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A study on application of healing performance of silica sand

Hong Gi. Kim, Jae Seok. Ryou , Yong Soo. Lee, Sang Won. Ha.

Abstract— The experiment, which is to evaluate crack-filling efficiency by self-healing when cracks occur by the external impact and internal stress, was conducted in this study. The crack-filling can be achieved by silica sand, which was applied self-healing ingredient. Therefore, recovery of crack was evaluated because it was verified feasible of silica sand, which was applied self-healing ingredient. As a result, when self-healing ingredient of silica sand surface reacts with water, it was verified that recovery of crack was achieved via silica sand, which was applied self-healing ingredient. Based on the results, it may be applied construction structure after various durability tests and analysis. Also, the repair mortar may be applied.

Keywords; self-healing, silica sand, coating, water soluble film, mineral materials

1. Introduction

Concrete structures have many severe problems due to deteriorations, such as crack of concrete, corrosion of steel and poor construction or as time advanced. Cracks, which are inevitable in concrete structures, lead to severe problems such as decline of durability and serviceability.

Hong Gi, Kim, Department of Civil Engineering
Hanyang University
Republic of Korea

Jae Seok, Ryou, Department of Civil Engineering
Hanyang University, Professor
Republic of Korea

Yong soo, Lee, Department of Civil Engineering
Hanyang University
Republic of Korea

Sang won, Ha, Department of Civil Engineering
Hanyang University
Republic of Korea

Many infrastructures, such as highway, tunnel, bridge etc. are necessary to repair and maintenance which are difficult and raise additional cost.

Also, maintenance period is never enough since ingredient of maintenance materials cannot unitize surface ingredient in crack at existing structure perfectly. Therefore, materials and methods are desirable to be developed in order to improve the durability of concrete structure. Many researchers have been studied Self-healing concrete and mechanism recently. Self-healing phenomena in cementitious materials has been noticed by the French Academy of Science in 1836 already [1]. Based on substantial experiment studies, it is possible to apply self-healing technique in concrete structure due to the combination of complicated chemical and physical processes [2]. Mainly, crack in concrete structure occurs along the surface of aggregate which known as ITZ(Interfacial Transition Zone). In this study, in order to improve the surface of aggregate which affects to the crack formation, coating with self-healing ingredients were applied. Also, following factors were considered;

1) In concrete mixing, coated aggregate should not react with water
2) After crack is generated, coated agent on aggregate surface should react with water which introduced into crack gap.

Therefore, when self-healing ingredient of fine aggregate surface reacts with water, it was verified that recovery of crack was achieved by coated fine aggregate.

2. Materials and Experiments

2.1. PVA film coating on silica sand surface with self-healing materials

In this study, in order to compare the self-healing performance of cementitious composite with various compositions of mineral admixture, such as expansive and geo-materials were used [3]. Based on self-healing capabilities are as shown in Fig. . The expensive agent and two geo-materials were used which are commercial products produced in Japan and USA.

The content of expansive material is indicated in table. 1. The geo-materials that used as swelling materials are mainly caused by the swelling of montmorillonite which is a swelling clay mineral [3]. Also, in order to coat the silica sand with self-healing ingredient, polymer and water soluble film were used [4]. It is necessary to prevent the reaction of self-healing ingredient which is coated on surface of silica sand with water when mixing concrete. Silica sand which size is between 0.7 to 1.2mm was selected because of the particle size in order to maintain coating thickness. Before coating the silica sand, it was sifted by sieve to remove the impurities and to maintain consistent particle size. The coating method is as follows (Fig. 1.);

(1) Diluted water and water soluble polymer within ratio of 5:5 were sprayed to the prepared silica sand surface.

(2) Prepared self-healing ingredients which are composed by expansive and swelling materials are sprinkled to the surface of pre-mixed silica sand.

(3) After above working procedure, water soluble film were sprayed as a coating material which is intended to prevent reaction of self-healing ingredients during concrete mixing process.

(4) When coating silica sand by water soluble film, heat was introduced to attach films on surface of silica sand.

(5) An additional 'spraying water soluble film, heat introduction' procedure were conducted in order to assure preventing unintended reaction during concrete mixing.

2.2 preparing specimens

All mortar specimens were manufactured 40x40x160mm prism and were used for all the analyses in this study. The w/c ratio = 0.5 and with a cement to sand ratio = 1:3 were manufactured according to ISO 697. All mortar mixture are indicated in table 2. In mortar mixture, healing agents were added to 1, 2.5, 5, 7.5, 10 % to cement ratio respectively. It was due to previous study that adding more than 10% to the cement ratio might occurs over expansion [4]. MD2 – MD6 specimens were prepared with different portion of healing agent in order to compare self-healing behavior except MD1 since it was manufactured as a control. After prepared specimens were removed in 24 hr, they were cured for 28days in chamber which is capable to retain constant humidity with temperature, and then cracks of specimens, which were introduced by three point bending test machine, were below 0.3mm. Acryl box were manufactured as a container to fill water above to crack surface and interact surface between acryl box and specimens were sealed with epoxy to prevent water-leakage to observe reaction of healing agent with water on crack surface.

2.3 Evaluation of self-healing efficiency

In order to investigate surface of specimens, microscope were used in x160 magnification. Since healing behavior of water cured specimens will fill internal pores inside of mortars with coated sand, relative dynamic modulus of elasticity were measured with normal mortar specimen in time elapse. Equation of relative dynamic modulus were used as refer to previous study by Lee. [4]

$$P_c = \left[\frac{{n_c}^2}{{n_0}^2}\right] \times 100$$

[1]

Where Pc is the relative dynamic modulus of elasticity depending on elapsed time (%), is the 1st horizontal vibration before introduction of crack, and is the horizontal vibration frequency after introduction of crack depending on the elapsed time.

As healing of crack surface occurs, water passing rate will be changed in normal mortar and mortar with coated aggregates. Since water permeability were expected to be decreased in mortar containing healing agent with crack closure, water permeability test were performed to verify healing behavior with time elapse regularly. In order to calculate water permeability, used equation is as follows [5];

$$k = \frac{aL}{At} \ln\left(\frac{h_1}{h_2}\right)$$

[2]

Where is water permeability coefficient (cm/s), is the cross sectional area of the pipette (cm²), L is the specimen thickness (cm), A is the cross sectional area of the specimen (cm²), t is the time (s), are the initial and final water heads (cm)

3. Results and Discussion

3.1 result of observation by microscope

All specimens that including coated silica sand with self-healing ingredient and general specimen were introduced a crack (less than 0.3mm) to observe the surface of specimens. The observation on surface of specimens have been studied for 1, 7, 24 day respectively. As a result, no changes were found in 1 day, however, surface of specimens presented self-healing phenomenon with time elapse. Meanwhile, in case of general specimens were not emerged in self-healing phenomenon. It is showed that crystalline were formed in general specimen after dried. Crystalline are expected to be CaCO3 , because this crystalline formed by reaction of leached Ca(OH)2 with the CO2 in the air on surface of specimen.
Specimens that containing coated silica sand with self-healing ingredient were not changed at initial stage. However, it is possible to confirm the recovery of crack of surface on specimens after 7 days. This phenomenon indicates that coated silica sand reacted with water due to melting of water soluble film coated on silica sand. As a result, crack remained on general specimen but crack on specimens that containing coated silica sand with self-healing ingredient was narrowed. It is expected due to formed ettringite by reaction of self-healing ingredient with water in crack. This phenomenon indicates that these products are sensitive to the pH condition and the water soluability. Result of this observation is shown as Fig. 3.

3.2 evaluation of self-healing using dynamic modulus of elasticity compared to existing specimens

In order to evaluate healing on crack surface, relative dynamic modulus was measured in accordance with time elapse in before and after introducing crack. As shown in Fig.4, which presents change according to different portion of healing agent, it was found that change of dynamic modulus of elasticity after crack introduced in initial stage at MD-1(prepared as a control) was not occurred with the time elapse. Meanwhile, other specimens coated with healing agent were measured almost 80% in relative dynamic modulus of elasticity as time elapse within 3days and almost increased up to 98% at 24days respectively. Also, specimen with 10% addition of healing agent was considered to be preferable. Result shows that higher proportion of healing agent which is coated on aggregate surface reveals higher value compare to lower proportions. However, it should be noticed that proper mixing rate of healing agent is desired since coating with excessive rate of healing agent may cause over expansion. It was observed that coated aggregate with healing agent is capable to reveal self-healing behavior under water supply, therefore, durability were restored.

3.3 permeability test

One of the important properties of self-healing is preventing water leakage. When crack occurs on concrete structure, durability and serviceability of infrastructures decreases due to water leakage. Therefore, in order to evaluate the self-healing performance, suitable water permeability is necessary to confirm the rate of water leakage quantity. The range of water permeability coefficient of all specimens is 1.4-2.0 x 10 (cm/s) after the introduction of crack as shown in Fig.5. In case of MD-1(general specimen), initial value was 2.0 and decreased during 7 days after crack induced, but it was not changed from 7days to 14 days. Also values in other specimens except MD-6 were decreased regularly which did not show a large difference. In particular, in case of MD-2 was not changed compare to MD-1(general specimens). However, in case of MD-6, it was decreased 59% to compare with initial value after 5 days and finally decreased 94% after 24 days. This result indicates that it is related to content of coated silica sand with self-healing ingredient. Therefore, the specimen of MD-6 is more reactive than other specimens because MD-6 contained as much amount as to fill crack according to self-healing performance with water. As a result, possibility of crack closure was verified through the autonomic healing of coated silica sand with self-healing ingredient.

4. Conclusion

In this study, in order to evaluate the self-healing performance of specimens that containing coated silica sand with self-healing ingredient was studied and verified. The efficiency of autonomic healing by healing agent that coated on silica sand by using mineral materials and organic materials was evaluated and demonstrated in terms of various experiments. The conclusions were arrived as follows;

i. According to result, specimens that containing 1 0 % coated silica sand revealed complete crack closing within 24 days because of formed ettrin gite by reacting self-healing ingredient with wate r in crack. It was observed via microscopy inve stigation.

ii. In the result of relative dynamic modulus of ela sticity shows that higher proportion of healing a gent which is coated on aggregate surface reveal

s higher value compare to lower proportions. Ho wever, it should be noticed that proper mixing r ate of healing agent is desirable since coating w ith excessive rate of healing agent may cause o ver expansion. It was observed that coated aggre gate with healing agent is capable to reveal self -healing behavior under water supply, therefore, durability were restored.

iii. From the water permeability results, the value o f MD-6(contain 10% coated silica sand) specime n was decreased about 59% to compare with ini tial value after 5 days and finally decreased up to 94% after 24 days. Therefore, possibility of c rack closing was verified through the autonomic healing of coated silica sand with self-healing i ngredient.

As a result, it was verified that the possibility of autonomic healing is capable by using mineral and organic materials. Also, it was verified that durability was improved by preventing water leakage. Finally, a further study that will need to verify a product via analysis using instrument, such as SEM and XRD is desirable.

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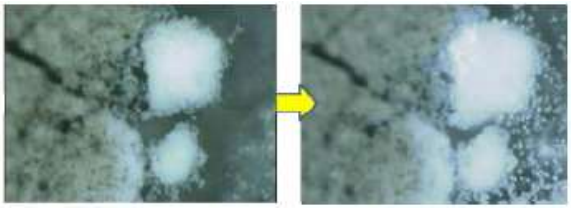
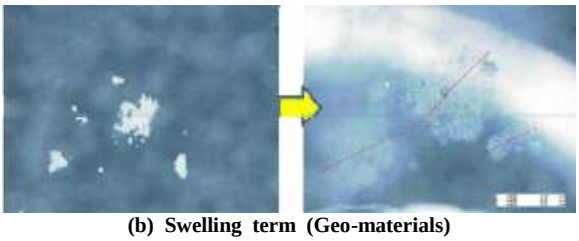
[5] ; Van Tittelboom, Kim, et al. "Self-healing efficiency of cementitious materials containing tubular capsules filled with healing agent." *Cement and Concrete Composites* 33.4 (2011): 497-505.



(a) Expansion term (Expansive agent



(b) Swelling term (Geo-materials)

Fig. 1. Design of cementitous composite materials with self-healing capability [3].

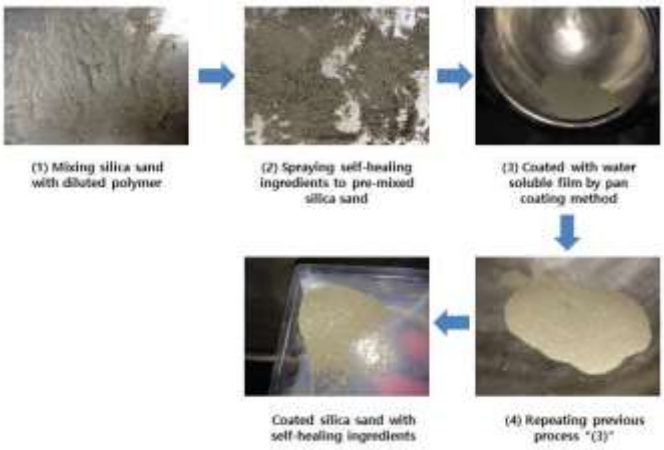
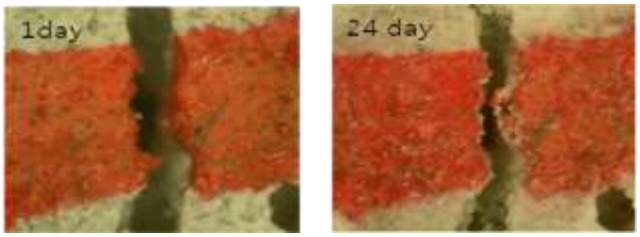
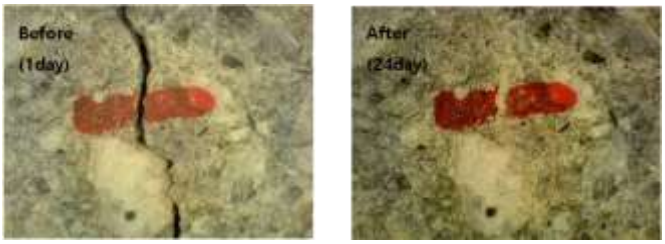


Fig.2. The method of coating and using materials.



(a) general specimen



(b) specimen that containing coated silica sand with self-healing ingredient

Fig. 3. Observation of crack closing due to self-healing performance using microscope : (a) general specimen and (b) specimen that containing coated silica sand with self-healing ingredient.

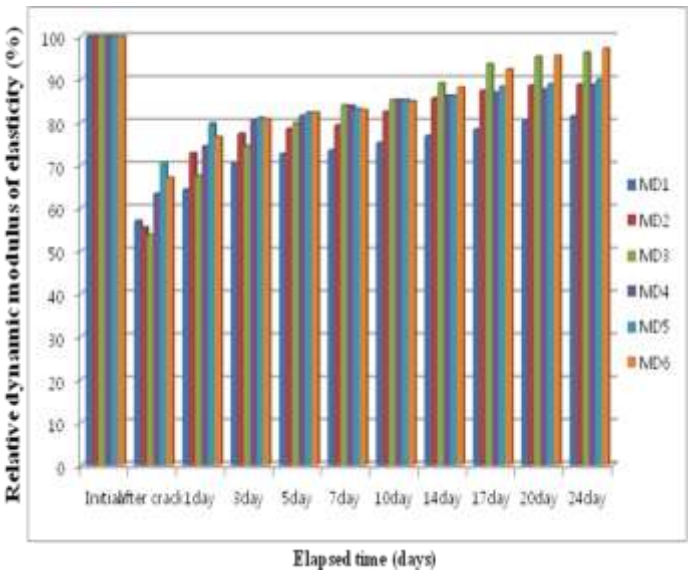


Fig. 4. Relative dynamic modulus of elasticity according to different portion of healing agent.

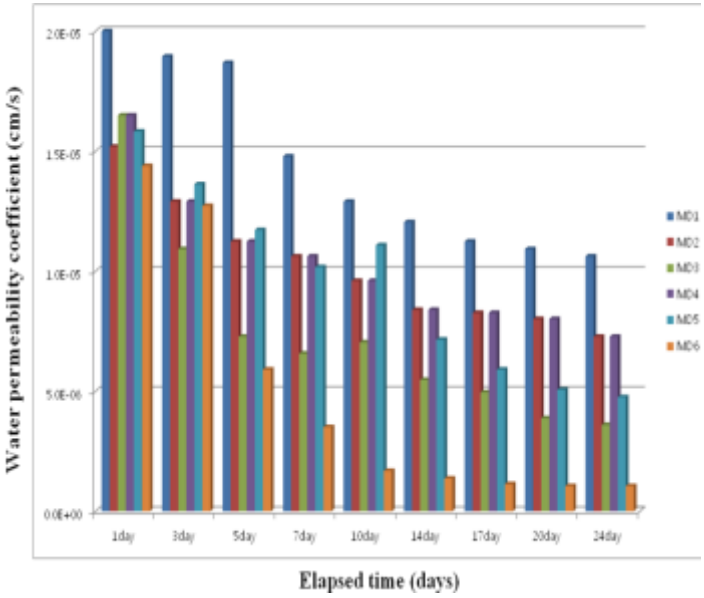


Fig. 5. shown the result. This result indicated that the range of water permeability of all specimens is 1.4-2.0 x 10 (cm/s) after the introduction of crack.

Table 1. Contents of Expansive Materials

Specific Gravity	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	F-CaO
2.8~3.0	1~5	8~15	0.3~2	50~55	0.5~2	27~31	16.0

Table 2. Mix design of Test Specimens

Types	W/B(%)	Unit Weight(kg/m^3)				
		W	C	S1(#5)	S2(#6)	AD(%)
MD 1	**50.0**	**225**	**450**	**1080**	**270**	-
MD 2						**C × 1**
MD 3						**C × 2.5**
MD 4						**C × 5**
MD 5						**C × 7.5**
MD 6						**C × 10**

*** AD : Healing agent**