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Study of Macrocell Corrosion of Coupled Rebars Using Electrochemical Techniques

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Abstract: **-- Corrosion, a result of chemical or electrochemical actions, is the most common mechanism responsible for deterioration of reinforced concrete (RC) structures. The phenomenon of corrosion is mainly governed by ingress of chloride ions or carbonation of RC structures. Both these actions cause a breakdown in the passive layer of concrete around the reinforcing steel resulting in active corrosion. Hence, monitoring of reinforcement corrosion is of significant importance for preventing premature failure of structures. The corrosion in RC element can take place in two ways – macrocell and microcell corrosion. Macrocell corrosion occurs when the actively corroding bar is coupled with another bar which is passive, either because of its different composition or because of different environment. On the other hand, microcell corrosion is the term given to the situation where active corrosion and the corresponding cathodic half-cell reaction take place at adjacent parts of the same metal. The aim of present paper is to study the influence of macrocell corrosion for coupled rebars using electrochemical techniques. RC slabs with four coupled reinforced steel bars were cast and subjected to accelerated corrosion. Two different grades of steel were used in the experimental work. From present research work, it can be concluded that corrosion condition of a coupled rebars can be identified more accurately using Tafel extrapolation technique than half call potential technique and the effect of microcell and macrocell corrosion on behavior of all rebars under corrosion is approximately same.**

***Index Terms*— Corrosion, Non-destructive techniques, Accelerated Corrosion, Half-cell potential, Macrocell Corrosion, Reinforced concrete structure, Tafel extrapolation technique.**

I. INTRODUCTION

Corrosion of steel bars embedded in reinforced concrete (RC) structures reduces the service life and durability of structures causing early failure of structure, which costs significantly for inspection and maintenance of deteriorating structures. The concept of non-destructive testing (NDT) is obtaining material properties of in place specimens without the destruction of neither specimen nor the structure effectively. Deterioration of concrete structures due to harsh environmental conditions leads to performance degradation of Reinforced concrete (RC) structures, and premature deterioration of structures before completing expected service life is major concern for engineers and researchers [1]. Exposure conditions and extent of maintenance affects the deterioration rate of structures. Some of the leading causes of concrete deterioration, resulting ultimately in reinforcement corrosion, include frost action in cold climates and physio-chemical effects in aggressive environments. A rise in chemical aggressively of the environment through the increasing use of de-icing salts, and an increase in land, water, and air pollution, has a1so contributed to the deterioration of concrete structures. Reinforcing steel embedded in concrete is normally protected against corrosion by the high alkaline environment provided by the surrounding concrete. The penetration of corrosion-inducing elements, such as oxygen, water, carbon dioxide, and chloride ions, is further limited by a concrete environment of low permeability. Furthermore, this low permeability retards the flow of electrochemical corrosion current due to increased electrical resistivity of the concrete [2]. In marine environment, the risk of corrosion on outdoor structures is very high. These effects result in age-related degradation of reinforced concrete structures while other reasons for degradation emanates from improper engineering of the structure. The durability of the structures is always a challenge to the designer for getting the desired service life. The performance of a structure in a particular exposure condition is a function of time and is related to durability and deterioration [3]. Many industrialized nations currently dedicate a considerable portion of the construction budget for restoration, repair and maintenance of old

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structures. The concept of non-destructive testing (NDT) is to obtain material properties "in place" specimens without the destruction of the specimens and to do the structural health monitoring. NDT using Rebound hammer, Ultra sonic pulse velocity, Half-cell potential, carbonation depth, rebar locator, Rapid chloride penetration test, electric resistivity meter test and vibration base analysis by data analoger are very popular and highly effective in conducting structural health monitoring [4]. Macrocell corrosion can occur when the actively corroding bar is coupled to another bar which is passive, either because of its different composition or because of different environment. Microcell corrosion is the term given to the situation where active corrosion and the corresponding cathodic half-cell reaction take place at adjacent parts of the same metal. According to [5], for high performance concrete, the difference between microcell and macrocell corrosion is far more significant than for ordinary Portland cement concrete because of its high resistance to ionic flow. The macrocell corrosion must co-exist with microcell corrosion of reinforcements in concrete [6]. Both macrocell and microcell corrosion mechanisms could play significant roles, and the total corrosion could be underestimated if either of them is overlooked. Present study aims to characterize the macrocell corrosion of coupled rebars using electrochemical techniques, in reinforced concrete slabs. The electrochemical techniques used are Half-cell potential and Tafel extrapolation. Interpretations of measurements were investigated experimentally. Hence focus of this paper is to study the effect of macrocell corrosion on coupled rebars.

II. EXPERIMENTAL PROCEDURE

2.1 Materials and specimen preparation

Rectangular RC specimens as shown in Fig. 1 with steel bars were cast. The experimental procedure comprised of studying corrosion activity on the RC rectangular specimens made with 12 mm diameter steel rebar having cover of 20mm. For casting of specimens, special moulds were fabricated as shown in Fig.2. Such samples were used for testing to create real life situation.

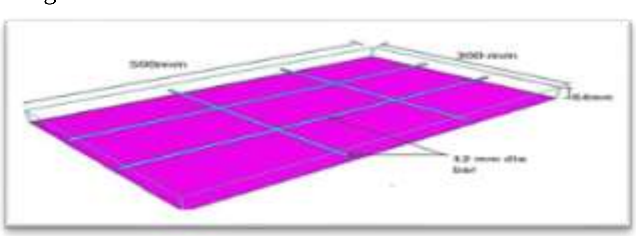

Figure 1: Rectangular RC specimen

Figure 2: Rectangular Moulds

Along with these specimens 3 concrete cubes having dimensions 150 mm x 150 mm x 150 mm were also cast and tested after 14 days curing for finding compressive strength of concrete as per IS 516-1959[7]. For all the specimens, M20 grade of concrete was prepared. Ordinary Portland cement of nominal strength 53Mpa was used for preparation of concrete mixes. Natural river sand confirming to zone II was used as fine aggregates and crushed stone of nominal size 10 mm was used as coarse aggregates. The concrete mix was designed as per IS10262:2009 and mix proportion obtained was 1:2.59:2.10 with water-cement ratio 0.5. A standard reinforcing bars of 400 mm and 600mm length of TMT 500 and CRS 500 grade was used for reinforcement in rectangular specimens. Before casting, the steel bar was drilled and threatened at one end to accommodate the copper screw for electrical connections. Then the bar was wire brushed to remove any surface scale. Epoxy resin was then applied for exposed length of 100 mm at steel-concrete interface from both sides of bar to protect this portion from the corrosion activity. The remaining middle portion of 200 mm was subjected to accelerated corrosion process. The epoxy resin was allowed to harden for 24 h and then the weight of reinforcing bar was recorded to an accuracy of 0.01 g. The slabs were cast in the special molding system and were removed from moulds after 24 h of casting and kept for curing for the period of 14-days at a room temperature and relative humidity of 100%. On 15th day the specimens were immersed in 5% NaCl solution, approximately double the salinity of seawater, at a room temperature for 24 h to ensure full saturation of the test specimen. From 16th day constant potential was applied to

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the specimen to accelerate the corrosion process using impressed current technique.

2.2 Accelerated corrosion set-up

In the present study, the specimens were subjected to accelerated corrosion using impressed current technique. The commonly used methods to induce corrosion in RC specimens are salt spray, Chloride diffusion, alternate drying and wetting in salt water and impressed current technique. Impressed current technique is confirmed to be valid method to study the corrosion process of steel in concrete [8]. In this method, the specimen is immersed in NaCl solution and a direct current is passed through the reinforcing bar making it as an anode and another metal in electrochemical process as cathode. In this investigation stainless steel mesh was used as cathode. The cathode and the specimen were placed in 5% NaCl solution. The steel bar (anode/ working electrode) of the beam specimen is connected to the positive terminal and the stainless steel plates (cathode/ counter electrode) are connected to the negative terminal of the DC power source [Figure 3]. The corrosion process is initiated by applying a constant voltage of 8 volts to the system. Anode to cathode current corresponding to constant applied voltage was monitored every day. The testing was stopped when crack due to corrosion was appeared and became distinct on the surface of the concrete specimen.

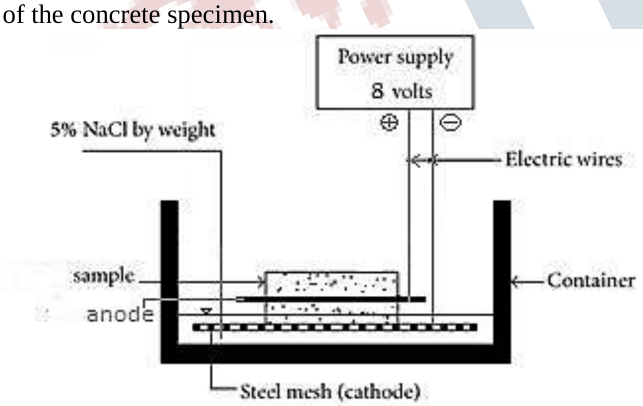

Figure 3: Schematic representation of accelerated corrosion Set-up

2.3 Corrosion Monitoring

Corrosion is an electrochemical process and there are various electrochemical and non-destructive techniques which are used to measure corrosion such as half-cell potential, linear polarization, Tafel extrapolation etc. In present study corrosion was monitored periodically till the end of testing using half-cell potential and Tafel extrapolation techniques. For HCP measurements, Saturated Calomel electrode (SCE) was used as reference electrode. Potentiostat model 1.0 (Crest Technology) was used to obtained Tafel plots. The scans were carried out at the rate of 0.5 mV/s between the potential range of -250mV and +250mV using specimen as working electrode, stainless steel mesh as cathode and SCE as a reference electrode. Prior to the measurement of half-cell potential, DC supply was interrupted for two hours. Electrochemical readings using both techniques were taken. All the measurements were taken using fresh NaCl solution every time. Location of Half-cell potential readings are shown in figure 5.

Figure 4: Testing setup

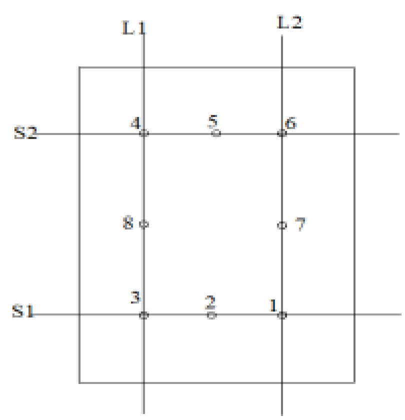

Figure 5: Location of HCP Readings

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III. RESULTS AND DISCUSSIONS

3.1 Half-cell potential and Tafel extrapolation studies

Variation of HCP with time for a specimen is given in Fig.6. For al specimens the potential indicated high probability of active corrosion condition (HCP w.r.t. SCE <-276 mV). The general trend of drop in potential readings indicates increasing probability of active corrosion. Later on the potentials started increasing indicating increase in concrete resistance and finally stabilized in high probability of active corrosion. This could be either due to accumulation of ions in concrete pore solution under the influence of an electric field or accumulation of corrosion products in concrete pores resulting into reduction of corrosion rate.

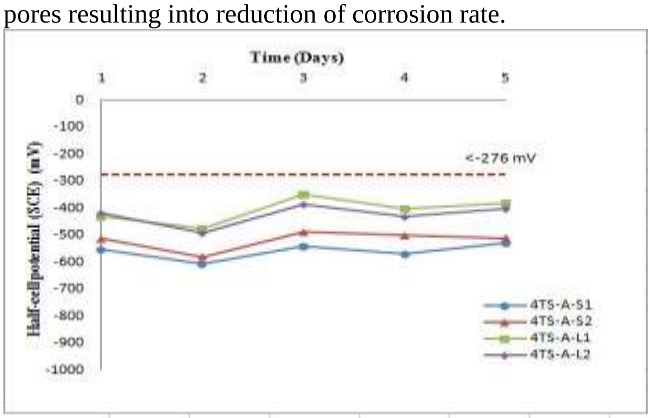

Figure 6: Typical variation of half-cell potentials with time

Although HCP is good indicator of initiation of corrosion, it is not quantitative method. Hence to monitor corrosion process, potentiostatic scans were obtained for all the specimens after measurement of HCP.

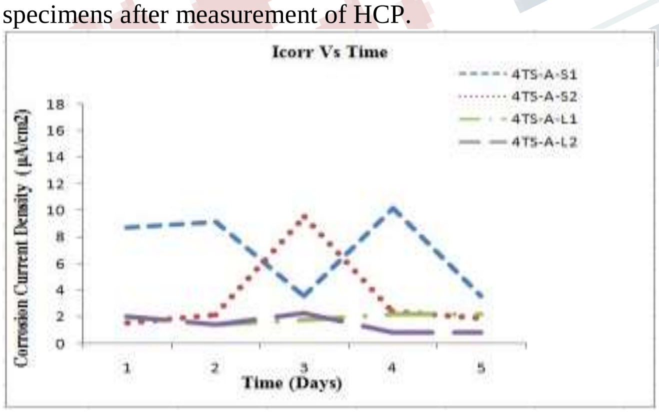

Figure 7: Typical Variation of corrosion current density with time

Variation of corrosion current density (Icorr) with respect to time for specimen is shown in fig.7 which shows that the variation for all specimens is perfectly in agreement with each other.

IV. CONCLUSION

In order to study the effect of macrocell corrosion on coupled rebars using electrochemical techniques, experimental investigation of a prototype in the laboratory is required. By simulating severe environmental condition and using slab specimens having connected rebars, exact effect on the structure in the field conditions can be predicted. This will helpful in checking and suggesting maintenance schemes for the RC structure at marine environment. In the present study, experimental investigations are done on a set of RC slabs with single and double accelerated corrosion and different steel and studied effect of macrocell corrosion on coupled rebars using Half-cell and Tafel extrapolation technique. The conclusions based on entire work are summarized as below.

- As per half-cell potential technique, it can be concluded that the effect of microcell and macrocell corrosion on behavior of all rebars under corrosion is approximately same.
- The corrosion current density values for specimens subjected to double acceleration are found to be always more than that of the specimens subjected to single acceleration. Thus based on magnitude of corrosion current density, the difference in behavior of specimens subjected to single acceleration in comparison to specimens subjected to double acceleration could be identified.

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