콘크리트의 균열부를 통한 염소이온 침투의 장기 실험연구

Long-Term Experiment of Chloride Penetration in Concrete through Cracks

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Abstract

Over the past few decades, considerable numbers of studies on the durability of concrete have been carried out extensively. The majority of these researches have been performed on sound uncracked concrete, although most of in-situ concrete structures have more or less micro-cracks. It is only recent approach that the attention has shifted towards the influence of cracks and crack width on the penetration of chloride into concrete. The penetration of chlorides into concrete through the cracks can make a significant harmful effect on reinforcement corrosion.

Author of this study examined the effect of cracks on chloride penetration by short tem experiment. However, it is necessary to accomplish the effect by long term experiment to get reliable goal. In this study, the long term experiment was carried out and the experimental result was compared with short term experiment. Crack tends to decrease with elapsed time because of self-healing. Especially this trend was obvious in concrete sample with wide crack with.

요 약

지난 수년간 콘크리트의 염소이온 침투와 유관되어 실험방법론 및 해석적 모델 기법의 개발에 많은 발전이 있어 왔다. 그러나 실제 콘크리트 구조물에는 다소의 균열이 존재하며 이는 장기 내구성에 큰 영향을 줄 수 있음에도 불구하고, 대부분의 연구들은 비균열의 콘크리트를 대상으로 연구되어 온 문제점이 있었으며 균열이 존재하는 콘크리트의 염소이온 침투에 대한 연구는 매우 드문 실정이다.

본 연구의 저자는 단기 촉진실험에 의하여 균열이 염소이온에 미치는 영향을 살펴보았다. 그러나 신뢰성있는 결과를 얻기 위해서는 장기 실험을 통한 고찰이 필요하다. 본 연구의 목적은 장기 및 단기 실험결과를 비교하였는데, 자기치료 효과에 의하여 균열이 시간이 경과함에 따라 감소하는 뚜렷한 경향을 확인할 수 있었다. 이러한 경향은 균열 폭이 클수록 자기치료에 의한 균열감소 효과가 더욱 뚜렷하였다.

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1. Introduction

Over the past few decades, a considerable number of studies on the durability of concrete have been carried out extensively. A lot of improvements have been achieved especially in both measuring techniques as well as modeling of ionic flows. However, the majority of these researches have been performed on sound uncracked concrete, although most of in-situ concrete structures have more or less micro-cracks. It is only recently that the attention has shifted towards the influence of cracks and crack width on the penetration of chloride into concrete. Although micro-cracks may not degrade the structural integrity immediately, they can affect the long-term durability performance of concrete structures by permitting penetration of aggressive substances into concrete easily. Accordingly the penetration of chlorides into concrete through the cracks can make a significant harmful effect on corrosion.

Author of this study accomplished short-term experiment to deal with chloride penetration through cracks in concrete[1]-[3]. For reliable study, however, it is necessary to carry out long-term experiment for this issue. The objective of this study is to examine the effect in the long term experiment. It is examined that self-healing can influence on the rate of chloride transport inwards significantly. In comparative study, crack effect of short term experiment is more obvious than that of long term experiment.

2. Experimental Design

2.1 Preparation of concrete

One concrete mixture was produced, as marked in Table 1. Concrete were exposed to air atmosphere at relative humidity of 65% and temperature of 20 ^oC for 26 days after 2 days of moist curing at temperature of 20 ^oC. After notch of size 5 × 5 mm and length 100 mm were created at the surface of concrete, two steel plates were attached in these samples.

LVDT was attached on the both sides of the concrete specimens to control CMOD. For fabricating artificial cracks, tensile stress was subjected to these two steel plates by the loading machine, 8872 series of INSTRON. Targeted crack widths were around 0.05 mm, 0.10 mm, 0.15 mm, and 0.20 mm. After cracks were generated in concrete specimens, notches were eliminated. Then, final size of the sample was 150 × 100 × 100 mm. The dimensions of cracked concrete specimens then were a diameter of 100 mm and a thickness of 50 mm. All sides of samples were coated with epoxy except for cracked side. Two cracked concrete specimens per intended crack width were prepared.

Table 1. Mixing Proportion of Concrete

28days strength (MPa)	Air (%)	Slump (mm)	G_{max} (mm)	w/c	Unit weight (kg/m^3)			
					Water	Cement	Sand	Gravel
28.5	4.5 ± 1.5	150 ± 10	16	0.50	185	370	720	1021

2.2 Examination of cracks

Before chloride immersion experiment, crack depth and crack width were measured by optical microscope Koeister. In general, epoxy impregnation is not needed for the measurement. After chloride immersion experiment, however, epoxy impregnated samples were used for crack examination. Following the crack, the crack width and crack depth of the section were investigated by using optical microscope DM RXP manufactured by LEICA Co. Ltd.

2.3 Natural immersion experiment of chloride

Cracked concrete samples were immersed in artificial sea water for 472 days, as shown in Figure 1. The temperature of the sea water was 20 ^oC and Table 1 shows the major constituents of the sea water. The water was renewed per two weeks. For measuring chloride penetration depth, the samples were splitted into three portions per sample and the surface was sprayed with 0.01 N $AgNO_3$ solution immediately. The distances of the colour transition were then measured by the vernier calipers.

Table 2 Chemical element of seawater

Chemical Element (*e*)	Cl	Na	Mg	SO_4	K	Ca	HCO_3
Volume (m mol/ *l*)	548	470	54	28	10	10	2

3. Results and Discussion


Figure 1 Immersion testing

Figure 2 presents crack width vs. crack depth. Although crack is healed in long term experiment, the ratio of crack width to crack depth is a bite same for all experiments.

Figure 3 shows decreased crack width with CMOD due to self-healing. As it is expected, crack tends to decreased for concrete with high CMOD. The trend is not clear, however, crack healing is obvious with CMOD.

Figure 4 shows chloride penetration depth of (un)cracked concrete. This trend is same with short term researches of author[1]~[3]. It is obvious that cracks with a large width have a significant effect on chloride penetration in short term experiment as well as long term experiment. Chloride penetration depth for the un-cracked part of the specimen (d_1) is a rather constant value (with some scatter) independent of the crack width. The chloride penetration depth (d_T) measured in the part of the specimen where the crack has been made increases linearly with increasing CMOD.

Figure 5 shows relative penetration depth (d_T / d_1), the ratio of chloride penetration of cracked concrete to that of uncracked concrete. The increase in penetration depth is correlated with CMOD. Two important examinations should be pointed out here. First, the chloride penetration through cracks is directly proportional to CMOD in long term experiment as well as short term experiment. Second, experimental result shows clearly that the relative penetration depth vs. CMOD is much slow in short term compared with short term experiment. It is thought that this is induced from self-healing.

Figure 6 represents chloride profile of concrete. Chloride contaminated border-line of long term concrete is quite ambiguous compared with that of short term concrete. This is because chloride had penetrated very slowly in long term concrete. Thus, chloride concentration profile with depth should be slow and this also leaded to fact that it was not easy to measure the border line with 0.01 N $AgNO_3$ solution.

According to previous studies of author[1]-[3], chloride ions couldn't penetrate up to the ending point of crack depths simultaneously as soon as cracks are created. The mostly likely reason for this is that cracks gradually become a narrow path for chloride penetration, going from the surface inwards. This rate of penetration is getting slower and slower going from the surface inwards. Another likely reason would be related to geometrical properties of cracks such as unconnectivity and tortuosity. It is inferred that self-healing can lead greatly to these kinds of geometrical properties of micro-cracks evolution, going from the surface inwards.

4. Concluding Remarks

There are many affecting factors which can influence on chloride penetration through crack for long duration and one of the representative factors seems to be self-healing. It is difficult to make out clearly the mechanism of self-healing. It is necessary to deal with the details by microstructure study. Next to the measurements of ingress through cracks it is becoming more and more important to be able to predict with models the exact crack widths and length in concrete structures to be able to design them for a desired service life.

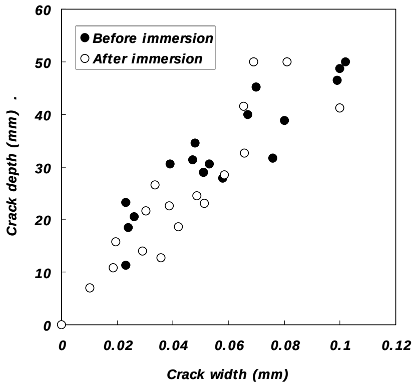


Figure 2 Crack width vs. crack depth

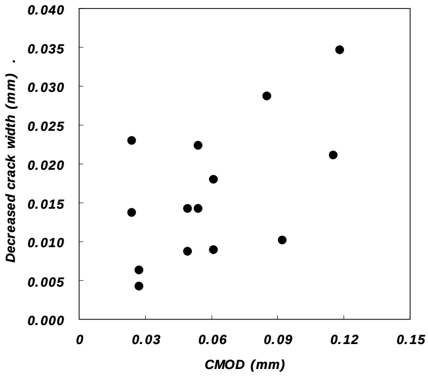


Figure 3 Decreased crack width due to self-healing

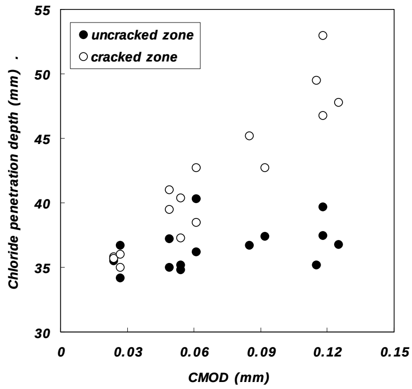


Figure 4 Chloride penetration depth

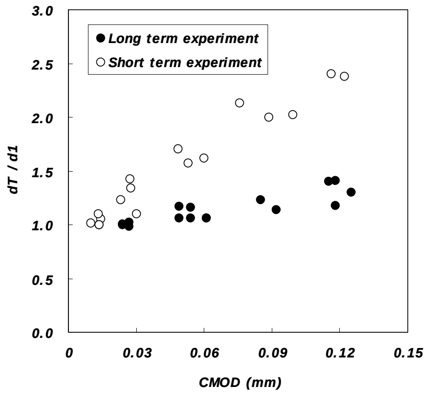
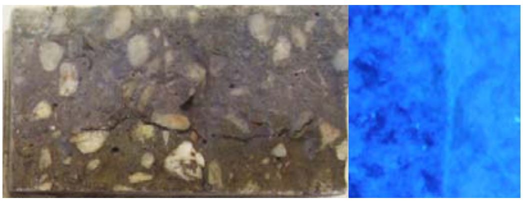


Figure 5 Relative penetration depth vs. CMOD

(a) short term exp.(left: Cl^- profile, right: crack picture)



(b)Long term ex. (left: Cl^- profile, right: crack picture)

Fig. 6 Chloride profile in cracked concrete (0.20mm CMOD)

References

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