EVALUATION OF THE PERFORMANCE OF THE PROTECTIVE SURFACE COATINGS FOR CONCRETE

Haimoon CHEONG*1 Hwangu YU*2 Taesong AHN*3 Byunghwan OH*4

ABSTRACT: Chloride penetration into concrete is the main cause of the corrosion of steel in concrete structures exposed to chloride-rich environments. Protective surface coatings are increasingly being applied to concrete structures to reduce chloride penetration. In this study, the performance of various surface coatings was evaluated. Most coatings showed good results for the various tests of the performance evaluation. Surface coatings can delay deterioration such as chloride-induced reinforcing bar corrosion effectively.
KEYWORDS: chloride, corrosion, surface coating, penetration

1. INTRODUCTION

Large-scale concrete structures directly exposed to seawater such as SeoHae Grand Bridge are increasingly constructed along the coast in Korea. Chloride ingress into concrete followed by reinforcement corrosion and deterioration of concrete structures is a major problem for many structures under chloride attacks. The previous experiences emphasized for the high quality of concrete structure for the assurance of long-term durability[1]. In the case of high quality of concrete structure, the typical protection methods against chloride attacks consist of: 1) thickening the cover thickness of concrete, 2) using cathodic protection, 3) applying a coating layer on the surface of concrete to reduce the penetration of chloride ion, and 4) using non-corrosive materials, such as epoxy coated re-bars, FRP, corrosion inhibitors etc..

Currently, various types of protective surface coatings are increasingly introduced in Korea, to reduce chloride penetration into concrete. In applying these materials, however, we have few reasonable standardized programs of tests for evaluating them. Therefore, in this study, the performance of surface coatings for protecting chloride ingress was evaluated, and proper test methods were investigated.

2. EXPERIMENTAL PROGRAM

2.1 Coating Materials

As shown in Table 1, five kinds of surface coating materials have been prepared to investigate the performance of coating materials effectively. Free films and surface-coated specimens were prepared. Free films were prepared by painting only with intermediate and top coating without substrate, and surface-coated specimens were prepared by painting on the substrate. Their painting methods were based on the manufacturer's recommendation. The specimens were cured in open air in the laboratory at room temperature for 28days(standard condition). For investigation of the performance after accelerated deteriorating condition, the specimens were exposed to the QUV accelerated weathering for 250 hours, seawater(3% NaCl)

*1 Highway Research Center, Korea Highway Corporation, Ph.D., Member of JCI
*2 Highway Research Center, Korea Highway Corporation
*3 Highway Research Center, Korea Highway Corporation, Ph.D.
*4 Department of Civil Engineering, Seoul National University, Ph.D.

Table 1 Type of Coating Materials

Speci-men	Chemical Component of Coating System				Thickness (㎛)**
	Primer	Putty	Intermediate Coat	Top Coat	
AS	epoxy	epoxy	acrylic silicone	acrylic silicone	50
EP	epoxy	epoxy	epoxy	epoxy	250
UR	polyurethane	PCM*	polyurethane	polyurethane	125
AC	acrylic	PCM*	acrylic	acrylic	400
AU	acrylic urethane	acrylic urethane	acrylic urethane	acrylic urethane	100

*Portland Cement Mortar **Intermediate coat + Top coat

for 15 days and alkaline solution(saturated $Ca(OH)_2$) for 15 days.

2.2 Experimental methods

Various tests employed in this study were summarized in Table 2.

(1) Water penetration test

Water penetration test for surface-coated specimens was performed according to JIS A 1404. $3kg_f/cm^2$ of water compressive force was applied.

(2) Vapor penetration test

Vapor penetration test for free films was carried out according to ASTM E 1653. Desiccant used was calcium chloride. The specimens were put in the test chamber of 23±0.6℃, and 50±2%R.H., and the weight of specimen was measured every 24 hours for 3 weeks until it became constant.

(3) Chloride penetration test

Chloride penetration test was performed by Japan Road Association's method. 70×70mm of free films were fixed on diffusion cells. 3% NaCl solution was filled in the one side of the cell and distilled water was also filled in the other side of the cell. The test set-up was kept for 30 days at 20℃ in laboratory. After 30 days, chloride ion concentration was analyzed in the distilled water.

(4) Bond strength test

Bond strength test of coatings with concrete was performed in accordance with JIS K 5400. Bond strength test with wet condition was also performed to evaluate the effect of water contained on concrete surface. The specimens have been stored in water for 10 days and then have been cured for 48 hours in dry condition before testing(JIS A 6909 5.8.3).

Table 2 The Tests Used in This Study

Test Method	Specimen Type	Condition*	Remarks
Water Penetration	Surface-coated Concrete	S, AW, N, A	σ_{28}=24N/mm^2
Vapor Penetration	Free Film	S, AW, N, A	
Chloride Penetration	Free Film	S, AW, N, A	
Bond Strength	Surface-coated Concrete	S, AW, W, N, A	σ_{28}=45N/mm^2
Crack-Bridging	Surface-coated Mortar	S, N, A	W/C=0.5
Accelerated Cl^- Ion Diffusion	Surface-coated Concrete	S	σ_{28}=24N/mm^2
Freezing-Thawing	Surface-coated Concrete	S	
Carbonation	Surface-coated Concrete	S	

*S : Standard, AW : QUV Accelerated Weathering for 250 hours, W : Wet Condition(JIS A 6909 5.8.3)
N : Seawater(3%NaCl) Immersion for 15 days A : Alkaline Solution(Saturated $Ca(OH)_2$) Immersion for 15 days

(5) Crack-bridging test

Crack-bridging test for surface-coated specimens was examined by Japan Highway's method(Zero Span Method). The specimens used were one face-coated mortar prisms. The specimens were extended at a speed of 5mm/min. The test was carried out at 20℃.

(6) Accelerated chloride diffusion test by applying electrical potential

To determine the chloride diffusion coefficient of surface-coated concrete specimens, the rapid test method proposed experimentally by Tang & Nilsson[2] was employed. The effective chloride diffusion coefficient was calculated using equation (1) proposed experimentally as follows:

$$D_{eff} = \frac{RTL}{ZFU} \frac{X_d - \alpha\sqrt{X_d}}{t} \quad (1)$$

D_{eff} : effective chloride diffusion coefficient determined by non-steady state migration test

Z : absolute value of ion valence F : Faraday constant t : test duration

U : absolute value of potential difference R : gas constant T : temperature

L : thickness of the specimen X_d : chloride penetration depth

(7) Freezing-thawing test and accelerated carbonation test

Freezing-thawing test for surface-coated concrete specimens was conducted according to ASTM C 666. Accelerated carbonation test for surface-coated concrete specimens was carried out at 40℃, 60% R.H., 10% CO_2 concentration for 4 weeks.

3. RESULTS AND DISCUSSIONS

3.1 Water penetration and vapor penetration

Most coating materials except acrylics had no water penetration. Also, water penetration was not shown after accelerated deteriorating test such as QUV accelerated weathering(AW), seawater immersion(N) and alkaline solution immersion(A). Acrylic coating material showed 0.17～0.83ml of water penetration after accelerated deteriorating test (Figure 1).

Figure 2 showed the vapor penetrations of surface coating membranes. The vapor penetration of acrylic coating membrane showed much larger than those of the other types. And the results showed larger penetration after accelerated deteriorating test.

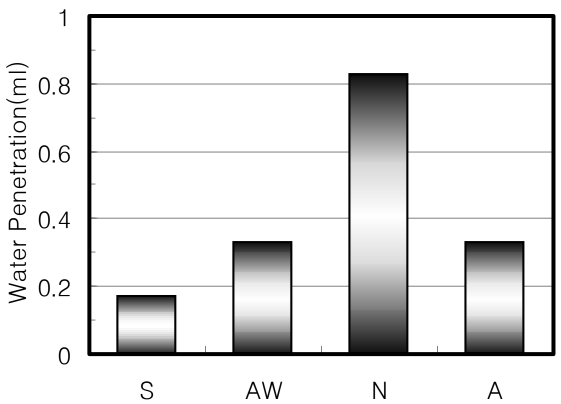

Figure 1 Water penetration of acrylics after accelerated deteriorating tests

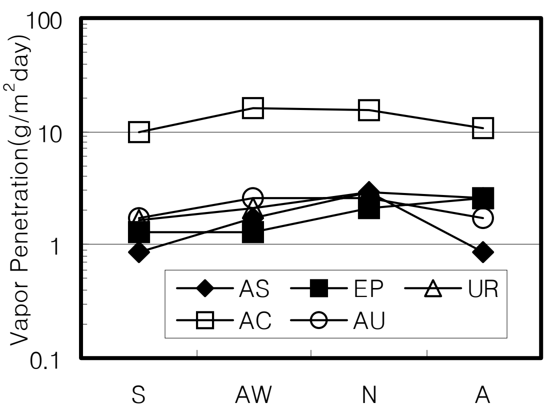

Figure 2 Vapor penetration of coatings after accelerated deteriorating tests

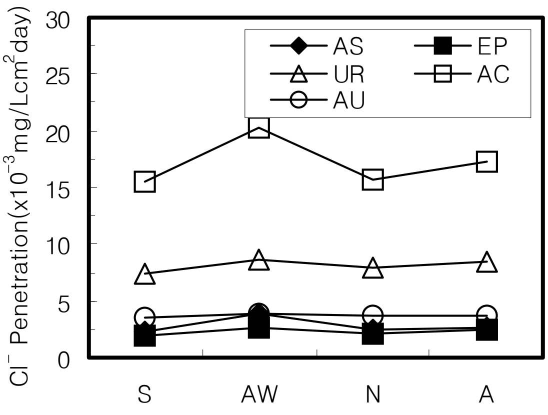

Figure 3 Cl⁻ ion penetration of various coatings after accelerated deteriorating tests

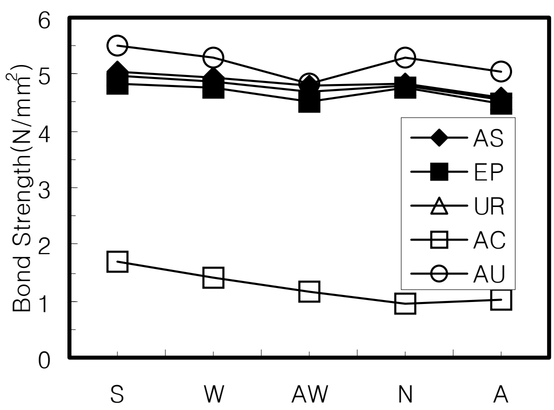

Figure 4 Bond strength of coatings with concrete

3.2 Chloride ion penetration

The result of chloride penetration test was given in Figure 3. As can be seen, chloride ion penetration increased in accelerated deteriorating tests. Especially, the effect of accelerated weathering and alkaline solution immersion was remarkable.

3.3 Bond strength

Fig. 4 showed the bond strength of the coatings with concrete. Exceptionally acrylics, most coatings showed over 4N/mm^2 of bond strength. The results by bond strength showed similar to those of water, vapor and chloride penetration tests. Acrylic coatings exhibited much lower bond strength, and the reduction rate after accelerated deteriorating test was more than other type materials. The results from accelerated weathering and alkaline solution immersion had a tendency to show less bond strength than those of seawater immersion.

3.4 Crack-bridging test

Figure 5 and 6 showed the results of crack-bridging test for various surface-coated specimens. The test results showed that the polyurethane type of coating exhibited much larger tensile strength than any other types, and elongation was much larger for acrylic type although its tensile strength was very low. The reduction of tensile strength and elongation after seawater and alkaline solution immersion were not so much. It is necessary to study further whether tensile strength and elongation would be proper to crack-bridging test.

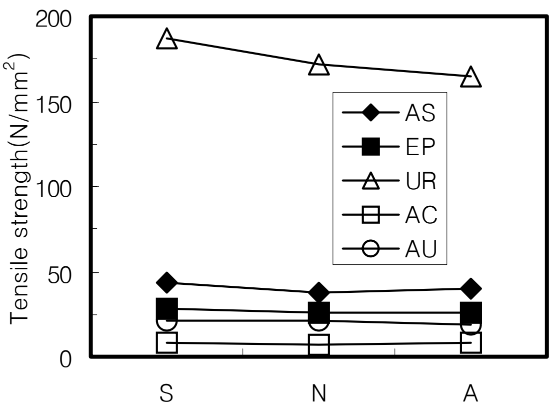

Figure 5 Tensile strength of coatings after accelerated deteriorating tests

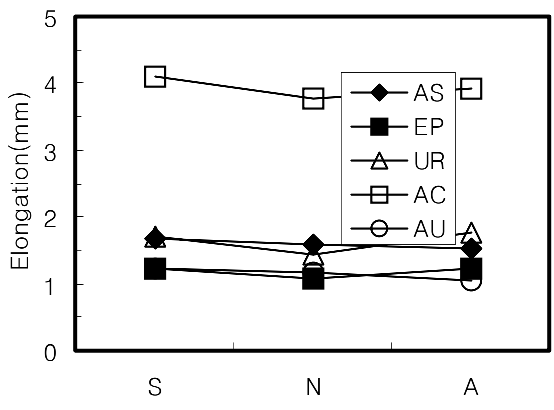

Figure 6 Elongation of coatings after accelerated deteriorating tests

3.5 Accelerated chloride diffusion test by applying electrical potential

Figure 7 gave the effective diffusion coefficients which took into account of the combined effect of coating materials and concrete specimens. Surface-coated specimens showed 10～20 times lower diffusion coefficients than plain specimen without surface coating treatment.

3.6 Freezing-thawing test and accelerated carbonation test

Figure 8 and 9 showed the results of freezing-thawing and acceleration carbonation test for surface-coated concrete specimens, respectively. The surface-coated concrete specimens were found to have good resistance of freezing-thawing and carbonation. Especially, the carbonation depth decreased greatly for surface-coated concrete specimens.

3.7 Discussions

Most coatings showed good results for the various tests of the performance evaluation. Their performances depended upon the types of coating materials[3]. In this study, acrylics showed poor performance in various accelerated penetration tests. Although the film thickness of acrylics was larger than other coatings, the results of various accelerated penetration test were poorer. It seemed that the penetration properties of coatings were affected much more by material characteristics than coating thickness. Figure 10 showed the relationship between chloride penetration and vapor penetration. Good relationship between protecting performances such as chloride penetration and vapor penetration for coating materials was given in this study(R^2=0.83).

Acrylics coatings revealed lower bond strength with concrete and larger elongation. It was thought that it was typical results for elastic material such as acrylics[4].

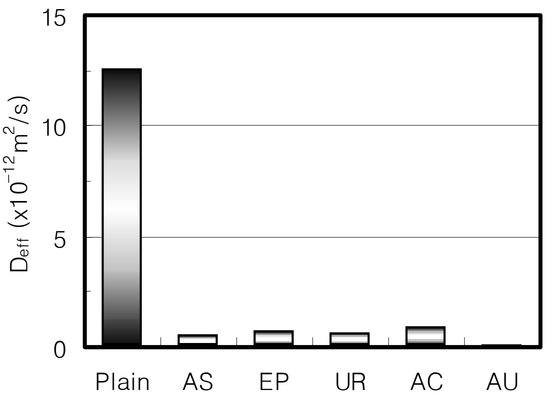

Figure 7 Effective diffusion coefficient of surface-coated concrete specimens

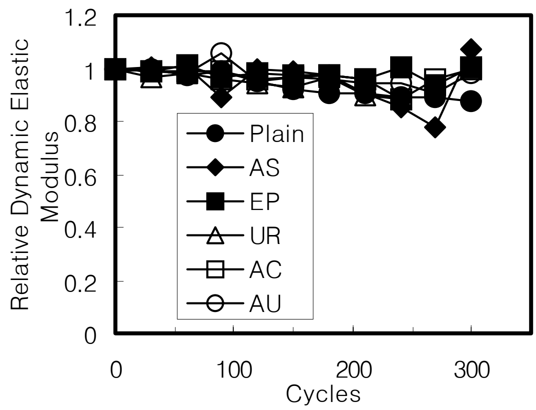

Figure 8 Relative dynamic elastic modulus of surface-coated concrete specimens

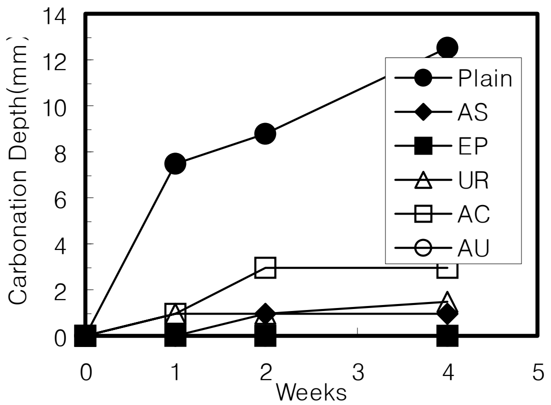

Figure 9 Accelerated carbonation depth of surface-coated concrete specimens

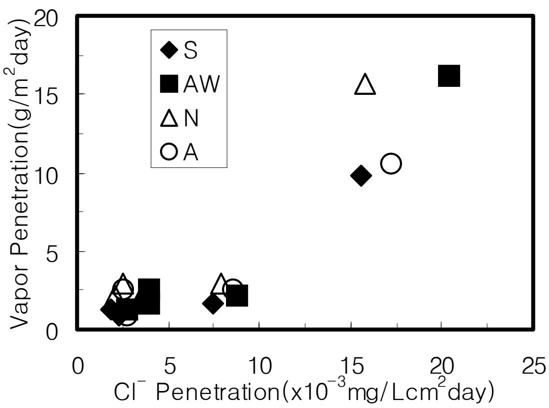

Figure 10 Relationship between Cl⁻ penetration and vapor penetration

The performance of surface coatings was reduced after accelerated deteriorating test. Figure 10 gave that 250-hours accelerated weathering influenced the penetration performances of coatings larger in this study. However, the field test results for coating materials were limited, the ranking of coating materials according to the results from this study can not be supported. For correlations with field testing, the field test for surface coating materials are conducting in marine environment.

4. CONCLUSIONS

(1) Most coatings showed good results by the various tests of the performance evaluation. The degree of performance depended upon the types of coating materials.

(2) Surface-coated specimens showed 10～20 times lower chloride diffusion coefficient than plain specimen without surface coating treatment. Surface coatings can delay deterioration such as chloride-induced reinforcing bar corrosion effectively.

(3) Acrylics showed poor performance in various accelerated penetration tests. It seemed that the penetration properties of coatings were affected much more by material characteristics than coating thickness.

(4) The performance of most surface coatings was reduced after accelerated deteriorating test. However, the field test results for coating materials were limited, the ranking of coating materials according to the results from this study can not be supported. It is necessary to study further for correlating accelerated testing with field testing.

REFERENCES

1. ACI222R, “Corrosion of Metals in Concrete”, ACI Manual of Concrete Practice (1999)
2. Tang,L. and Nilsson,L.O.,”Rapid Determination of the Chloride Diffusivity in Concrete by Applying Electrical Field”, ACI Materials Journal, Vol.89, No.1, pp.49～53 (1992)
3. NCHRP Synthesis 209, “Sealers for Portland Cement Concrete Highway Facilities”, Transportation Research Board, National Academy Press (1994)
4. Concrete Engineering Series, No.26, pp.217-218, Japan Society of Civil Engineers (1997)