# Electrochemical Experimental Measurement of Macrocell Corrosion Half-cell Potential Replicating the Re-corrosion of Actual Refurbished Works in RC Structures

*Raja Rizwan Hussain*[*]

CoE-CRT, Civil Engineering Department, College of Engineering, King Saud University, Riyadh, 11421, Saudi Arabia.
[*]E-mail: raja386@hotmail.com

The re-appearance of corrosion on refurbished corroded RC structures under chloride attack is a multifaceted phenomenon which clearly needs further investigation due to limited amount of literature available in the past having a difference of opinion. In this paper electrochemical experimentation has been conducted replicating the actual patch repair works in the construction field. Steel reinforced concrete experiment specimen was cast having no chloride content in the middle portion and 5% chloride at the two ends. Here, the middle portion with no chloride content simulates the actual patch of new concrete in the repaired portion of reinforced concrete affected by chloride induced corrosion. From the experiment results it was found that the specimen having no chloride content at the middle portion showed high corrosion potential and chloride contaminated both sides of the specimen showed even more corrosion than before being repaired due to the separation of anode and cathode and development of a macro-cell. This has practical implications that need to be considered for an effective and durable repair. The research indicates that much of the needed research should focus on identification of corrosion mechanisms to effectuate the successful patch repair in reinforced concrete structures. In the future, more specimens should be tested for variable chloride concentrations.

## 1. INTRODUCTION

One of the most extensive durability problems is re-corrosion of black mild steel bars in repaired chloride contaminated concrete. It causes the degradation of concrete structures, and this gives rise to concerns about structural safety, integrity, and serviceability. Patch repair is the most commonly used method for rectifying localized damage in steel reinforced concrete due to corrosion. It entails removal of loose concrete that has cracked, spalled, or delaminated; often, the application of a surface

treatment on the steel; and replacement of the defective concrete with patching materials, which normally re-establishes the original profile of the member. Several researchers have studied the patch repairs of corroded reinforced concrete. Past researchers [1] have studied long term corrosion performance of rebar embedded in cement concrete under macro cell corrosion condition. One study shows that the major cause of degradation of the repairs arises from the adverse interaction between the repaired area and adjacent unrepaired areas which in turn stems from poor performance of the repaired area as a result of mechanical failures [2]. The principles of electrochemical incompatibility have been widely discussed [3-7], corrosion of RC structures has been investigated [8-15] and the existence of macrocell corrosion has been experimentally demonstrated [16-23]. It has been emphasized [24-26] that both microcell and macrocell corrosion could coexist in active corrosion, and a newly induced macrocell might not necessarily suppress existing microcell corrosion. But, when it comes to patch repair of the corroded reinforced concrete structure, a few researchers have studied the macrocell corrosion incorporating the actual patch repair works used in the construction industry which leads to the objectives of this paper.

## 2. EXPERIMENTATION

### 2.1. Materials

Deformed round carbon steel bars 13 mm in diameter were used as reinforcing material in the experiment specimen. Ordinary Portland cement (OPC) as per JIS R5210 specifications was used.

**Table 1.** Mix proportions

| Total Chloride (%mass of binder) | W/C | OPC (kg/m$^3$) | Fine aggregate (kg/m$^3$) | Coarse aggregate (kg/m$^3$) |
|---|---|---|---|---|
| 5% at ends | 0.45 | 371 | 756 | 1031 |
| 0% in middle | 0.45 | 371 | 756 | 1031 |

Natural river sand passed through sieve No. 4 (4.75-mm openings), was used as fine aggregate for all concrete mixes. Its density and water absorption were 2.65 g/cm$^3$ and 2.21%, respectively. Crushed sandstone with a maximum size of 20 mm was used as coarse aggregate with density of 2.70 g/cm$^3$ and water absorption 0.59%. Table 1 will illustrate the mix proportion of the specimens.

### 2.2. Preparation and Scheme

Experimental specimen was prepared for macro-cell corrosion experiment simulating the actual patch repair work in the construction field. This specimen was prepared having its two extreme ends containing 5% total chloride content presuming the chloride contaminated concrete in the actual case

and the middle portion of the specimens with no chloride content presuming to be the repaired portion in the actual construction repairs as shown in figure 1.
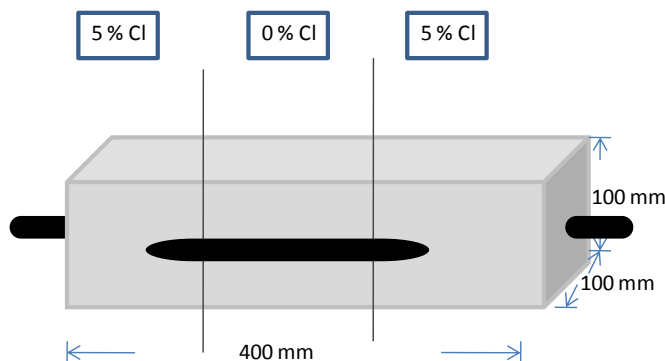


**Figure 1.** Experiment Specimen.

This was done to create an artificial macro-cell resembling the one developed originally in case of repair works in the actual field of concrete structures due to the separation of anode and cathode and development of macro-cell though containing no chloride content as shown in figure 2a. In chloride contaminated concrete rapid corrosion of reinforcement occurs resulting in cracking and spalling of concrete. The general idea is to replace the spalled concrete with a fresh patch and the steel is assumed to be safe from further corrosion as shown in figure 2b. But in actual practice, this patch renders as a mode of variation in the properties being free from chloride in a chloride contaminated concrete structure. Two steel rebars of different sizes were used in the preparation of the specimen as shown in figure 1. One longer rebar coming out from the ends of the specimen was used for the macro-cell corrosion potential measurements and the other small one was used to facilitate and observe the complete macro cell corrosion phenomenon occurring inside the specimen unaffected from the external environment. The corrosion potentials readings of this specimen were taken for one year to experimentally corroborate the objectives of this research.
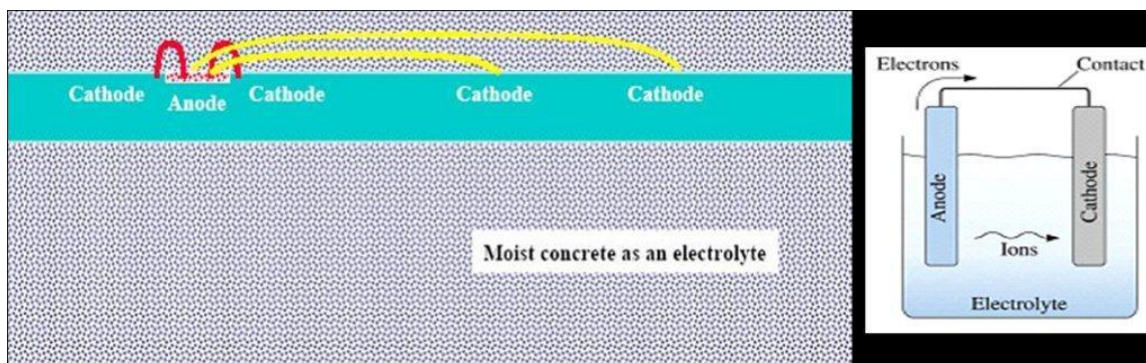


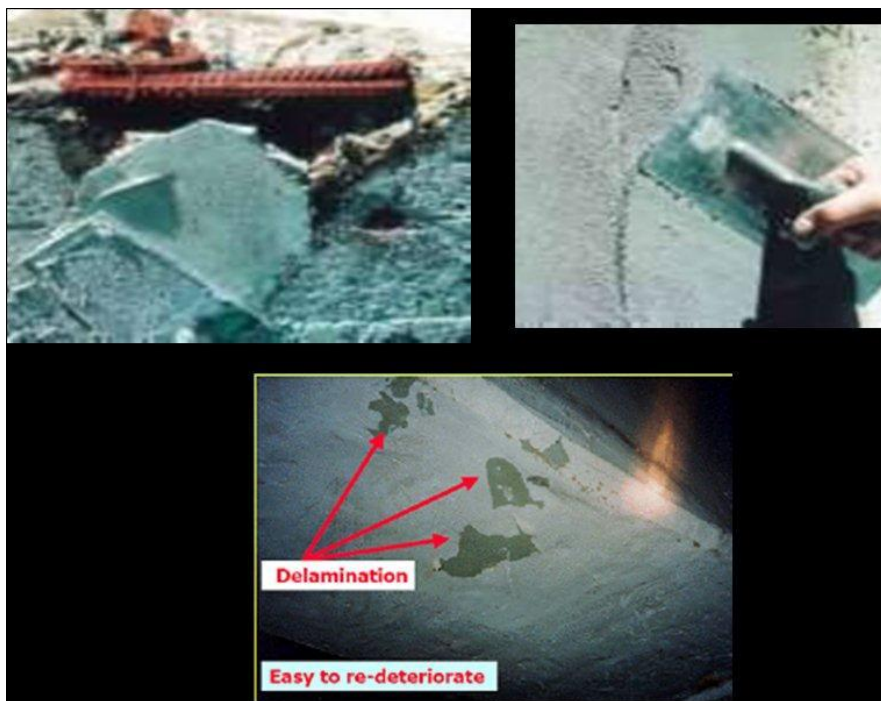**Figure 2(a).** Separation of Anode and Cathode

**Figure 2(b).** Actual Patch Repair Works.

## 3. EXPERIMENT RESULTS AND DISCUSSION

After one year of corrosion potential observations the experiment specimen was split into two along the longitudinal direction to view the actual behavior of corrosion in the specimen at the ends and at the middle portion. This cut section for macro-cell corrosion experiment simulating the actual patch repair work in the construction field is shown in the figure 3. From the visual observation of this cut section it is quite clear that the middle portion having no chloride content remained un corroded but from the experimental results of corrosion potential values as shown in figure 4, re-corrosion of the repaired reinforced concrete patch although containing no chloride content can be assumed.

The other worth noticing observation was the appearance of the cracks at the two ends that propagated towards the centre no chloride contaminated portion showing much higher corrosion rate (due to macro-cell formation) than normally corroded (due to micro-cell formation) reinforced concrete for a chloride concentration of 5%. The very high chloride induced corrosion potential of -0.62 Volts at the two extreme ends is actually due to the macro-cell formation (anodic in nature) which also induces a macro-cell corrosion potential (cathodic in nature) of -0.55 Volts in the middle no chloride portion.
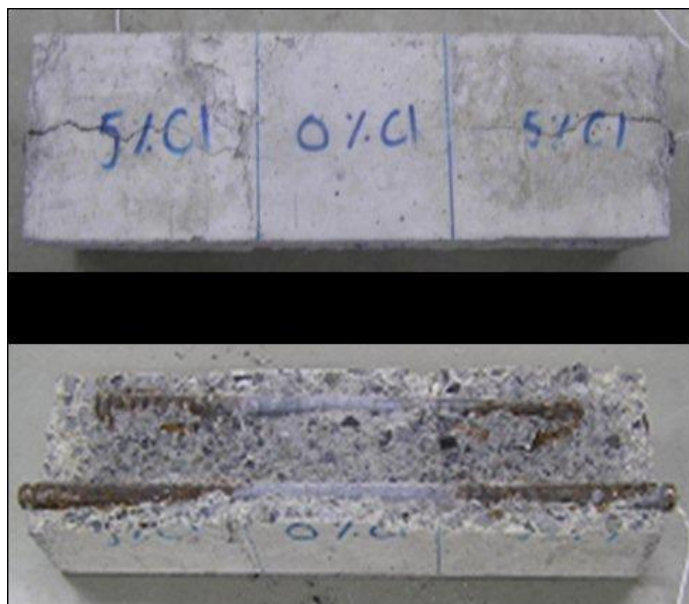
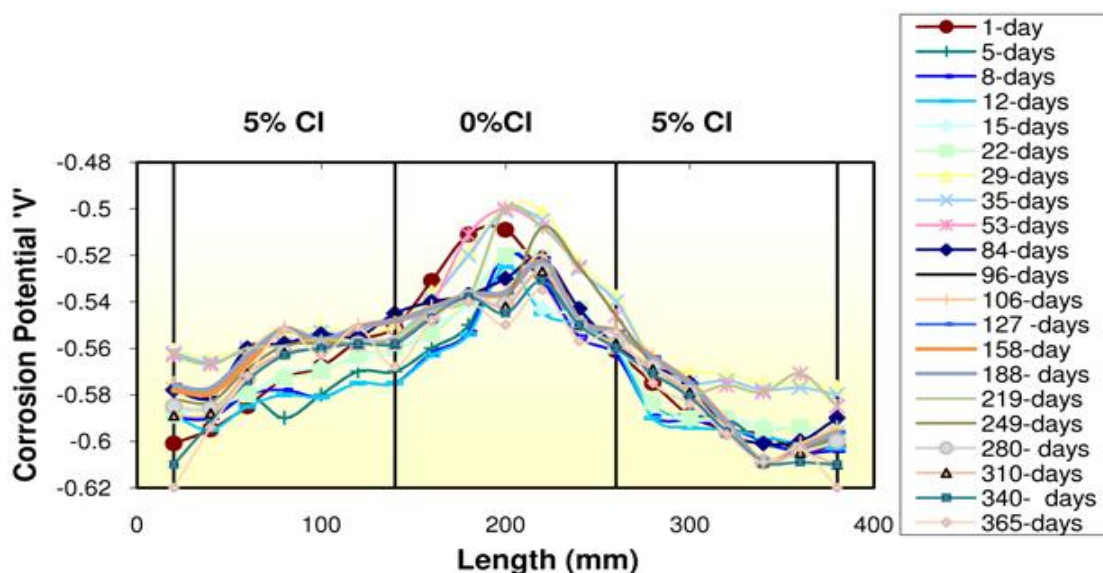**Figure 3.** Cross-section of the Experiment Specimen.



**Figure 4.** Macro-cell Corrosion potential Experiment Results.

The experiment results of this paper confirm the formation of cathode in the repaired no chloride contaminated middle portion and active anode in the two chloride contaminated ends of the experiment specimen. This results in forming of macro-cell and causing even higher corrosion around the repaired no chloride reinforced concrete section in the chloride contaminated concrete. It has practical implications that need to be considered for an effective and durable repair of corroding reinforced concrete structures. This research pin points and identifies a new corrosion mechanism which can be effectively utilized to effectuate the successful patch repair in corroding reinforced concrete structures by new and innovative methodologies.

## 4. CONCLUSION

It can be concluded from the experiment results that the chloride induced anodic corrosion potential of -0.62 Volts at the two extreme ends of the specimen caused a macro-cell cathodic corrosion potential of -0.55 Volts in the middle no chloride portion which shows that even those patches of the reinforced concrete which are repaired and considered as safe against corrosion in the construction field, can get more corrosion in the form of macro-cell in the surrounding chloride contaminated areas of reinforced concrete. The authors believe that this research though simple is novel and will bring substantial changes as it will open new windows in the field of repair and maintenance of corroded reinforced concrete for professional field engineers as well as researchers. New patch repair materials and techniques are expected to emerge in the future as a consequence of this paper. In the future, more specimens should be cast and tested for variable chloride concentrations. This will unveil the effect of different percentage of chloride ions on the magnitude of induced macro-cell corrosion in the refurbished area of corrosion damaged RC structures.

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