Verification of practical effectiveness of various applications of electrochemical chloride extractions for cement concrete

Maintaining and prolonging the service life of existing reinforced concrete structures are crucial contributions of civil engineers to solve the sustainability issues. Electrochemical chloride extraction (ECE) is one of the maintenance and repair methods to prevent further deterioration of a reinforced concrete structure that is exposed to chloride environments. It arose to answer the question that when the source of corrosion, chloride ions, is extracted or eliminated out the zone around steel reinforcement, it is not clear if the corrosion of steel reinforcement stops, the passive layer is re-passivated or the deterioration progress could be slowdown. Theoretically, the principle of ECE is similar to cathodic protection since a direct current is applied on reinforced concrete structure in which steel reinforcement is used as a cathode and a temporary anode is set up on the surface of concrete. However, the application of the high current or the large quantity of cumulated-applied charge number by using ECE can result in the adversities on binding capacity of hydrated cement products or the diffusibility of concrete matrix. Consequently, these adversities would affect future durability of reinforced concrete structure. Therefore, how to reduce the charge number applied with preserving the efficiency of ECE needs to be investigated. Furthermore, while there have been many structures using fly ash and granulated blast furnace slag as mineral admixtures to improve durability of reinforced concrete structure, there are very few studies of ECE on concrete or cement pastes containing them. Therefore, this research included two objectives.

Firstly, the effects of electrical current application thanks to the conduct of ECE on hydrated cement products of cement pastes, especially on C-S-H phase, were investigated. A pair of modified migration cells were used with the applied current density of 4.5 A/m² and synthesized pore solutions as electrolytes for 8 weeks. Three types of cement pastes with the size of 40 mm by 40 mm by 160 mm were prepared with the water-to-binder ratio of 0.4 including ordinary Portland cement (OPC), fly ash cement (FC) and ground granulated blast furnace slag cement (SC) pastes. After casting, these paste specimens were cured in saturated calcium hydroxide for three months before stopping the hydration process by immersing them into acetone. These pastes were sliced into the size of 40 mm by 40 mm by 5 mm before applying the extraction. Chloride source was supplied by adding 1.5 percent of sodium chloride with respect to weight of binder during mixing cement pastes. After extraction, the acid-soluble and water-soluble chloride contents significantly reduced. Portlandite content increased proportionally with the time of extraction in OPC and FC pastes. Some unsteady gel phases were
obtained after a short time the extraction was stopped. Furthermore, the alteration and decomposition of C-S-H were inevitable with different rates depending on the type of cement. The breakage of the chain of calcium silicate hydrate was obtained and the rates of breakage seemed proportionally to the period of ECE application, especially the dimer-silicate chain. Therefore, how to lessen the time of the electrical current application or in another term how to reduce the amount of applied charge number, but still preserving the chloride removal efficiency is necessary to study. Sequentially, intermittent application of ECE needs to be taken into account.

Secondly, based on the necessity of carrying on more study on intermittent application of ECE in order to remediate the adversities of ECE by using large amounts of cumulated-applied charge number, the experimental research program was conducted. It focused on investigation of the capacity of intermittent application of ECE on extracting chloride compared to continuous application and finding out the adequate period for current-off and current-on intervals in order to uphold or preserve the chloride extraction efficiency. Two modes of intermittent applications and a continuous application of ECE were conducted on reinforced concrete blocks with the size of 20 cm by 20 cm by 10 cm. These concrete blocks were contaminated chloride by exposing the NaCl solution containing 3.5 percent of chloride ions with wet and dry cycles. In each cycle, the concrete blocks were immersed in salt solution for 6 hours and then dried for 66 hours. After 60 cycles of immersing, since the chloride content in concrete at the zone beside the steel reinforcements was approximately 1.4-1.6 kg/m$^3$, the extraction was applied with the electrical current density of 1 A/m$^2$ with respect to concrete surface. The result indicated that intermittent applications expressed much greater charge-efficiency than continuous application in removing chloride, though the quantity of chloride extracted in three modes were approximate. Since the cumulated applied charge number exceed 800-900 A.hour/m$^2$, concrete matrix tended to be unstable and the decomposition of C-S-H phase may take place. Furthermore, sodium ions inclined to agglomerate with hydroxide, a product of cathodic reaction, to form NaOH in concrete at the zone beside steel reinforcement.

The less adverse effects of ECE on C-S-H phase was obtained by using the intermittent application. Conclusively, intermittent application is the potential means to apply ECE in order to remediate the adverse side effects of continuous application of ECE on concrete properties.

Furthermore, this research figured out that intermittent applications would be conducted with sophisticated applications which comprise of several different periods of current-off and current-on. At the first stage of extraction process, the time for current-on could be lasted for couple days before interrupting it for approximately 2-3 days. However, after that first stage, the time for current-on should be lessened, approximately 1.5-2 days, and the break of the electric current should be iterated more often during conducting ECE.