International Journal of Industrial Engineering
http://ijie.gjpublications.com/
Vol. 1, No. 4, 2017. Page 129-134.
ISSN: 2456-8449.

Research Article

Study on Effectiveness of Electrochemical Re-Alkalization in Concrete

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Abstract

Electrochemical Re-alkalization (ER) is a method of regaining concrete alkalinity which is lost by carbonation reaction. The steel reinforcement corrosion induced by carbonation and chloride can be controlled by a non-destructive alternative method based on the application of an electric field to the steel-concrete system by an external anode. Reinforced concrete cubes were casted using the OPC (Ordinary Portland Cement) with a water cement ratio of 0.45. Cathodic polarization measurement test were conducted and the current flow was monitored for different electrolyte such as saturated $Ca(OH)_2$, saturated $Ca(OH)_2$ solution+0.1 M $CaCO_3$ and saturated $Ca(OH)_2$+Cement extracted solution. The reinforced concrete cubes were treated with dilute HCl to simulate the degraded concrete and subjected for electrochemical Re-alkalization treatment. The Re-alkalization treatment was applied for 3 days with a current density of 1 A/m² and the electrolyte filled in the containers with 0.1 M $CaCO_3$ + saturated $Ca(OH)_2$ solution and 0.1 M extracted cement solution + saturated $Ca(OH)_2$ solution. The reinforcements (cathode) are connected to the negative terminal and the SS container is connected to the positive terminal of the power source. After the treatment is completed, the increase in alkalinity was observed by spraying Phenolphthalein indicator. The pH values of the treated concrete samples have increased pH above 12.5. The compression strength of the treated specimen shows higher gain of about 25%.

Keywords: Degraded Concrete; Carbonation; Re-alkalization; Alkalinity; Compression Strength.

Introduction

The steel reinforced concrete structure serves better in well maintained condition. In concrete, the alkaline chemicals present, passivity the metal surface so that it does not rust/corrode. But, widespread deterioration of concrete structures is encountered, more significant among the coastal structures, due to the corrosion of the embedded steel, in spite of the alkalinity of the concrete. Among the mechanisms of deterioration, corrosion due to carbonation usually occurs in reinforced concrete structures (RC), especially in urban areas, which usually have a high concentration of carbon dioxide emitted into the environment by vehicles or industrial plants. Carbonation (process by which CO_2 reacts with the alkalis present in the pore solution of the concrete matrix) reduces the alkalinity of the concrete to pH values of 9.0 or less [1].

Reinforced concrete is a composite material that relies on the high compressive strength of concrete and the high tensile strength of steel for its mechanical performance. Steel has poor corrosion resistance and concrete has good anti-corrosion properties [2]. The hydration process of concrete leads to the formation of hydroxides which raises the pH level of the cement to around 12.5 and provides a stable oxide layer on the steel surface, which prevents the anodic dissolution of the steel. Reinforced concrete failure is caused by the corrosion of the steel reinforcing bars as a result of the de-stabilization of the oxide layer. When the passivity of the steel partly or completely breaks down, either as result of carbonation or chlorides, the corrosion will start. This means that the electrochemical potential of the steel locally becomes more negative and forms anodic areas, while the other portions of the steel which have the passive layer interact will act as catchment areas for oxygen and will form Cathodic areas.

Re-alkalization treatment has been used for repairing concrete with severe carbonation in

Received: 11.07.2017; Received after Revision: 15.07.2017; Accepted: 16.07.2017; Published: 31.07.2017

concrete cover. The principle of the method is based on the mass transfer of ions in an electrolyte solution due to the influence of an external electrical field. The technique involves the application of a high intensity DC current for a short period, typically a few days, between steel reinforcements acting as a cathode and an extended anode placed in an external electrolyte which is in contact to the surface of the concrete. The aim of the treatment is to re-establish high alkalinity around the steel reinforcement by promoting the production of hydroxyl ions at the steel cathode and inward migration of alkali ions from the external electrolyte [3].

In order to achieve this aim, alkali solutions such as calcium carbonate have been commonly used as the external electrolyte. In the practice, the preparation of ER is similar to Cathodic protection systems, but Cathodic protection is a permanent system, and ER is a temporary measure (3 days). The ER is achieved by applying a voltage between an anode and cathode (Rebar). Under the passage of electrical current (up to 1 A/m^2), the electrolyte, an alkaline solution is transported into the concrete toward the re-bars [4, 5]. At the same time, the electrochemical production of hydroxyl ions increases the alkalinity on the surface of re-bars; re-passivity re-bars, and prevents the corrosion to occur. This method can raise the alkalinity of concrete to a pH greater than 10.5 [6,7].

Research methodology

Experiment based on electrochemical polarization

Polarization measurements were carried out with NI Hardware and LAB View Coding under potentiodynamic conditions. This instrument itself is having programs to evaluate corrosion parameters such as corrosion current (Icorr), corrosion potential (Ecorr). Three electrode cell consist of a specimen as a working electrode, Ag/AgCl electrode as a reference electrode, and Platinum cylinder as a counter electrode was used in this experiment. The working electrode was re-barring steel disk axially embedded in a Teflon holder to offer a flat disc shaped exposed surface area of 0.708 cm^2. The steel discs were mechanically polished with different grades of emery papers up to mirror finish, degreased with acetone then rinsed with distilled water and dried before each electrochemical experiment. Specimen was immersed in Saturated $Ca(OH)_2$ solution, Saturated $Ca(OH)_2$solution+$CaCO_3$ and Saturated $Ca(OH)_2$solution+cement exacted solution.

Prepared solution will be placed in beaker and place steel cylinder into the solution in beaker and place the calomel electrode in other beaker containing distilled water connect those two solutions with glass tubes containing (KCL+ Agar) gel and then connect the whole assembly to the NI Hardware and LAB View Coding software (Figure 1).

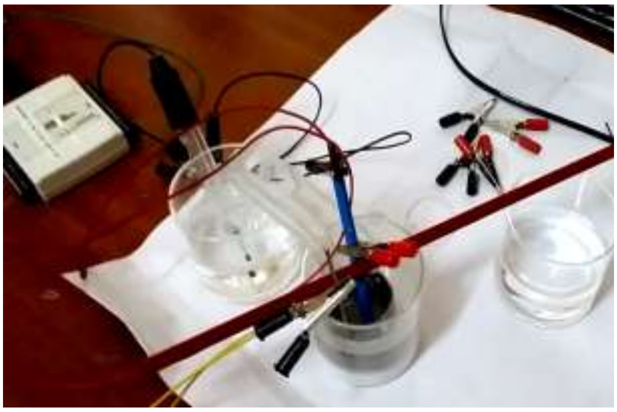

Figure 1. Electrochemical polarization setup

Preparation of specimens

Reinforced concrete cubes of size 100mm×100mm×100mm of 15 cubes were casted using OPC and 0.45 water to cement ratio according to mix design of M_{35} grade of IS 10262-2009 (Table 1). The reinforcement consisted in three parallel re-bars of 10 mm diameter for each cube 3 steel re-bars of 8 cm were embedded in a concrete cover and leave 4 cm on the surface of the concrete cubes and keep it for 24 hours, after that removed the moulds. Keep the cubes in the autoclave machine for 18 hours for curing that completes the 28 days of curing (Figure 2).

Table 1. Mix proportion of M_{35} grade concrete

Final Mix Ratio	Cement	FA	CA	W/C
kg/m^3	476	803.3	849	214.24
Ratio	1	1.68	1.78	0.45

Acid treated cubes

The nine reinforced concrete cubes of size 100mmx100mmx100mm were immersed in 5 liter water with 250 ml dilute HCl for an hour after 28 days of curing (Figure 3).

Figure 2. Reinforced concrete cubes after casting

Figure 3. Reinforced concrete cubes immersed in dilute HCl

Electrochemical Re-Alkalization Treatment

The ER treatment is applied for 6 acid treated reinforced concrete cubes of size 100x100x100mm and then placed in the steel container (Figure 4). The 3 left side container containing 0.1 M $CaCO_3$ with saturated $Ca(OH)_2$ solution is filled up to below the surface of the cubes and the remaining 3 right side container containing 0.1 M cement extracted solution with saturated $Ca(OH)_2$ solution is filled. A constant current of 1 A/m² of steel reinforcement was applied between the two electrodes for 3 days, the cathode (-) charge will be connected to the steel rebar and the anode (+) charge will be connected to the steel container. During treatment, the electrolyte is transported into the carbonated concrete. The dominant transport mechanism may vary, but electro osmosis and migration of ions are the two main contributors [8]. Simultaneously, electrolysis at the steel surface produces a very alkaline environment [9].

The positive ions in the electrolyte (an alkaline solution) move towards the reinforcement whilst hydroxyl ions are produced at the steel reinforcement due to the reduction of water [10]. The method, is best applied to carbonated concrete where the material is still sound.

Figure 4. ER treatment for acid treated reinforced concrete cubes

Results and discussion

Phenolphthalein indicator test

Phenolphthalein is widely used as a pH indicator for concrete pH measurement. The concrete surface after application of phenolphthalein indicator, if it changes the pink color that shows the expression of higher pH .The colorless surface indicates reduction of pH on the concrete may be due to acidification or carbonation process .The Re-alkaline process supposed to make degraded concrete into highly alkaline conduction. In our project the Re-alkalized treated with both $Ca(OH)_2$+$CaCO_3$ solution and $Ca(OH)_2$+cement extracted solution shows buildup of alkaline condition on the acid treated specimen.

The figure 5 shows clearly that the more alkalinity created in $Ca(OH)_2$+cement extracted solution. The figure 6 shows the loss of pH due to acid treatment in which the surface of the concrete does not turn into pink color.

Figure 5. Phenolphthalein indicator sprayed in the fresh fracture Re-alkalized treated cut specimen

Figure 6. Phenolphthalein indicator sprayed in acid treated cut specimen

Polarization test result

In the figure 7, the red curve i.e. saturated $Ca(OH)_2$ solution+$CaCO_3$ belongs to 0.4 mA, and black curve i.e. saturated $Ca(OH)_2$+ Cement extracted solution belongs to 0.6 mA. In the figure 8 the red curve i.e. saturated $Ca(OH)_2$ belongs to 0.004 mA.

The Cathodic polarization measurement shows the current flow using different electrolyte such as saturated Ca(OH)2, saturated Ca(OH)2 solution + 0.1M CaCO3 and saturated Ca(OH)2+Cement extracted solution. The Cathodic polarization result shows that the saturated Ca(OH)2 solution has very less current for electrochemical Re-alkalization process. In the case of saturated Ca (OH) 2 solution +CaCO3 has shown 0.4mA current and finally for saturated Ca(OH)2+Cement exacted solution has shown 0.6mA current. Based on the above evaluation higher the mobilization of hydroxyl ions, in the anode side this is the very well evidence in the Electrochemical Re-alkalization experiment.

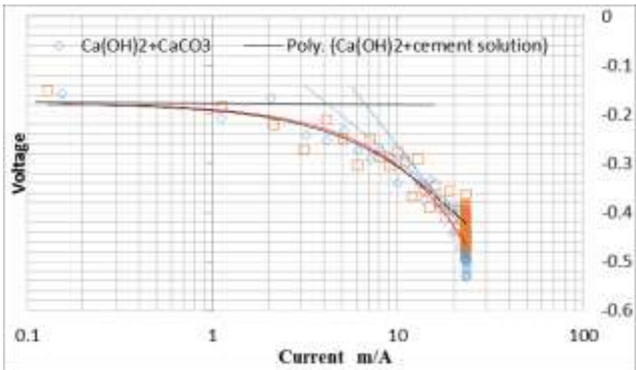

Figure 7. Polarization test graph for 2 samples

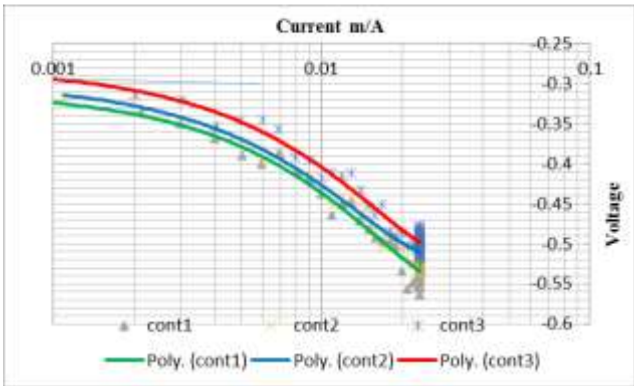

Figure 8. Polarization test graph for $Ca(OH)_2$ sample

pH test result

The figure 9 shows the state of pH in different layers of the different condition of the concrete .The acid treated specimen got reduced to 9.7 pH from the controlled specimen which is 11.7 pH. The acid treated specimen were subjected to Re-alkalization process with different electrolyte for 72 hours .Re-alkalization treated with $Ca(OH)_2$ solution +$CaCO_3$ specimen shown higher pH about 12.47 and the Re-alkalization treated with $Ca(OH)_2$+cement extracted solution shown more pH ,reach to 12.57.

Titration test result for chloride

The figure 10 shows the chloride ion presence is more in the acid treated specimen.

Where as in the Re-alkalization treated specimen less chloride ion were present.

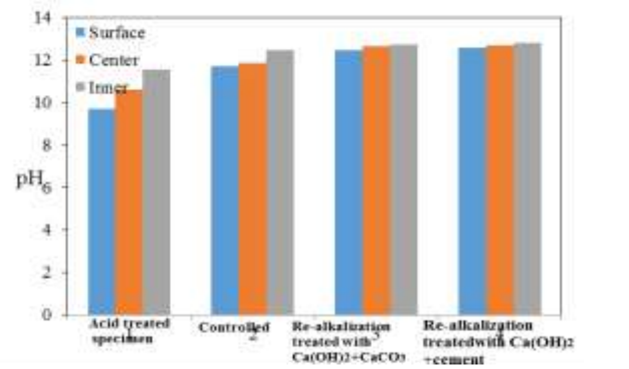

Figure 9. The pH test results for four types of specimen

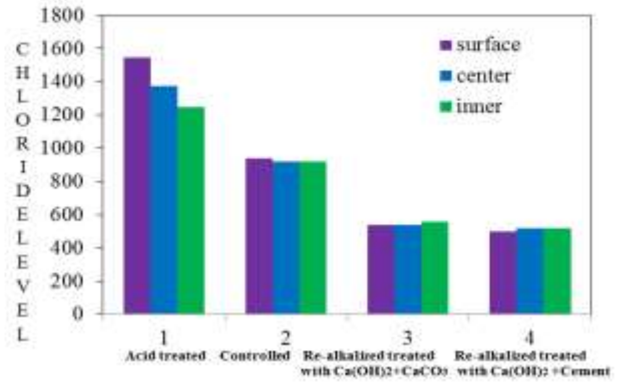

Figure 10. Titration graph for four types of specimen

Compression test result

The specimens were subjected to compression strength test, in that the acid treated specimen shows almost equivalent to controlled specimen (Figure 11). But Re-alkalization treated with $Ca(OH)_2$ solution+ $CaCO_3$ specimen shown higher strength, in that Re-alkalization treated with $Ca(OH)_2$+cement extracted solution specimen has got increased by 25% of the strength.

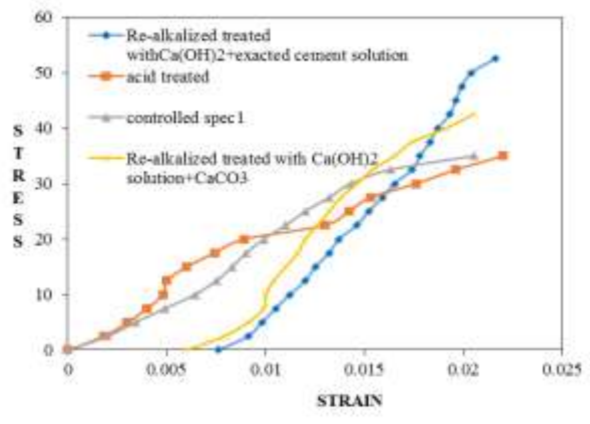

Figure 11. Compression test graph for four types of specimen

Conclusions

The Cathodic polarization measurement shows the current flow using different electrolyte such as saturated $Ca(OH)_2$, saturated $Ca(OH)_2$ solution +0.1 M $CaCO_3$ and saturated $Ca(OH)_2$+ Cement extracted solution. In that saturated $Ca(OH)_2$+Cement extracted solution has shown higher current of 0.6mA. The higher current flow makes more mobilization of hydroxyl ions to the anode side that is very well evidenced in the Electrochemical Re-alkalization experiment. The pH values of Re-alkalization treated concrete with $Ca(OH)_2$ solution +$CaCO_3$ specimen shown higher pH about 12.47 and the Re-alkalization treated with $Ca(OH)_2$ + Cement extracted solution shown more pH, reach to 12.57. The chloride ion presence is more in the acid treated specimen, where as in the Re-alkalization treated specimens less chloride ion were present. Those treated specimen were subjected to compression strength test, in that the acid treated specimen shows almost equivalent to control specimen. But Re-alkalization treated with $Ca(OH)_2$ solution+ $CaCO_3$ specimen shown higher strength, in that Re-alkalization treated with $Ca(OH)_2$+Cement extracted solution specimen has got increased strength by 25%. Phenolphthalein indicator sprayed on the Re-alkalization treated with both $Ca(OH)_2$+$CaCO_3$ solution and $Ca(OH)_2$+cement extracted specimen, in which the colorless turn into pink color shows buildup of alkaline condition . In the case of acid treated specimen the surface of the concrete does not turned into pink color.

Conflicts of Interest

Authors declare no conflict of interest.

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