I-2 Requirements for concrete protective coating materials considering concrete surface properties

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ABSTRACT: Concrete is widely used in construction because it is known as a high durable material. However, concrete structures exposed to various environmental conditions have a problem that results in deterioration of the structure due to harmful substances introduced from the outside. Various methods have been proposed to prevent corrosion of reinforcing steel in concrete, one of these methods is coating the surface of concrete. However, since the coating material was originally developed to prevent corrosion of steel, there are some factors to be taken into consideration for its direct application to concrete. In this paper, concrete properties were examined and applicaion of coating materials in cases such as cracks, internal moisture, surface and voids were examined. Therefore, this study aims to contribute to the development of surface coating materials for ensuring durability of concrete structures.

KEY-WORDS: Concrete, durability, surface property, coating, porous, steel, ventilation.

INTRODUCTION

Concrete is the most widely used construction material due to the economic advantage and its ease of use, as well as its high durability [1]. Many types of facilities constructed using concrete are located in various environmental conditions such as underground, factory area, and marine environment. These structures in the harmful environments have a high potential for cracking and erosion caused by the outside factors such as moisture, deleterious chemical and gas intrusion. These causes result in the degradation of the concrete performance, especially for the reinforced concrete.

Since they are exposed to the various reasons described above, the service life of the structures is decreased and the safety issue becomes a major concern resulting in a great economic loss [2]. Therefore, in recent years, inspection, diagnosis and assessment of the facilities have been strengthened with respect to durability, and repair work on concrete structures is being conducted [3].

Until recently, various measures have been proposed to improve the durability and service life and to prevent the performance degradation of the concrete structures constructed under various environmental conditions. An effective method to protect concrete against moisture, salt, noxious gas, and chemical attack is to apply coating to the surface of the concrete.

Since the advantages of the ease to apply and the excellent effects on the prevention of performance deterioration, it is recognized and used widely as an efficient method for repair and maintenance. In the case of Korea, since the first application of the coating method in 1990s, this method has been applied to long-span bridges constructed in marine environment, such as Seohae Bridge, Yeongjong Bridge, Shingeoje Bridge, Incheon Bridge, Yi Sun-shin Bridge [4-6]. However, since the repair coating material was originally developed to prevent corrosion of steel, there are factors to be taken into consideration for its direct application to concrete.

The objecitve of this paper is to analyze the limitations of the existing coating materials as prevoously discussed, and to explain how to obtain suitable durability considering the location and environment the concrete structure is located in.

Concrete characteristics from the point of use of coating materials

Concrete structures exposed to various environments are protected by surface finishing with coating materials to prevent the penetration of harmful factors. However, unlike steel, the surface of concrete is porous, there are properties of concrete to be considered such as pH, moisture release, cracking. Therefore, it is necessary to precisely understand the inherent characteristics of concrete and the finishing coating materials to use.

Cracks

Compared to high compressive strength, concrete has a low tensile strength (generally 1/10 of the compressive strength), vulnerable to tensile stress. Generally, when the tensile stress acting on the concrete structure exceeds the tensile strength of the concrete, cracking occurs. This phenomenon is a typical disadvantage of concrete. Cracking occurs in any form in general concrete structures except for pre-stressed concrete. In addition, cement paste, which plays the most important role in forming the concrete, shrinks about 1% of the absolute volume during the curing processes accompanied by tensile force generated at the interface between the shrinkage-free aggregate and the shrinking cement paste. These result in micro-cracks.

It is almost impossible to completely prevent the cracking in the concrete structure. As previously mentioned, reducing the degree of crack distribution and the crack width is more effective than that of suppressing the crack itself. If cracks are generated on the concrete surface damaging to the coating film which is the final protective layer, the degradation of the concrete structure is accelerated by allowing the harmful factors to penetrate. Eventually, the durability of the concrete sturcture is degraded and the service life is shortened.

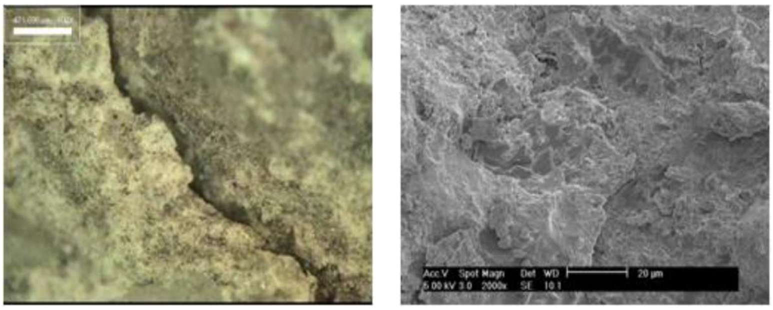


Fig. 1. The appearance of cracks in concrete

Internal moisture

Concrete is a complex material using hydration reaction of cement and water. The water to cement ratio is between 0.4 and 0.5 for general use concrete. The water is decreased as fresh concrete hydrates from fresh to hardened concrete. The water decrease is accelerated at a lower ambient humidity as the water is evaporated from the surface of concrete. Thus, the degree of water loss can be dependent on the degree of the ambient humidity. In the case of cement paste, water loss occurs in the capillary pores first, and followed by the water loss in the medium capillary pores and the small capillary pores sequentially. When the relative humidity is lowered to about 45 to 55% or less, the water absorbed on the surface of the solid products is removed, and further the moisture of the C-S-H gel layer may be removed. All of this moisture can be removed at room temperature, and the rate can be further accelerated to a temperature of 105 ° C [7].

The size of the pores in the cement ranges from 10 μm to less than 0.5 nm. Therefore, depending on the pore size, the role of water in the pores is different. If the pore size is largely divided into capillary pores and gel pores, the capillary pores are the remaining portions of the pores filled with water and exist between the non-hydrated cement particles. Water migration and ion diffusion are relatively easy through the pores. The gel pore is essentially regarded as a part of C-S-H and, it is difficult to identify the gel pore with equipment such as SEM [8]. Table 1 below shows the classification of the pore size present in the hydrated cement paste and the role of water depending on pore size.

If water contacts with the uncoated concrete surface, moisture can be absorbed into the concrete, but for any reason, the moisture can be evaporated into the atmosphere. Therefore, when an impermeable coating is formed, a vapor pressure is generated at the interface, which causes coating film swelling, detachment and peeling. In order to prevent such problems, generally, water content is limited to below a certain level when concrete surface coating is applied. However, this is not a perfect measure for the internal water movement. Therefore, moisture migration should be considered as one of concrete characteristics in using coating materials. A coating film formation technique having ventilation is required as an alternative method.

Table. 1 Pore Size Classification in Hydrated Cement Pool and Role of Water According to Pore Size.

Designation	Diameter	Classification	Role of water
Capillary pore	10,000～50nm	Macropores	Behavior with large amounts of moisture
	50～10 nm	Large mesopores	Small surface tension generation
Gel pore	10～2.5 nm	Small mesopores	Large surface tension generation
	2.5～0.5 nm	Micropores	Strongly adsorbed moisture; no moisture curves formed
	< 0.5 nm	Interlayer spaces	-

Surface and porous

The particular noteworthy of the concrete features from the coating application perspective is that concrete has the porous and irregular surface, unlike the steel surface. In the case of using the coating material, it is necessary to take measures to prevent the coating material from being absorbed into the pore or bubbling due to the existence of such pores. In general, there are some measures to minimize the drawbacks, for example, grinding the surface, using a permeable primer to the surface, or adjusting the surface with a surface treatment material (putty) in the form of a slurry.

The comparison with steel, which is the most commonly used construction material in addition to concrete, shows significant difference. The comparison of various properties of concrete and steel is shown in Table 2.

Table. 2 Pore Size Classification in Hydrated Cement Pool and Role of Water According to Pore Size

Designation	Concrete	Steel
pH	High Alkali	-
Moisture	Internal water	No water
Surface	Porous Surface	Closed Surface
Surface treatment at Coating	Putty Application	Surface Polishing
Crack	Crack	No Crack

Requirements of Concrete Coating Materials

Crack resistance

The inevitable cracking of concrete has been pointed out becuase cracks occur for any reason. If the generated cracks are structurally acceptable, the coating material to be applied to the surface concrete should have adequate elasticity to increase the resistance to cracking and to maintain the coating. The coating can effectively block the external deterioration factors and protect the structure to improve durability. Occasionally, more acitve measures are taken to the cracks to prevent further deterioration. There are researches on developimg methods to resistant cracking using a microcapsule healing agent [9], and on the assessment of the effects of crack healing on the surface cracks [10]. The mechanism is that the deterioration factors are prevented by its self-healing sealing the cracks. However, if the coating has adequate elongation and the coating is not damaged, it will be possible to protect the structure even if no action is taken.

Ensure ventilation

The coating film formed on the concrete surface should prevent the deterioration factor and ensure ventilation so that the internal moisture can be evaporated to the outside in order not to swell the coating film, resulting in the disbondment. Since the concrete surface is porous and irregular, the coating material can be absoorbt, then bubbles are easily generated. The thin coating film can be vulnerable to an external impact. The water in the concrete has the property of evaporating in the direction of contact with the atmosphere, which causes expansion pressure. Hence, if the concrete protection layer is an impermeable coating film having no air ventilation, the coating material may cause problems such as swelling and disbondment.

To solve this problem, it is necessary to improve the concrete surface pore structure by using a material capable of filling the pore. The change in pore structure on the concrete surface affects the migration of moisture from the concrete. For example, water vapor (0.0004 ㎛ in diameter) generated from the inside can be moved, and through C-S-A (Calcium Silicate Aluminate) or C-S-H (Calcium Silicate Hydrate) and a three-dimensional network structure capable of hydrogen bonding (Fig. 2), it is possible to ensure the ventilation of the coating by adjusting the finishing coating material to 0.02 to 0.1 ㎛ or less pore size [11,12].

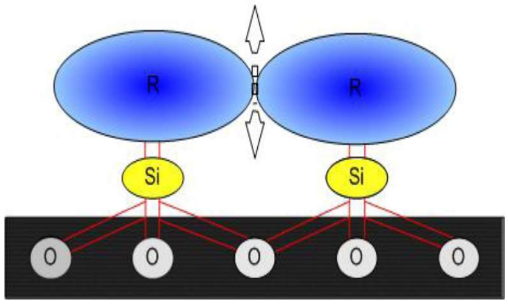
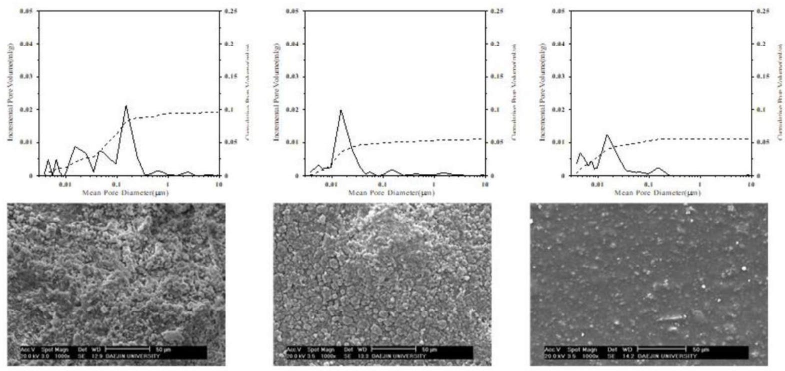


Fig.2. 3D Mesh Structure



(a) Pore structure of concrete, Image of Surface(SEM, 100X)

(b) Pore structure of Primary treatment, Image of Surface(SEM, 100X)

(C) Pore structure of Coating, Image of Surface(SEM, 100X)

Fig.3. Pore structure analysis by MIP (mercury porosimetry)

Fig. 3 (b) shows an example of improving the pore structure by the first treating the surface with an inorganic material made of fine powder. This material is also intended to protect concrete even if some coatings are damaged by external impacts.

As the surface of structures is protected by the first surface teatment selecting an apporopriate coaing material, a completly protecitve layer can be formed. The coating material applied at the top has a less permeable structure than those of the first surface treatment. In the case of the final finish coating material shown in Fig. 3 (c), it is converted to 0.02 ~ 0.1 ㎛ finer pores than the pore structure of the first surface treatment material having a pore structure distribution of 0.02 ~ 1.0 ㎛ to make the coating material have the function of ventilation and waterproofing. As the results, the occurrence of whitening and swelling can be prevented.

Surface treatment method

Concrete surfaces are often coated after surface treatment because the surfaces are irregular and porous. There is a variety of materials used as surface treatment materials. Putties of synthetic resin, one of organic type are generally used. However, concrete's minerals has different material properties from synthetic resin based putty. This difference acts as a factor to lower the adhesion strength with the concrete surface. Therefore, it is necessary to take the material properties into account when selecting the surface treatment material.

The surface treatment material may be manufactured in an inorganic form in order to improve disadvantages such as adhesion deterioration factors caused by different series of materials. Table 3 compares the adhesion performance between the organic putty, which is a dry type of adhesion, and the inorganic putty, using cement hydration. Fig. 4 shows the comparison of the concrete shapes, inorganic putty, concrete and organic putty with SEM photographs. As shown in the photographs of Table 3 and Fig. 4, the inorganic putty using the cement hydration reaction was superior in adhesion strength compared to the case of using the putties of synthetic resin, and it was obseved that the surface treatment material (putty) and concrete were integrated. Of course, there will be a way to improve the concrete surface in various forms and to secure the adhesion performance of the coating.

Table 3. Comparison of Bond Strength of surface treated materials

Designation			Inorganic Putty	Organic Putty
Bond Strength (MPa)	Dry state	3.25	0.7	
	Wet state	3.21	-	

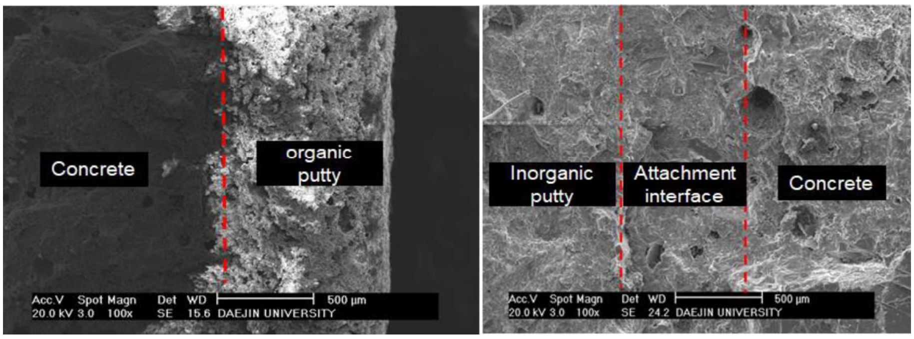


Fig. 4. Comparison of adhesion interface according to surface treatment materials

Application example of salt preventive coating

As described above, Korea has started to apply the salt preventive coating to the long bridge since the 1990s. Especially, the long bridge which is constructed on the sea is an important structure to prevent the salinity for maintenance management. In this chapter, the description of the prevention mechanism of salting is excluded and the application example of coating is explained. In the case of Seohae Grand Bridge located in Asan Bay, South Korea, concrete surface was applied with water repellent and water - repellent paint, and steel pipe(Φ =12 ㎜) was used as a sacrificial steel pipe.

Fig. 5. Seohae Bridge and Yeong-Jong Bridge

Youngjong Bridge is a bridge connecting Youngjong Island and Incheon. It was constructed in 1995 and completed in 2000. At the time of construction, the salt preventive coating was applied to the concrete surface. In addition to this, Coatings were applied to the concrete surface of bridges constructed at sea to prevent damage by salt, such as Shin Geoje Bridge, Incheon Bridge, and Yi Sun Bridge. The Fig. below shows the bridge.

Fig. 6. Shingeoje Bridge, Incheon Bridge and Yi Sun-shin Bridge

CONCLUSIONS

The requirements of coating material considering concrete characteristics were examined from the coating application perspective which is one of the ways of improving the durability of concrete structures constructed in various environments.

The coating material for concrete requires proper elongation to resist cracks inevitably, and it is necessary to improve the surface of the concrete before coating. In addition, ventilation should be ensured to prevent swelling and disbondment due to expansion pressure generated by moisture migration. In order to secure such performance, this research has tried to improve the concrete surface with inorganic putty using cement, and to ensure the ventilation of the coating film by using a coating agent and putty having proper air ventilation. Furthermore, the material aspect of the coating material for protecting the concrete structure, the usage aspect, and the exposure environment can be additionally considered.

This study hopes that the research and experience of many researchers and construction engineers in the future will develop the technology for applying the surface coating material to the concrete structure, and hopes that this review will be helpful for the technology development.

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