

# Novel Method for Preventing Macro-Cell Chloride Induced Corrosion in the Simulated Repaired Reinforced Concrete Patch and Its Electrochemical Verification

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This research paper introduces a successfully developed patch repair technique for the chloride contaminated reinforced concrete to avoid macro cell corrosion in the repaired reinforced concrete patches in actual field construction. From the experiment results it is corroborated that by putting buffer at contact steel area between the contaminated concrete and repaired concrete patch there is no development of macro cell corrosion in the repaired concrete patch which was found earlier when no buffer was used. The method developed is also verified in this paper by the help of electrochemical experimentation. This new technique which is presented in this paper is novel and has practical implications that need to be considered for an effective and durable repair.

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**Keywords:** Patch repair, reinforced concrete, buffer, half-cell potential, chloride, corrosion, electrochemistry.

## 1. INTRODUCTION

Structural degradation of concrete structures due to the corroding reinforcing steel is one of the most extensive durability problems and gives rise to concerns about structural safety, integrity, and serviceability. The cost of rehabilitating such structures is very significant and it consumes too much money on construction. Patch repair is the most commonly used method for rectifying localized damage in 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. Vedalakshmi et al. studied long term corrosion performance of rebar embedded in cement concrete under macro cell corrosion condition [1]. 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], and the existence of macrocell corrosion has been experimentally demonstrated [8-14] emphasized that both microcell and macrocell corrosion could coexist in active corrosion, and a newly induced macrocell might not necessarily suppress existing microcell corrosion.

In the previous study [15] done by the authors, the phenomenon of macro corrosion in repaired patches of the chloride contaminated reinforced concrete structure was deeply studied incorporating the actual patch repair works used in the construction industry. But, how to minimize or completely stop this development of macro cell in chloride contaminated concrete repaired patches was remained as scope for future research. This forms the objectives and basis for this research which is also a pending patent at the US patent office.

## 2. EXPERIMENTATION SCHEME

### 2.1 Materials

Deformed round carbon steel bars 13 mm in diameter were used as reinforcing material in the experiment specimens. Ordinary Portland cement (OPC) as per JIS R5210 specifications [16] was used. Natural river sand passed through JIS A1102 sieve No. 4 (4.75-mm openings) [17], was used as fine aggregate for all concrete mixes. Its density and water absorption were 2.65 g/cm<sup>3</sup> 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<sup>3</sup> and water absorption 0.59%. Table 1 will illustrate the mix proportion of the specimens.

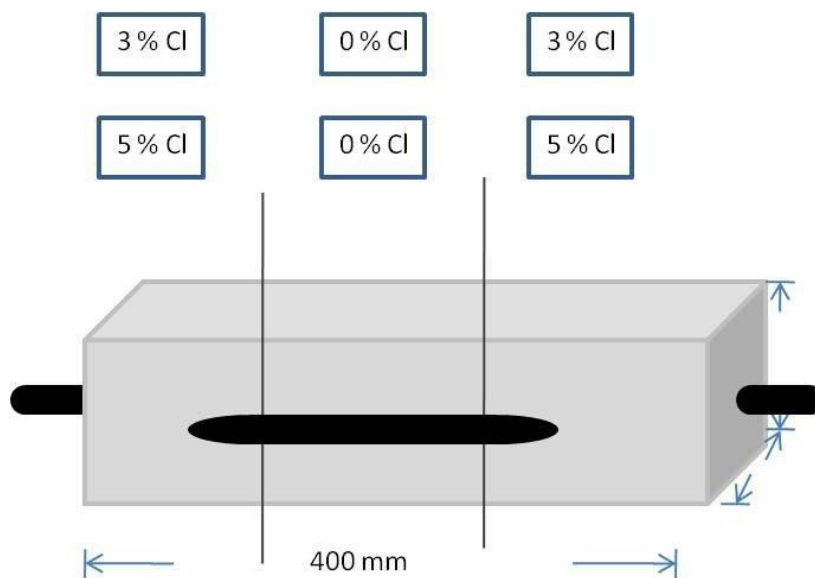
**Table 1.** Mix proportions

Specimens	Total Chloride (%mass of binder)	W/C	OPC kg/m <sup>3</sup>	Fine aggregate kg/m <sup>3</sup>	Coarse aggregate kg/m <sup>3</sup>
1 and 2	5% at the ends	0.45	371	756	1031
3 and 4	3% at the ends	0.45	371	756	1031

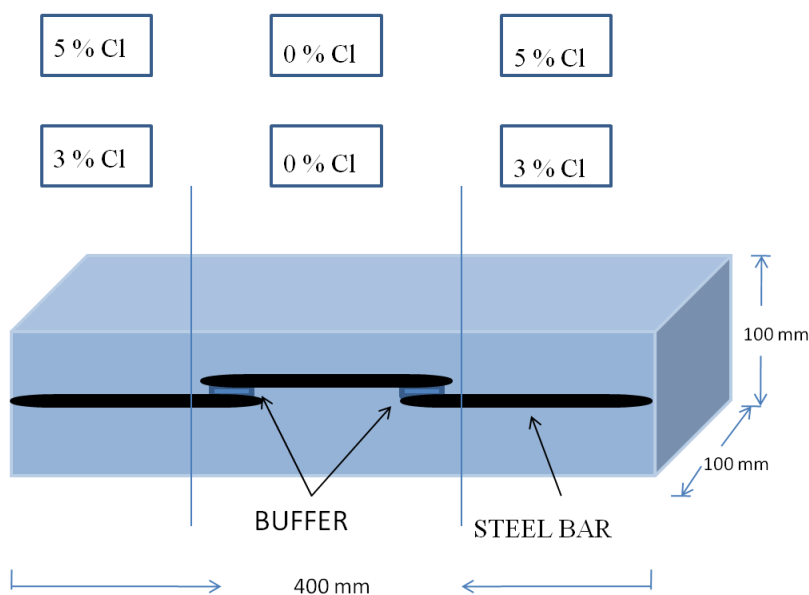
### 2.2. Specimen preparation and innovative technique for preventing the development of the macro-cell corrosion in patch repairs

This experimental investigation is an extension of the author's previous research finding [15] in which specimens were prepared for macro-cell corrosion experiment simulating the actual patch repair

work in the construction field. The two sides of these specimens were cast first containing chloride 5% and 3% chloride content respectively at the extreme ends. The middle portion of these specimens was cast after 24 hours with no chloride content presuming to be the repaired portion in the actual construction repairs to stop or minimize the chloride movement from contaminated to non contaminated portion of these specimens. The purpose was to create an artificial macro-cell resembling the one developed originally in case of repair works in the actual field of concrete structures. The schematic diagram of these specimens is shown in fig. 1.



**Figure 1.** Macro-cell corrosion specimens simulating patch repair without buffer.



**Figure 2.** Specimens with buffer at contact steel area between chloride contaminated and uncontaminated middle portion of the specimens.

Now in this research the same methodology is followed for experimentation using the specimens having same dimensions and chloride content as above, but to avoid the formation of macro cell due to the separation of anode and cathode; a buffer is put at the contact steel area of the middle and the end portions of the specimens. The schematic diagram of the buffer (plastic) at contact between the middle and the end portions steel of the specimens is shown in fig. 2. Further fig. 3 is a comprehensive illustration of the stepwise experimental methodology implied for casting the specimens in this research.



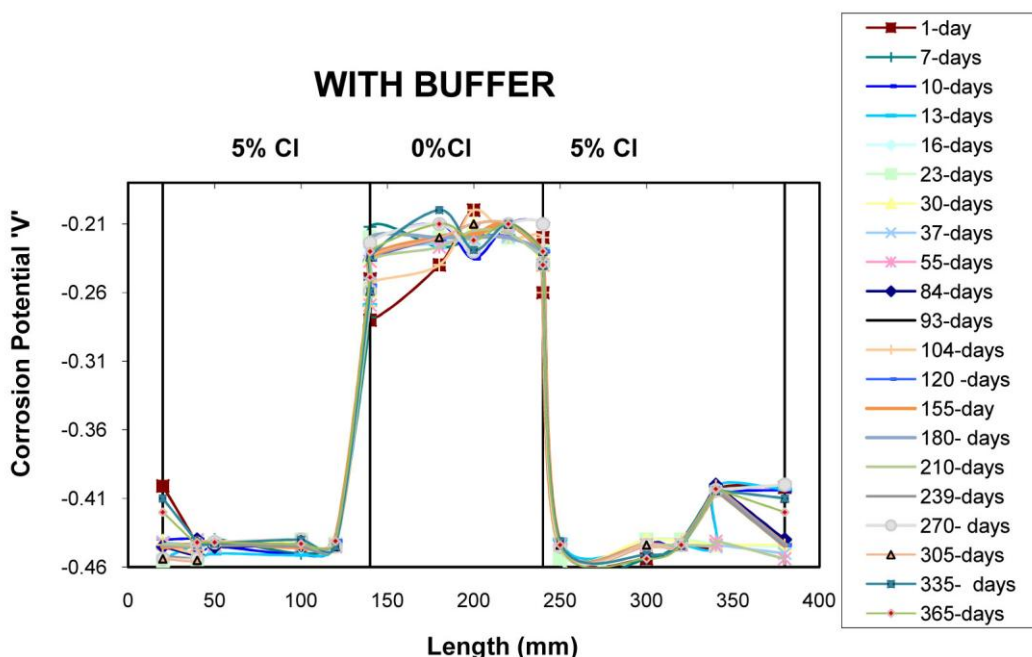
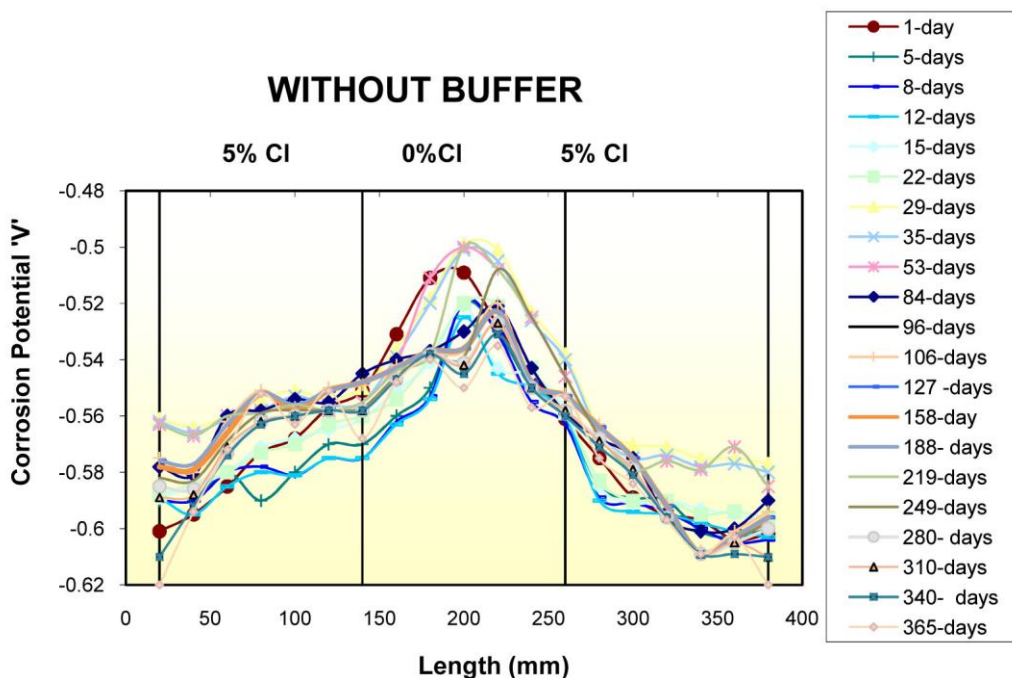
**Figure 3.** Experimental methodology for avoiding re-corrosion in repaired portion of chloride contaminated concrete.

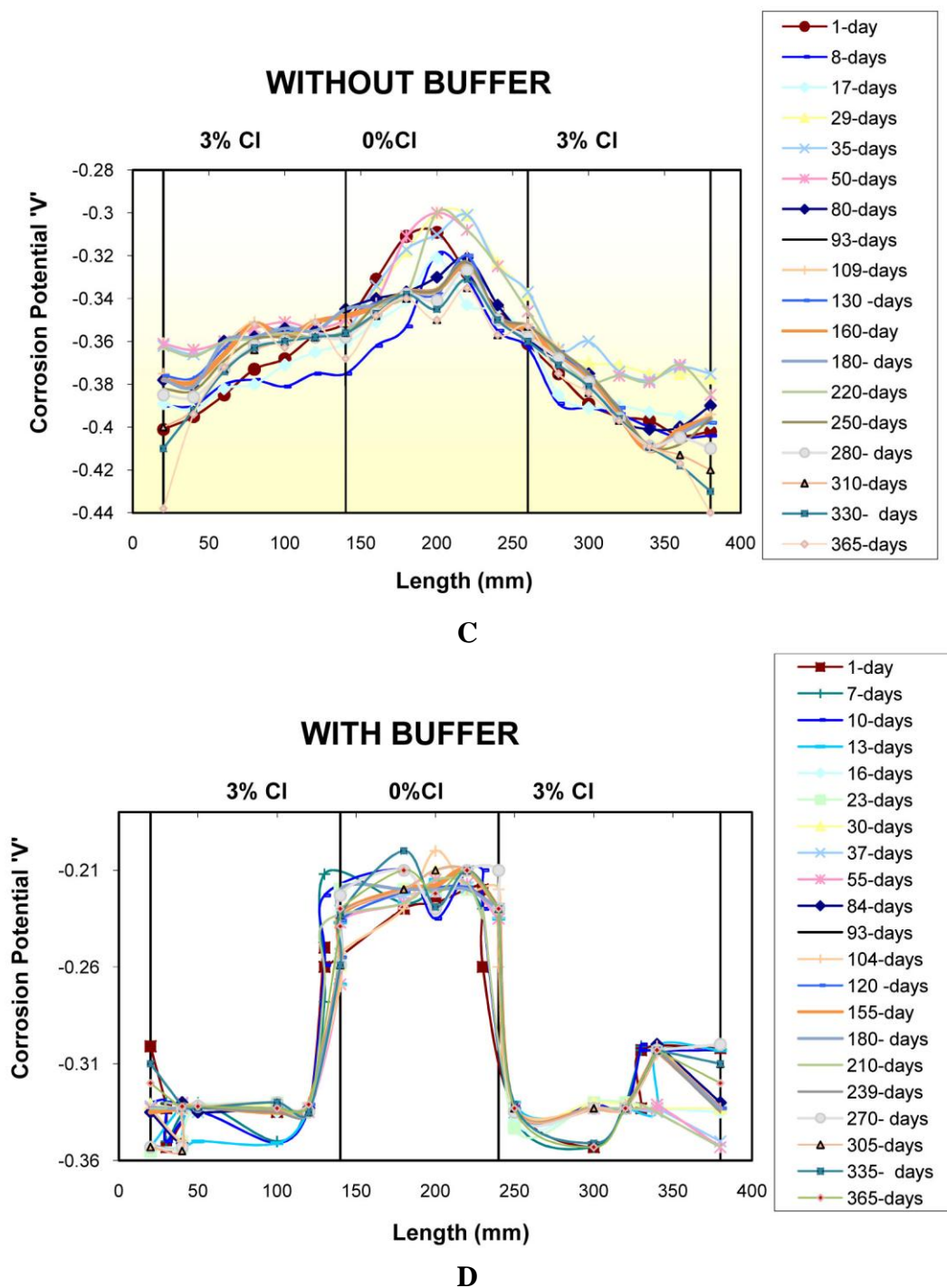
Half-cell potential measurement is probably the most common method used for measuring the risk of reinforcement corrosion. There are many researchers [18- 20] who done research on chloride induce corrosion of reinforced concrete using corrosion potential for measurements. The corrosion potentials readings of the specimen are taken for one year using copper-copper sulfate reference electrode (CSE) in accordance with standard specifications ASTM C 876-91 [21] to experimentally corroborate the objectives of this research.

### 3. RESULTS AND DISCUSSION

After one year of corrosion potential readings the results are compared with our previous study of macro corrosion in repaired patches of chloride contaminated concrete [15]. The following results are obtained on comparison;

1) At the middle non contaminated portion of the specimen #1 and #2, maximum corrosion of -0.230 Volts is found as compared to the high -0.55 Volts in the middle no chloride portion when no buffer was used at the contact steel area of the middle and end portions of the specimens as shown in fig. 4. This low corrosion potential value of -0.235 Volts at middle shows that there is no corrosion at the middle portion of these specimens having buffer at contact steel area between middle and end portions.





**Figure 4(a-d).** Comparison of Corrosion potential in specimens having 5 % and 3% contamination at the ends with and without buffer at the contact steel area between middle and contaminated portions.

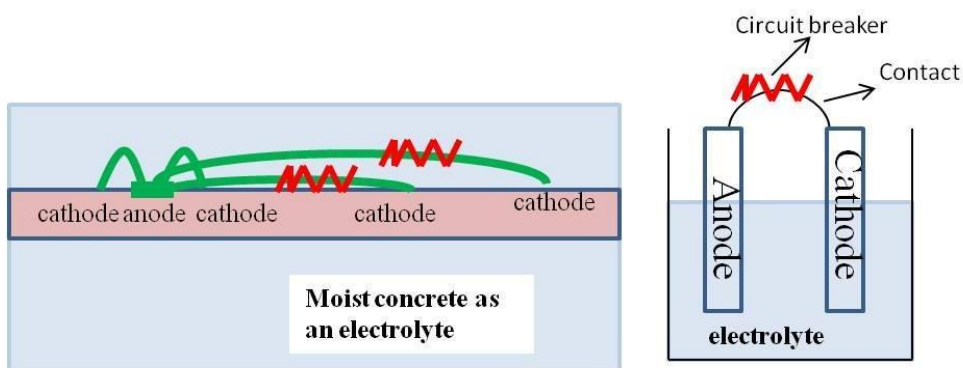
Furthermore this low corrosion potential value also suggests that there is no separation of anode and cathode and development of the macro cell in the middle portion simulating the actual patch repair in the field. This phenomenon is illustrated in fig. 5.

2) The maximum corrosion potential reading of the specimens #1 and #2 containing 5% chloride content at the ends is found to be -0.456 Volts as compared to high chloride induced

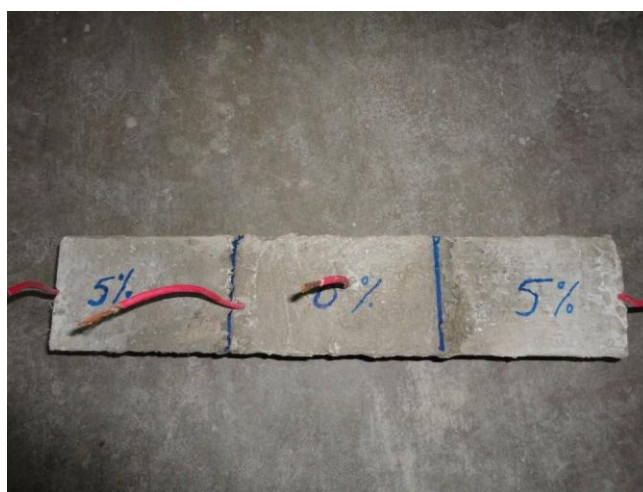


potentials of -0.62 Volts which was found when no buffer was used at the contact steel area of the middle and end portions of the specimens. This shows that corrosion potential readings are lowered when buffer is used at the contact steel area of the middle and end portions. This comparison is illustrated in fig 4.

3) There is no appearance of crack formation after one year in the specimen having 5% chloride content at the end as compared to the previous studied specimen without buffer at contact steel between end and middle portions fig 6a and fig. 6b. Previously it was found that there was cracking at the two ends of the 5% chloride content specimen that propagated towards the centre no chloride contaminated (control) 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% [22]. The very high chloride induced corrosion potential of -0.62 Volts at the two extreme ends of that high chloride contaminated specimen was actually due to the macro-cell formation (anodic in nature) which also induced a macro-cell corrosion potential (cathodic in nature) of -0.55 Volts in the middle no chloride portion. Fig. 6 shows the comparison of crack propagation in specimens having 5% chloride contamination at the end with and without buffer after one year.



**Figure 5.** No formation of macro cell because of circuit breaker (buffer).



(With buffer)

A



(Without buffer)

**B**

**Figure 6(a-b).** Comparison of cracks propagation in specimens with and without buffer at the contact steel area between middle and uncontaminated portions.

4) In the 3 % chloride contaminated specimens (#3 and #4) at the end, the corrosion potential of -0.354 Volts is obtained as compared to high -0.44 Volts when no buffer was used between steel contact at middle and end portions of the specimens. This result is the same as obtained in specimen #1 and #2 proving that corrosion potential is lowered in both cases having 3% and 5% chloride at the end when buffer is used at contact steel between portions of the specimen.

5) In specimen #3 and #4, the corrosion potential of -0.21 volts at the middle non contaminated portion is obtained as compared to -0.31 Volt at the middle when no buffer was used. This -0.21 volts at the middle portion of the specimen is almost the same as obtained in specimen #1 and #2 showing no effect of chloride content (3% and 5%) at the end confirming no corrosion at this middle portion simulating the actual patch repair. It is also proving that there is no electric conductivity between middle and end portion with the use of buffer as shown in fig 5.

The experiment results of this paper confirm that there is no phenomenon of cathode formation in the repaired no chloride contaminated middle portion and active anode in the two chloride contaminated ends of the experiment specimens which was previously found by the authors [15]. This shows that there is no macro-cell corrosion development at the middle uncontaminated concrete portion simulating the actual repairs in field. It has practical implications that need to be considered for an effective and durable repair of corroding reinforced concrete structures.

The innovative repair technique which is presented in this paper to avoid macro corrosion in the repaired patches of the reinforced concrete structures is novel and simple to be utilized in the construction field for repairs. Its application is economical and will minimize the cost of repairs. Furthermore, this new technique will remove the durability and serviceability repair issues of the corroding reinforced concrete structures.

#### 4. CONCLUSION

This paper presents the innovative technique that can prevent or minimize the re-corrosion in the repaired patches of the corroded reinforced concrete by experimental investigation which has not



been explored in the past. From the experiment results of this research it is found that by using buffer at the contact steel area between 5% chloride contaminated end portions and uncontaminated portions of the specimens, the chloride induced corrosion potential of -0.454 Volts at the extreme ends and low corrosion potential of -0.23 Volts at the middle portion is obtained. This -0.454 Volts corrosion potential was earlier -0.62 Volts at the two extreme ends in the same specimens but without buffer at the contact steel area and caused a macro-cell cathodic corrosion potential of -0.55 Volts in the middle no chloride portion simulating the actual repair and proved re-corrosion in repaired patches of corroded reinforced concrete. However this threat of re-corrosion of repaired concrete patches is successfully tackled by putting buffer at the contact steel between middle new steel and end portions of the old steel in the specimens which is evident from the low corrosion potential of -0.23 Volts at the middle no chloride portion. In 3 % chloride contaminated specimens, the corrosion potential -0.354V is obtained at the two ends and -0.23V at the middle as compared to earlier high -0.44V at the two ends and -0.31 Volt at the middle when no buffer was used which again shows that there is no corrosion at the middle no chloride portion because of buffer which acts as circuit breaker between anode and cathodic potential and stops the formation of macro cell. This confirms the experimental authenticity of this research. The authors believe that the simple innovative repair technique applied in this research is novel. It will be highly recommended for successful repairs in the construction industry because its application is simple for professional field engineers and it is economical as well minimizing the cost of repairs of corroded reinforced concrete. Furthermore it is expected that this new technique will remove the durability and serviceability issues of the corroding reinforced concrete structures.

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