Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Prediction of Chloride ion Penetration for Concrete Impregnated with Silane Water-repellent Material

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ABSTRACT

It was reported in the previous papers that the concrete impregnated with the silane water-repellent material had the high resistance for the chloride ion penetration (Liu et al. 2010). But the chloride ion prediction method for the concrete impregnated with the silane water-repellent material is not established yet. In this study, we immersed the concrete impregnated with the silane water-repellent material in salt water, and calculated the apparent diffusion coefficient and surface chloride ion content by using the solution of the diffusion equation based on Fick's second law of diffusion. Besides, we suggested the chloride ion prediction method for the concrete impregnated with the silane water-repellent material. On the method, we regarded the concrete applied with the silane water-repellent material as the two-layer material and set the apparent diffusion coefficient of the concrete impregnated with the silane water-repellent material and the concrete not impregnated with the silane water-repellent material, respectively.

Keywords. Silane water-repellent material, Chloride ion, Fick's second law of diffusion Apparent diffusion coefficient, Surface chloride ion content

OUTLINE OF EXPERIMENT

Type of silane water-repellent materials. Table 1 shows the type of silane water-repellent materials. Type A, Type B and Type C are the high concentration silane water-repellent material. Their effective ingredient concentration is over 80 mass%. Type D is the conventional type which effective ingredient concentration is 10 mass%. The volume of application was referred to the recommended volume of the each maker.

Materials and mix proportions of concrete. We used the ordinary portland cement, the hill sand as fine aggregate, the crushed hard sand stone as coarse aggregate, and the air-entraining and water reducing admixture as chemical admixture. Table 2 shows the mix proportions of concrete.

Specimens. The size of specimens was 100 x 100 x 100 mm. After being demolded on the day following the placing day, the specimens were cured in seal at 20 degree Celsius until the age of 7 days and dried in thermo-hygrostatic room at 20 degree Celsius and 60% R.H.

Table 1. Type of silane water-repellent materials

Types	Bases	Effective ingredient concentration	Volume of application
Type A	Alkyl alkoxysilanes and reactive siloxane	80 mass%	200 g/m^2
Type B	Alkyl alkoxysilanes and siloxane	Over 90 mass%	200 g/m^2
Type C	Alkyl alkoxysilanes	Over 98 mass%	220 g/m^2
Type D	Poly-alkyl alkoxysiloxane	10 mass%	200 g/m^2

Table 2. Mix proportions of concrete

Slump (cm)	Air content (%)	W/C (%)	s/a (%)	Unit content(kg/m^3)			
				W	C	S	G
12	4.5	50	45.0	160	320	814	1016

until the age of 28 days. The silane water-repellent material was applied with brush at the age of 28 days and the specimens were cured in air n thermo-hygrostatic room at 20 degree and 60% R.H. until the age of 56 days. And then, the specimens were immersed in 10 mass% NaCl solution for 71 days in accordance with JSCE-G 572. The five surfaces of the specimens except the surface applied with the silane water-repellent material were sealed with the epoxy resin.

Test items. The penetration depth of silane water-repellent material was measured at the age of 56 days. The splitted specimens were soaked in water for one minute and the thickness of water-repellent layer was measured as the penetration depth of the silane water-repellent material in accordance with JSCE-K 571. The chloride ion concentration profile for concrete was measured by the electron probe microanalysis (EPMA) (Mori et al. 2007) after immersed in 10 mass% NaCl solution for 71 days.

RESULT AND DISCUSSION

Penetration depths. Figure 1 shows the penetration depths of silane water-repellent material. The penetration depths of Type A, Type B and Type C were deeper than that of Type D. It is therefore inferred that the high concentration silane water-repellent material is easy to penetrate into concrete. This is because the volume of effective ingredient of silane water-repellent material increases as the effective ingredient concentration becomes high, when the application volume of silane water-repellent material is the same.

Chloride ion concentration profiles. Figure 2 shows the examples of the chloride ion area analysis results of concrete by EPMA after immersed in 10 mass% NaCl solution for 71 days. Figure 3 and 4 show the chloride ion concentration profiles of concrete calculated from Figure 2. The penetration depth of chloride ion of the untreated concrete was approximately 20mm. The penetration depth of chloride ion of the concrete impregnated with Type D was approximately 15mm. On the other hand, the penetration depths of chloride ion of the concrete impregnated with the high concentration silane water-repellent materials (Type A, Type B and Type C) were approximately 10mm. It was confirmed that the high concentration silane water-repellent materials had large effect on preventing the ingress of chloride ion. Besides, the surface chloride ion content of the concrete impregnated with the high concentration silane water-repellent materials (Type A, Type B and Type C) was less than that of the untreated concrete. This is because the surface of concrete impregnated with the high concentration silane water-repellent materials has well water-repellent. The chloride ion concentration profiles of concrete impregnated with Type D was similar to that of the untreated concrete. It is inferred that Type D has little effect on preventing the ingress of chloride ion because of the low concentration of the effective ingredient.

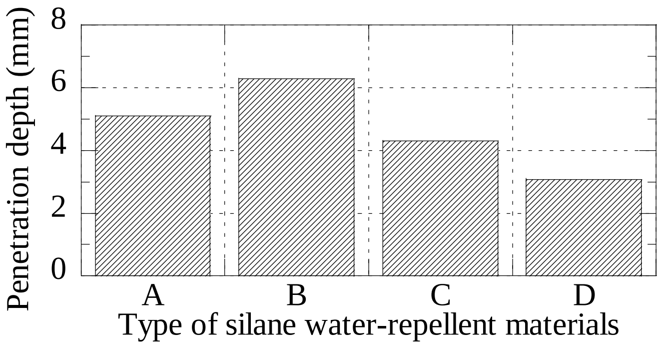

Figure 1. Penetration depths

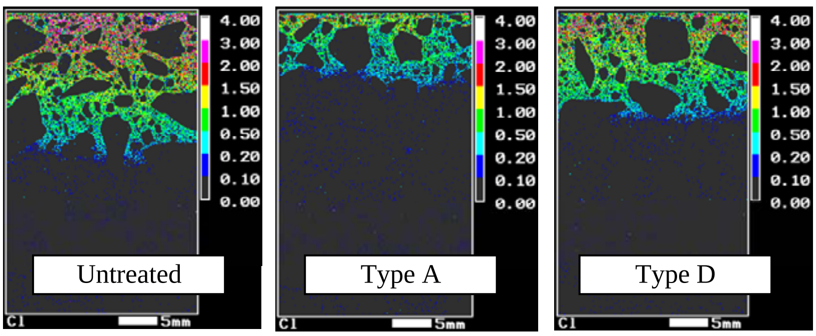

Figure 2. Examples of area analysis results of chloride ion by EPMA

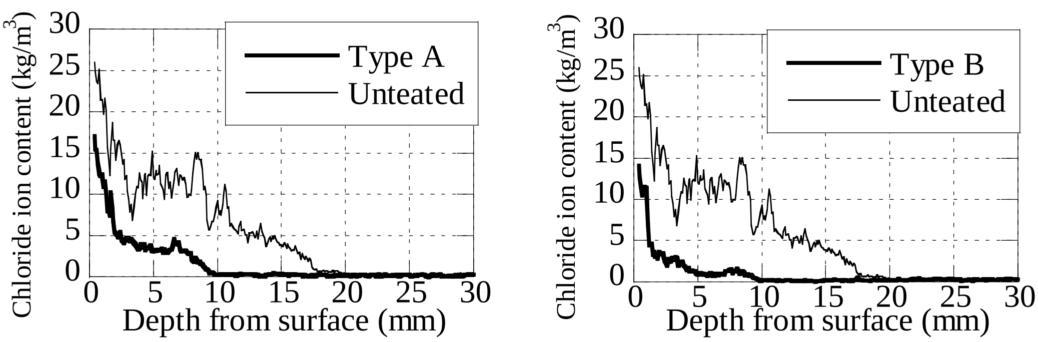

Figure 3. Chloride ion concentration profiles (Type A and Type B)

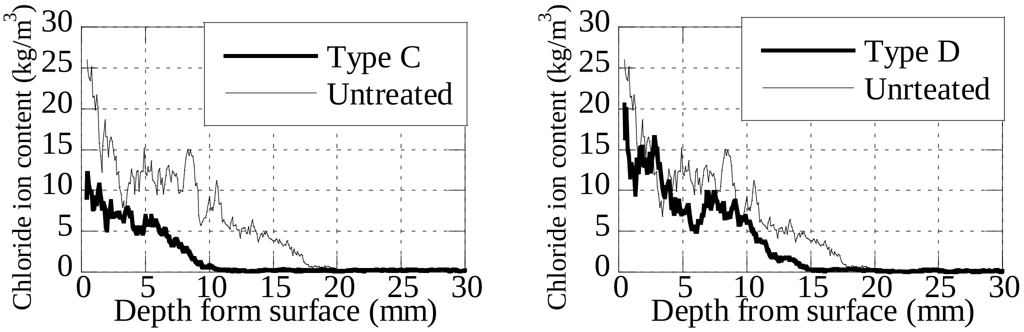

Figure 4. Chloride ion concentration profiles (Type C and Type D)

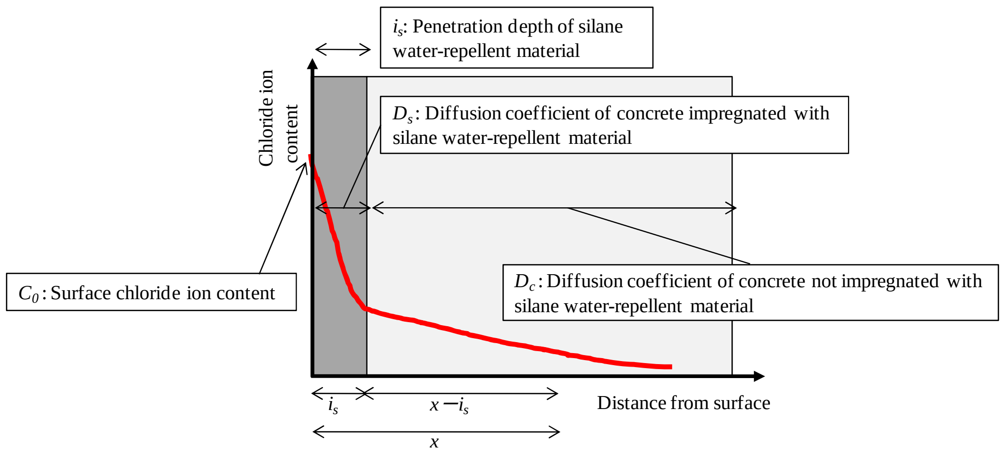

Figure 5. Chloride ion penetration model of concrete with silane water-repellent material

Chloride ion penetration model of concrete with silane water-repellent material. Figure 5 shows the chloride ion penetration model of the concrete impregnated with silane water-repellent material. We regarded the concrete applied with the silane water-repellent material as the two-layer material and set the apparent diffusion coefficient of the concrete impregnated with the silane water-repellent material and the untreated concrete. The chloride ion content of the concrete applied with the silane water-repellent material was calculated according to Equation 1 based on Fick's second law of diffusion.

Figure 6 and 7 show the apparent diffusion coefficient and the surface chloride ion content calculated by using the solution of Equation 1. The apparent diffusion coefficient of the concrete impregnated with the high concentration silane water-repellent materials (Type A, Type B and Type C) was approximately 80%-90% less than that of the untreated concrete. It became obvious that the apparent diffusion coefficient of the concrete was remarkably decreased by the high concentration silane water-repellent materials. The surface chloride ion content of the concrete impregnated with the high concentration silane water-repellent materials (Type A, Type B and Type C) was approximately 40%-50% less than that of the untreated concrete. But there were the difference between the measured value and the calculated value of the surface chloride ion content of the concrete impregnated with the silane water-repellent materials. Therefore, further study is required to improve the confidence of this model. Figure 8 shows the comparison between the measured chloride content and the calculated chloride content by the model suggested in this study. The chloride content calculated by the model suggested in this study substantially corresponded with the measured chloride content.

$$\begin{aligned}
&for \quad 0 \le x \le i_s \\
&C(x,t) = C_0\left(1 - erf\left(\frac{0.1x}{2\sqrt{D_s \cdot t}}\right)\right) + C(x,0) \\
&for \quad i_s < x \\
&C(x,t) = C_0\left(1 - erf\left(\frac{0.1}{2\sqrt{t}}\left(\frac{x-i_s}{\sqrt{D_c}} + \frac{i_s}{\sqrt{D_s}}\right)\right)\right) + C(x,0)
\end{aligned} \tag{1}$$

where, C(x,t): chloride ion content (kg/m^3) at depth x from surface of concrete, C(x,0): initial chloride ion content (kg/m^3), C_0: surface chloride ion content (kg/m^3), i_s: penetration depth of silane water-repellent material (cm), D_c: apparent diffusion coefficient of concrete not impregnated with silane water-repellent material (cm^2/year), D_s: apparent diffusion coefficient of concrete impregnated with silane water-repellent material(cm^2/year), t: time (year), x: distance from surface (cm), erf: error function

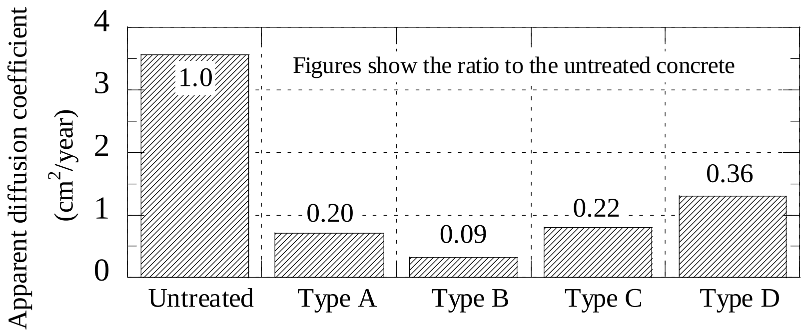

Figure 6. Apparent diffusion coefficient

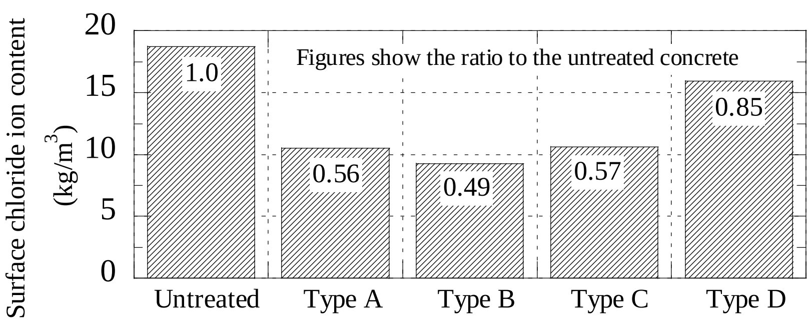

Figure 7. Surface chloride ion content

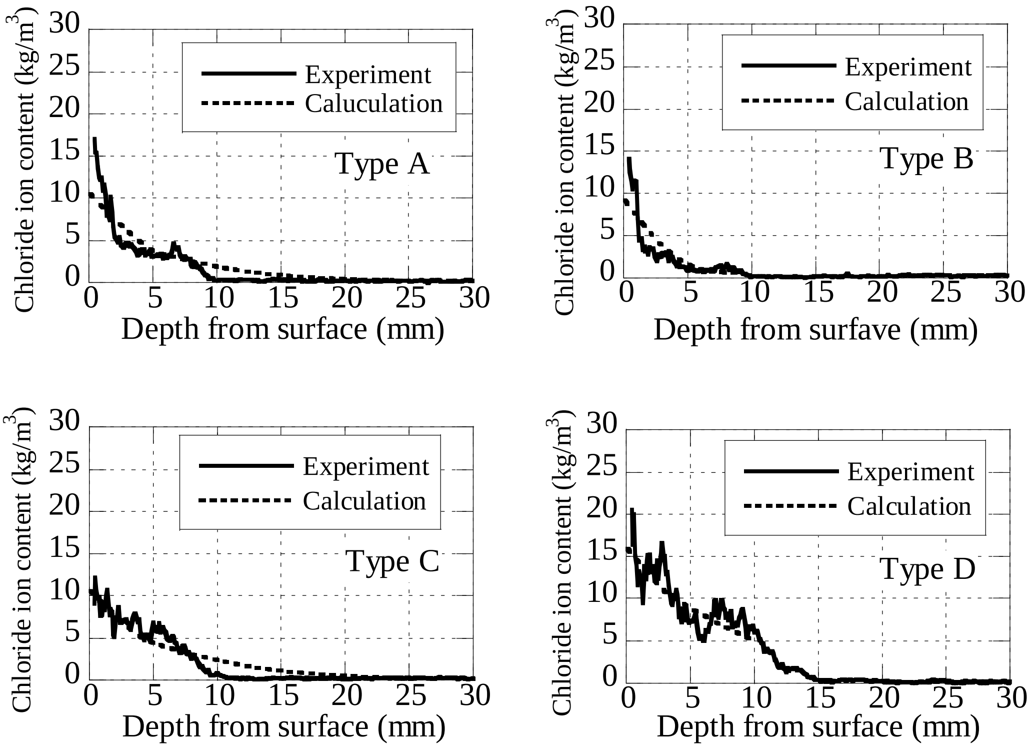

Figure 8. Comparison between experiment and calculation by the model

CONCLUSIONS

(1) It was confirmed that the high concentration silane water-repellent materials had large effect on preventing the ingress of chloride ion.

(2) The surface chloride ion content of the concrete impregnated with the high concentration silane water-repellent materials was less than that of the untreated concrete.

(3) It became obvious that the apparent diffusion coefficient of the concrete was remarkably decreased by the high concentration silane water-repellent materials.

(4) We suggested the chloride ion prediction method for the concrete impregnated with the silane water-repellent material. On the method, we regarded the concrete applied with the silane water-repellent material as the two-layer material and set the apparent diffusion coefficient of the concrete impregnated with the silane water-repellent material and the concrete not impregnated with the silane water-repellent material, respectively.

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