

Efficiency of Chloride Ion Extraction in Different Applications

Graduate School of Engineering, Hokkaido University
Faculty of Engineering, Hokkaido University
Faculty of Engineering, Hokkaido University

Student Member Nguyen Thi Hai Yen
Fellow Hiroshi YOKOTA
Member Katsufumi HASHIMOTO

1. Introduction

Today, the severe effect of chloride ions on shortening the service life of reinforced concrete structure is uncontroversial, although the mechanism and the role of chloride ion in triggering the corrosion progress are still uncertain. The shortening service life influences not only to the budget, but also the sustainability issue, the issue which currently attracts a lot attention. Electrochemical chloride extraction has been studied and widely applied as one of techniques to mitigate the deterioration of reinforced concrete structures which is contaminated chloride ions (1-7). However, there are very few studies on intermittent application and the advantages of intermittent application are still uncertain (8-9). Therefore, in this study the efficiency of chloride ion removal on intermittent application and continuous application was discussed.

2. Experimental Procedure

Thirty three (33) reinforced concrete blocks with the cross section as shown in Fig. 1 were cast with the mix proportions as presented in Table 1. Ordinary Portland cement was used. After curing for 1 month at approximately 95% RH by covering the concrete blocks with wet burlap and 20 °C, they were coated with epoxy except the bottom surface. Then, they were immersed in 3.5 % NaCl solution where the free-epoxy surface exposed to salt solution with wet and dry cycle. Each wet and dry cycle included 6 hours of wetting following by 66 hours of drying at the condition of approximately 70% RH and 20 °C.

Table 1 Concrete mix proportions (kg/m³)

W/C	Water	Cement	Sand	Coarse aggregate
0.4	165	412	790	1020

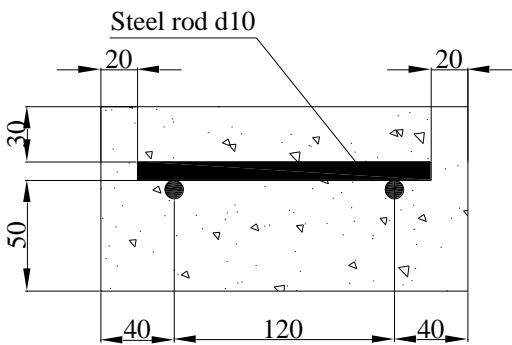


Fig. 1 Cross section of reinforced concrete block

After 60 cycles of immersing, since the chloride content in concrete at the zone beside the steel bars reached approximate 1.4-1.6 kg/m³, the extraction was applied 10 weeks with current density of 1 A/m² and saturated calcium hydroxide was used as electrolyte. 10 blocks were conducted with the continuous mode. The other 10 blocks were applied with intermittent mode where the current was turned on for 5 days and then following by turning off 2 days. The rest of concrete blocks reserved for operating the other tests. After the interval of two weeks of extraction, two blocks of each mode were stopped. The applied charge number after each certain period of applications is presented in Table 2.

Concrete powder was collected by drilling the block at different depths. The powder samples were ground by pulverizing machine with acetone as a lubricant and then dried in desiccator for 3 days by using an aspirator at 6 kPa.

The acid-soluble chloride content in these samples was analyzed in accordance with ASTM C1152/C1152M. Approximately 10 g of concrete powder was weighed in the Becker by using an analytical scale with the accuracy of ±0.0001 g. About 10 mL of deionized water was poured into the Becker. This mixture was dispersed to break any lumps by using a magnetic agitator. Then 20 mL of HNO₃ 1:2 was poured into the mixture and keep agitating at 60 °C within 10 minutes. After filtering the mixture through the filter paper, the filtrate was titrated with silver nitrate AgNO₃ 0.1 N.

Table 2 Applied charge number (A.hour/m²) at certain period of different applications

Weeks	2	4	6	8	10
Continuous Application	336	672	1008	1344	1680
Intermittent Application	240	432	624	816	1008

3. Results and Discussions

Figure 2 presents the remaining chloride content in concrete at the depth 4-5 cm from the concrete surface versus time of extraction. Approximate 50% to 57% of initial acid-soluble content was repulsed away that zone of concrete after first two weeks of extraction. It shows clearly that at first two weeks of extraction process the continuous application gave approximately 10 % more efficient on removing chloride than the intermittent application. That higher level of efficiency in

continuous mode was lower after 4 weeks and 6 weeks of extraction. At the end of 8 weeks and 10 weeks of extraction process, the efficiency in removing chloride at the zone beside concrete is not much different, although it seems slightly more efficient on the intermittent application.

From Fig. 2, it is also shown that the efficiency of removing chloride dropped quickly after first two weeks of extraction, especially in the continuous application, from the end of two weeks to the end of 4-week extraction, only 7 % of chloride ion was removed. The later period was also much lower, only approximately 3 % chloride was extracted for each two weeks.

It was similar in the intermittent application, however, at the later period, it showed a more efficiency than that in the continuous application. 10% of chloride were removed in the period from 2 to 4 weeks in extraction process. After that, for each two weeks, approximately 5-6% of chloride were removed until the end of the extraction process. Therefore, at the end of the process the efficiency of these applications was not significant.

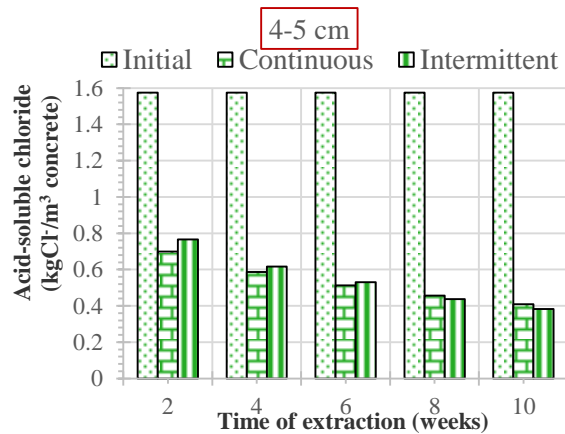


Fig. 2 Remaining of acid-soluble chloride content in concrete at the depth of 4-5 cm from the concrete surface

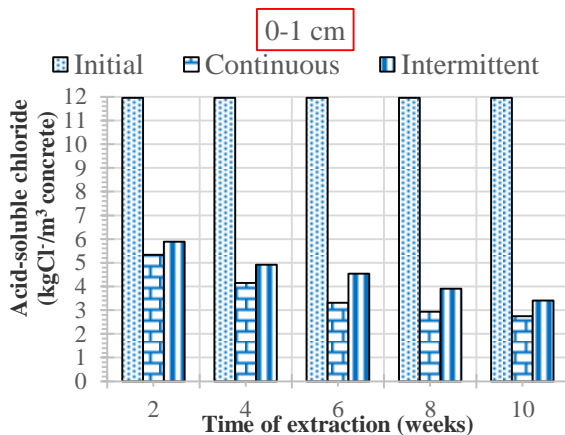


Fig. 3 Remaining of acid-soluble chloride content in concrete at the depth of 0-1 cm from the concrete surface

The chloride content which still remained on the concrete at

the surface of blocks after each period of extraction is shown in Fig. 3. In contrast to the zone beside the steel bars, that diagram shows that the remaining content of chloride in concrete since using the intermittent application is higher than that in the continuous application whole process of extraction. At first two weeks of extraction process, approximately 50% of chloride were removed. After that first two weeks the efficiency was significantly lower, it was about 10% in the period from 2 to 4 weeks and 5% in the period from 4 to 6 weeks. The later period, it was just about 1-3 % for each two weeks of extraction. At the end of the process, approximately 77% of chloride were removed in the continuous application and 70% in the intermittent application.

Although more than 70% of chloride were removed at the end of extraction process, the remaining chloride at the surface of concrete was still greatly high, approximately 2.9 to 3.5 kg/m³ of concrete. Consequently, the redistribution of chloride ions after the application was stopped is spontaneous. Therefore, coating the surface of concrete after extraction treatment seems necessary to prevent the further intrusion of chloride ions into concrete.

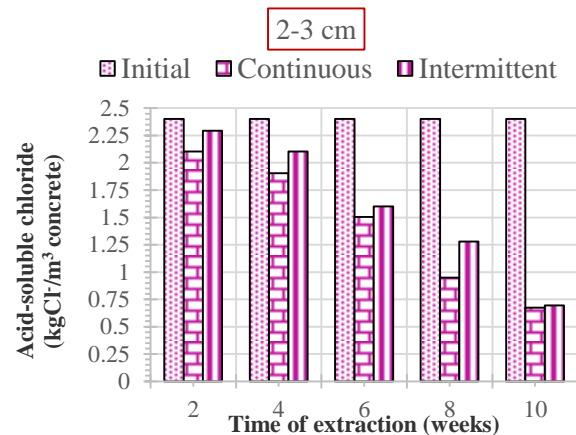
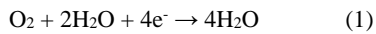


Fig. 4 Remaining of acid-soluble chloride content in concrete at the depth of 2-3 cm from the concrete surface

On the contrary to the concrete near the electrodes as steel bars or at the surface of concrete block, the removal of chloride in concrete at the middle zone, from 2 to 3 cm, as presented in Fig. 4 was much lower at first four weeks of the extraction process. Only approximate 10% of chloride were removed in continuous application within first two weeks. It was even lower than that in the intermittent application. There was no much difference in the following two-week- period of extraction progress, from 2 to 4 weeks.

However, at the later periods the efficiency was higher and it did not reduce significantly as the other depths. It is easy to understand in Fig. 4 that the most efficiency period in removing chloride at this zone was from 4 to 8 weeks of extraction in the continuous application, while in the intermittent application it lasted until the end of extraction process, 10 weeks.

As well-known, the generation of hydroxide ions takes place as the result of cathodic reactions as presented in Equations (1) and (2) during the current application. The more time the current is applied, the more concentration of hydroxide ions is generated.



Therefore, it can be understood that at first two weeks of extraction, when the concentration of chloride ions in pore solution beside the steel bars was still high, chloride ions are one of the main ions which carried the charge of the current beside hydroxide ions. However, since the generation of hydroxide took place and dominated in the ionic fluid, chloride with smaller concentrations showed less effect on the current transference. Consequently, the efficiency of chloride removal dropped quickly.

Nevertheless, while the ions in pore solution of concrete at the zones beside electrodes are impacted strongly and directly by the electrical field and the generation of hydroxide ions, which can certainly vary the relative concentration of these ions in pore solution, the influence of electrical field to the ions in pore solution at the middle zone is certainly less than that in the near-electrode zones. Furthermore, the repulsion of chloride and hydroxide ions from cathode can cause the stuck of it at the middle zone at the first four weeks of extraction process. After that period, since the concentration of chloride in ionic fluid was significant lower, that stuck could be resolved and chloride ions accumulated at that zone easily removed.

It is obvious that the number of charges which conducted in the continuous application was significantly higher than in the intermittent application as presented in Table 2. Accordingly, hydroxide ions were generated more at the cathodic zone, and it resulted in the lower efficiency in removing chloride at the later period compared to the intermittent application. Therefore, at the end of extraction process the efficiency of the two applications was insignificant. However, the much lower of total number of charges which applied in the intermittent application is assumed to cause less drawbacks, which is always the questionable issue since using electrochemical chloride extraction as a method to mitigate the deterioration of reinforced concrete structure exposed to chloride environment.

4. Conclusions

The following conclusions were drawn in this experimental study:

- 1) Approximate 50% to 60% of chloride ions were removed within first two weeks of extraction. After that period, the efficiency of extraction progress dropped quickly.
- 2) At the end of first four weeks, continuous extraction

showed a slightly more efficiency in removing chloride ions. However, since the hydroxide ions were generated during the application of the current the efficiency of intermittent application became more.

- 3) After 10 weeks of extraction process the efficiencies of the two applications were insignificantly different.

Acknowledgment

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