pISSN 1598-2033
eISSN 2233-5706
Journal of the Korea Institute of Building Construction, Vol. 12, No. 4
http://dx.doi.org/10.5345/JKIBC.2012.12.4.377
www.jkibc.org

Evaluation of Impact Resistance of Steel Fiber and Organic Fiber Reinforced Concrete and Mortar

Kim, Gyu-Yong[1] Hwang, Heon-Kyu[2*] Nam, Jeong-Soo[1] Kim, Hong-Seop[1] Park, Jong-Ho[3] Kim, Jeong-Jin[4]
Department of Architectural Engineering, Chungnam University, Yuseong-Gu, Daejeon, 305-764, Korea [1]
Division of Building Works, Hyundai Amco, Seocho-Gu, Seoul, 140-846, Korea [2]
Building Material, Sampyo Engineering & Construction, Gwangju-Si, Gyeonggi, 464-080, Korea [3]
Building Material, Lotte Engineering & Construction, Yongsan-Gu, Seoul, 140-846, Korea [4]

Abstract

In this study, the Impact resistance of steel fiber and organic fiber reinforced concrete and mortar was evaluated and the improvement in toughness resulting from an increase in compressive strength and mixing fiber for impact resistance on performance was examined. The types of fiber were steel fiber, PP and PVA, and these were mixed in at 0.1, 0.5 and 1.0 vol.%, respectively. Impact resistance is evaluated with an apparatus for testing impact resistance performance by high-speed projectile crash by gas-pressure. For the experimental conditions, Specimen size was 100×100×20, 30mm (width×height×thickness). Projectile diameter was 7 and 10 mm and impact speed is 350m/s. After impact test, destruction grade, penetration depth, spalling thickness and crater area were evaluated. Through this evaluation, it was found that as compressive strength is increased, penetration is suppressed. In addition, as the mixing ratio of fiber is increased, the spalling thickness and crater area are suppressed. Organic fibers have lower density than the steel fiber, and population number per unit area is bigger. As a result, the improvement of impact resistance is more significant thanks to dispersion and degraded attachment performance.

Keywords : impact resistance performance, projectile, destruction grade, penetration depth, spalling thickness, crater area

1. Introduction

As brittle failure resulting from earthquake, impact and other factors is a frequent occurrence in cement–based composite materials like mortar and concrete, studies have been conducted to improve toughness through the mixing of fiber. Fiber is used for reduction in shrinkage, shotcrete, and as a material for repair and reinforcement. Steel fiber is mainly used due to its excellent toughness. However, though when steel fiber is mixed, the toughness is more greatly improved than when organic fiber is mixed, under a mix proportion condition, steel fiber has high intensity per unit area, and the volume of steel fiber to be mixed will decrease compared to the organic fiber. For this reason, the specific surface area of steel fiber is believed to decrease, which leads to rather low attachment performance compared to organic fiber. In Korea, previous research on the impact resistance performance of cement–based composite materials was mainly done under low–speed impact conditions, including static and drop tests. Recently, a few studies have been conducted under high–speed impact conditions[1,2]; however, there are still some restrictions on the evaluation method and model development. In other countries,

Received : December 6, 2011
Revision received : June 12, 2012
Accepted : June 18, 2012
* Corresponding author : Hwang, Heon-Kyu
[Tel: 82-10-5343-1032, E-mail: hghwang@hyundai-amco.co.kr]

Table 1. Design of experiment

Specimen					Impact condition					Evaluation contents
					Projectile					
	F_{ck} (MPa)	Fiber types	Fiber content (vol.%)	Thickness (mm)	Material	Diameter (mm)	Mass (g)	Impact speed (m/s)	Impact energy (J)	
Concrete	24 40 60	Plain	–	30 (20)	Steel	10 (7)	4.04 (1.4)	350	245 (85.75)	· Mechanical Properties 1) Compressive strength · Impact resistance performance 1) Destruction grade 2) Penetration depth 3) Spalling thickness 3) Crater area
	24	STF[1], PP[2] PVA[3]	0.1 0.5 1.0							
Mortar	24	Plain	–	30						
		PP, STF PVA, STF+PP STF+PVA	0.1 0.5 1.0							

1) STF : Steel fiber, 2) PP : Polypropylene, 3) PVA : Polyvinyl alcohol
( ) : Additional experiment condition of concrete considering gravel

cement–based composite materials were tested using an apparatus through a high–speed projectile crash to evaluate the impact resistance performance when given a direct impact[3,4], on which basis an analysis model was developed and tested[5,6]

Hence, this study aims to review the effect of the compressive strength of and fiber mix proportion in mortar and concrete on impact resistance performance under a high–speed crash condition, using an apparatus for testing impact resistance performance by high–speed projectile crash. In addition, considering the thickness of concrete and the crash energy of the high–speed projectile, data on the evaluation of impact resistance performance is collected to be utilized in the future as fundamental data for impact resistance performance design of fiber reinforced cement composite.

2. Experiment plan and method

2.1 Experiment plan

Table 1 shows the experiment plan for this study. Three plain specimens were made at W/B 57, 38 and 29%, respectively, to evaluate the impact of compressive strength on penetration depth. In addition, to evaluate the influence of fiber mix on spalling thickness and crater area, the concrete specimens were made at W/B 57% by adding steel fiber, PP and PVA to be 0.1, 0.5 and 1.0 vol%, respectively. Mortar specimens were made under the same condition as the fiber–reinforced concrete specimens, and specimens were also made by adding the same proportion of steel fiber+PP and steel fiber+PVA, respectively, as the single mix condition. The projectile crash test was performed under the test condition of specimen 30 mm thickness, projectile 10 mm diameter, and crash speed 350m/s. Another test was conducted under the condition of specimen 20 mm thickness, projectile 7 mm diameter and crash speed 350 m/s, in consideration of the effect of aggregate.

The compressive strength was evaluated as the mechanical property, and the impact resistance performance was evaluated by inspecting the surface of the specimens including destruction grade, penetration depth, spalling thickness and crater area.

2.2 Materials

As shown in Table 2, the materials used in this study are Portland cement manufactured by S company (density of 3.15g/cm^3), and fly ash (density of 2.30g/cm^3) used as an admixture. Sea sand was used as fine aggregate and broken gravel (maximum size of 20mm) was used as coarse aggregate. The types of fiber were steel fiber, PP and PVA.

Table 2. Properties of material

Material	Properties
Cement	Portland cement(Density 3.15g/cm^3, Fineness 3,630cm^2/g)
Fly ash	Density 2.30g/cm^3, Fineness 3,228cm^2/g
Sand	Sea sand(Density 2.6g/cm^3, Absorptance 0.97%)
Gravel	Broken gravel(Maximum size 20mm, Density 2.62g/cm^3 Absorptance 0.90%)
STF	Length 30mm, Diameter 500㎛ Tensile strength 1,140MPa, Density 7.85g/cm^3
PP	Length 12mm, Diameter 25㎛, Density 0.91g/cm^3 Tensile strength 600MPa
PVA	Length 12mm, Diameter 40㎛, Density 1.3g/cm^3 Tensile strength 1,600MPa

2.3 Experiment method

2.3.1 Concrete and mortar mixing method

The mix proportion of concrete and mortar is as indicated in Table 3. The air content was controlled by 1.1~1.2% from 4% to prevent deterioration to the fiber attachment by air content. When the fiber mixed concrete is applied to the actual members, the decrease in air content would not cause any significant differences, since the members would be affected little by freezing-thawing. The fiber was mixed using a 100L-volume forced pan-type mixer to spread fiber evenly and satisfy the target flowability.

Table 3. Concrete and mortar mix proportions

	F_{ck} (MPa)	W/B (%)	S/a (%)	Unit weight(kg/m^3)				
				W	C	FA	S	G
Concrete	24	57	49	185	276	49	864	906
	40	38	47	170	380	67	796	905
	60	29	45	162	475	84	728	896
Mortar	24	57	100	240	358	63	1535	-

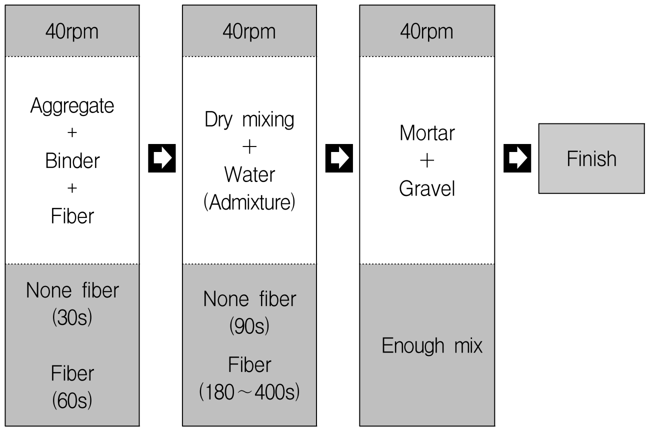


Figure 1. Concrete and mortar mixing method

2.3.2 Test specimen manufacture

A cylindrical test specimen with dimensions of 100x200mm was manufactured to test compressive strength. An angular specimen with dimensions of 100x100x400mm was manufactured and then water cured for 28 days. As shown in Figure 2, the specimen was cut to 20 and 30 mm thick.

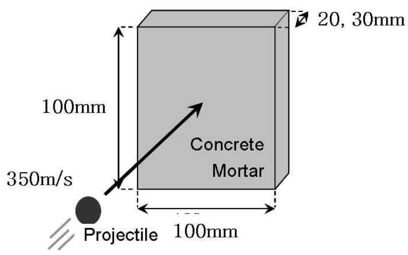


Figure 2. Specimen for evaluation of impact resistance performance

2.3.3 Compressive strength test

The compressive strength was measured using a UTM after grinding the specimen at a certain age in compliance with the Test Method of Concrete Compressive Strength stipulated in KS F 2405.

2.3.4 Performance evaluation of impact resistance

Figure 3 illustrates the apparatus for testing using a high-velocity projectile that ejects compressed gas at a given time to operate the projectile carrier. The velocity of the projectile was measured using a speed measuring sensor that is attached immediately before the test specimen chamber. The carrier was manufactured for the projectile to be separated from the carrier in the chamber to give an impact to the specimen. For the performance evaluation, nitrogen gas was used to provide the velocity of 350m/s.

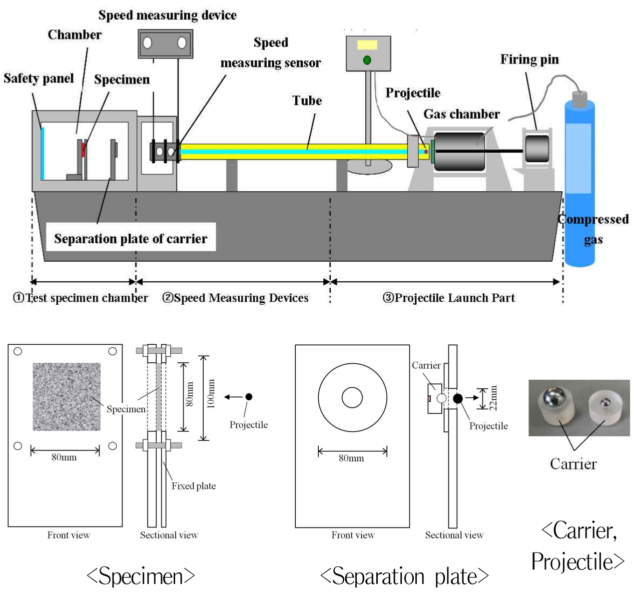
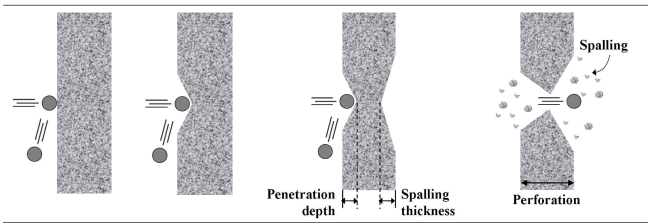


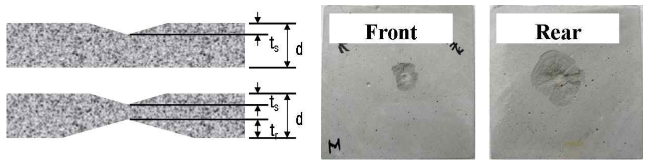
Figure 3. Apparatus for testing impact resistance performance by high velocity impact of projectile

The conventional evaluation method was set only for evaluation at a low velocity range, and it is difficult to set a standardized evaluation method since the test apparatus and condition for an evaluation at a high velocity range are different for each researcher. Referring to the previous literature[2,3,5], the performance evaluation was implemented as indicated in Table 4 and Figure 4. At the 1st step of the evaluation, the destruction grade was estimated through inspection of the surface shape after a crash test. At the 2nd step of the evaluation, penetration depth and spalling thickness and crater area were evaluated on the specimens found to have front and rear destruction.

Table 4. Destruction grade of specimen by impact test

(ⅰ)Clear	(ⅱ)Penetration	(ⅲ)Spalling	(ⅳ)Perforation





where, d : Specimen thickness(mm)

t_s : Penetration depth of front(mm)

t_r : Spalling thickness of rear(mm)

$$\frac{\text{Crater area}(mm^2)}{\text{Specimen area}(mm^2)}$$

(a) Penetration depth and spalling thickness

(b) Crater area

Figure 4. Penetration depth, spalling thickness and crater area of specimen by impact test

3. Experiment results and considerations

3.1 Mechanical properties

Table 5 indicates the compressive strength of concrete and mortar at 28 days. The compressive strength showed by plain concrete at W/B 38 and 29% was 27.8MPa and 64.1MPa, respectively. The compressive strength of plain concrete and fiber–mixed concrete at W/B57% was measured as being between 15 and 24MPa. The more fiber was mixed, the lower the compressive strength due to the mixing of heterogeneous material in concrete, but there were no significant differences that could affect the research.

Table 5. Compressive strength of concrete and mortar

Fiber type	W/B (%)	Fiber content (vol.%)	Compressive strength(MPa)	
			Concrete	Mortar
Plain	57	-	23.3	22.9
	38	-	47.8	-
	29	-	64.1	-
PP	57	0.1	21.8	24.8
		0.5	20.3	23.9
		1.0	20.8	23.4
PVA		0.1	23.2	24.2
		0.5	24.2	24.3
		1.0	21.0	24.2
STF		0.1	22.2	22.9
		0.5	20.0	23.2
		1.0	23.1	21.8
STF+PP		0.1	-	23.4
		0.5	-	19.3
		1.0	-	15.8
STF+PVA		0.1	-	23.3
		0.5	-	23.7
		1.0	-	25.8

3.2 Impact resistance performance

3.2.1 Destruction grade estimation through inspection of the surface shape

Tables 6 and 7 are the surface shape and destruction grade of the concrete and mortar specimens after the test. Perforation was found both on the plain concrete and mortar specimens. On the other hand, penetration and spalling were found on the front and rear, respectively, of the fiber–mixed specimens. The larger the volume of fiber mixed, the less rear spalling was found.

3.2.2 Front penetration control by compressive strength

Figure 5 illustrates the penetration depth by compressive strength after the crash test. Perforations were found on the concrete with compressive strength of 24MPa and 40MPa under the test condition of the specimen 30mm thickness, the projectile 10mm diameter and crash velocity of 350m/s, while penetration and spalling were found on the front and rear, respectively, of the concrete with a compressive strength of 60MPa. Penetration and spalling were found on the front and rear of all the specimens under the test condition of specimen 20 mm thickness, projectile 7 mm diameter and the crash velocity of 350m/s. The penetration depth by the high–velocity projectile was decreased as the compressive strength was increased, and there was no effect found by the fiber mixing.

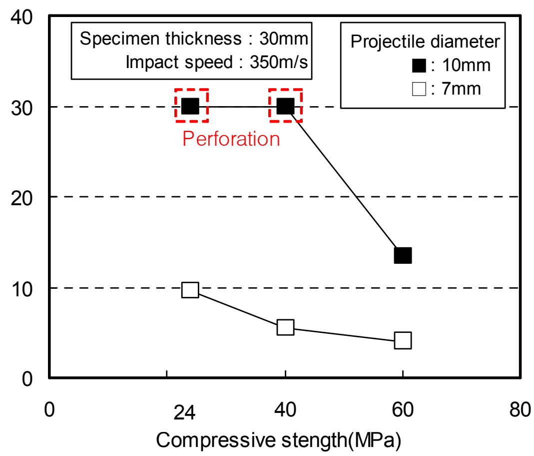
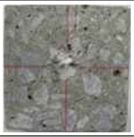


Figure 5. Penetration depth by compressive strength(concrete)

3.2.3 Rear spalling control by fiber type and content

Figures 6 and 7 illustrate spalling thickness and crater area by fiber type and content. The fiber mix proportion was increased to be 0.1, 0.5 and 1.0 vol.%, and the spalling thickness and crater area were decreased accordingly. In addition, the specimen with steel fiber 1.0 vol.% showed penetration on the front and spalling on the rear while the specimen mixed PVA fiber at 0.5vol% did

Table 6. Destruction grade of Concrete

Specimen ID	Plain					
	Front	Rear				
Specimen condition						
Destruction grade	Perforation					
Specimen ID	PP(0.1 vol.%)		PVA(0.1 vol.%)		STF(0.1 vol.%)	
	Front	Rear	Front	Rear	Front	Rear
Specimen condition						
Destruction grade	Spalling		Spalling		Spalling	
Specimen ID	PP(0.5 vol.%)		PVA(0.5 vol.%)		STF(0.5 vol.%)	
	Front	Rear	Front	Rear	Front	Rear
Specimen condition						
Destruction grade	Spalling		Crack of rear		Spalling	
Specimen ID	PP(1.0 vol.%)		PVA(1.0 vol.%)		STF(1.0 vol.%)	
	Front	Rear	Front	Rear	Front	Rear
Specimen condition						
Destruction grade	Crack of rear		Micro-crack of rear		Spalling	

not show any spalling on the rear. Moreover, in the comparison of spalling thickness and crater area by fiber type at each mix proportion, the spalling thickness and the crater area was decreased in the order of PVA〉PP〉steel fiber.

In the research findings, when PVA, an organic fiber, was added at 1.0 vol.%, the rear spalling control was shown to be the highest. It is believed that provided that flowability is not affected, the higher the volume of fiber added, the more the spalling thickness and the crater area are decreased.

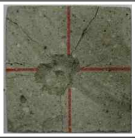
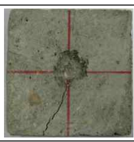
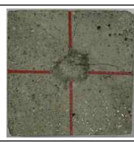
3.2.4 Rear spalling control by fiber hybrid condition

Figures 8 and 9 illustrate the spalling thickness and the crater area under the fiber hybrid condition. When the steel fiber was mixed with PP or PVA, the spalling thickness and the crater area were further decreased, improving the rear saplling control, compared to when single fiber was mixed. This is believed to be due to the fact that when the population number of organic fiber was increased, it affected the rear spalling control, and finally improved the rear spalling control.

3.2.5 Impact resistance performance of steel fiber and organic fiber

The analysis of the spalling thickness and the crater area by fiber type and content under single fiber condition or fiber hybrid condition showed that the spalling thickness and the crater area were more significantly decreased when organic fiber was mixed together than when steel fiber was

Table 7. Destruction grade of mortar

Specimen ID	Plain		PP(0.1 vol.%)		PVA(0.1 vol.%)	
	Front	Rear	Front	Rear	Front	Rear
Specimen condition						
Destruction grade	Perforation		Spalling		Spalling	
Specimen ID	STF(0.1 vol.%)		STF+PP(0.1 vol.%)		STF+PVA(0.1 vol.%)	
	Front	Rear	Front	Rear	Front	Rear
Specimen condition						
Destruction grade	Spalling		Spalling		Spalling	
Specimen ID	PP(0.5 vol.%)		PVA(0.5 vol.%)		STF(0.5 vol.%)	
	Front	Rear	Front	Rear	Front	Rear
Specimen condition						
Destruction grade	Crack of rear		Crack of rear		Spalling	
Specimen ID	STF+PP(0.5 vol.%)		STF+PVA(0.5 vol.%)			
	Front	Rear	Front	Rear		
Specimen condition						
Destruction grade	Spalling		Spalling			
Specimen ID	PP(1.0 vol.%)		PVA(1.0 vol.%)		STF(1.0 vol.%)	
	Front	Rear	Front	Rear	Front	Rear
Specimen condition						
Destruction grade	Crack of rear		Micro-crack of rear		Spalling	
Specimen ID	STF+PP(1.0 vol.%)		STF+PVA(1.0 vol.%)			
	Front	Rear	Front	Rear		
Specimen condition						
Destruction grade	Spalling		Penetration			

mixed only. Under a mix proportion, the population number of organic fiber per unit area was more than that of steel fiber due to its low density, which is considered to improve the distribution in the matrix as well as the attachment performance.

In addition, as illustrated in Figure 10, as the crash impact tends to be delivered to the rear radially, the rear spalling shape was identical to the crash impact direction in the plain specimens and organic fiber mixed specimens. However, it was shown that the steel fiber mixed specimens were significantly affected by the fiber arrangement.

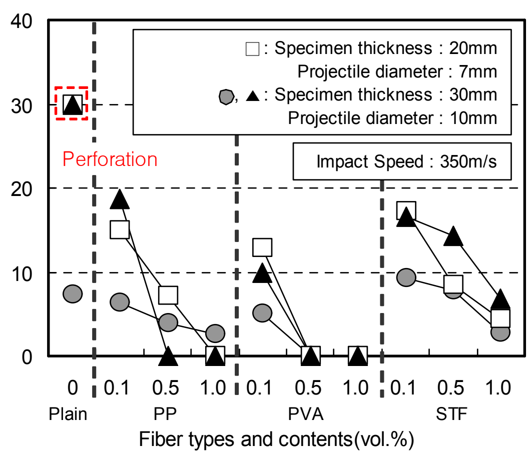


Figure 6. Spalling thickness by fiber type and content

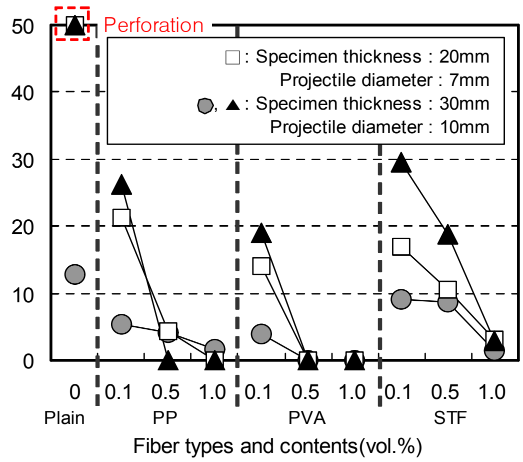


Figure 7. Crater area of rear by fiber types and contents

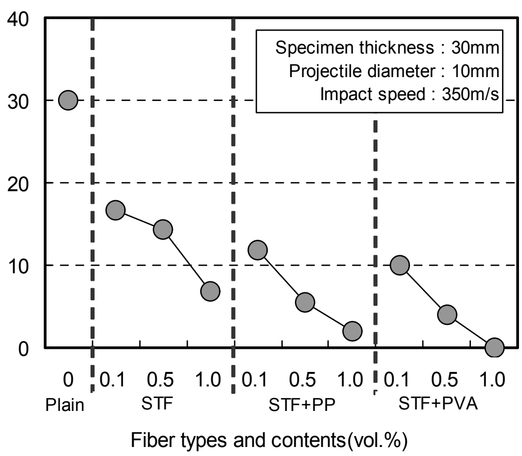


Figure 8. Spalling thickness by fiber hybrid condition

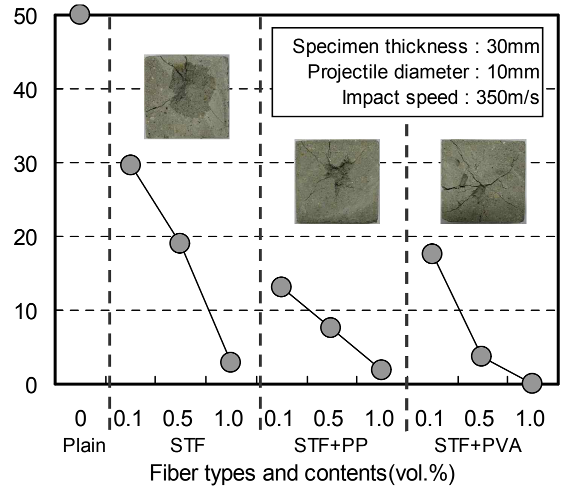


Figure 9. Crater area of rear by fiber hybrid condition

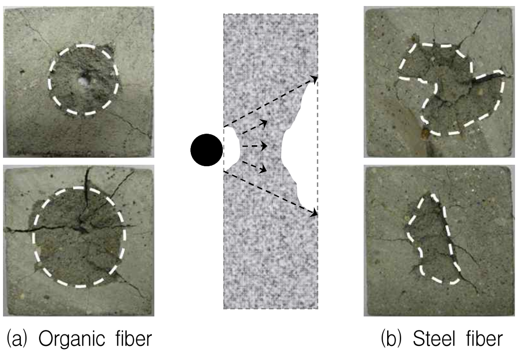


Figure 10. Mortar specimen condition according to fiber types

4. Conclusion

The findings related to the impact resistance performance of the steel fiber and organic fiber mixed concrete and mortar are as follows:

1) In terms of penetration depth, the higher the compressive pressure, the deeper the depth, but the influence of the fiber mix was not significant.
2) Fiber mix improved toughness, and spalling thickness and crater area caused by the high velocity projectile were decreased.
3) It is believed that under a mix proportion, the population number of organic fibers per unit area was more than that of steel fibers due

to its low density, improving the attachment performance and decreasing the spalling thickness and the crater area by high velocity crash.

Acknowledgement

This work was supported by the National Research Foundation of Korea(NRF –No.2010–0014723) grant funded and Brain Korea 2th(BK21) by the Korea government(MEST)

References

1. Kim HS, Kim GY, Miyauchi H, Nam JS, Jeon YS, Koo KM. Evaluation of Impact Resistance Performance of High Strength Concrete by Projectile Size and Compressive Strength. Proceedings of the Korea Institute of Building Construction; 2011 May 20; Dong-Eui Unversity. Seoul (Korea); the Korea Institute of Building Construction; 2011. p. 7-10.
2. Jeon YS, Kim GY, Nam JS, Kim HS, Miyauchi H. A study of the destruction condition of high strength concrete impacted by high speed projectile. Journal of the Korea institute for structural maintenance inspection. 2011 May;15(1):253-6.
3. Zhang M H, Shim VPW, Lu G, Chew CW. Resistance of high-strength concrete to projectile impact. International Journal of Impact Engineering. 2005 April;31(7):825-41.
4. Dancygier AN, Yankelevsky DZ. High strength concrete response to hard projectile impact. International Journal of Impact Engineering. 1996 February;18(6):583-99.
5. Koji MIWA, Masuhiro BEPPU, Tomonori OHNO, Masaharu ITOH, Masahide KATAYAMA. An estimation method of local damage in concrete plates by the modified theoretical model. Journal of Japan society of civil engineers. 2009 October;65(4):844-58.
6. Masuhiro BEPPU, Koji MIWA, Tomonori OHNO, Masanori SHIOMI. An experimental study on the local damage of concrete plate due to high velocity impact of steel projectile. Journal of Japan society of civil engineers. 2007 March;63(1):178-91.
7. Nam JS, Kim GY, Jeon JG, Jeon YS, Kim HS, Hwang HK, Miyauchi H, Kim MH. Impact resistance performance of mortar by mixing condition of fiber. Summaries of Technical Papers of Annual Meeting; 2010 September 09-11; University of Toyama. Toyama (Japan); Architecture Institute of Japan; 2010. p. 539-40.
8. Kim GY, Nam JS, Miyauchi H. Evaluation on impact resistance performance of fiber reinforced mortar under high-velocity impact of projectile. Journal of the Architecture Institute of Korea. 2011 September;27(9):101-8.
9. Jeon YS, Kim GY, Nam JS, Kim HS, Lee TG, Kim MH. Evaluation on blast resistance performance of concrete using fiber reinforced mortar panel and air space. Proceedings of the Korea Institute of Building Construction; 2010 Nov 12; Chungnam National Unversity. Seoul (Korea); the Korea Institute of Building Construction; 2010. p. 31-4.