A-2-3 Effect of surface treatment materials on corrosion protection of concrete structures subjected to chloride attack: An experimental study

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ABSTRACT: The effects of surface protection method on improving the durability of concrete structures are studied. The focuses are placed on the types of surface treatment materials and initial state of concrete (with and without cracks). The specimens used in this research had been exposed to splash zone simulated by shower for 10 years before tests. After exposure, the impregnation depth of water repellent agents, the carbonation depth of concrete and the corrosion condition of steel rebars were measured to examine how the surface protection influenced the corrosion. It was seen that the effect of surface treatment on suppressing the carbonation of concrete was marginal but the corrosion prevention effect depends on the types of water repellent agent. Two types of water repellent agents with large impregnation depths were found to be highly effective in corrosion protection regardless of the existence of cracks in concrete.

KEY-WORDS: Surface treatment material, water repellent agent, concrete, exposure test, corrosion protection.

INTRODUCTION

Chloride attack is one of the major causes of deterioration of marine reinforced concrete structures (RC structures). It is known that deterioration factors associated with the chloride attack are water, oxygen and chloride ion. Thus, preventing the invasion of these factors is a reasonable approach to protect marine RC structures from chloride attack, so as to secure their long-term durability performance. There are two common approaches to achieve the above objective. One is to improve the performance of concrete and/or to increase the cover depth of concrete. The other is to protect the concrete from the penetration of deterioration factors by surface protection methods. In this research, we focused on the latter approach. Investigations were conducted to assess the resistance against chloride attack of marine RC structures that were applied with a water repellant agent and other surface improvement agents. Use of water repellant agents and other surface improvement agents can suppress the penetration of deterioration factors such as water and chloride ion from surrounding environments. It is also a cost-effective means due to the convenience in construction. However, the depths of impregnation of these agents differ depending on their types and the initial condition of concrete [1]. In addition, such differences possibly cause large variations in the degree of performance improvement. For a reliable application of these surface treatment materials in marine RC structures, the performance and different types of surface treatment materials as well as the variations of their performance need to be examined. In this study, long-term field exposure tests were conducted to investigate the durability performance of concrete impregnated by six different surface treatment materials [2].

EXPERIMENTAL OUTLINE

Specimens

The mix proportion of concrete used in this experiment is shown in Table 1. The raw materials used in concrete were ordinary Portland cement (density=3.14g/cm^3), sand from Oigawa river, Shizuoka Prefecture, Japan (surface dry density=2.59g/cm^3, water absorption rate=2.04%) as fine aggregate, and crushed sandstone from Oume in Tokyo (Gmax=20mm, water absorption rate=2.65g/cm^3) as coarse aggregate. The water to cement ratio was 0.68. Prism type specimens of 100*100*150mm were prepared (see Fig. 1). Two deformed steel bars with a diameter of 10 mm were embedded in the specimen with 45 mm and 17.5 mm thick concrete cover, respectively, from the two opposite sides of the specimens. The specimens were cured in the water for 28 days. After that, except the two exposure surfaces, all other four surfaces were coated with epoxy resins.

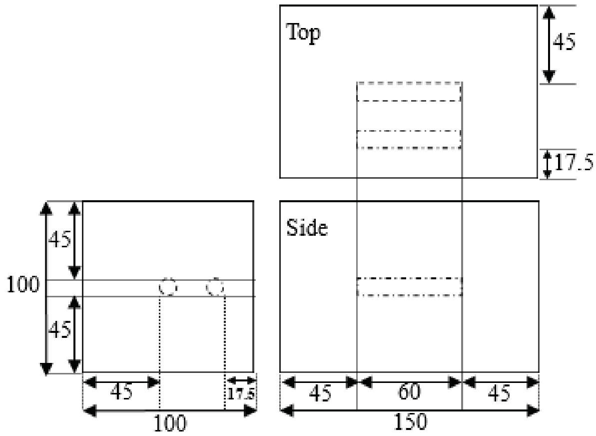

Fig.1. Specimen overview

Table 1 Mix proportion of concrete

G_{max} (%)	Slump (cm)	W/C (%)	Air (%)	s/a (%)	Unit amount (kg/m^3)				
					W	C	S	G	AE water reducing agent
20	12	68.0	4.0	49.0	165	243	912	970	0.608

Types of surface treatment materials used in this experiment is shown in Table 2. Four kinds of water repellant agents (A, liquid; B, cream; C, gel; D, liquid) and two kinds of surface improvement agents were used. It should be noted that the impregnation depth of water repellent agents is significantly influenced by the moisture content rate of concrete. In this study, concrete has been sufficiently dry before the implementation of water repellent agents. In general, the cream and gel types of water repellant agents have good resistance to liquid droplets and dryness and thus have high permeability. Surface improvement agents E and F are silicate type and acrylic silicate type, respectively. A brush was used to apply all the surface treatment materials. Afterwards, the specimens had been cured indoor at a constant temperature of 20 degree Celsius for two weeks. Specimens without any surface treatment were also prepared as reference.

Table 2 Types of surface treatment materials

	Type	Appearance	Components	
A	Silane	liquid	Silane resin Isopropyl alcohol Methanol	34-35% 45-50% 5-10%
B	Silane/Siloxane	cream	Alkylalkoxysilane Ethanol	N.A.
C	Silane/Siloxane	gel	Trietoxysilane Ethanol	90-% 1-5%
D	Siloxane	liquid	Silane/Siloxane-based Distilled liquid	60-100%
E	Silicate	liquid	Super silicate particle catalyst	30-60% 1-5%
F	Acrylic silicate	liquid	Emulsion	

Fig. 2 shows how the specimens were prepared. Three types of specimens were prepared. The first type had no crack. In the second type cracks were introduced through splitting tests before the surface treatment. In the third type cracks were introduced after the surface treatment. The surface moisture content was about 4.0% for specimens when the surface treatment materials were implemented.

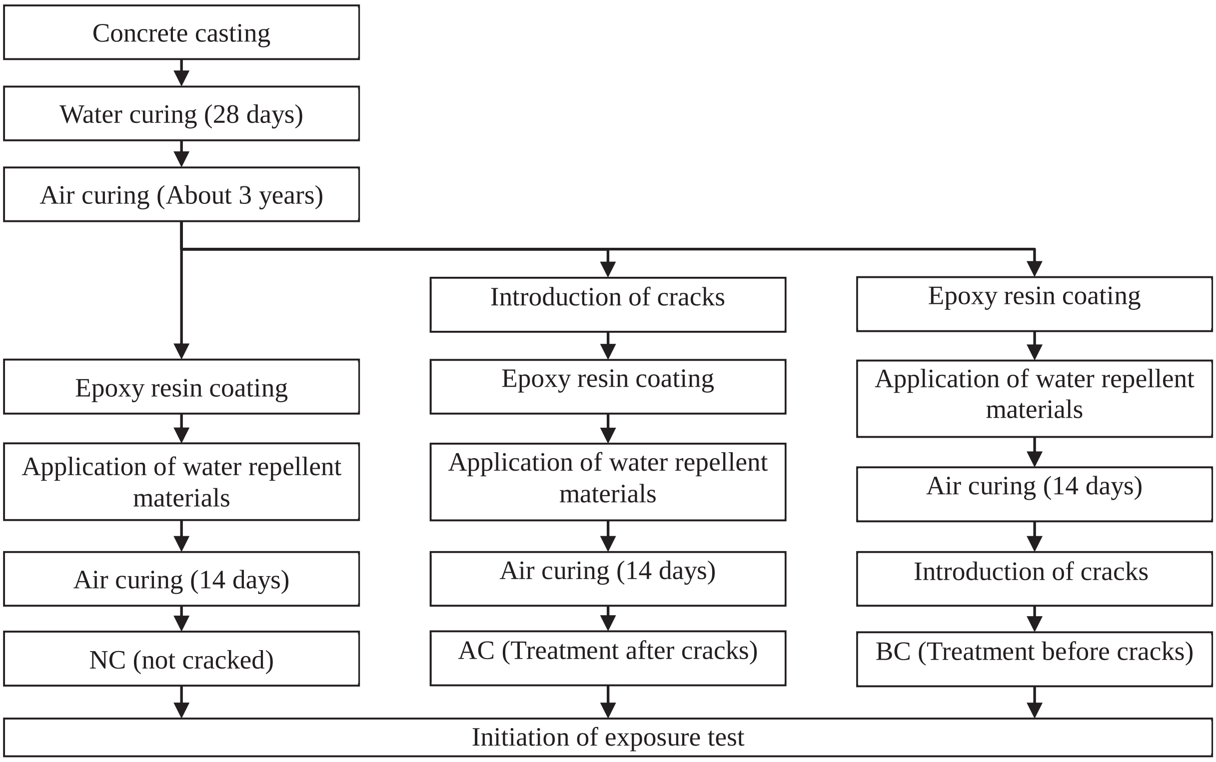

Fig.2. Procedures of specimens' preparation

Exposure test

All the specimens with the surface impregnated materials were exposed to simulated splash zone using seawater shower. This facility is located in the Kurihama bay (Yokosuka, Kanagawa prefecture, Japan) and has artificially repeated dry and wet cycles, that is, sea shower for about four hours and natural drying in the air for eight hours for each cycle (Fig.3). One day consisted of two cycles and the total exposure period was 10 years.

Fig.3. Exposure test facility

Measurement

The impregnation depth of different surface treatment materials, the depth of carbonation, and the corrosion of steel bars were observed after 10 years exposure.

Impregnation depth

After the exposure, the specimens were split and the impregnation depths at both un-cracked (sound surface) and cracked parts were measured by judging the water repellency range by spraying water against the split concrete surface. Five points were measured for the un-cracked locations and three points were measured for the cracked locations. The average of the measurements was used to define the depth of water repellency.

Carbonation depth
The carbonation depth of concrete was measured for the un-cracked and cracked locations in the same way as adopted for measuring the impregnation depth. Phenolphthalein solution was used for the measurement and the average of the measurements was used to define the carbonation depth.

Corrosion
The mass of corroded rebars was measured after the acid dissolution treatment. The mass difference between the virgin steel bars and corroded ones was defined as the corrosion weight loss. The corrosion weight loss ratio was calculated as the corrosion weight loss divided by the mass of virgin steel bars.

EXPERIMENTAL RESULT AND DISSCUSSION

Water repellency
Fig. 4 illustrates the result of the depth of water repellency of a sound concrete surface before and after the long-term exposure, while Fig. 5 illustrates the depth of water repellency of AC and BC specimens. The specimens treated with agents E and F, which were silicate-based surface treatment materials, do not hold water repellency. When the agents A, B, and C were treated to a sound concrete surface, the values of the impregnation depths before and after exposure were the same. In addition, the agent C (gel) achieved the largest penetration depth, and B (cream) performed better than A (liquid). On the other hand, the agent D just had 3 mm impregnation depth before exposure and such a water repellent layer got lost after ten years exposure. From these findings, it seems that the water repellants mixed with silane can provide better long-term water absorption prevention performance. However, the water repellants made of siloxane only may exhibit a declining performance in the long run.

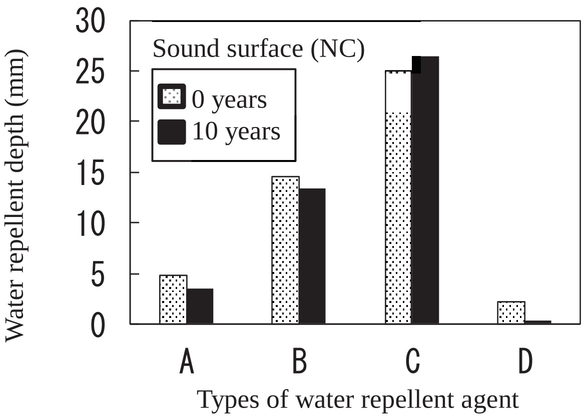

Fig.4. water repellent depth of NC specimens

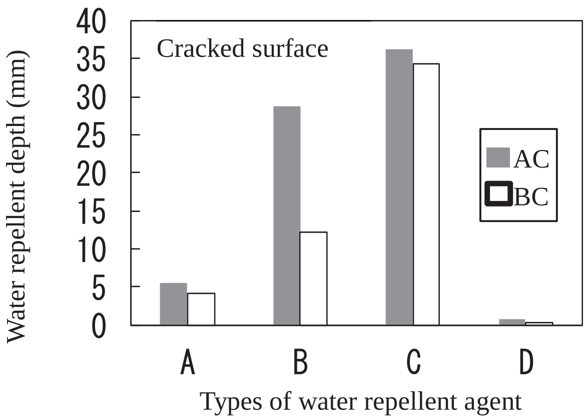

Fig.5. water repellent depth of AC&BC specimens

For cracked concrete specimens, the depths of water repellency were generally similar (Fig. 5) to those observed in non-cracked concrete specimens. However, the depth of water repellency of the specimen treated with the agent B after crack, was obviously larger than that of the specimen treated before crack. In addition, the agents B and C achieved similar water repellency depths in concrete treated after cracking. Similarly, in cracked specimens, C (gel) performed the best. The cream type B performed better than the liquid type A. D had poor long performance.

Carbonation
Fig. 6 shows the results of carbonation depth in the concrete. In the sound area, the carbonation resistance of those treated with a water repellant agents (in particular A and C), tended to be higher than that of non-treated ones, while silicate-based agents led to a slightly higher value of carbonation as compared to the reference (i.e., 0). In the cracked surfaces, the carbonation depth became significantly larger as compared to the reference. In the wet environments such as a splash zone, water ingress was prevented by the water repellent agent however the carbonation may be accelerated. Such a tendency even became more remarkable in case of cracked concrete. Such an influence should be considered during the design of repair. Overall all the surface impregnation materials used in present study could not be expected to suppress the carbonation of concrete.

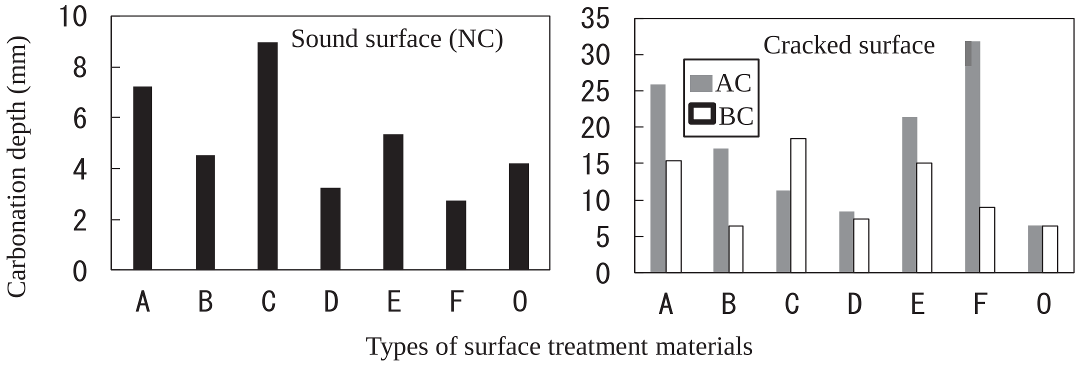

Fig.6. Carbonation depth

Corrosion

Fig. 7 shows the result of corrosion weight loss ratios of the internal steel rebars after the long-term exposure. The corrosion weight ratios of steel bars in the NC specimens treated with A, B and C were lower than the specimens without treatment regardless of thickness of cover depth of concrete. However, water repellent agent D did not have any corrosion protection effect. The corrosion prevention effect is thought to be directly correlated to the water repellency effect. On the other hand, for the silicate-based agents the weight loss of steel rebar located in the thin cover depth (i.e., 17.5 mm) was even higher compared to the reference case; the steel bar placed in the thick cover depth (i.e., 45 mm) achieved a certain level of corrosion protection effect compared to reference case. Overall, for sound concrete surface silane-based water repellant agent achieved a high level of corrosion protection and silicate-based material agents achieved a certain level of corrosion protection in case of thick cover depth.

For cracked concrete specimens (i.e., AC and BC), the weight loss of steel bars placed at the thin cover depth of specimens was all lower compared to the reference specimens regardless of the type of surface treatment materials and the statues of cracks. However, as for steel bars placed in the thick cover depth, only the agents B and C had noticeable effects on the corrosion prevention. This was due to that the agents B and C had high permeability, which succeeded in preventing the cracked surface from chloride attack. From the above, it seems that the water repellent agents B and C performed the best in terms of corrosion protection regardless of the existence of cracks.

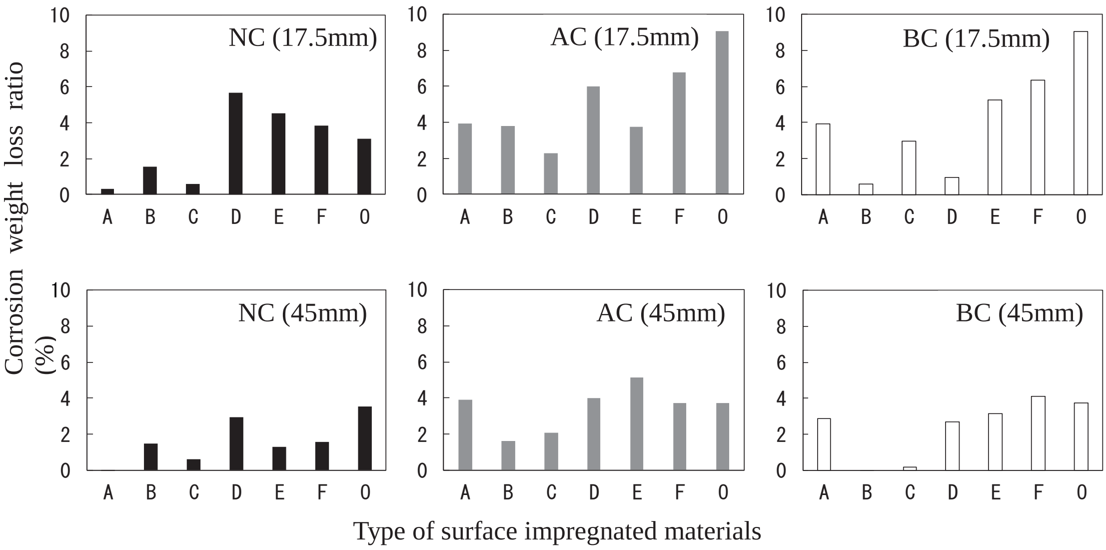

Fig.7. Corrosion *the number in () is cover depth

CONCLUSIONS

In this research project, a 10-year exposure test program was conducted to evaluate the long-term efficiency of applying different surface treatment materials for concrete with and without the existence of cracks in marine environments. It can be concluded from the investigations that all the surface treatment materials could hardly suppress the concrete carbonation. The effect in preventing the corrosion of the internal steel rebars depended highly on the surface treatment materials used. The gel and cream type water repellent agents performed the best in both cracked and un-cracked concrete due to their relatively high impregnation ability.

REFERENCES

[1] Y. AKIRA, J. G. DAI, E. KATO, H. YOKOTA. *Influence of Concrete Moisture Condition on Repair Performance of the Impregnating Materials,* Proceedings of the Japan Concrete Institute, 29(2007): 535-540 (in Japanese).

[2] J. G. DAI, Y. AKIRA, E. KATO, H. YOKOTA. *Investigation of Chloride Ingress in Cracked Concrete Treated with Water Repellent Agents,* Proceedigns of the 5th Int. Conf. on Water Repellent Treatment of Building Materials (Hydrophobe V), Aedificatio Publishers, (2008): 299-310.