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Effectiveness of Galvanic Protection on the Reduction of Chloride Content in Concrete

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ABSTRACT

Protection of reinforcement corrosion is one the paramount task in the concrete structures exposed to marine environment. This is mainly caused by the chloride ingress and break down of passivity. In such a situation the foolproof solution lies in maintaining a chloride free passive environment around the steel throughout the service life of the concrete structures. The present investigation deals with the evaluation of effectiveness of galvanic protection on the reduction of chloride content in concrete. Towards this objectives, the performance of galvanic protection of steel in concrete was evaluated on experimental concrete specimens of size 150 × 150 × 300 mm were cast with chloride uncontaminated and chloride contaminated concretes. The cathodic protection system was energized by installing a ribbon type magnesium composite anode inconjuction with ion conductive polymer backfill at the anode concrete-interface and the experiment was continued to over a period of 600days. At the end of every 10th day, the periodical data with regard to cathodic protection was measured. After a specific period, the concrete core samples were collected and the water soluble chloride was determined upto different distance from anode. The result showed that in the case of control system (wit out CP), the chloride concentration increased with increasing depths and also a usual diffusion type curve was obtained; whereas a lower level of chloride (near steel) and a linear profile is exhibited for the concrete specimens with CP applied system. This supports to assertion that the chloride ions are moved away from cathode (steel) by the action of cathodic protection.

Key words: Reinforcements, chloride ions, chloride profile, concretes, cathodic protection.

1. INTRODUCTION

The corrosion prevention techniques enhance the cost effectiveness and durability of reinforced concrete structures. Since metal surface is covered by passive film due to the stable alkalinity offered in concrete. (pH = 13), which prevents the steel rebar from corrosion [1,2]. Nevertheless, the aggressive chloride ions ingresses through the micro pores of the concrete surface, reaches steel to causes break down of passivity and ultimately initiate the corrosion process at the steel surface [3].

The role of water soluble chloride in the acceleration of steel rebar corrosion has been reported by several authors [4, 5, 6]. It is pragmatic that the rebar corrosion is initiated when the tolerable limit of chloride in concrete exceeds 0.6 kg/m^3 or 0.2 % [8,9]. The most imperative contamination of concrete is due to the numerous usage of deicing salts or the marine environment. In such a situation, cathodic protection is one of the fool-proof solution to stop the corrosion process and to sustain the chloride free passive environment around the steel reinforcement in concrete [10, 11]. The analysis of chloride profile obtained were also related to the gravimetric weight loss of reinforcement [12, 13]. The chloride profile is also correlated with the alkalinity of concrete and percentage of chloride reduction in various environments.[14]

The accelerated steel reinforcement corrosion is reported due to the reaction of critical amount water soluble chlorides exist in concrete. In this present investigation, the retrieved concrete samples were chemically analyzed to evaluate the active role of free chloride on rebar corrosion.

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The effective performance of galvanic CP system was evaluated by analyzing the chloride content in concrete for various depths to comprehend its effects.

2. EXPERIMENTAL APPROACH

2.1. Casting of concrete specimens

Figure 1 shows the dimensional details of experimental concrete specimens used in this study. In this present investigation, the experimental concrete specimens of size 150mm × 150mm × 300mm were cast using 1: 1.53: 1.93 mix proportion with a water cement ratio of 0.50. Ordinary Portland Cement (OPC) 43 grade cement was used to cast all the experimental concrete specimens. Before casting, the aggregates were meticulously washed with double distilled water to remove any interfering ions present in the aggregates. Two set of concrete specimens were cast. In one set, no chloride was added while in another set 1% chloride by the weight of cement was dissolved in double distilled water and added with concrete mixture so as to make homogenous medium. Two numbers of cold twisted deformed rebars of size 16mm in diameter and 200mm in exposed length was pickled and derusted in a standard mineral acid, washed in running water, air dried and embedded in concrete at a clear cover of 50mm from the top surface of the concrete as shown in figure 1.

2.2. Cathodic protection

A 10mm wide and 20mm long strip type magnesium composite anode was installed at the slot provided in the concrete surface and fixed with the help of nonmetallic clamps. Similarly a 10mm diameter and 20mm long ionic conductive polymer backfill in sheet form was inserted in between the anode-concrete interface. The cathodic protection system was energized by short circuiting the anode and the cathode (steel) terminals. The potential of steel got shifted towards the cathodic direction. The CP test was continued over a period of 600days. The galvanic current flowing through the anode to cathode (steel reinforcement) was also measured at an irregular intervals and the galvanic current profile was compared

2.3. Chloride content determinations

At the decisive stage of experiment, the galvanic protection experiment was terminated, dismantled and core samples were collected for various depths from anode to cathode steel. Then the core samples of 10mm, 20mm, 30mm, 40mm & 50 mm were sliced and ground in to fine powdered to pass 300mm sieves as shown in figure 2. The aqueous extract was prepared by by digesting 1 part of powder mass with 1 part of triple distilled water for 24 hours, stirred and shaken in a mechanical shaking machine for one hour and filtered. A specific volume of extract is pipette out to a clean conical flask and titrated against 0.01N $AgNO_3$ as per the standard analytical procedure [15]. The chloride content was expressed in terms of weight % to cement. The results were also plotted against the gravimetric weight loss of embedded steel rebars.

2.4. Determination of alkalinity

The aqueous extracts were prepared for the core samples of 10mm retrieved from near anode and near cathode steel. Alkalinity was measured by dipping the glass membrane pH electrode into the standard volume of aqueous extract using a pH meter (Orion Star-A 111 pH Bench top meter). Prior to measurement, the glass membrane electrode was cleaned in deionised water and calibrated using the standard buffers 4.0 and 9.2. The alkalinity results are discussed.

3. RESULTS AND DISCUSSION

The results of analysis of water soluble chloride profile for M30 grade chloride free concrete (control system) subjected to with CP and without CP (control system) treated under atmospheric exposure are shown in figure 3. It can be seen that as the chloride concentration is generally increases with increasing

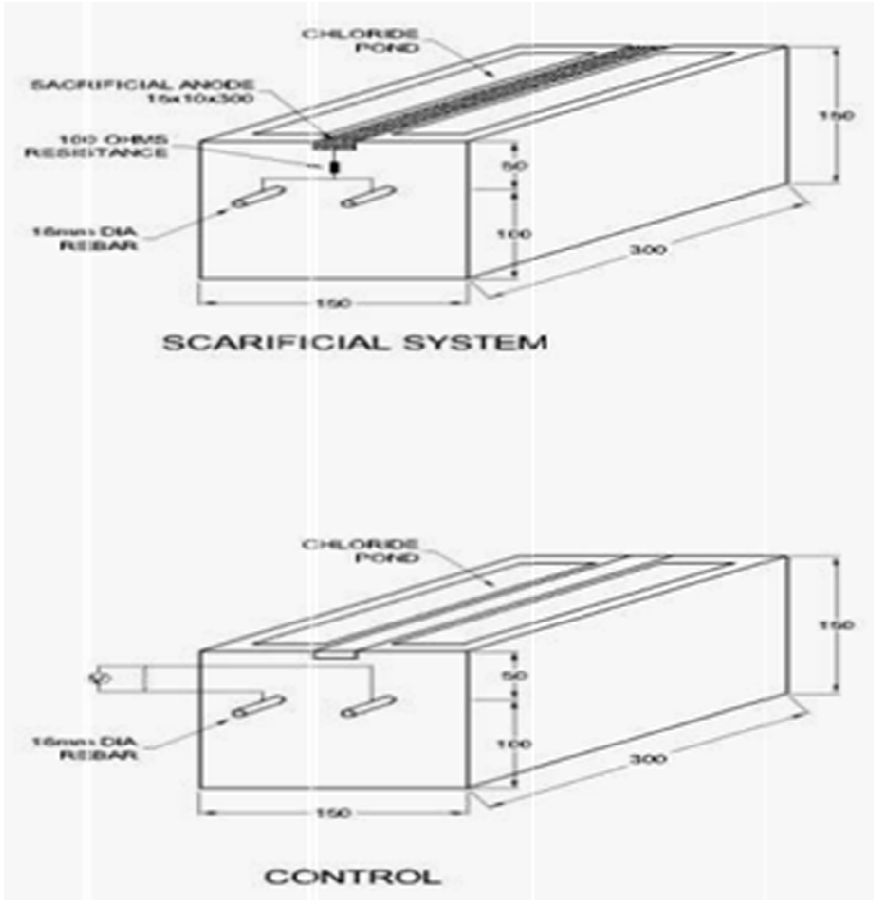

Figure 1: Schematic diagram of concrete specimens used for cathodic protection experiments

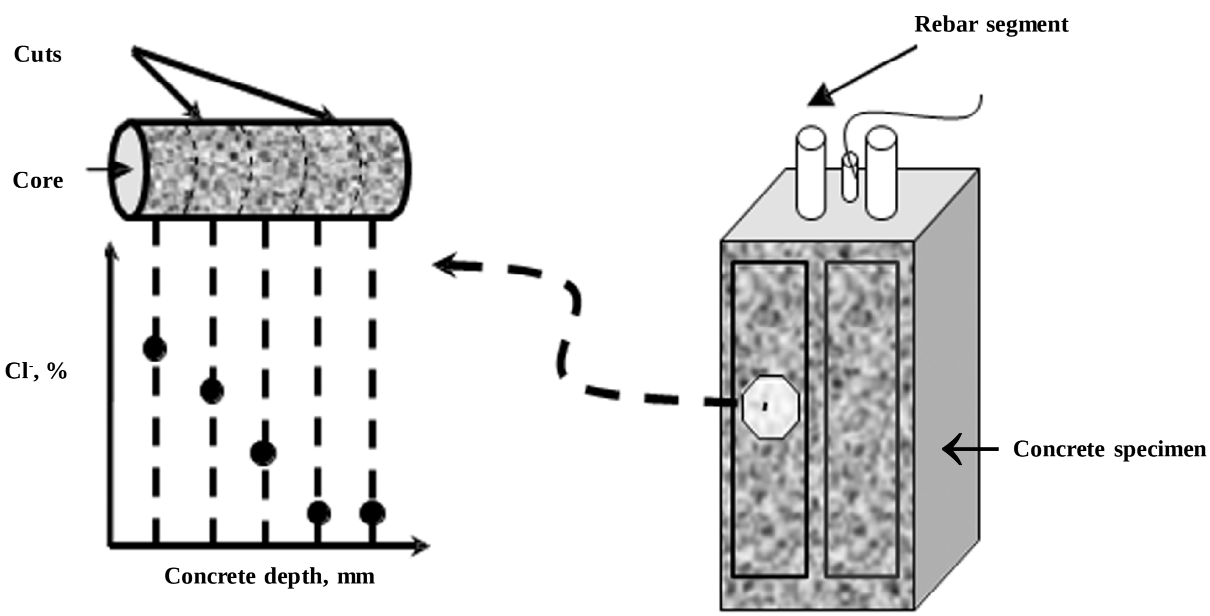

Figure 2: Core extraction and chloride profile determination procedure for a CP system

depths for control system. In the case of control system, the chloride content estimated near cathode (steel) is found to be as high as 0.716 % and at the top surface the chloride content is found as low as 0.459 %. It is also observed that in the case of CP applied system, the chloride concentration decreases with increasing depths. It shows a linear profile [19]. In the case of M30 grade containing no initial chloride contamination subjected to atmospheric exposure, the chloride content estimated near cathode (steel) is found to be as low

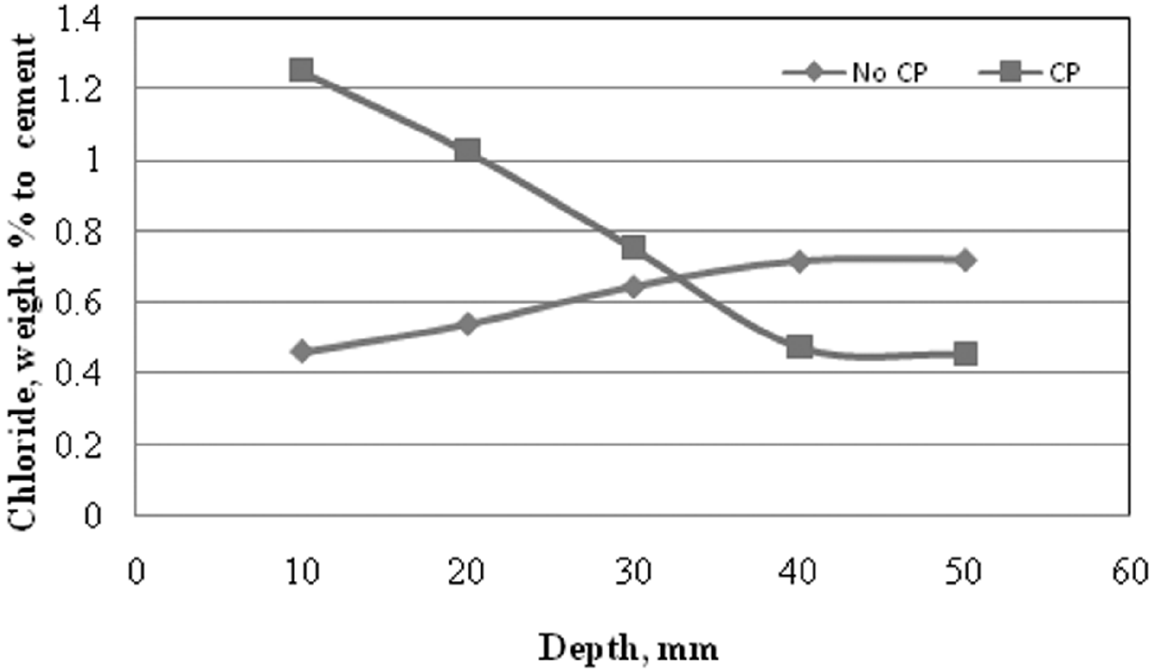

Figure 3: Comparison of chloride profile for M30 grade concrete containing no chloride-subjected to normal exposure

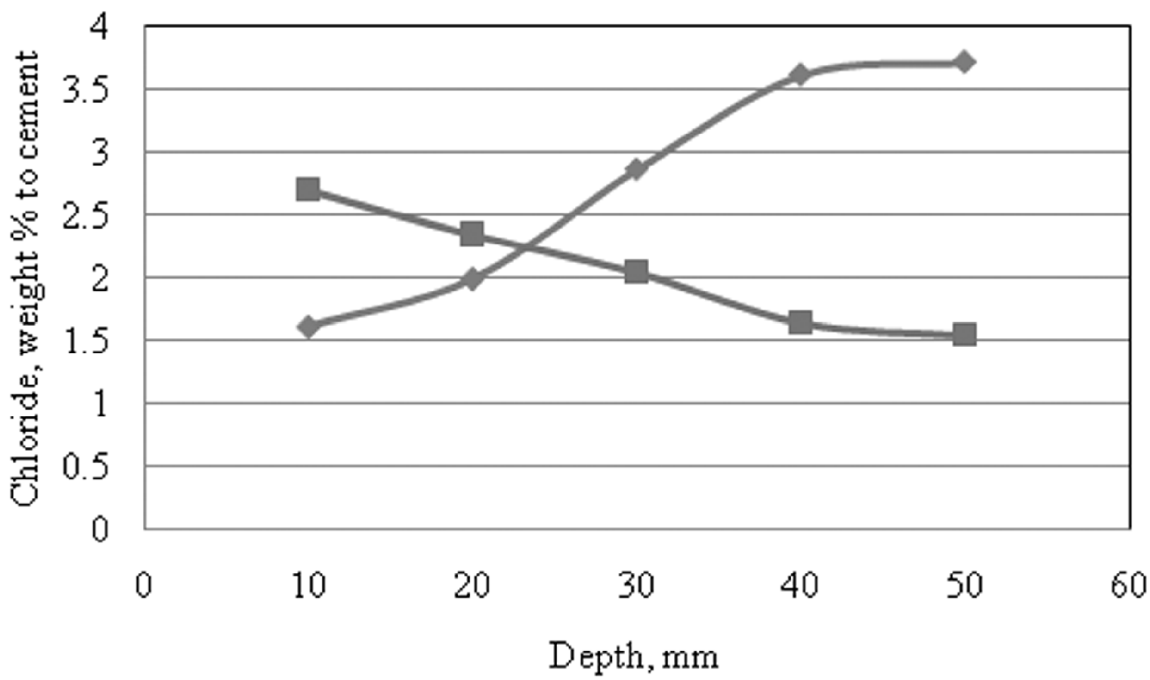

Figure 4: Comparison of chloride profile for M30 grade concrete containing 1% chloride subjected to normal exposure

as 0.459 % and near anode is found to be 1.248% on CP system. The percentage of chloride reduction is also found in the range of 55-60% under normal exposure shows the effective performance of CP. This supports the assertion that the chlorides are moved away from the rebar by the action of CP [16,17].

Figure 4 shows the results of analysis of water soluble chloride profile for M30 grade concrete containing 1% chloride subjected to with CP and without CP (control system) treated under atmospheric exposure. It is also shown that the chloride content estimated near the cathode is found to be 3.625% and near anode the chloride content is found as low as 1.62 % on control system. The trend is quite nature because the chloride ions are penetrates towards cathode causes break down of passivity and accelerating steel rebar corrosion.

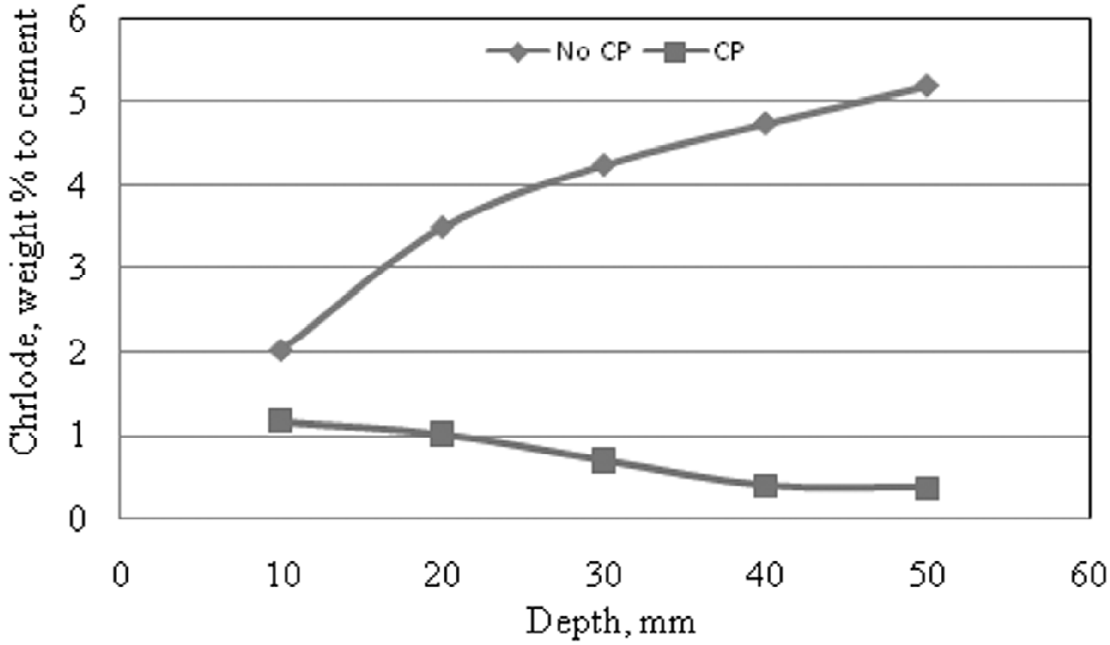

Figure 5: Comparaison of chloride profile for M 30 grade concrete containing no chloride- subjected to alternate wet & dry exposure

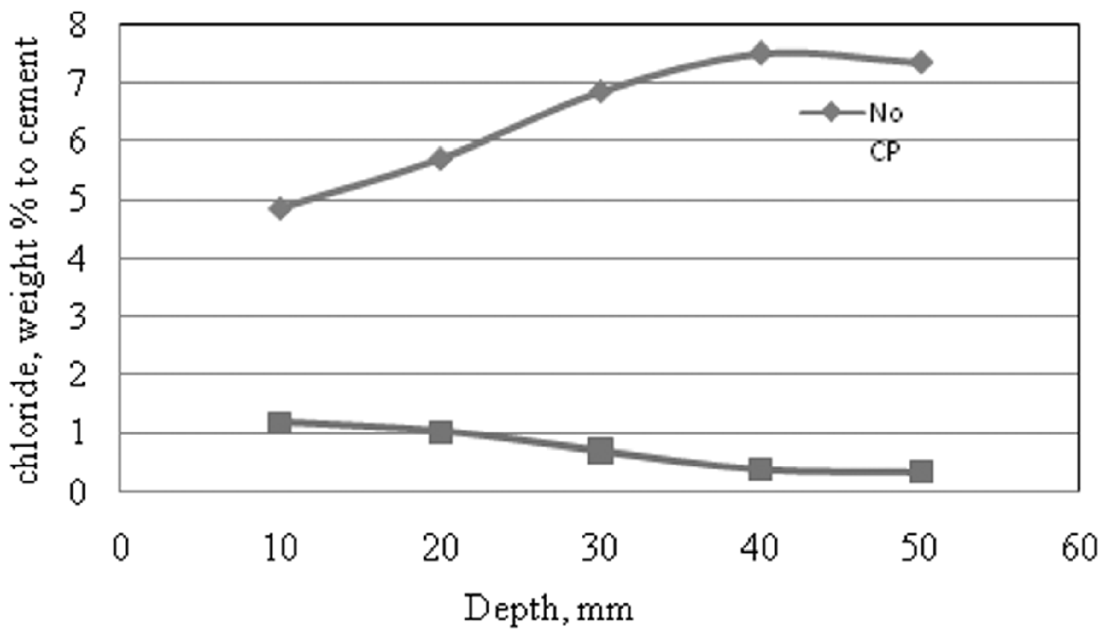

Figure 6: Comparison of chloide profile for M30 grade concrete containing 1% chloride subjected to alterate wet & dry exposure

The results of analysis of water soluble chloride profile for M30 grade chloride free concrete subjected to with CP and without CP (control system) treated under alternate wet & dry exposure are shown in figure 5. It is observed that in the case of control system, the chloride content estimated near cathode (steel) is found to be as high as 5.259 % and at the top surface the chloride content is found as low as 2.02 %. It is also observed that in the case of CP applied system, the chloride content near cathode is found to be as low as 0.459 % and near anode is found to be 1.175%.

Figure 6 shows the chloride profile for M30 grade concrete containing 1% chloride subjected to with CP and without CP (control system) treated under alternate wet & dry exposure. It is shown that the chloride content estimated near the cathode is 7.501% and near anode the chloride content is found as low as 4.85 % on control system. In the case of CP system, it shows that the chloride content estimate near cathode is

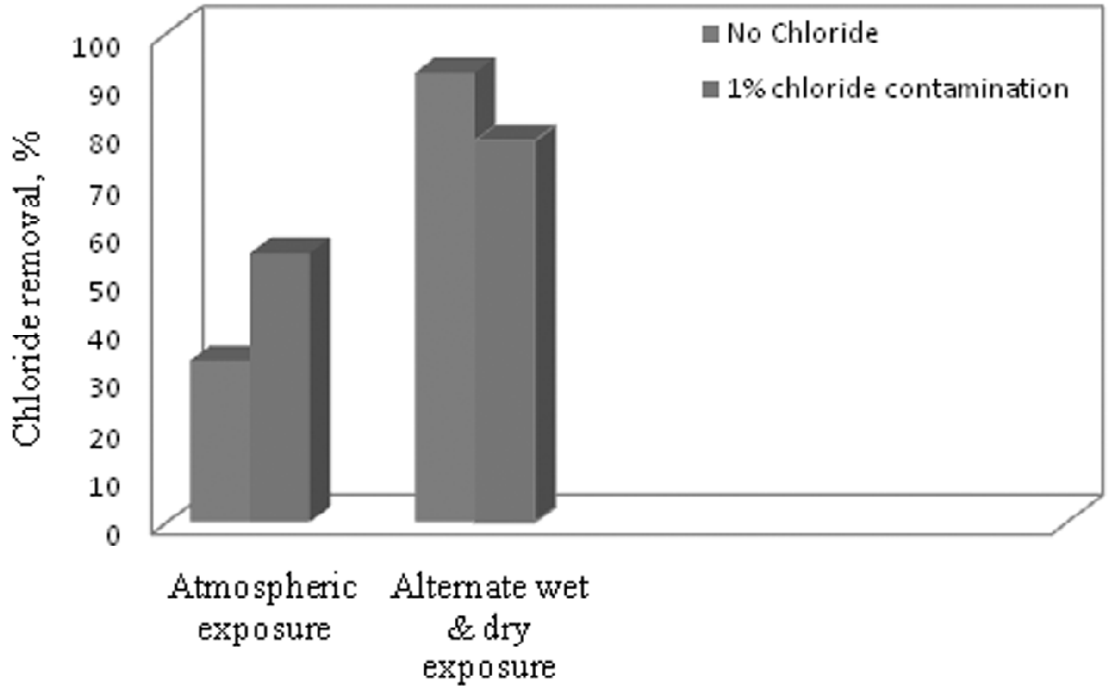

Figure 7: Effect of cathodic protection on chloride removal under various exposure conditions

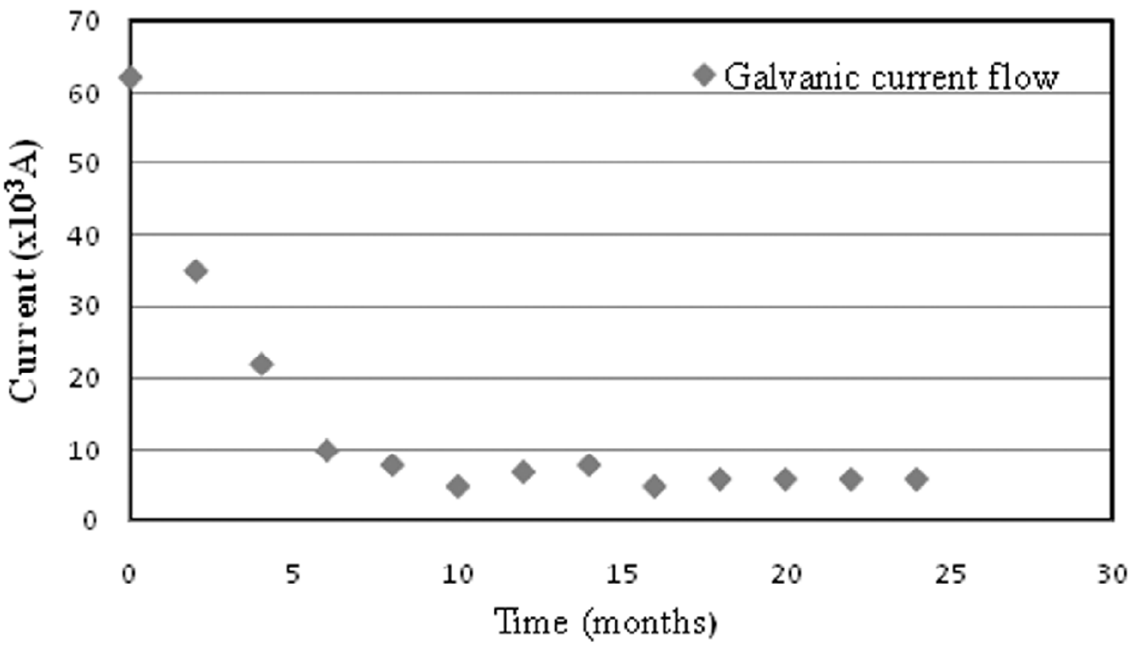

Figure 8: Galvanic current flow-time time profile in concrete with time on application of CP

found to be as low as 1.65% and near anode the chloride content is found to be as high as 2.705%. The percentage of chloride reduction is also shown in figure 7. It is observed that the chloride content is estimated as high as 68 to 92% due to the higher cement content in the mix design of rich mix grade concretes. This supports the assertion that the chlorides are moved away from the rebar by the action of CP [18,19]

Figure 8 shows the galvanic current flow–time profile for galvanic protection system. Initially a higher galvanic current of 60mA/m^2 is found to flow for magnesium anode, which decreased to 30mA/m^2 due to the formation of oxide film at the anode concrete interface [20]. The decreasing trend in galvanic current flow with exposure period is probably due to the increased resistivity, which reduces conductivity of concrete. Then the current flow is reduced to attain steady state value of 20mA/m^2 at the end of 24th month of exposure. In this study, the composite sacrificial anode based on magnesium anode is capable to delivering adequate

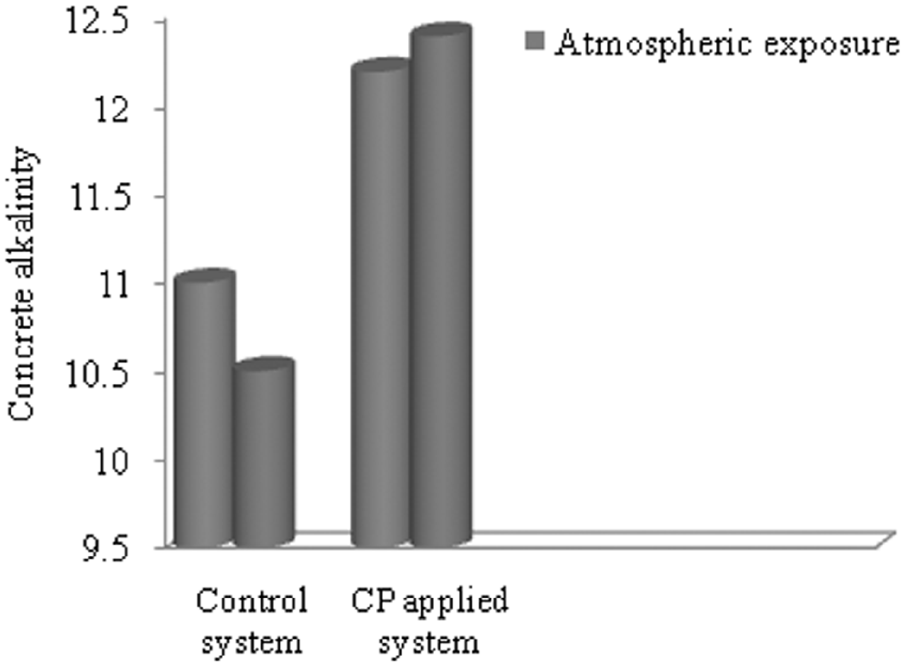

Figure 9: Alkalinity profile for cathodically protected and unprotected concrete specimens

cathodic protection current by a factor of 2 to 3. It is higher than the normally recommended protection current for CP of steel in concrete [21,22]. Thus the strip type magnesium composite anode is found to confer efficient galvanic protection on embedded steel rebars in concrete over a period of 24months

Figure 9 shows the comparative trend in alkalinity for protect and unprotected concrete. For control specimen the alkalinity around the cathode is found to be as low as 10.5-11, whereas in the case of CP systems, a higher alkalinity (pH=12.4) is measured around the steel cathode thereby maintaining stable passivity over a period of 600days.

4. CONCLUSIONS

a. The cathodic protection system based on strip type magnesium composite anode along with ion conductive polymer backfill offers a fool-proof solution with regards to corrosion protection of embedded steel rebars in concrete.

b. Analysis of water soluble chloride revealed the increasing trend of chloride concentration with different depths for control system (without CP system), whereas a lower level of chloride (near the steel) and a linear profile is exhibited by the chlorides in the sample taken from the concrete specimens with CP applied. This supports the assertion that the chlorides are moved away from the rebar by the action of CP.

c. The percentage of chloride removal is also found to be in the range of 33 to 55% under normal exposure and in alternate wet and dry exposure the chloride removal is found to be 78 to 92%.

d. Analysis of alkalinity around the steel rebar on cathodically protected specimens has also revealed that stable passivity (pH = 12.4 to 12.6) is maintained throughout the test period showed the effective performance of CP.

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