Journal of Ceramic Processing Research. Vol. 16, Special. 1, pp. s50~s55 (2015)

JOURNAL OF
Ceramic
Processing Research

Crack repair effects of injection method using organic/inorganic composite materials

Kyoung-Min Kim[a], Tae-Ho Ahn[b]*, Kwang-Bo Shim[b], Sin-Young Bang[c], Jun-Hui Park[c] and Kwang-Ho Sho[d]

[a]*Technology Development Team, Daewoo Institute of Construction Technology, Republic of Korea*
[b]*International Sustainable Engineering Materials (ISEM) Center, Ceramic Materials Institute & Division of Advanced Materials Sci. Eng., Hanyang University, Seoul 133-791, Korea*
[c]*SERIC R&D Center, SERIC Co., Ltd., 521, HIT, 222 Wangsimni-ro, Seongdong-gu, Seoul 133-791 Korea*
[d]*Department of Architectural Engineering, Wonkwang University, 460 iksan-si, Jeonbuk 570-749, Korea*

In this research, properties of new crack repair materials using organic and inorganic composite (OAI) materials were investigated under various crack conditions. Especially, this study aims to develop new composites repair materials as needed to follow the crack and its repair method. Crack repair methods such as injection method and surface treatment repair method using self-healing capability for the practical industrial application were examined in comparison with normal crack repair method as the epoxy injection. From these results, it was confirmed that the sealing and injection effects through the cracks from field tests could be improved by OAI.

Kew words: crack, organic/inorganic composites, injection method, repair, self-healing.

Introduction

In general, concrete is perceived as a construction material of excellent durability, but due to various reasons, cracks occur in concrete structures. Infiltration of CO_2, chloride, and sulfate due to occurrence of concrete crack becomes a cause for large decrease in durability of concrete structure [1]. To repair the cracks affecting the durability performance of a concrete structure, organic repair materials of epoxy and urethane types are usually used. However, because organic repair materials basically have different material characteristics than the base concrete, economic loss occurs due to increase of repair cost when performing a repair that does not require a high performance, i.e., more bond strength than necessary. Furthermore, in wet cracks and water-leakage cracks, the durability decreases rapidly within 1-2 years after repair from reoccurrence of cracks due to hydrolysis, the need for repairing again becomes higher [2,3]. Hence, recently, there has been increasing interest in domestic and internationally on crack repairing methods using new types of organic/inorganic composite materials or 100% inorganic materials to supplement the disadvantages of organic/inorganic materials [4]. Accordingly, by mixing a small amount of organic type with excellent performance in an inexpensive inorganic type, a new economical and effective organic/inorganic composite material will be developed, which can be applied to wet cracks and water-leakage cracks as well as dry cracks while maintaining a certain level of performance as a repair material; and its applicability in actual field and performance will be examined.

*Corresponding author:
Tel : +82-2-891-5380
Fax: +82-2-891-5381
E-mail: thahn@hanyang.ac.kr

Experimental

Raw materials

The inorganic powder used in this study is a new inorganic powder based on the micro cement considering economic efficiency, workability, and durability, and its physical and chemical properties were are in Table 1.

The organic materials used in this study are two liquid types: Type A is a white liquid obtained by diluting in water the mixture of epichlorohydrin-bisphenol type resin, which is based on bisphenol resin, and propylene glycol methyl ether, at a certain ratio and Type B is a yellow liquid obtained by diluting in water the mixture of the denaturalize aliphatic polyamine at a certain ratio on the basis of denaturalize polyamide amine, and it is used in a concept of hardener.

Organic/Inorganic Composites

The organic/inorganic composite used in this study was developed by mixing the developed inorganic powder and two liquid - type organic materials, and the mixing ratios were derived through a preliminary

Table 1. Characteristics of inorganic powders.

Size (μm)	Density (g/cm^3)	Chemical Composition (%)				
		SiO_2	Al_2O_3	CaO	MgO	SO_3
2.8 ~ 10	2.97	28.9	12.4	48.1	5.0	2.3

experiment. Inorganic powder was around 60% of matrix, two liquids were around 40% of matrix. Fig. 1 shows organic and inorganic composite materials in this research

Injection method of repair materials

For the injection depth performance evaluation in this study, the experiment was carried out by dividing it into micro crack injection, applicability of crack with existence of water, and water permeability after injection. For the injection performance evaluation at a micro crack, a acryl panel (simulated crack of 0.2 mm) was fabricated and the injection phenomenon and injection depth were evaluated for the inorganic and organic/inorganic composite repair materials. In Fig. 2(a) and (b), the simulated cracks were fabricated by using an acryl panel, and the crack width was assumed to be 0.2 mm to set up an extreme environment when injecting. Also, the organic/inorganic composite was injected by using a portable injection device that can be easily obtained in the field, as shown in Fig. 2(c). The goal of experiment was to examine the injection phenomenon along with the crack injection depth while injecting the developed material by using the fabricated acryl panel. The slump, bond strength, and compressive strength tests were conducted according to the Korean Industrial Standards (KS), and after the mock-up test, the constructability was evaluated by injecting the product in the on-site wall cracks.

Injection Apparatus

In this study, the injection performance was evaluated by mainly using two types of injection plugs and two types of injectors, as shown in Fig. 3. Furthermore, by designing the injectors to be compatible with the syringe type injection plugs and high pressure injection type plugs used much in South Korea, the convenience of the injectors was improved since a separate dedicated plug was not necessary.

Although it can be changed and used according to the conventional plug and use, the plug developed to be suitable for organic/inorganic materials was designed considering the characteristics of organic/inorganic composite crack injection material. Since it can be

Fig. 1. Raw materials of organic and inorganic composites.

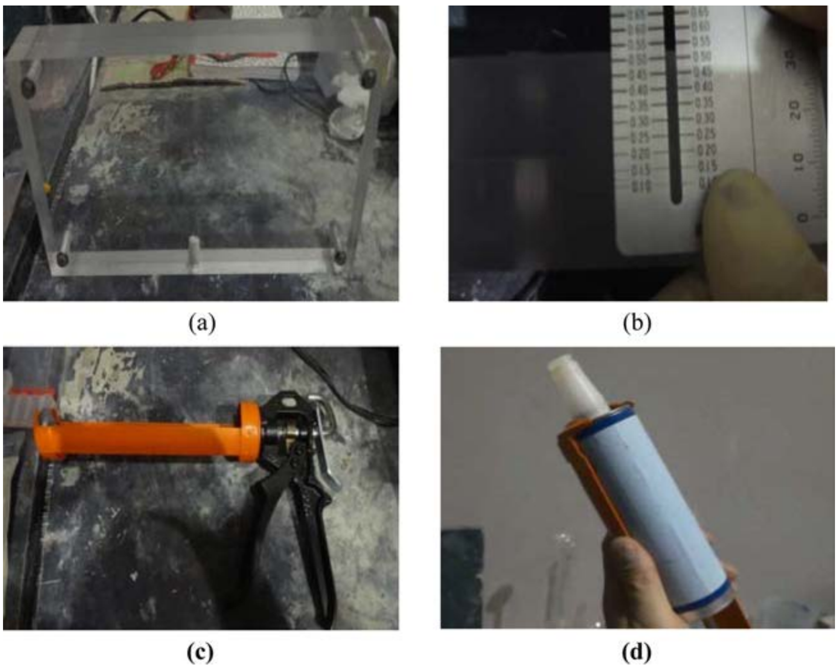

Fig. 2. Injection equipment of composite repair materials for indoor test (a) Artificial crack on acryl panels (b) Checking width of crack by scale bar (0.2 mm) (c) Injection equipment of organic/inorganic composite (d) injection cylinder.

(a) (b) (c)

Fig. 3. Various injection plugs (a-b) and simple injectors (c).

controlled to use only the required amount at a crack, it is economical, and since it is not a dedicated plug that has to be absolutely used, the conventional plugs and developed plugs can be freely selected according to the user and surrounding environment conditions.

Results and Discussion

For the slump of the organic/inorganic composite material, the fluidity was checked through a mini-slump test. As a result, the slump result of 130 mm was obtained, as shown in Fig. 4. It was determined to be sufficiently injected inside a crack with the required viscosity of the injection material, and injection would be possible in the crack even at a low pressure. Fig. 5 shows the inorganic type and organic/inorganic composite injected in the acryl panel.

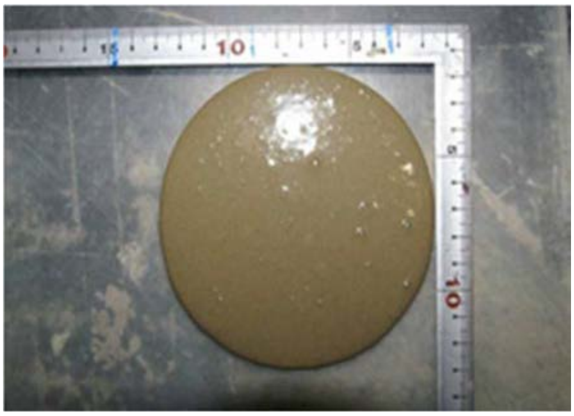

Fig. 4. Mini slump result of organic and inorganic composite repair materials.

Table 2 shows the result of comparing the injection depth and fluidity between the developed inorganic type and organic/inorganic composite, and the inorganic type penetrated about 5 cm in a straight line from the injection place of the surface crack. Also, in the case of organic/inorganic composite, about 20 cm was penetrated in an oval shape from the injection place of surface crack, and there was no material separation. Fig. 5 shows the injection depth and propensity test.

The bond strength of organic/inorganic composite was 4.8 MPa and its performance satisfied the KS criteria and showed high tendency compared to the common inorganic injection materials. However, it showed a lower tendency compared to the organic type while showing a performance between that of inorganic injection material and that of organic injection material, so it was determined that a certain level of integration with the base concrete would be possible.

Table 2. Comparison between depth and shape of injection.

	Injection depth (cm)	Distributed shape
Inorganic	5	Straight
Organic and inorganic composites	20	Oval

(a) (b)

Fig. 5. Injection depth and Shaped test. (a) injection performance of inorganic materials, (b) injection performance of organic and inorganic composite.

Table 3. Physical properties of organic/inorganic composite materials.

	7 days	28 days
Compressive strength	16.9 MPa	28.8 MPa
Tensile strength	-	2.9

Fig. 6. Core samples from cracked concrete after injection of organic/inorganic composites.

The epichlorohydrin-bisphenol a resin belonging to thermosetting resin is a polymer, and since it solidifies hard as heat is applied, it does not deform even when a large force is applied. Moreover, because it has chemical resistance and insulating property, it is mainly used an adhesive. Also, because it has a property that is mainly used in paints and coating materials, it can increase the adhesive strength of the organic/inorganic composite crack injection material, confirming its improved performance compared to that of an inorganic crack injection material.

The compressive strengths of common organic types range usually 50-60 MPa and those of inorganic types (polymer cement type) range 20-40 MPa, and although there are some difference between companies, the strength of an inorganic crack injection material is shown to be relatively higher than that of an organic type. However, in the case of crack injection materials, high strength is not required for repairs, and since a role of crack repair material can be performed as long as an appropriate strength is maintained for the crack in the existing base concrete, the performance as crack injection material can be affirmed if at least a similar degree of strength as the inorganic injection material is maintained. Accordingly, the 28 day compressive strength of organic/inorganic composite was 28.8 MPa as shown in Table 3. i.e., a compressive strength at a level of inorganic type was displayed. Also, because the organic/inorganic composite crack injection material formed in the early age adhered to the interface of the base concrete, it maintained its strength and performed similar to a conventional inorganic type, showing its stability as a crack repair material.

Furthermore, Fig. 6 shows a core collected at the location of injection in a field mock-up test, and the 28 days aging compressive strength was about 30-35 MPa, a trend similar to the compressive strength measured in a general laboratory. When examined with naked eyes, the integration of base concrete and injection material was confirmed.

Fig. 7. shows the injection process of organic/inorganic composite materials in the concrete specimens. The core was collected after the organic/inorganic composite materials using crack injector. As a result, it was confirmed that injection was performed to the end of crack with the same fluidity performance as a conventional organic repair material.

For the performance evaluation of the organic/ inorganic composite injection material developed in this study, a field application evaluation was conducted using the same method used for the conventional epoxy injection method at an actual exposed concrete crack, as shown in Fig. 8. For the injector and packer, a specially fabricated injector was used, and the crack was sealed with epoxy and hardener, and it was made sure the injected liquid did not flow out. Afterwards, the repair material was injected in the crack with the injector. One day after the injection, after removing the packer and sealing around the injection location, the injection location was exposed in atmosphere for 28 days and the progress was observed. It was confirmed that the material injected in the 0.3 mm crack was completely filled through the concrete cleavability specimen and mock-up test's concrete core specimen.

Fig. 9 shows the organic/inorganic composite core collected from the construction site, and as a result of

Fig. 7. Injection test of organic and inorganic composite materials on the cracked specimens

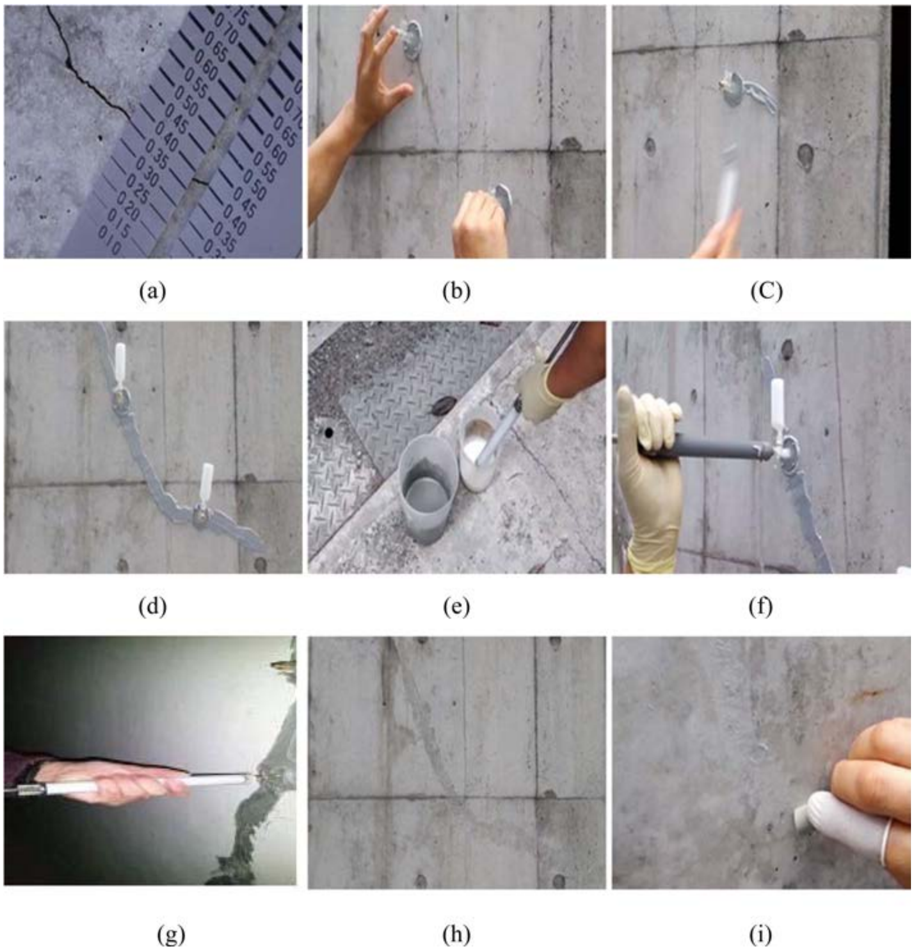

Fig. 8. Field tests the foreground and construction order. (a) Check cracks, (b) plug installation, (C) crack sealing operations, (d) complete plug operation, (e) preparing injection materials, (g) organic and Inorganic composite injection, (h) completed construction (1 day after), (i) surface finish. Also, when the rough surface of the sealant and plug part were finished simply with a crack repair stick material having crack self-healing agents developed with the surface finishing method of Fig. 8(i). The appearance of crack following injection can be finished cleanly, confirming the possibility of an effective smart repair method system.

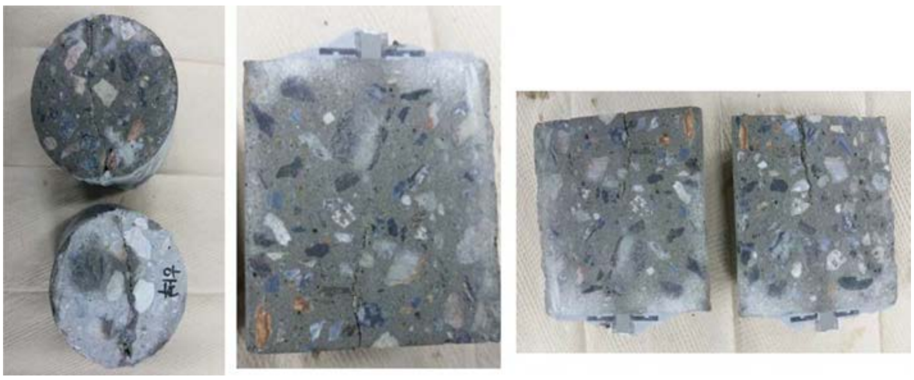

Fig. 9. Split Section of Core samples from construction site after the injection process.

checking the core crack, it was confirmed that repair is possible even to a tiny part (below 0.25 mm) of a crack. Also, this study was conducted in such a way that more economic efficiency can be ensured compared to the organic type through development of new type of organic/inorganic composite, which maintains the advantages of conventional crack injection materials and reduces the disadvantages: the workability was improved compared to common an inorganic type, the durability performance was similar to that of an inorganic type, and the injection depth and propensity displayed an effect equal to the advantage of an organic type.

Conclusions

In this study for development of repair material for cracks in concrete structures, a crack repair material was developed by mixing bisphenol A and polyamide-based organic and inorganic composite materials, and along with the aim to improve the usability and economic efficiency, the strength properties and durability properties of the repair material were analyzed in comparison with the organic type and inorganic type, and as a result of examining its potential, the following results were derived.

1. Through the injection performance evaluation of the organic/inorganic composite, it is determined, from the injection depth and fluidity tendency similar to those of an organic type, that the crack depth and adhesion performance can be improved at a crack, which was disadvantage of a conventional inorganic type.

2. The bond strength was lower than that of an organic type, but owing to its higher bond strength compared to the reference value, it is determined that it is economically better than the conventional organic type since only a necessary performance is provided, and can be integrated with base concrete and improve upon the conventional disadvantages through its higher adhesion than the conventional inorganic type.

3. The compressive strength was lower than that of the organic type, but since it was higher or similar to that of the inorganic type, it was able to provide the required strength, confirming its improved performance compared to the conventional inorganic type.

In summary, with the injection tendency and depth performance at a level of the organic type, and the adhesion performance, integration with base concrete, and compressive strength at the levels of the inorganic type, respectively, the organic/inorganic composite supplemented the disadvantages of the organic type and the inorganic type, securing economic efficiency as a more economic repair material than the conventional organic type.

Acknowledgments

The authors would like to thank the Daewoo Institute of Construction Technology for Daewoo E&C Co., Ltd., the research project “Development of smart repair systems” for financially supporting this work.

References

1. V.C. Li, M Lepech, “Crack resistant concrete material for transportation construction” Transportation Research Board Conf. (2004).
2. T.H. Ahn, S.Y. Bang, K.M. Kim, K.H. Sho, the Korea Institute of Building Construction, 15[1] (2015) 228-229.
3. T.H. Ahn, S.Y. Bang, K.B. Shim, Proceedings of the Korea Concrete Institute 27[1] (2015) 247-248.
4. T.H. Ahn, T. Kishi Journal of Ceramic Processing Research 16[1] (2015) 117-123.