18th International Conference on Structure mechanics in reactor technology
Beijing, China, August 8-12, 2005
SMiRT18-J05-5

BEHAVIOR OF RC PANELS RETROFITTED WITH ARAMID FIBER SHEETS TO MISSILE IMPACT

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ABSTRACT

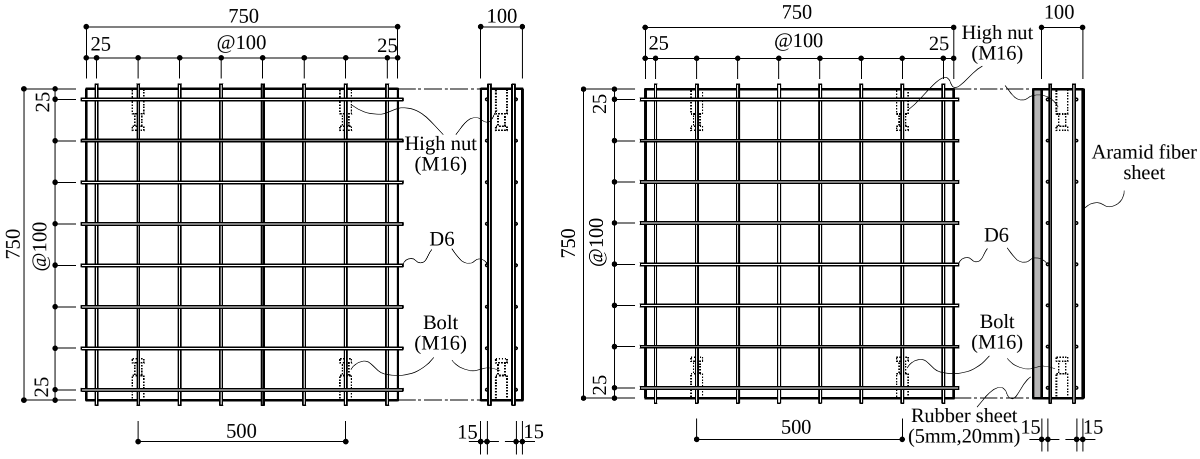
An experimental study of behavior of RC panels retrofitted with aramid fiber sheets and rubber sheets subjected to missile impact is reported. The objective is to consider the effect of aramid fiber sheets and rubber sheets on perforation and scabbing of RC panels subjected to high-velocity impact of projectile. Six RC panel specimens of 750mm square were prepared. Rubber sheet and aramid fiber sheet were used as surface reinforcement on front side of RC panel and on rear side, respectively. Parameters being studied are thickness of rubber sheets and velocity of projectile. The panel specimen was suspended vertically by two steel wire ropes to allow free movement after projectile impact, and was subjected to a projectile. In this study, non-deformable type of projectile with a hemispherical head was used. Tests results show that reinforcement by the aramid fiber sheet and rubber sheet reduces local damage of RC panels effectively, and that the aramid fiber sheet also has an effect on preventing scattering the concrete.

Keywords: missile impact, aramid fiber sheet, concrete, air pressure, rubber sheet, perforation

1. INTRODUCTION

Since an unexpected extreme load, such as an accidental aircraft crash or unexpected terrorist attack, would results in both local and in overall dynamic response of the target wall, the necessity to design nuclear-related facilities for an extreme load condition is well recognized for their social importance. The reinforced concrete (RC) panel has usually been used with the nuclear-related facilities, and a plenty of studies have been conducted in the past on behavior of reinforced concrete panel subjected to missile impact. Furthermore, these include on using different types of wall materials, different arrangement of reinforcement of concrete wall to reduce or prevent local damage. Several methods to improve damage resistance of reinforced concrete panel have been recommended based on those past studies. [1]-[2] Recently, for example, the steel plate reinforced concrete is expected as impact resistance structure, since it is effective to prevent the projectile from perforating the walls due to the steel plates covering the concrete surface. Some studies on impact resistance of layered RC panel, which is made of two RC panels and buffer material between them, reported that layered RC panel had an effect on local damage such as scabbing and perforation. [3]-[4]

In this paper, the reinforcement of RC panels by rubber sheet and aramid fiber sheet was proposed, and an experimental study on the behavior of RC panels retrofitted with aramid fiber sheets and rubber sheets to missile impact was carried out. These sheets are pasted to RC panels. Hence, this method of the reinforcement of RC panel using these sheets is able to be applied to existing buildings. The objective is to consider the effect of aramid fiber sheets and rubber sheets on perforation and scabbing of RC panels due to high-velocity impact of projectile.



(a) RC (B) AF

Fig.1 – Dimension and detail of the specimens

Table 1 – Properties of concrete

Age of concrete (days)	Compressive strength (MPa)	Splitting tensile strength (MPa)
26	25.2	2.13
28	26.2	-
29	25.8	-
62	25.7	1.73

2. TEST PROGRAM

2.1 Specimens and Materials

In all, six RC panels of 750mm square were prepared with thickness of 100mm. Parameters studied include thickness of rubber sheets and velocity of projectile. See Table 2 for details of parameters.

The specimens were divided in to two series: RC and AF. The specimens in series RC were prepared as control specimens. In series AF, the RC panels were reinforced with rubber sheets and aramid fiber sheets. The detail of specimens is presented in Figure 1. All specimens were reinforced with deformed bar of 6mm diameter (D6) at spacing of 100mm. The yield strength and the tensile strength of deformed D6 used in this experiment are 477MPa and 606MPa, respectively.

Rubber sheets were used in expectation of decrease of stress waves, which occur and transmit due to the impact of projectile and cause scabbing. The rubber sheets are made of natural rubber with hardness of 65, and with two different thicknesses, 5mm and 20mm. These rubber sheets were set on front face of RC panel specimens with CR (chloroprene rubber) bond. While, aramid fiber sheets were stuck to rear face of RC panel specimens with epoxy resin in expectation of prevention of the scatter of concrete after missile impact. The tensile strength of the aramid sheet is 2060MPa.

Concrete with design compressive strength of 30MPa was used in this experiment. A coarse aggregate with maximum size of 10mm was used. The compressive and splitting tensile strength of concrete used in this study was shown in Table 1.

2.2 Test Setup

In this study, a spherical head of non-deformable type projectile with a mass of about 0.5kg and diameter of 45mm was used. The projectile, shown in Figure 2, was with the head and body made of steel and aluminum, respectively. The material properties of projectile are shown in Table 2. This projectile was ejected by air pressure at a target velocity of 175m/sec, 215m/sec and 250m/sec. These velocities of projectile were determined based on the past experiment.[5] In other words, in order to investigate the effect of reinforcement with aramid fiber sheet and rubber sheet on perforation, the projectile velocities with which the RC panel specimens had been perforated were used. The velocity of the projectiles was measured by three methods; 1) an electro-optical device, 2) a high

Table 2 – Properties of projectile

	Material	Yield strength (MPa)	Tensile strength (MPa)	Young's modulus (MPa)
Head	S45C	636	725	249
Body	A5056	219	306	84

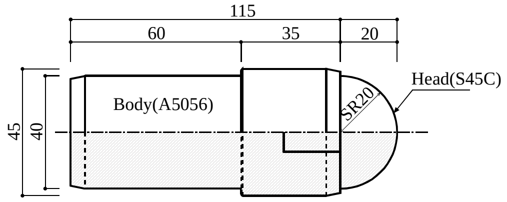


Fig.2 – Missile projectile

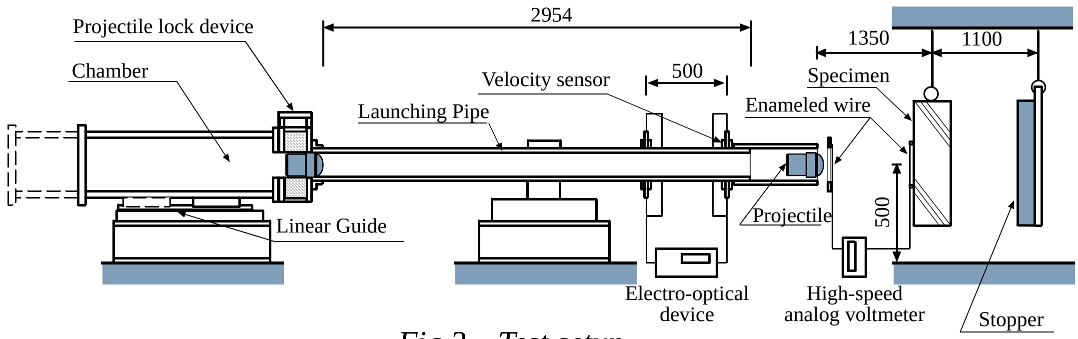


Fig.3 – Test setup

speed camera, and 3) a high-speed analog voltmeter. The electro-optical device consisted of two infra-red light emitting diodes, located at a fixed distance of 0.5m from each other, and two matching receivers. The high speed camera, which is capable of recording 4000 frames per second, was used to record the missile projectile approaching the specimen. Moreover, enameled wires, through which electric current was passed, were equipped on the front face of specimen and the tip of launching pipe. When the projectile was discharged and the current was off due to projectile, a time lag was measured by a high-speed analog voltmeter. This time lag was used to calculate the velocity of the projectile.

The panel specimen was suspended vertically in front of the gun by two steel strings to allow free movement after impact (see Figure 3). After testing, the weight of breaking off concrete debris of all specimens was measured. The dimension of damage area of both front and rare faces of RC panels was also examined, and the bulging height of AF specimen was taken.

3. TEST RESULTS AND DISCUSSION

In Figure 4, the photographs by the high speed camera at impact are shown. The projectiles before and after testing are shown in Figure 5. From these pictures, it can be known that the projectile did not deform after impact.

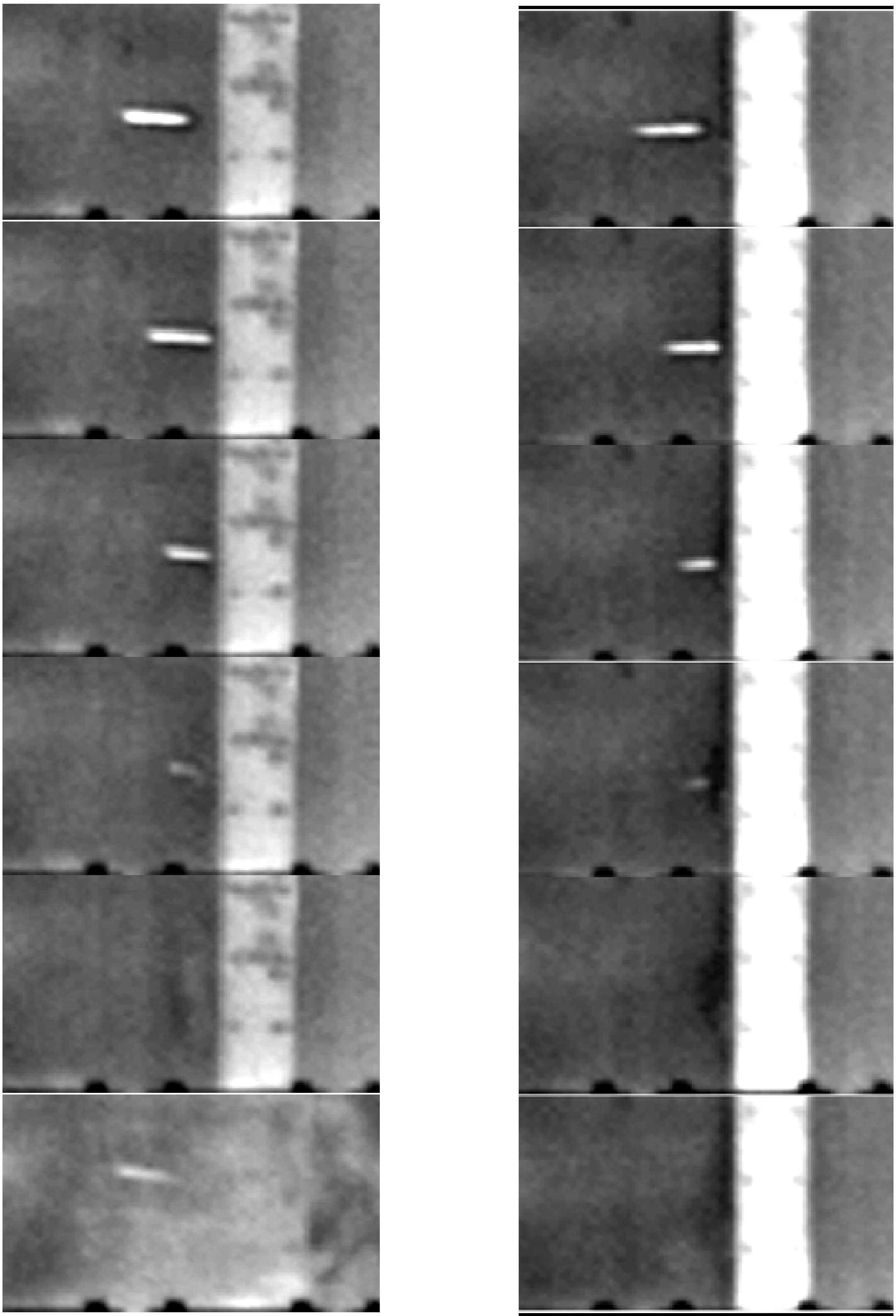
Based on both measurements taken using the three methods previously mentioned and calculation value based on theoretical formula, the velocities of missile projectile were decided with three classes; 160m/sec, 200m/sec and 235m/sec. In Figure 6, the process to decide missile velocity is illustrated.

The test results are indicated in Table 3. Here, the failure mode of specimens is divided as shown in Figure 7. Three types of failure mode for RC and four types for AF are applied. Figure 8 and Figure 9 show representative failure conditions of the tested specimens.

3.1 MODE OF FAILURE

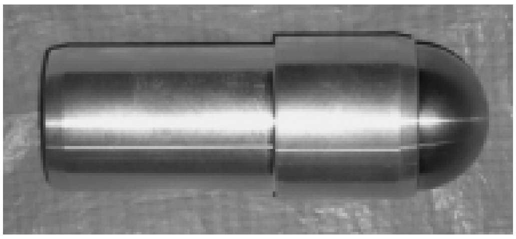
RC-1 and RC-2 differed only in the missile velocity and are failed in scabbing and perforation, respectively. It can be seen from Figure 8 (a), that a through-hole was made in the RC-1, but the projectile bounced off the specimen after impact. Therefore, it was judged that the failure mode of RC-1 is scabbing. The spalling area of front face of RC-2, which was tested with velocity of 200m/s, was bigger than that of RC-1 that which was subjected to projectile with the velocity of 160m/s. However, the spalling area of rear face of RC-2 was smaller than RC-1. Moreover, the spalling area of rear face of RC panel was bigger than that of front face, and this is common to the damage of RC panels. [5]

All specimens in series AF failed in bulging, but the bugling heights were very small. After impact tests of AF-1 and AF-2, the projectiles were bounced off the specimens and the rubber sheets with thickness of 5mm were torn radially due to impact (see Figure 9 (a)). While, with AF-3 and AF-4 which were covered by rubber

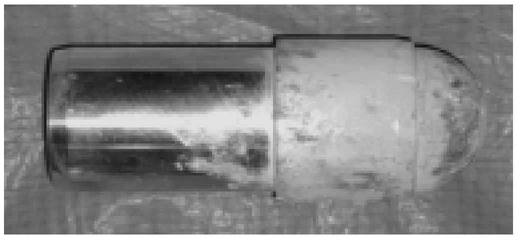


(a) RC-1 *(b) AF-3*

Fig.4 – State of failure

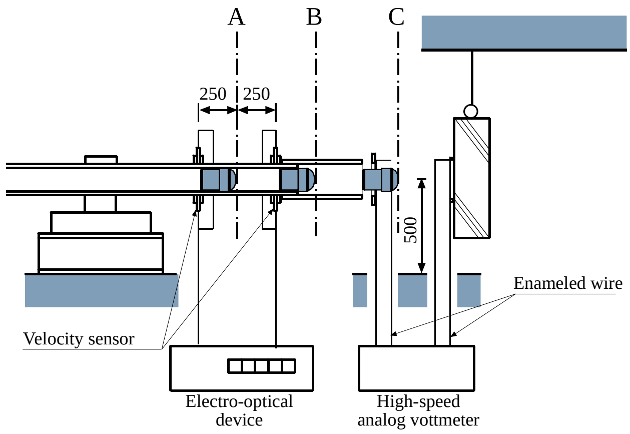


(a) Before testing

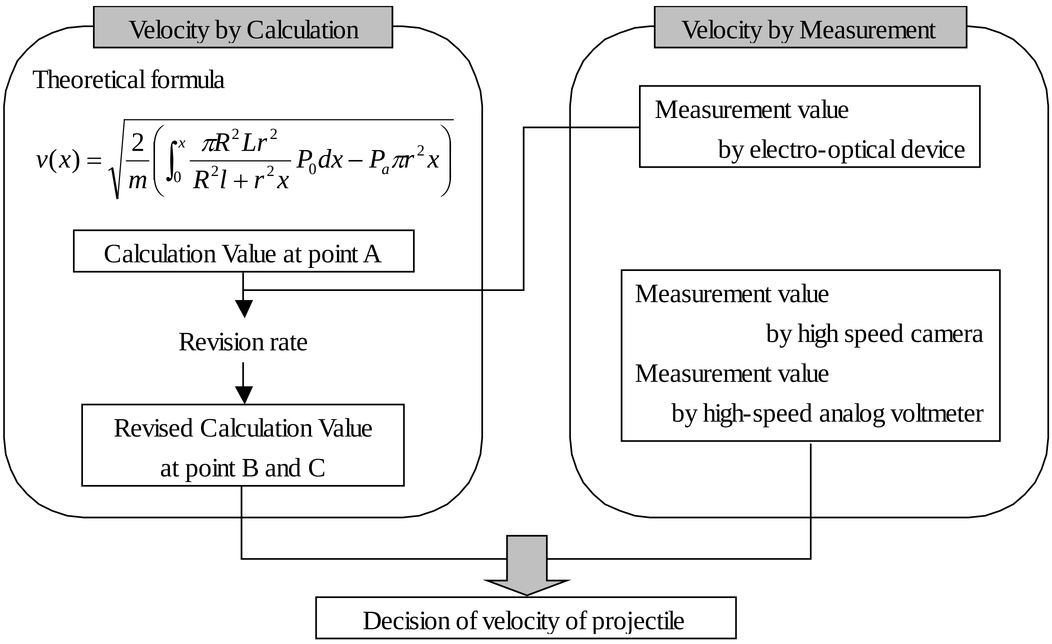


(b) After testing

Fig.5 - Projectile before and after testing



(a) Point for calculated velocity



(b) Flow chart

Fig.6 – Process to decide missile velocity

Table 3 – Parameters and test results

Specimen		Parameter			Test result				
Series	Name	Surface reinforcement		Missile velocity (m/sec)	Failure mode	Weight of flying concrete (kgf)	Spalling area (cm^2)		Bulging height (mm)
		Front face	Rear face				Front face	Rear face	
RC	RC-1	-	-	160	Scabbing	2.85	168	865	-
	RC-2	-	-	200	Perforation	2.60	291	566	-
AF	AF-1	Rubber sheet 5mm	Aramid fiber sheet	160	Bulging	0.75	-	-	3.25
	AF-2			200	Bulging	1.10	-	-	8
	AF-3	Rubber sheet 20mm		200	Bulging	0.44	-	-	6
	AF-4			235	Bulging	0.24	-	-	(12.75)

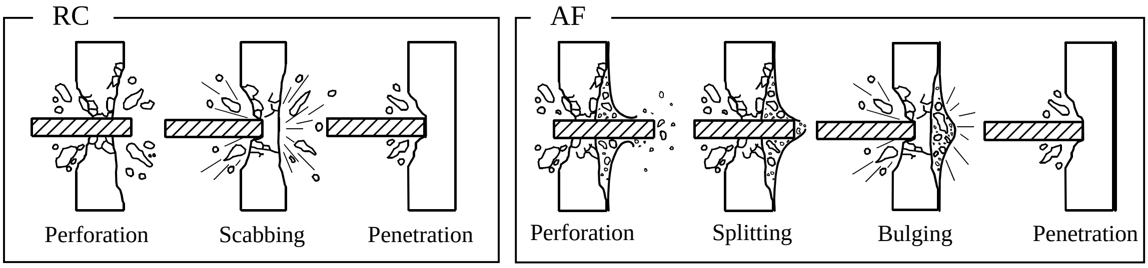
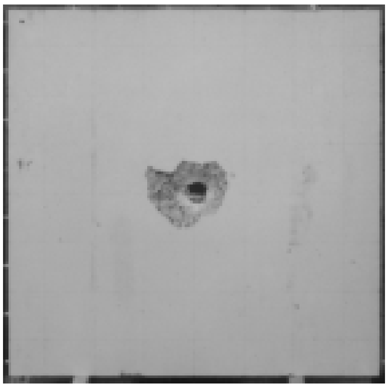
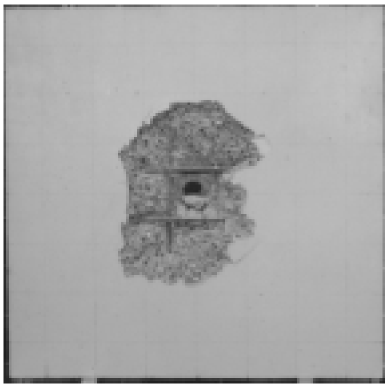


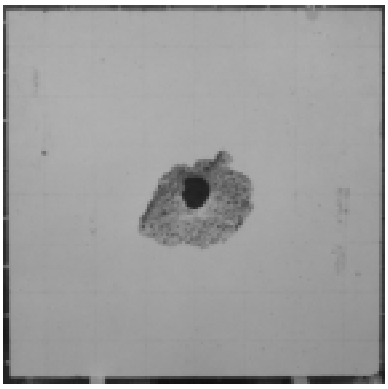
Fig.7 – Failure mode



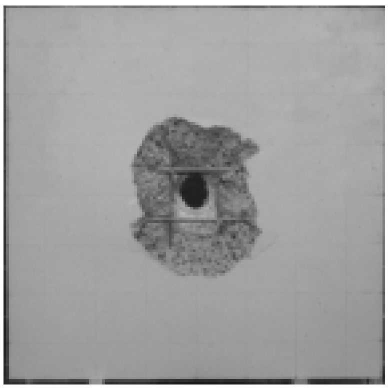
(a) Front face of RC-1



(b) Rear face of RC-1

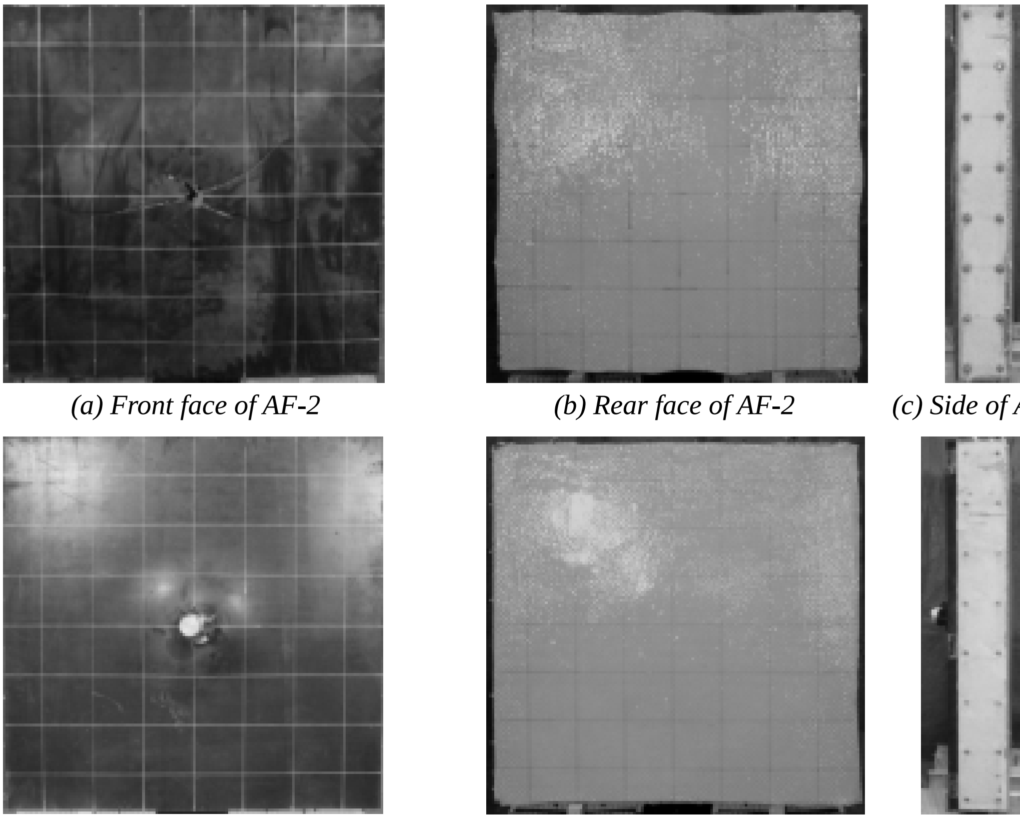


(c) Front face of RC-2



(d) Rear face of RC-2

Fig.8 – Damages of specimens in series RC



(a) Front face of AF-2 (b) Rear face of AF-2 (c) Side of AF-2

(d) Front face of AF-3 (e) Rear face of AF-3 (f) Side of AF-3

Fig.9 – Damages of specimens in series AF

sheet with thickness of 20mm, the projectiles stopped inside the specimens. The projectile did not perforate the rubber sheet of AF-3 completely and protruded from the specimen (see Figure 9 (f)). The rubber sheet of AF-4 was perforated by the missile projectile.

On the rear face of AF-1and AF-2, the fiber reinforced plastics, which was made of chloroprene rubber bond, have circular cracks with diameter of about 80mm around the center of specimens. However, the aramid fiber sheets in itself of these specimens were not damaged. Any crack on the rear face of AF-3 could not be observed. As for AF-4, a part of the aramid fiber sheet exfoliated from the specimen after testing.

3.2 EFFECT OF REINFORCEMENT SCHEME

Though RC-2 which was tested with the velocity of 200m/sec failed in perforation mode, all specimens in series AF failed in bulging mode. In Table 4, comparison by failure mode between specimens in series RC and AF is shown. It can be observed that specimens in series AF did not failed in perforation even if they was subjected to the projectile with more than perforation velocity of RC panel. The missile velocity of AF-2 was more than the perforation velocity of RC panel, and the depth of penetration of AF-2 was 45mm. This also indicates the difference of damage between specimens in series RC and AF. Therefore, it was found that rubber sheet and aramid fiber sheet reduced the degree of local damage and have an effect on impact resistance.

As mentioned above, it could be observed circular cracks on the rear faces of specimens using rubber sheet with thickness of 5mm, and the aramid fiber sheet of AF-4 came off the RC panel with quarter area. However, the

Table 4 – Comparison by failure mode

Specimen	Thickness of rubber sheet	Velocity of projectile (m/sec)		
		160	200	235
RC	-	○	●	
AF	5mm	□	□	
	20mm		□	□

●: Perforation ○: Scabbing (RC) □: Bulging (AF) aramid fiber sheets of all specimens in series AF did not split and they could avoid scattering the broken pieces of concrete. Moreover, the bulging heights of all specimens in series AF were so little that it could hardly be observed. In other words, the aramid fiber sheets were hardly deformed by missile impact. It is found from these results that aramid fiber sheet on rear face of RC panel could effectively avoid scabbing of RC panel.

AF-2 and AF-3 were tested with the same velocity of projectile, 200m/sec, and differed the thickness of rubber sheet. The bulging heights of these specimens were little different. From this result, it is found that the difference in thickness of rubber sheet in the range of 5mm to 20mm had no effect on the degree of local damage. However, the rubber sheet with thickness of 5mm was torn due to impact. On the other hand, the damage area of rubber sheet with thickness of 20mm was only the point of impact and the scatter of broken concrete on the front face was prevented. From the condition after impact in Figure 4, it can be observed that the concrete was prevented from flying due to impact on both front face and rear face of RC panel.

4. CONCLUSION

In this study, the impact test was carried out with RC panels retrofitted with aramid fiber sheets and rubber sheet. Non-deformable projectiles with a hemispherical head were used. The parameters studied include velocity of missile projectile and thickness of rubber sheet. From this experimental investigation, the following conclusions can be drawn:

1. It was observed that the perforation and scabbing was prevented effectively with the RC panels covered with rubber sheet and aramid fiber sheet.
2. The aramid fiber sheet which was used on rear face of RC panel was effective to prevent the scatter of concrete due to scabbing after missile impact.
3. Regarding the rubber sheet which was pasted on front face of RC panel, there was little difference in effect on the reinforcement between two kinds of thicknesses of rubber sheet, 5mm and 20mm.

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