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Effects of moisture condition and internal water movement on penetration property of chloride ion in concrete

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ABSTRACT

In this study, influences of moisture condition in concrete on the rate of water movement and penetration property of chloride ion into concrete. In experimental investigations, water absorption tests are carried out by using salt water in order to clarify the rate of internal water movement depends on the moisture condition in mortar, and its effect on the penetration property of chloride ion. From the experimental results, penetration property of chloride ion shows different trend depending on the internal water condition in mortar. Especially, in case of absolute dry condition, the penetration rate of chloride ion will be much larger because of advection process than that in diffusion process in mortar with water saturated condition. Moreover, at the surface part of mortar, additional chloride content due to diffusion process can be also confirmed on distribution of chloride content due to advection process during absorption test. Therefore, in order to assess the penetration of chloride ion, effects of both advection and diffusion processes depending on moisture condition of mortar should be considered.

Keywords. Chloride Penetration, Moisture Condition, Water Movement, Diffusion process, Advection process

1. INTRODUCTION

In performance verification of maintenance system for concrete structures, clarifying the penetration property of chloride ion is most important to estimate incubation period of deterioration due to chloride attack. Generally, it is assumed that the chloride ion penetrates into concrete by diffusion mechanism governed by Fick's Second Low. Specification of Japan Society of Civil Engineers suggests the evaluation method based on the diffusion process and equations to estimate the apparent chloride diffusion coefficients of concrete depends on cement type, mix proportion, and surface chloride concentration in o environmental condition of the structure [Japan Society of Civil Engineers (2008)]. Though this assessment method is simple and generally versatile, the accuracy is not very high. This is attributed to the fact that apparent diffusion coefficient includes not only concentration diffusion but also the effects of both chloride ion migration with water movement and immobilization of chloride ion in pores. For example, distribution of penetrated chloride ion in concrete structures differs by location, weather and maintenance system. In addition, numerous past researches also show the existence of differences in chloride distributions not only in same structure but also in same member. One of the strongest factors of this phenomenon is chloride content at the surface of concrete structures. It means penetration property of chloride, that is to say, apparent diffusion coefficient in diffusion model differs according to environmental condition. Addition to that, recently, it is frequently reported that effects of both chloride ion migration due to water movement in concrete by wet and dry cycles and immobilization of chloride ion by hydration product of cement should be considered in assessment of penetration of chloride ion. However, there are a few case studies about relationship between water movement and chloride ion movement, and those are not enough to clarify the mechanism of chloride penetration in actual phenomena [Koike et al. (2012)] .

Therefore, in this study, several experimental investigations are carried out to build the assessment method that links water movement to chloride ion migration. Especially, in this study, moisture condition in concrete is focused upon, because it is expected that moisture condition influences on rate of water movement and penetration property of chloride ion. From the results of experimental study, effects of moisture condition and internal water movement on penetration property of chloride ion in concrete are examined in this paper.

2. EXPERIMENTAL OVERVIEW

Table 1 shows the mix proportions using high early strength Portland cement (here-in-after called HPC) and ordinary Portland cement (here-in-after called OPC). Water cement ratio (here-in-after called “W/C”) is fixed at 0.4, 0.5 and 0.6. For each W/C, total volume of mortar is adjusted to satisfy the target mortar flow value, 150±10 mm. Cylindrical specimens of 5cm in diameter and 10cm in length are prepared. Demolded specimens are cured in wet condition for 7 days, and then water absorption test is carried out. Initial moisture conditions in mortar are of two types, i.e., saturated condition and absolute dry condition. Fig. 1 shows the method of water absorption test. Here, absorption face of the specimen is completely soaked in 10% NaCl solution. However, opposite face of the specimen can be exposed to atmosphere. There are two sealing types, one is "Closure type", where every surfaces except absorption face are covered with sealant and the other type is "Open type" where every

Table 1. Mix Proportion

Mixture type	W/C (%)	Volume ratio of cement paste	Sand/Cement	Unit Weight (kg/m^3)		
				Water	Cement	Sand
OPC40	40	0.470	2.1	262	656	1399
HPC50	50	0.430	2.9	262	525	1505
OPC50	50	0.430	2.9	263	527	1505
OPC60	60	0.400	3.6	262	436	1584

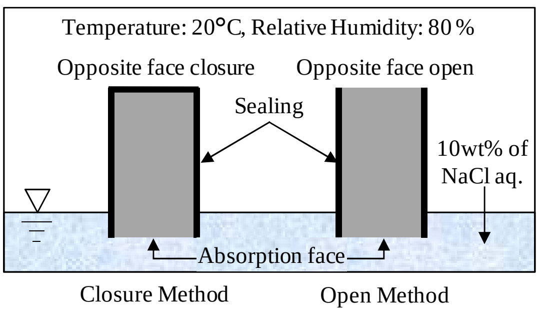

Figure 1. Water absorption test setup

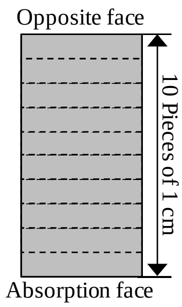

Figure 2. Specimen cut for testing

surfaces except absorption face and the opposite face are covered with sealant. The specimens are cut to obtain 10 slices of 1 cm each as shown Fig. 2 to measure water content and chloride ion content in each predefined absorption days (0, 1, 3, 7 days) for which the specimens are subjected. Then, the test pieces are oven dried at 105°C to measure the weight in absolute dry condition. Water content is assessed as relative water content in each test pieces which is obtained from ratio of water absorption content to saturated water content. Water absorption content of test piece can be determined from the difference between the weight at the end of experiment and the one in absolute dry condition. Also, saturated water content for each test piece can be determined from the difference between the weight in the absolute dry condition and one in the saturated condition. Chloride ion content in the specimens is measured as total chloride ion in each test pieces by JCI-SC4 (Japan Concrete Institute standard).

3. RESULTS AND DISCUSSION

3.1 Experiment on mortar under saturated condition

(1) Relative water content

Fig. 3 and Fig. 4 show temporal change of relative water content when absorption test is begun from saturated condition in mortar. In any of these cases, the water contents of all specimens in the specimen are almost 100 % at saturated condition, in spite of differences in cement types, W/C, sealing methods and absorption time.

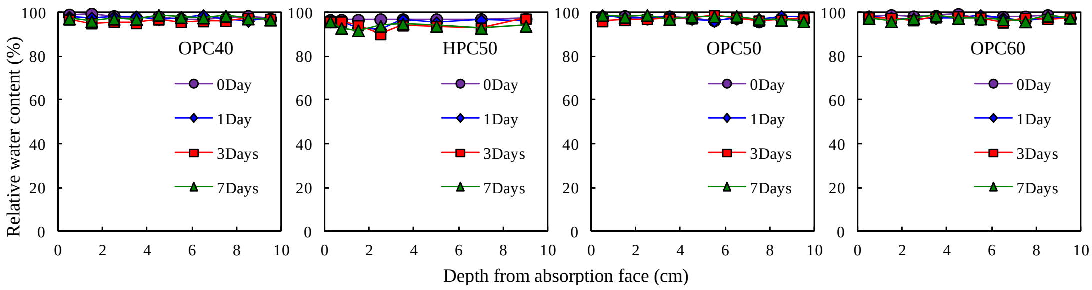

Figure 3. Distribution of relative water content by closure method

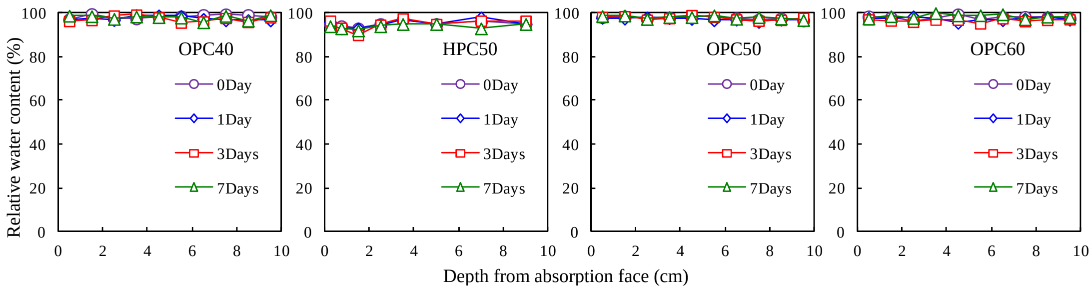

Figure 4. Distribution of relative water content by open method

(2) Total chloride ion content

Fig. 5 and Fig. 6 show temporal change of total chloride ion when absorption test is begun for mortar under saturated condition. In any of these cases, the profile of chloride ion penetration is similar to that of diffusion profile. Here, differences in total chloride ion content between closure method and open method at 7 days absorption for HPC50 is focused upon. The chloride ion, in case of open method, penetrated deeper into the specimen comparing to closure method. Such an effect is caused by migration of chloride ion due to water movement in compensation for evaporated water from opposite face which is exposed to atmosphere. Therefore, advection process of water in the specimens is considered to be the main factor. However, in the case of OPC, such differences in both types of sealing methods are not observed. Fig. 7 shows apparent diffusion coefficient of chloride ion after 7 days of absorption test. Chloride diffusion coefficient increases with increase in W/C. Secondly, regarding the differences in cement type, the variation is observed for different sealing methods in HPC50. On the other hand, such differences in coefficient due to sealing methods are not observed in OPC series.

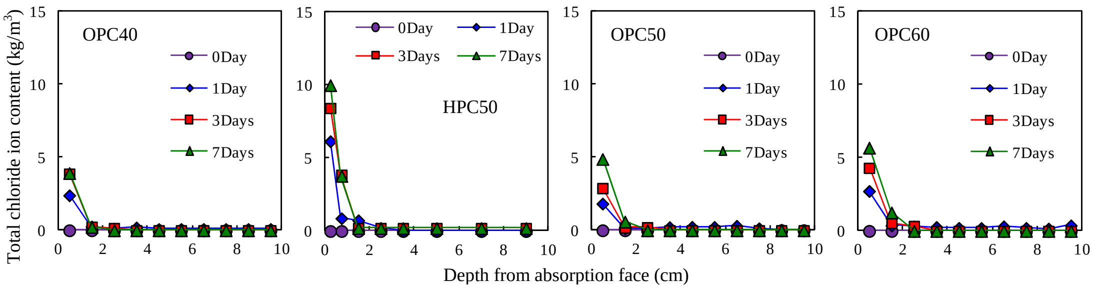

Figure 5. Distribution of total chloride ion content by closure method

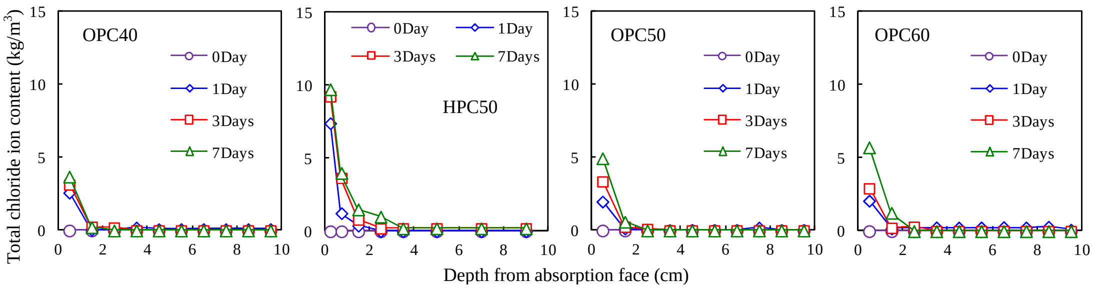

Figure 6. Distribution of total chloride ion content by open method

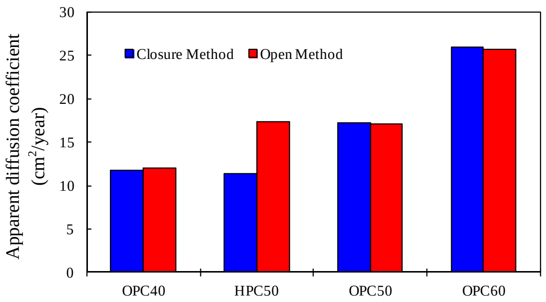

Figure 7. Apparent diffusion coefficient in each type of specimens

3.2 Experiment on mortar under absolute dry condition

(1) Relative water content

Fig. 8 and Fig. 9 show temporal change of relative water content when absorption test is begun for mortar under absolute dry condition. In all of the cases, the specimens rapidly absorb the water from absorption face to a depth of 4 cm after only one day of absorption. Water content in deeper positions exceeding depth of 4 cm from absorption face is confirmed for longer duration of absorption. In addition, difference in reduction of relative water content from 4 cm to 10 cm depth is observed for different sealing methods. In case of open method, the relative water content decreases gradually with a gentle slope. On the other hand, relative water content drastically decreases in closure method. This phenomenon is because of prevention of water movement by closing the opposite face which forms a layer of air in the specimens.

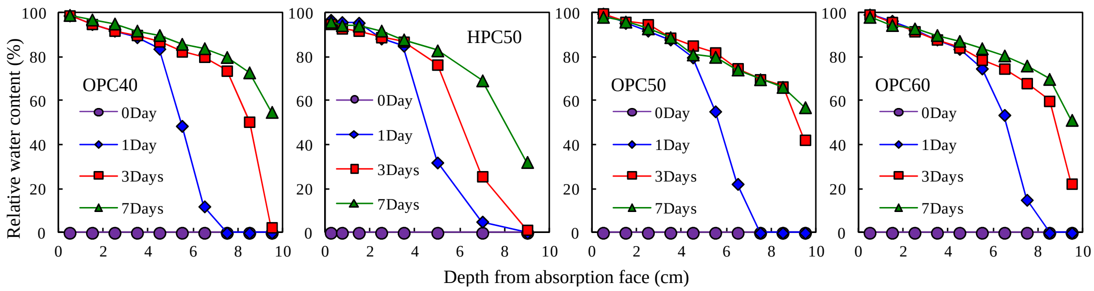

Figure 8. Distribution of relative water content by closure method

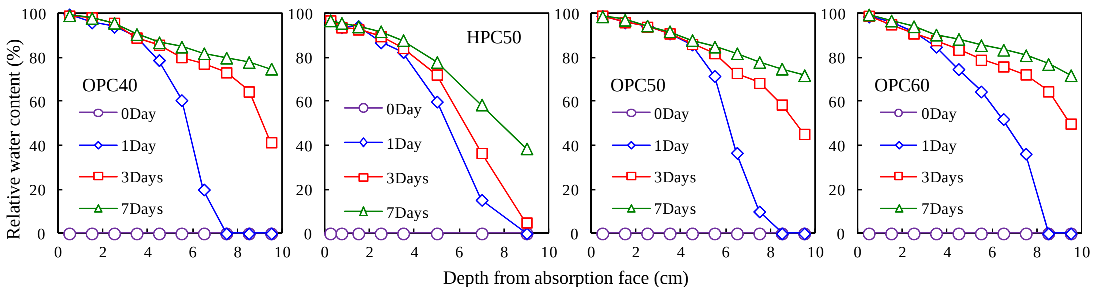

Figure 9. Distribution of relative water content by open method

(2) Total chloride ion content

Fig. 10 and Fig. 11 show temporal change of total chloride ion when absorption test is begun for mortar under absolute dry condition. In all cases, chloride ion penetrated to same depths of specimens as in case of water absorption content. This phenomenon occurs due to the advection process in the specimens with penetration of chloride ion within water movement. Also, the chloride ion moved deeper into the specimens with water movement as shown in Fig. 8 and Fig. 9. However, despite migration of the chloride ion with water movement, distribution profile of total chloride ion content does not match with the profile of relative water content. Especially at the surface region, profile of chloride ion content shows similar profile in case of diffusion process.

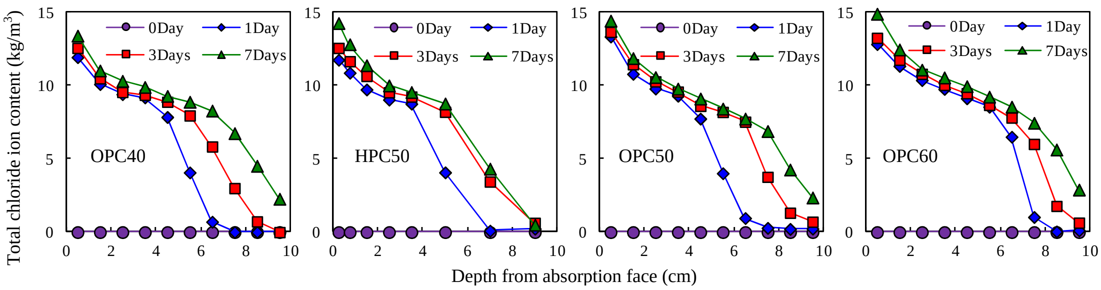

Figure 10. Distribution of total chloride ion content by closure method

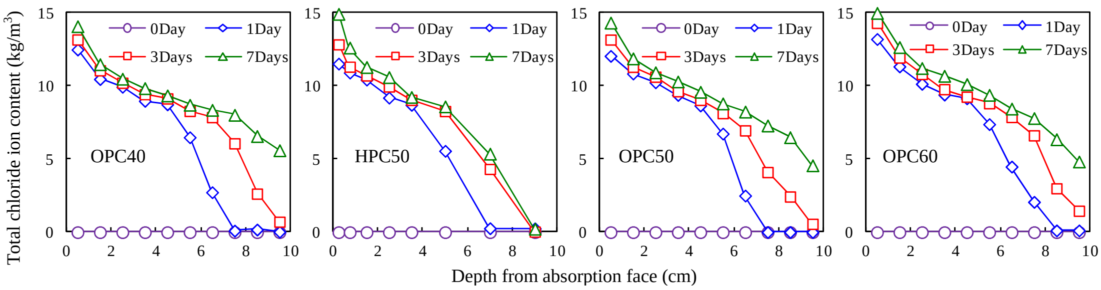

Figure 11. Distribution of total chloride ion content by open method

Therefore, measured value of total chloride ion content is compared with assumed value from the water content in mortar. The assumed value of total chloride ion content is calculated from relative water content by assuming NaCl concentration in water in mortar is always constant at 10% during water absorption. Fig. 12 and Fig. 13 shows result of comparison of measured value of total chloride ion content and assumed value. Distribution of both measured value and assumed value indicates an inflection point in distribution curves and the both trend lines has an intersection point. In case of region between surface of specimen and intersection point, difference between measured value and assumed value is regarded as the effect of diffusion process of chloride. On the other hand, in case of deeper region from intersection point in the specimens, rate of water movement is faster than that of chloride ion migration. The results of relative water content of mortars under absolute dry condition (in Fig. 8 and Fig. 9) are compared with the intersection points in Fig. 12 and Fig. 13. The intersection point matches with the relative water content of about 80%. According to a study on water movement [Akita et al. (1990)], water can move through capillary pores as liquid phase in the high water content region having more than 80 % of relative water content. On the other hand, in case of relative water content is much less than 80%, the water diffuses in the form of water vapour. Therefore, in deeper regions of specimens, it is considered that chloride ion content decreases drastically due to effects of water vapour. Also, the region of overlap of distribution of both measured value and assumed value shows total penetrated chloride ion content in advection process.

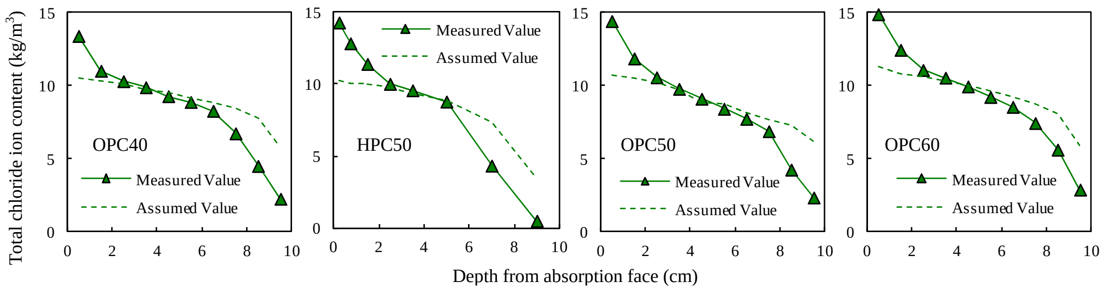

Figure 12. Comparison of measured value of chloride ion content with assumed value by closure method

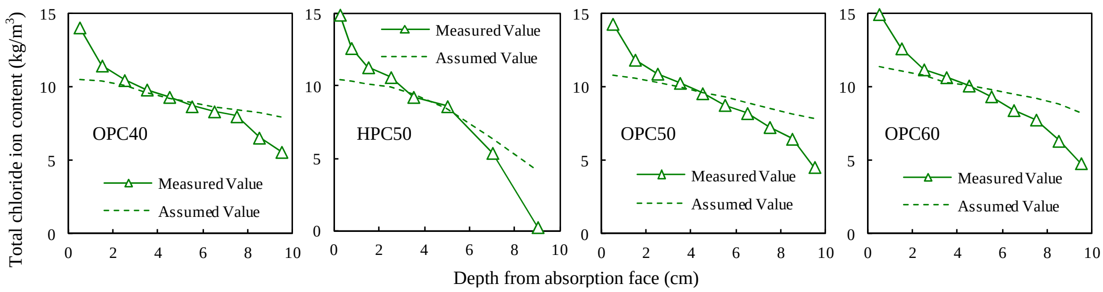

Figure 13. Comparison of measured value of chloride ion content with assumed value by open method

The apparent diffusion coefficients which are calculated without the effect of advection process from total chloride ion content at 7days absorption are illustrated in Fig. 14. Those coefficients are much larger than that obtained from the experiment on mortar under saturated condition. This variation is considered to be the effect of water movement in capillary pore with the difference in absolute dry and saturated conditions. From those results, water and chloride ion are assumed to have different penetrate mechanism and have own specific pore diameters to migrate depending on moisture condition in concrete. In addition, immobilization of chloride ion also occurs in the capillary pore.

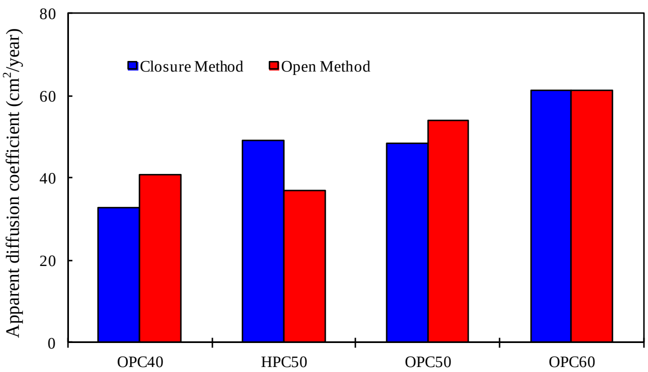

Figure 14. Apparent diffusion coefficient without effect of advection process in each type of specimens (absolute dry condition of mortar)

4. CONCLUSION

In this study, as experimental investigations, water absorption tests were carried out by using salt water to clarify internal water movement and penetration property of chloride ion in mortar with several moisture conditions. From the examination, following results were obtained:

(1) The property of water movement differs depending on cement types, W/C, initial water content and sealing methods.

(2) In case of no water movement, the chloride ion penetrates according to concentration diffusion process. Also, in case of considering water movement, penetration of chloride ion is governed by both advection process and diffusion process.

(3) In case of experiment on absolute dry condition of mortar, water moves through capillary pores as liquid phase at high water content region more than 80% relative water content. On the other hand, in case of relative water content is much less than 80%, the water diffuses in the form of water vapour.

(4) From the results of comparison of assumed value of total chloride ion with measured value, in deeper regions of specimen, it is considered that chloride ion content decreases drastically due to effects of water vapour. Also, the region of overlap of distribution of both measured value and assumed value shows total penetrated chloride ion content by advection process.

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