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Damage Evaluation of Aramid Fiber Reinforced Cement Composites by High Velocity Impact†

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The purpose of this study is to evaluate the impact resistance of aramid fiber reinforced cement composite through the impact test of high velocity projectile. The mechanical performance of aramid fiber reinforced cement composite depended on length, oiling agent of surface and volume ratio of fiber. This result affected the impact resistance of the aramid fiber reinforced cement composite. We identified that volume ratio of 1.5 % and oiling agent ratio of 1.2 % are suitable with regard to the fiber dispersion, the mechanical performance and the impact resistance of the aramid fiber reinforced cement composite. This means that matrix of the cement composite and interfacial properties of fiber vary depending on the oiling agent of surface and volume ratio of aramid fiber. Thereby the mechanical performance and impact resistance of cement composite can be improved.

Keywords: Aramid fiber, Oiling agent, Mechanical properties, High velocity projectile, Impact resistance.

INTRODUCTION

In recent years, the fiber reinforced cement composite has been widely used in the field of construction and the research for high performance of the fiber reinforced cement composite is being expanded. The fiber reinforced cement composite improves the various performance such as tensile strength, flexural strength, shear strength, crack control and impact resistance. Generally, steel fiber, polyvinyl alcohol fiber, polypropylene fiber and polyethylene fiber are used as a reinforcing fiber for cement composites. Application of fiber reinforcement varies depending on the performance of the fiber such as tensile strength and thermal resistance.

Recently, loss of human lives has increased all over the world due to the explosive terror and the explosion of plant facilities[1-3]. For this reason, interest in improving impact resistance of construction materials is increasing to ensure the safety of the building structure that protects human lives. Many researchers have studied on impact resistance to apply fiber reinforced cement composite that has high mechanical properties[4-8].

Aramid fiber, meanwhile, has been used most widely in the field other than construction to improve the impact resistance. It has been used as a material of body-armor or bomb proof helmet. In particular, aramid fiber processed into sheet has been used for seismic reinforcement in the construction sector. However, there are not many studies on impact resistance of fiber reinforced cement composite using the aramid fiber.

Therefore, we evaluated the impact resistance of aramid fiber reinforced cement composite by impact with the high velocity projectile. In addition, the effect on mechanical properties and impact resistance of aramid fiber reinforced cement composite depending on length, oiling agent of surface and volume ratio of fiber was examined.

EXPERIMENTAL

Materials and mixture proportions: Mechanical properties of materials are shown in Table-1. The materials used in the production of fiber reinforced cement composite mixtures were Type-I portland cement, Class-F fly ash. The aramid fibers with a diameter of 11 μm and a length of 6 mm and 12 mm are purposely manufactured with a tensile strength of 2920 MPa. The surface of Aramid fibers is coated with a proprietary hydrophobic oiling agent of 0.7 % and 1.2 % by mass to tailor the interfacial properties between fiber and matrix for mechanical properties of cement composite. The mix proportions of the normal and aramid fiber reinforced cement composites

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TABLE-1
MECHANICAL PROPERTIES OF THE USED MATERIALS

Materials	Mechanical properties
Cement	Ordinary portland cement, Density: 3.15 (g/cm^3), Fineness: 3770 (cm^2/g)
Fly ash	Density: 2.30 (g/cm^3), Fineness: 3228 (cm^2/g)
Silica sand	Density: 2.64 (g/cm^3), Absorption ratio: 0.38 (%)
Aramid fiber	Density: 1.44 (g/cm^3), Tensile strength: 2920 (MPa); Length: 6, 12 (mm), Diameter: 11 (μm), Oiling agent ratio: 0.7, 1.2 (%)

TABLE-2
MIX PROPORTIONS

Mix ID[a]	W/B	Fiber (V_f %)	Fiber length (mm)	Oiling agent ratio (%)	Unit weight (kg/m^3)				
					Water	Cement	Fly ash	Sand	HRWR[b]
Plain	0.4	-	-	-	452	960	169	395	-
A-1.0-6-0.7	0.4	1.0	6	0.7	452	960	169	395	0.016
A-1.5-6-0.7	0.4	1.5	6	0.7	452	960	169	395	0.023
A-1.0-6-1.2	0.4	1.0	6	1.2	452	960	169	395	0.012
A-1.5-6-1.2	0.4	1.5	6	1.2	452	960	169	395	0.018
A-2.0-6-1.2	0.4	2.0	6	1.2	452	960	169	395	0.024
A-1.0-12-0.7	0.4	1.0	12	0.7	452	960	169	395	0.018
A-1.5-12-0.7	0.4	1.5	12	0.7	452	960	169	395	0.026

[a]Aramid fiber-Fiber (V_f %)-Fiber length (mm)-Oiling agent ratio (%)
[b]Superplasticizer (high-range water reducer)

are shown in Table-2. The water/binder ratio (W/B) was 0.4 and unit weight of the binder was 1129 kg/m^3. High range water reducer was added to the mixture until the desired fresh aramid fiber reinforced cement composite characteristics. All of the mixtures were prepared in a standard mortar mixer to produce the fiber reinforced cement composite specimens because the relatively high mixing effort imparted by this type of mixer facilitates the dispersion of small diameter aramid synthetic fibers.

Impact test set-up: High velocity impact test equipment and installation condition was given in Fig. 1. In the impact tests, the target specimens were subjected to the projectile

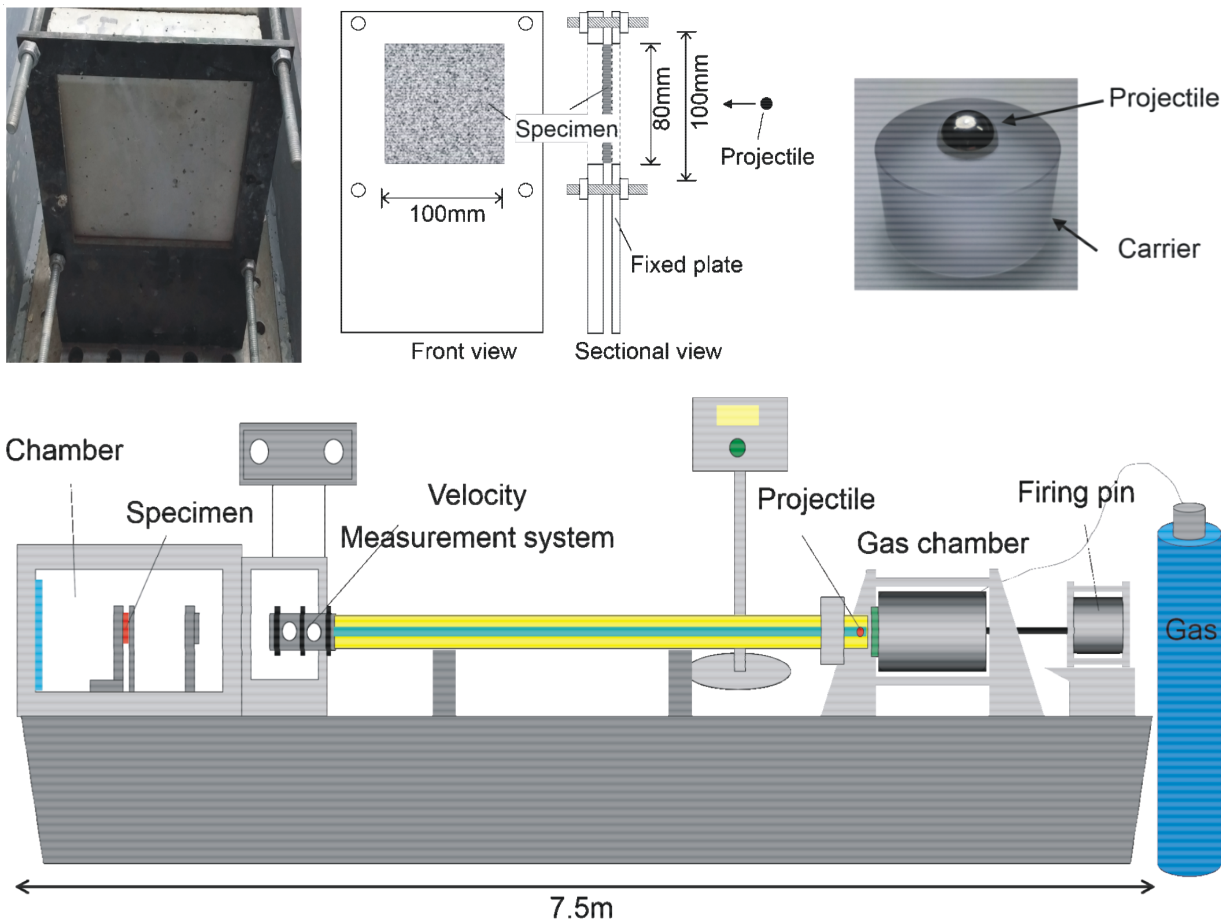

Fig. 1. Impact test set-up

impact with impact velocity in the range of 342-360 m/s. 304 Steel sphere of 5 mm in diameter was used as a projectile. 304 Steel sphere was glued on the nose of a carrier made of high-density polyethylene and polycarbonate. The carrier was separated by a sabot-catcher just before the impact. The size of the specimen used in the impact test was 100 mm × 100 mm × 15 mm and was fixed by a fixing plate. The local damage of concrete plates is commonly classified into three modes, cratering, scabbing and perforation as shown in Fig. 2. The extent of the damage to each specimen was quantified graphically by mapping the craters on the front and back sides and comparing the crater area, A1, to the total area, A1 + A2. This is demonstrated in Fig. 3. The percent of local damage was calculated by 100 % × A2/ (A1 + A2).

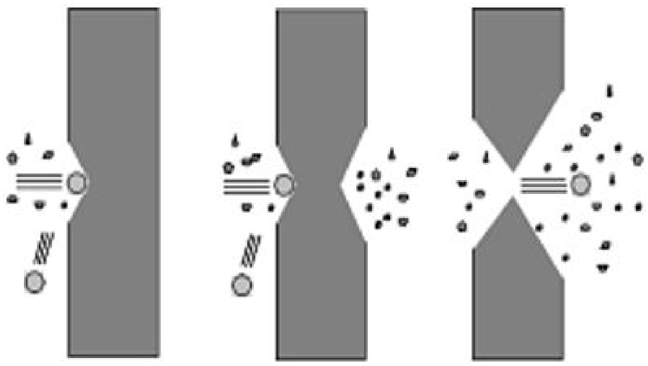

Fig. 2. Failure modes of local damage

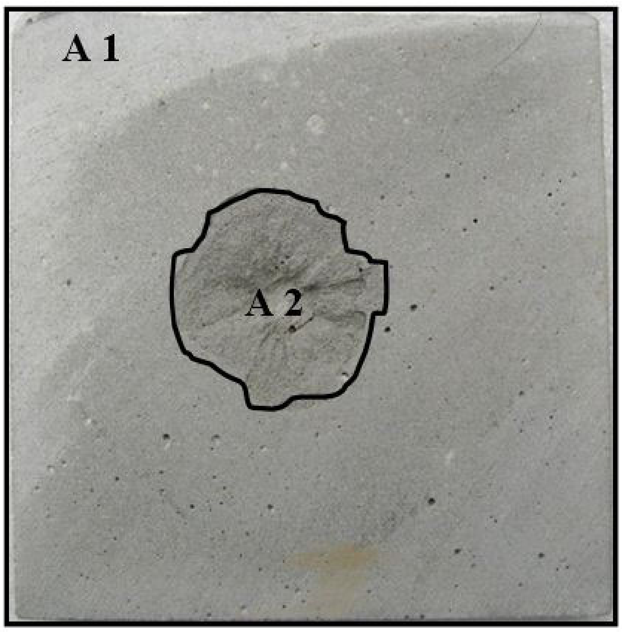

Fig. 3. Damage mapping on specimen

RESULTS AND DISCUSSION

Fresh and hardened characteristics: The workability, or free deformability, of each mixture was measured by the flow parameter. As defined by KS L 5111 (Korea Agency for Technology and Standard, 2005), which is similar to ASTM C 1437, the horizontal flow is the average of the largest diameter and the orthogonal diameter. Table-3 indicates the flow of fresh cement composite and the result of mechanical performance evaluation of hardened cement composite. The flow of fresh cement composite meets target value of 150 ± 20 mm by adding HRWR. Workability, however, was reduced as the volume ratio of fiber increased. It is considered that decline of workability interrupt that the aramid fiber diffuses into matrix of cement composite.

TABLE-3
FRESH AND HARDENED CHARACTERISTICS

Specimen ID	Flow[a] (mm)	Average compressive strength (MPa)	Average split tensile strength (MPa)	Average flexural strength (MPa)
Plain	170	55.0	1.49	2.37
A-1.0-6-0.7	158	40.0	3.01	7.48
A-1.5-6-0.7	135	44.7	3.92	10.83
A-1.0-6-1.2	155	37.4	3.08	10.17
A-1.5-6-1.2	140	37.4	3.96	13.32
A-2.0-6-1.2	139	33.5	4.38	14.91
A-1.0-12-0.7	144	39.1	3.43	8.03
A-1.5-12-0.7	138	43.6	4.17	12.63

[a]Target of flow: 150 ± 20 mm

Compressive strength tests were carried out in accordance with ASTM C 39 and the splitting tensile strength tests were done according to ASTM C 496. Flexural strength tests were done according to ASTM C1609. Evaluation of mechanical properties of cement composites cured in an environmental chamber at 23 ± 2 °C and a relative humidity of 60 ± 5 % until the age of testing, respectively. Compressive strength of plain specimen was measured as 55 MPa. That of the aramid fiber reinforced cement composite was reduced more than 10 MPa compared to plain specimen regardless of reinforcement conditions. In case of splitting tensile strength and flexural strength, those of the aramid fiber reinforced cement composite were improved significantly compared to plain specimen. We also confirmed that those strength of the aramid fiber reinforced cement composite are improved as the volume ratio and the length of the aramid fiber increase.

In addition, the splitting tensile strength and flexural strength of the aramid fiber reinforced cement composite were improved as oiling agent ratio increased and the improvement effect was significant in terms of flexural strength.

Superficial damage: The post failures and damaged plain specimen and aramid fiber reinforced cement composites in the case of fiber ratio 1.5 (V_f %) subjected to projectile impacts are shown in Fig. 4, respectively. It can be seen in Fig. 4 that in case of plain specimen, the failure mode was "penetration". In the case with aramid fiber reinforced cement composites, the failure modes were "cratering" and "scabbing", where the degree of damage was less than that of "no fiber reinforcement".

The results of superficial damage of front and back sides are shown in Figs. 5 and 6. In case of plain specimen, superficial damage in back side is larger about 12.8 % than front side. On the other hand, the superficial damage of all aramid fiber reinforced cement composites were reduced in the front side. The superficial damage in back side was also reduced according to increase in oiling agent ratio of the aramid fiber.

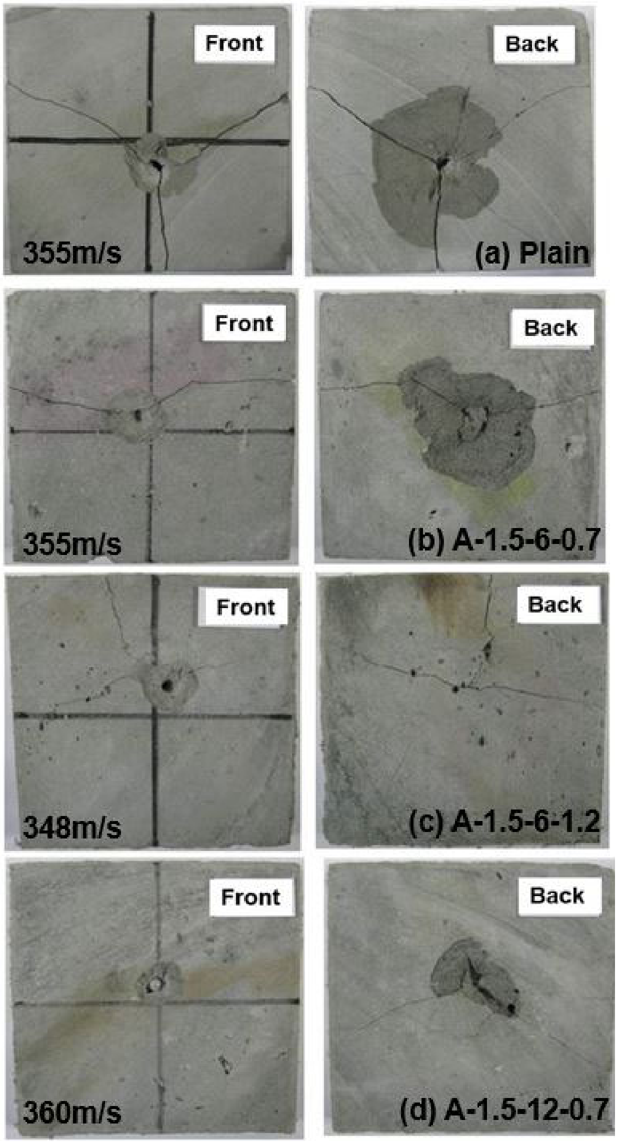

Fig. 4. Damage in the case of plain and fiber ratio 1.5 (V_f %)

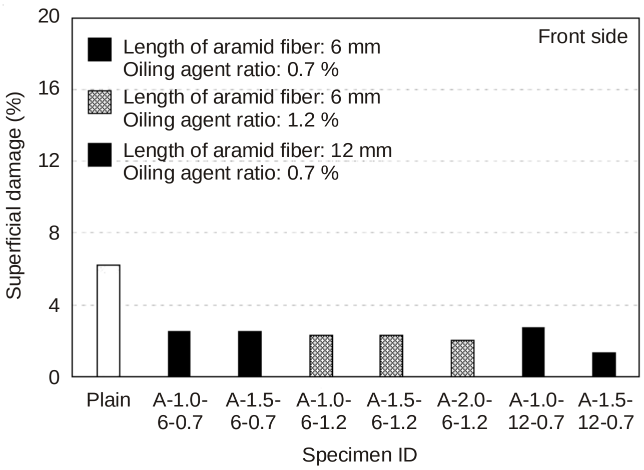

Fig. 5. Superficial damage in the front side

In addition, the impact resistance of the aramid fiber reinforced cement composites was improved as volume ratio and length of the fibers increased under the same conditions with oiling agent ratio.

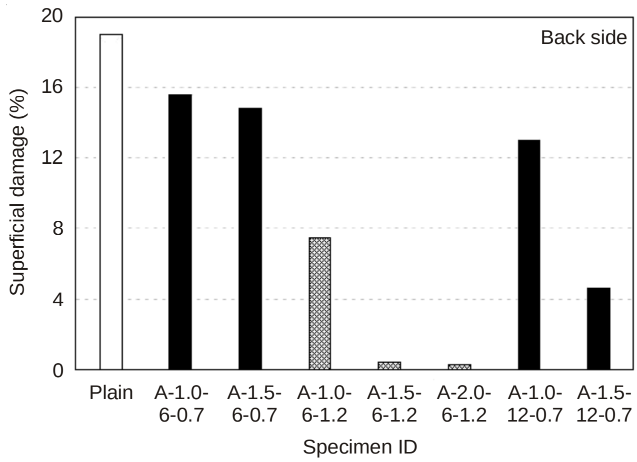

Fig. 6. Superficial damage in the back side

Depth of cratering and scabbing: Figs. 7 and 8 indicate the depth of cratering and scabbing for plain specimen and aramid fiber reinforced cement composites. The depth of cratering of the plain specimen was less than that of the aramid fiber reinforced cement composites, but the depth of scabbing of the plain specimen was about twice as much more than that of the aramid fiber reinforced cement composites. This results from that the point where scabbing occurs is moved to the back side of the specimen due to reinforcement of the aramid fiber. These result can be analyzed that the crack range causes scabbing decreased and thereby the aramid fibers have contributed to reduce the disruption that occurs on the back side. It was found that distributing fiber equally by oily treatment within the cement composite is effective for reducing scabbing rather than the effect of length.

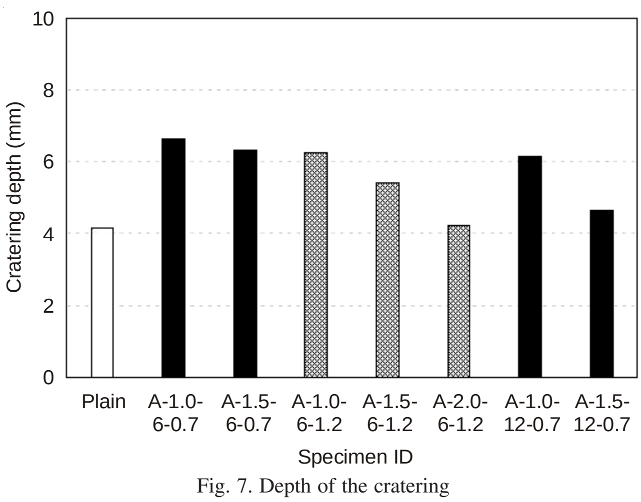

Fig. 7. Depth of the cratering

Ratio of mass loss: Fig. 9 shows the ratio of mass loss the specimens after impact tests. As the results of the impact test, the mass loss ratio of the Plain specimen was the highest as 7.54 % and that of the aramid fiber reinforced cement composites was measured as 0.94 to 3.79 %. The mass loss according to high velocity projectile impact depended on the fracture on the back side rather than the front side. It is considered that the improvement in tensile strength and flexural strength by reinforcing cement composites with the aramid fiber is related to reduction of fracture on the back side. In

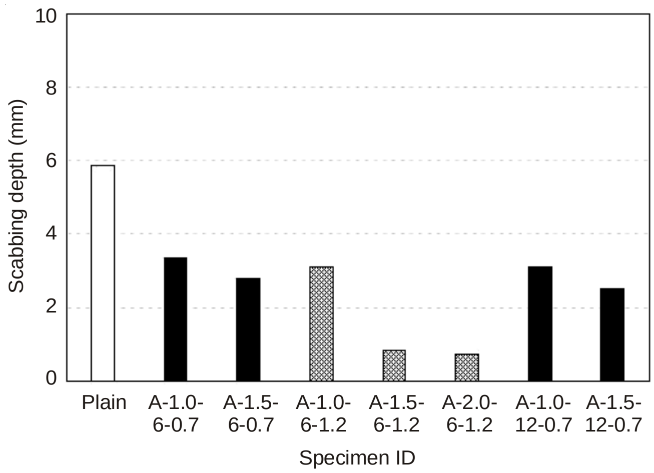

Fig. 8. Depth of the scabbing

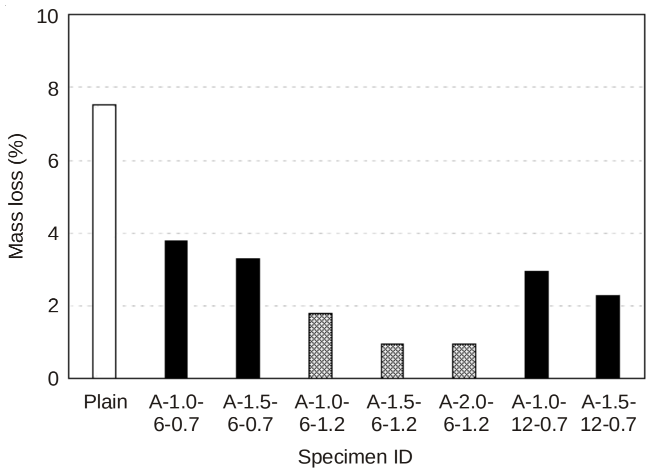

Fig. 9. Ratio of mass loss of the specimens after impact tests

particular, while the length and the volume ratio of fiber have an effect to the impact resistance, it is important to improve the surface property to distribute fiber equally for raising effectiveness. In this study, we examined the impact resistance of the aramid fiber reinforced cement composites and suggested the properties of fiber for improving impact resistance.

Conclusions

• We identified that the workability of the fresh cement composite was irrelevant to the volume ratio of fiber and that the aramid fiber of 6 mm and oiling agent ratio of 1.2 % was appropriate. The amount of the high range water reducer (HRWR) was also reduced.

• The mixing efficiency of aramid fiber reinforced cement composites was improved according to increasing of oiling agent ratio of fiber surface. In addition, this result affected impro-vement in the impact resistance.

• Increasing of fiber volume ratio was affected to the improvement of mechanical deformability in the aramid fiber reinforced cement composites. It was also found that increasing the length and volume ratio of mixed fibers can result in the increase of resistance for scabbing.

• The tensile and flexural performance exhibited the high effectiveness on the impact resistance of aramid fiber reinforced cement composites as compared with compressive strength. Based on the above discussion, if the volume ratio increases in high workability condition, the damage of matrix caused by high velocity impact will be reduced due to improvement in attachment efficiency between fiber and matrix.

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