber content, rapidly. The filling ability of L-type was badly showed above polypropylene fiber content 0.75%. Also, the compressive strength was decreased with increasing the fiber content, but the flexural strength was shown higher than that of the concrete without fiber. At the impact resistance, drop numbers for reaching in final fracture were increased with increasing the fiber content. Also, the drop numbers for reaching initial fracture of 1mm were increased with increasing the fiber content. At the acid resistance, the percent of original mass was decreased with increasing the fiber content.

Keywords : High performance concrete, Polypropylene fiber, Flowing ability, Filling ability, Strengths, Impact resistance, Sulfuric acid resistance

I. Introduction

Recently, the research works and usage of the high-performance concrete (HPC) have increased tremendously. The HPC is a relatively new product and its characteristics differ from that of the normal concrete. According to Zia et al,[8),12)] the HPC is defined as concrete, which meets special performance and uniformity requirements that cannot always be achieved routinely by using conventional materials and normal mixing, placing and curing. The requirements may involve enhancements of characteristics such as placement and compaction without segregation, long-term mechanical properties, early age strength, volume stability or service life in severe envi-

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ronments.[3),8),10)]

Also, the plain concrete is a brittle material, with low tensile strength and strain capacities. To help overcome these disadvantage, there has been a steady increase, since the late 1960s, in the use of the fiber reinforced concrete(FRC). The fiber reinforced concrete may be defined as a concrete incorporating relatively short, discrete, discontinuous fibers. Artificial(polymeric) fibers have become increasingly common in recent years. Most artificial fibers have lower elastic modulus than that of the normal concrete. At the relatively low fiber volumes currently used in industrial practice, they are most effective in reducing the amount of plastic shrinkage cracking, though they also provide some toughening and impact resistance. The polypropylene fibers are the most low-modulus artificial fibers.[4),6),9)]

Therefore, in this study, the polypropylene fiber reinforced high performance concrete that mix fly ash(PPF), blast furnace slag(PPB) of industrial byproducts and polypropylene fiber to improve greatly concrete property is developed.[1),7)] Also, slump flow, Box-type filling ability, L-type flow and L-type filling ability with polypropylene fiber content in cement paste are performed for evaluation of flow ability, workability, and the compressive strength, flexural strength, impact resistance and acid resistance in hardened concrete are performed for evaluation of strength and durability.

Ⅱ. Materials

1. Cement

An normal Portland cement specified KS F 5201 is used in this study and its physical properties and chemical composition are shown in Table 1.

2. Aggregates

Fine aggregate is gathered from the Geum river in Daejeon and the coarse aggregate used is crushed stone. The physical properties of aggregates used are shown in Table 2.

Table 2 Physical properties of aggregates

Item	Size (mm)	Specific gravity (20℃)	Absorption ratio (%)	Fineness modulus	Unit weight (kgf/m³)
Fine aggregate	< 4.75	2.62	2.35	2.35	1,471
Coarse aggregate	4.75~20	2.64	2.62	7.28	1,449

3. Polypropylene Fiber

Polypropylene fiber used is domestic S company product, and its shape and dimension are

Table 1 Physical properties and chemical composition of cement

(Unit : %)

Specific gravity (20℃)	Setting time (h-m)		Chemical composition							
	Initial	Final	SiO_2	Al_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Fe_2O_3
3.15	5-7	7-20	21.09	4.84	63.85	3.32	3.09	1.13	0.29	2.39

shown in Table 3.

Table 3 Physical properties of polypropylene fiber

Length (mm)	Absorption ratio(%)	Specific gravity	Melt point	Tensile strength (kgf/㎠)	Young's modulus (kgf/㎠)	Acid and alkali resistance
19	0	0.91	162℃ over	3,500~7,700	35×10^3 over	Very high (inactivity)

4. Cementitious Material

Cementitious material used is fly ash and blast furnace slag, and its physical properties are shown in Table 4.[11)]

Table 4 Physical properties of cementitious material

Type	Specific gravity (20℃)	Specific surface (㎠/g)	Unit weight (kgf/㎥)	Grain size (mm)	Color
Fly ash	2.39	3,152	1,072	〈 0.15	Gray
Blast furnace slag	2.92	4,401	1,077	〈 0.15	White

5. Water Reducing Admixture

Superplasticizer whose principal ingredient naphthalene sulfonate was used for strength and flowing increase, and its general properties are shown in Table 5.

Table 5 General properties of superplasticizer

Specific gravity (20℃)	PH	Color	Freezing point (℃)	Principal ingredient	Unit weight (kgf/㎥)
1.20	9±1	Dark brown liquid	-2	Naphthalene sulfonnate	1,190

6. Mixing Proportions and Manufacture

Mix proportions is designed so that invest practical utilizing of industry product and fluidity, filling, early and long term strength of the high performance concrete containing fly ash and blast furnace slag 20% of binder weight.[5),7)] Also, the polypropylene fiber of 19 mm is used for crack control, flexural rigidity promotion and durability elevation by drying shrinkage. The polypropylene fiber used is 0%, 2.5%, 0.5%, 0.75%, 1.0% by weight ratio of total binder. The superplasticizer and water−cement ratio for reaching target slump with fiber content increase are increased. Meanwhile, superplasticizer used is 1.5~2.0% of total binder to reduce water−cement ratio and improves fluidity, and mix design are shown in Table 6.

Specimens are prepared according to the Korean Standard Testing Methods, KS F 2405 (Specimen preparation methods for strength measure of concrete). All the specimens are demolded after cured at 20±1℃ for one day, and cured again at 20±1℃ for 28 days.

Ⅲ. Methodology

1. Flowing and Filling Test

A combination of qualitative observations and measurements is applied to evaluate these characteristics. The measurement of the slump flow indicates the free deformability of the mixture. The slump flow is the average diameter of the horizontal flow.[3)]

In the box filling ability test, if the paste is filled in box of left and lifts central board, the paste

Table 6 Mix design of polypropylene fiber reinforced high performance concrete

Mix type	GV (%)	Sr (%)	Unit weight (kgf/m^3)									P.P (%)	S.P (%)
			Cement	Fly ash	Blast furnace slag powder	C+F	C+B	W/B	Sand	Gravel			
PPF	50	47	420	105	-	525	-	0.35	840	730		0	1.5
	50	47	420	105	-	525	-	0.35	840	730		0.25	1.6
	50	47	420	105	-	525	-	0.36	840	730		0.5	1.6
	50	47	420	105	-	525	-	0.38	840	730		0.75	1.8
	50	47	420	105	-	525	-	0.40	840	730		1.0	2.0
PPB	50	47	425	-	110	-	535	0.35	840	730		0	1.5
	50	47	425	-	110	-	535	0.35	840	730		0.25	1.6
	50	47	425	-	110	-	535	0.36	840	730		0.5	1.6
	50	47	425	-	110	-	535	0.38	840	730		0.75	1.8
	50	47	425	-	110	-	535	0.40	840	730		1.0	2.0

* G_V : Volume ratio of coarse aggregate, S_r : Volume ratio of fine aggregate
* P.P : Polypropylene fiber(ratio of binder weight), S.P : Superplasticizer(ratio of binder weight), C : Cement, F : Fly ash, B : Blast furnace slag,
* W/B : Water/(cement + fly ash or blast furnace slag powder),
* PPF : Polypropylene fiber reinforced high performance concrete (fly ash)
* PPB : Polypropylene fiber reinforced high performance concrete (blast furnace slag)

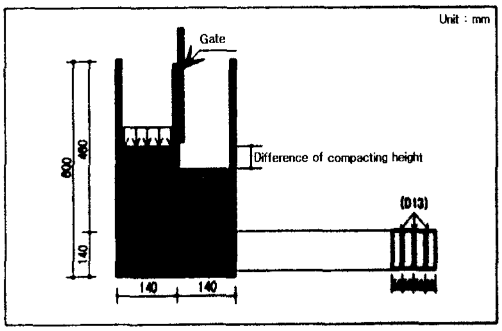


Fig. 1 Box filling ability test apparatus

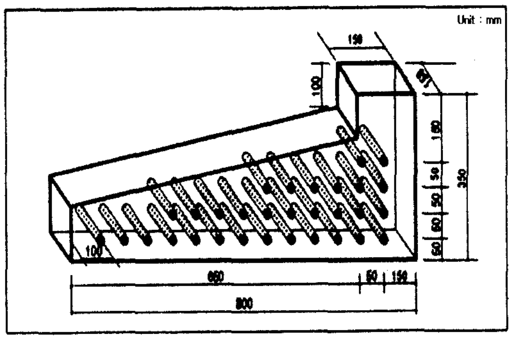


Fig. 2 L-type filling ability test apparatus

is moved to right because pass D13's reinforced bar as Fig. 1, and this time, filling ability is measured by height difference of left and right paste.

The L−type flow test is measured final arrival distance and the arrival speed when the divided plate lift after fill up paste.[2)]

The L−type filling ability test is judged filling ability for final filling state with the naked eye after pass to lower step inputting paste in entrance as Fig. 2 and the each step is parted in excellent, good, plain and bad.

2. Strength

The compressive and flexural strength tests are carried out according to the KS F 2405 (Compressive strength test method for concrete), KS F 2408 (Flexural strength test method for concrete), respectively. The sizes of specimens are ø10×20 mm and 60×60×240 mm.

3. Impact Resistance

The impact resistance is measured drop number of final and initial fracture of 1 mm dropping a 2 kg steel weight in 50 cm height according to the KS F 2221 (Test method of impact for building boards).

4. Sulfuric Acid Resistance

The sulfuric acid resistance is measured at an interval of 7 days after deposit in sulfuric acid (H_2SO_4) 5% solution and compared with weight difference in surface dry condition after polishing surface of specimen with iron brush.

Ⅳ. Results and Discussion

The polypropylene fiber reinforced high performance concrete mixed fly ash, blast furnace slag and polypropylene fiber to improve concrete properties is developed. The slump flow, Box filling ability, L-type flow, L-type filling ability, compressive strength, flexural strength, impact resistance and sulfuric acid resistance test are performed. Test results are shown in Table 7, 8 and 9.

1. Slump Flow

The slump flow of polypropylene fiber reinforced high performance concrete using fly ash(PPF) and blast furnace slag(PPB) are de-

Table 7 Flowing ability test results of polypropylene fiber reinforced high performance concrete

Type	Fiber content (%)	Slump flow		Difference of box height (cm)	L flow		L-type filling ability
		Length (cm)	50 cm reach velocity (cm/s)		Length (cm)	Reach velocity (cm/s)	
PPF	0.00	65 * 65	5.9	2	82	1.2	Excellent
	0.25	60 * 60	4.9	2	74	1.3	Excellent
	0.50	54 * 55	3.5	5	51	3.4	Excellent
	0.75	41 * 42	-	13	45	4.2	Bad
	1.00	30 * 30	-	Closed	25	4.4	Bad
PPB	0.00	65 * 66	6.0	2	83	1.1	Excellent
	0.25	60 * 60	4.9	2	76	1.3	Excellent
	0.50	55 * 55	3.7	5	61	3.4	Excellent
	0.75	40 * 42	-	13	46	4.3	Bad
	1.00	30 * 31	-	Closed	25	4.0	Bad

creased with increasing the polypropylene fiber content as seen Table 7 and Fig. 3, and decreased in the polypropylene fiber content 0.75%. This reason is thought that the fiber content is increased because it is mixed with the polypropylene fiber by weight ratio for unit binder content and due to fire ball of fiber, aggregate and paste. The flow velocity for reaching slump flow 50cm is decreased rapidly with increasing the fiber content as seen in Fig. 3.

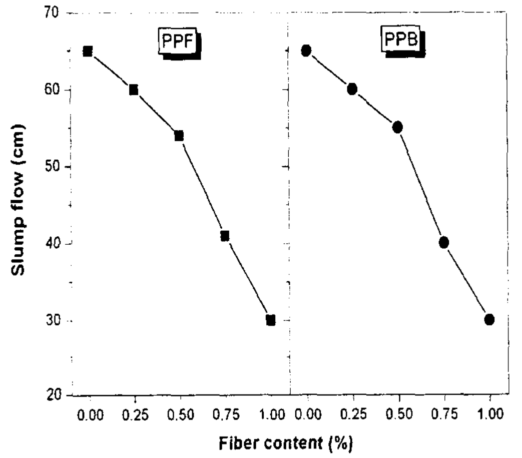


Fig. 3 Slump flow by fiber content

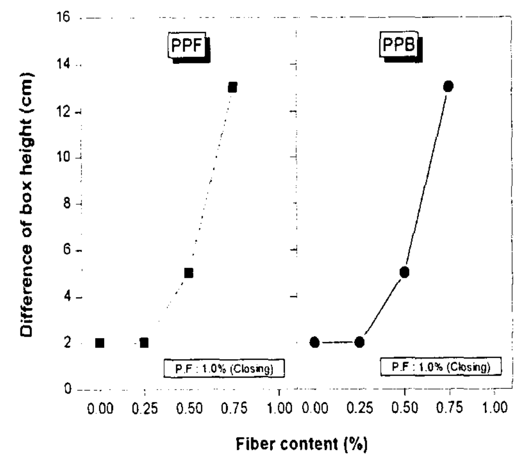


Fig. 4 Difference of box height by fiber content

2. Box Filling Ability

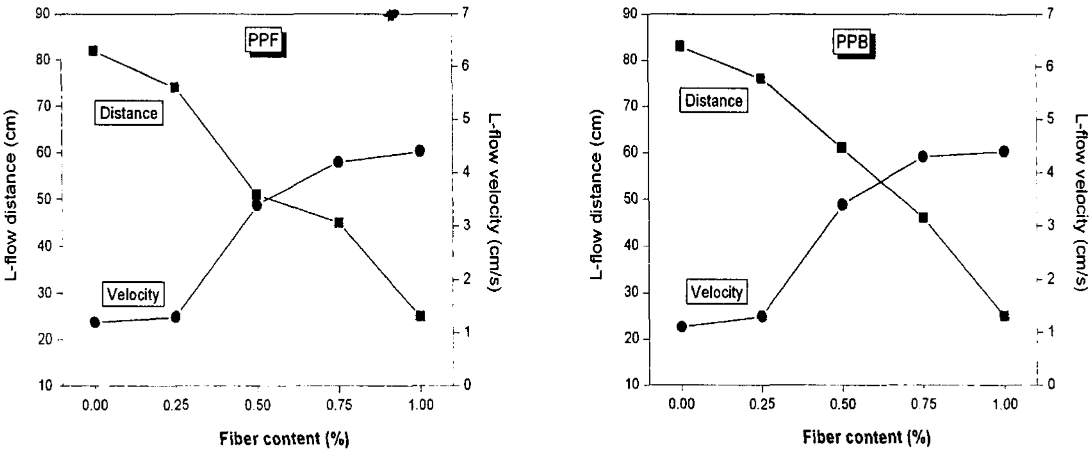
Table 7 and Fig. 4 shows difference of box height. The difference of box height of PPF and PPB is showed in 2~13 cm within the polypropylene fiber content 0.75% and greatly increased with increasing the polypropylene fiber content. On the other hand, the difference of box height in PPF and PPB of fiber content 1% is closed by segregation due to increasing the water-cement ratio and superplasticizer.

3. L-type Flow

Table 7 and Fig. 5 shows the final flow distance for L-type flow. The final flow distance for L-type flow are in the range of 25~74 cm in the PPF and 25~76 cm in the PPB, respectively. It is decreased with increasing the polypropylene fiber content than the flow distance of concrete 82 cm and 83 cm that do not mix polypropylene fiber. Also, the flow ability must consider usability because it is rapidly decreased in the polypropylene fiber content 0.5% or above. The final arrival velocity of flow distance is increased with increasing the polypropylene fiber content.

4. L-type Filling Ability

The L-type filling ability is showed in excellent within polypropylene fiber content 0.5%. But it is appeared in all bad in the polypropylene fiber content 0.75% or above. Specially, the filling ability is rapidly decreased regardless of fly ash and blast furnace slag in the polypropylene fiber content 0.75% or above.



(a) (b)

Fig. 5 L-type flow by fiber content

Table 8 Strength and impact resistance test results of polypropylene fiber reinforced high performance concrete

Type	Fiber content (%)	Curing age (days) 7		28		91		Drop number	
		C.S*	F.S*	C.S	F.S	C.S	F.S	Fracture of initial (1mm)	Fracture of final
PPF	0.00	270	51	362	74	477	79	1	1
	0.25	258	58	328	81	453	89	3	7
	0.50	241	63	297	86	399	96	6	12
	0.75	199	57	277	69	340	84	11	24
	1.00	177	48	239	65	313	80	15	37
PPB	0.00	329	55	420	74	473	79	1	3
	0.25	302	65	400	81	469	89	3	6
	0.50	281	72	362	87	410	97	5	13
	0.75	242	61	296	73	350	79	9	22
	1.00	194	57	240	69	309	75	14	35

* C.S : Compressive strength(kgf/cm^2), F.S : Flexural strength(kgf/cm^2)

5. Compressive Strength

Table 8 shows the compressive strength of PPF and PPB according to polypropylene fiber content. At the curing age 7 days, the compressive strength of PPF and PPB with polypropylene fiber are in the range of 177~258 kgf/cm^2 and 194~302 kgf/cm^2, respectively. They are decreased by 4~34% and 8~41% than those of high performance concrete without polypropylene fiber. At the curing age 28 days, the compressive strength of PPF and PPB with polypropylene fiber are in the range of 239~328 kgf/cm^2 and 240~400 kgf/cm^2, respectively. they are decreased by 9~34% and 5~43% than those of the high performance concrete without polypropylene fiber. At the curing age 91 days, the compressive strength of PPF and PPB with polypropylene fiber are in the range of 313~453 kgf/cm^2 and 309~469 kgf/cm^2, respectively. They are decreased by 5~34% and 1~35% than those of the high performance concrete without polypropylene fiber.

6. Flexural Strength

Table 8 shows the flexural strength of PPF and PPB according to polypropylene fiber content. At the curing age 7 days, the flexural strength of PPF and PPB with polypropylene fiber are in the range of 48~63 kgf/cm^2 and 57~72 kgf/cm^2, respectively. They are increased by 12~24% and 4~31% than those of the high performance concrete without polypropylene fiber. At the curing age 28 days, the flexural strength of PPF and PPB with polypropylene fiber are in the range of 65~86 kgf/cm^2 and 69~87 kgf/cm^2, respectively. The flexural strength of PPF and PPB within fiber content 0.5% is increased than that of the high performance concrete without polypropylene fiber. But, the flexural strength of PPF and PPB of fiber content 0.5% above is decreased than that of the high performance concrete without polypropylene fiber. At the curing age 91 days, the flexural strength of PPF and PPB with polypropylene fiber are in the range of 80~96 kgf/cm^2 and 75~97 kgf/cm^2, respectively.

7. Impact Resistance

Table 8 shows impact resistance of PPF and PPB with polypropylene fiber content. The drop number for reaching final fracture of PPF and PPB with polypropylene fiber are in the range of 6~37. They are greatly increased than those of the high performance concrete without polypropylene fiber(1~3). The drop number for reaching final fracture is increased with increasing the fiber content. Also, the drop number of reaching initial fracture of 1mm of PPF and PPB with polypropylene fiber are in the range of 3~15. They are increased greatly than those of the high performance concrete without polypropylene fiber(1~3).

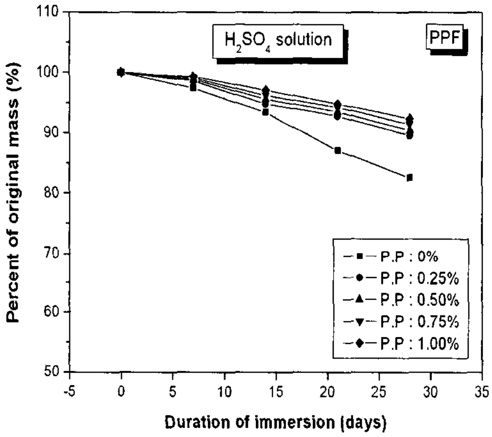
Table 9 Sulfuric acid resistance test results of polypropylene fiber reinforced high performance concrete

Type	Fiber content (%)	Percent of original mass for immersed time (%)			
		7days	14days	21days	28days
PPF	0.00	97.4	93.4	87.1	82.6
	0.25	98.6	94.8	92.8	89.6
	0.50	98.8	95.6	93.5	90.5
	0.75	99.1	96.2	94.2	91.5
	1.00	99.3	97.1	94.8	92.4
PPB	0.00	95.1	90.5	84.0	76.9
	0.25	97.2	94.3	91.3	87.4
	0.50	97.6	94.9	91.9	88.6
	0.75	98.2	95.6	92.6	89.5
	1.00	98.6	96.3	93.5	91.2

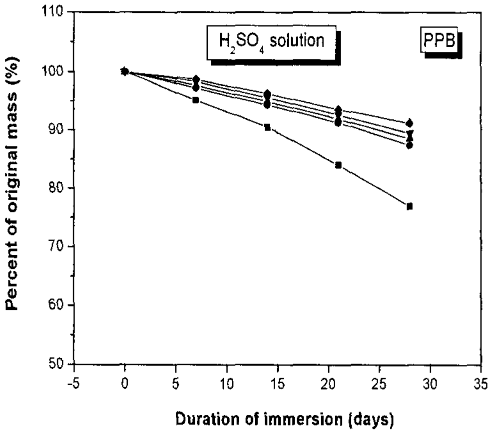
8. Sulfuric Acid Resistance

Table 9 and Fig. 6 shows percent of original mass of PPF and PPB with polypropylene fiber.

The percent of original mass of PPF and PPB is decreased with increasing the fiber content as Fig. 6. The percent of original mass of PPF and PPB in fiber content 1% is decreased approximately 8% and 9% at immersed 28 days, respectively. Also, the percent of original mass of PPF is decreased than that of PPB. Photo 1 shows porosity by erosion and gypsum creation by reaction of sulfuric acid and calcium hydroxide.

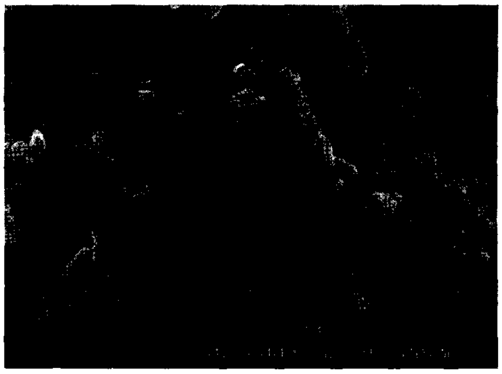


(a)



(b)

Fig. 6 Percent of original mass vs. duration of immersion in H_2SO_4 5 % solution



(a) Fly ash

(b) Blast furnace slag

Photo 1 SEM of concrete immersed in H_2SO_4 5% solution

V. Conclusions

This study was performed to evaluate the flowing ability and mechanical properties of polypropylene fiber reinforced high performance concrete.

The following conclusions were drawn :

1. The slump flow was decreased with increasing the polypropylene fiber content, rapidly. In the box-type filling ability, the difference of box height was increased with increasing the fiber content. Also, the box-type filling ability

was closed in fiber content 1%. The final flowing distance of L-type was decreased with increasing the fiber content. Also, it was decreased in the polypropylene fiber content 0.75% or above, rapidly. The filling ability of L-type was badly showed in polypropylene fiber content 0.75% or above.

2. The compressive strength was decreased with increasing the fiber content. At the curing age 28 days, the compressive strength of PPF and PPB with polypropylene fiber were in the range of 239~328 kgf/cm^2 and 240~400 kgf/cm^2, respectively. At the curing age 91 days, the compressive strength was appeared 300 kgf/cm^2 above in all type.

3. The flexural strength of PPF and PPB with fiber were in the range of 65~86 kgf/cm^2 and 69~87 kgf/cm^2 at the curing age 28days, respectively. The flexural strength of PPF and PPB within fiber content 0.5% was increased than that of the concrete without polypropylene fiber.

4. The drop numbers for reaching final fracture of PPF and PPB with polypropylene fiber were in the range of 6~37. It was greatly increased than that of the concrete without polypropylene fiber. The drop numbers for reaching in final fracture were increased with increasing the fiber content.

5. In the acid resistance, the percent of original mass of PPF and PPB was decreased with increasing the fiber content. The percent of original mass of PPF and PPB in fiber content 1% was decreased by approximately 8% and 9% than that of the concrete without polypropylene fiber in immersed age 28days, respectively.

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