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Full Length Research Paper

An experimental investigation of binding types of reinforcing steel rebars subjected to aggressive solutions under cathodic protection against corrosion

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Reinforcement corrosion in reinforced concrete structures results in significant reduction in durability and may cause premature failure. This study presents an experimental investigation of corrosion in reinforcing steel rebars with different binding types exposed to aggressive solutions of various concentrations under cathodic protection. The corrosion rate in the steel bars for different types of serial bindings was determined through their electrical current resistance. An increase in electrical current resistance represents an increase in corrosion at binding points with time. The study results indicate that the steel rebars under cathodic protection produced relatively less corrosion rate than those without any protection in the same aggressive solutions. The results also show that the type of binding in reinforcing steel has a great influence on corrosion rate.

Key words: Corrosion, reinforcing steel rebar, cathodic protection, aggressive solution, reinforcement binding type.

INTRODUCTION

Reinforcing steel provides both strength and ductility only through bond and anchorage to the concrete. The performance of this connection can decrease as a result of deterioration of the steel, concrete or both. The durability of reinforced concrete structures, therefore, is highly correlated with the ability of concrete to protect the embedded reinforcement against corrosion as well as the resistance of the concrete against chemical and physical factors. As a fact a considerable number of existing structures are being deteriorated with time by reinforcement corrosion due to several environmental exposures (Kapasny and Zembo, 1993; Fu and Chung, 1997; Fang et al., 2004).

When corrosion develops, Fe(II) ions are released, which hydrolyze water molecules giving $Fe(OH)_2$ and protons as follows: $Fe^{+2} + 2H_2O \rightarrow Fe(OH)_2 + 2H^+$. During corrosion, rust degrades the bond between steel rebar and concrete and thus reduces the service life of the structure. Various studies have been presented in the literature to evaluate the effects of corrosion on the bond strength (Fang et al., 2004; Cabrera, 1996; Lundgren, 2002; Lee et al., 2002; Ormellese et al., 2006; Bellezze et al., 2006; Montes-Garcia et al., 2010).

Different protection methods have been applied to prevent corrosion in reinforced concrete structures in highly aggressive environments. Among these, rebar galvanizing, rebar coating with epoxy paints, the incorporation of inhibitors during concrete mixing, and the waterproofing or impermeabilizing of the concrete are commonly used methods. However, they are subject to certain limitations (Nürnberger, 1996).

Cathodic protection previously was used for liquid tanks, ships and offshore structures. Nowadays, it has became one of the most reliable and economical alternative to halt corrosion in reinforced concrete structures whatever the chloride contamination with the use of new types of anodes (Wyat and Irvine, 1987; Pedeferry, 1998; Orlikowski et al., 2004; Hassanein et al., 2002; Hamidiye, 2008).

The objective of this is to investigate the effect of

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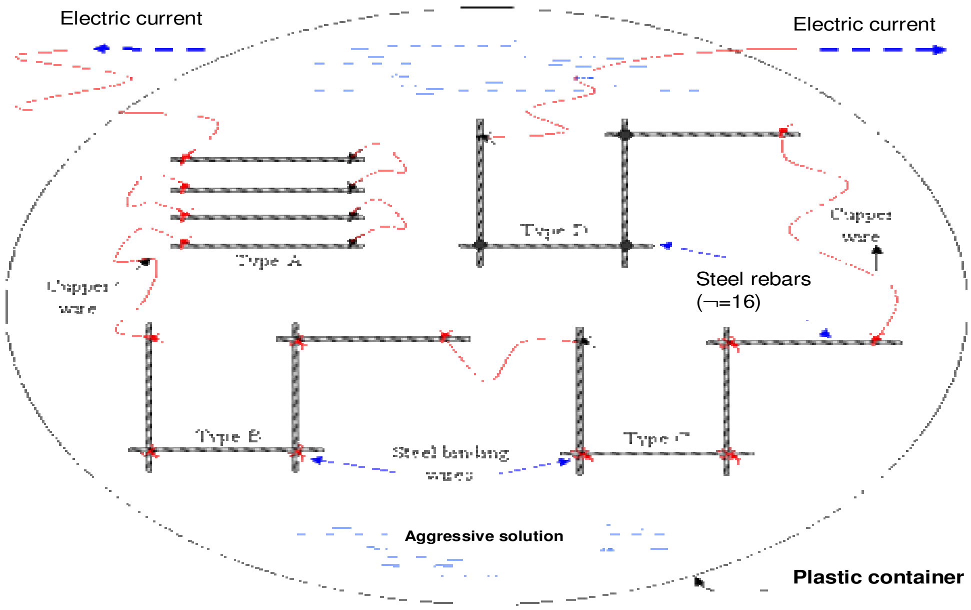

Figure 1. A group of steel rebars with different binding types.

Table 1. Chemical solutions used in the experiments.

Chemicals	Percentage of solution (%)	Weight of chemicals (g)	Weight of water (g)	Total weight (g)
	1	10	990	1000
NaCl	2	20	980	1000
	4	40	960	1000
	1	10	990	1000
Na_2SO_4	2	20	980	1000
	4	40	960	1000
	1	10	990	1000
O_2	2	20	980	1000
	4	40	960	1000
Waste coal powder	50	500	500	1000

reinforcement binding against corrosion under external cathodic protection. For this purpose, a series of experiments was conducted using reinforcing steel rebars with different binding types exposed to selected aggressive solutions of various concentrations.

MATERIALS AND INSTRUMENTS

In the experiments, the effect of cathodic protection against corrosion was examined through the comparison of steel rebars with and without cathodic protection. In the study, two different variables were considered, namely four types of bindings of steel rebars (¬=16 mm) and four different chemical solutions with three different concentrations. The measurement of corrosion rate was achieved using a resistance measurement device.

Steel rebar specimens

All steel rebars were prepared in accordance with the standard specification code of ASTM A416 Gr. 270. The rebars cut in 6 cm length were utilized in the experiments where each specimen consisted of four rebars. Four different binding types called A, B, C and D were tested to investigate the corrosion rate at touching points of rebars. As shown in Figure 1, for Type A, the steel rebars were serially connected to each other with copper wires without any direct touch. For Type B, they were connected with a single steel wire at the end points. Similar to the previous binding type, for Type C, the rebars were connected with double steel wires. Finally, for Type D, the rebars were welded to each other at their end points. A, B, C and D binding types of specimens were connected by copper wires to form a test group.

Aggressive solutions

In our study, we used sodium chloride (NaCl), sodium sulfate (Na_2SO_4), oxygen (O_2) and waste coal powder including carbon dioxide (CO_2) as aggressive solutions. Table 1 shows the weight percentages of aggressive solutions in one liter of water. The prescribed chemical solutions are commonly known as the most aggressive solutions for steel reinforcement causing corrosion and eventually loss of adhesion between steel rebars and concrete.

The test specimens and solutions were put in plastic containers which were covered by thin plastic films in order to prevent evaporation of solutions.

Instruments

For cathodic protection, a GW GPC-3030D model electrical power supply (dual tracking with 5 V fixed) and a GW digital multimeter GDM-8145 model (max. 20 A and DC 1200 V) were utilized in this study (Figure 2). The power supply was continuously operated during the test period of twenty days. The increase in electrical resistance was measured by the multimeter in every two days.

(a)

(b)

Figure 2. Electrical instruments; (a) power supply, (b) digital multimeter.

Experimental setup and methods

In our study, two series of 10 test groups were prepared. In order to compare the effectiveness of cathodic protection, the first series was subjected to external electrical current while the second series was not. As shown in Figure 3, each group of specimens was put in a separate plastic container filled with the preset percentages of solutions given in Table 1. The specimens in the container were located away from each other to prevent electrical transmittance. In each series, the groups were connected to each other with copper wires to transmit the electrical current.

During the test, for cathodic protection, a relatively low electrical current (0.388 mA) from the power supply was applied to one end of the first series and neutralized from the other end. The loss of electrical current or the increase in electrical resistance, for each group of specimens, was measured using the multimeter in every two days. The test was continued up to 36 days until the electrical current transmittance was almost stopped across the series due to corrosion at the contact point of specimens. The increase in electrical resistance is also measured for the whole series in order to correlate the individual group measurement data. At the end of the test period, for each specimen in every group, the loss of electrical current was measured in order to evaluate the performance of binding types. For the second series, which was not provided any cathodic protection, the same measurement procedure was followed.

Figure 3. The first series of 10 groups subjected to corrosion under cathodic protection.

RESULTS, DISCUSSION AND CONCLUSION

The measurements were continued until the electrical current transmittance across the series ceased. For the first series under cathodic protection, measurements were carried out for 36 days, while, for the second series with no protection, they were performed for only 6 days. The measurements for both cathodic protection and no protection are displayed in Figures 4 to 7.

Figure 4 indicates the temporal variation of electrical resistance for all groups of the first series in aggressive The temporal variation of electrical resistance for the groups in waste coal powder with and without cathodic

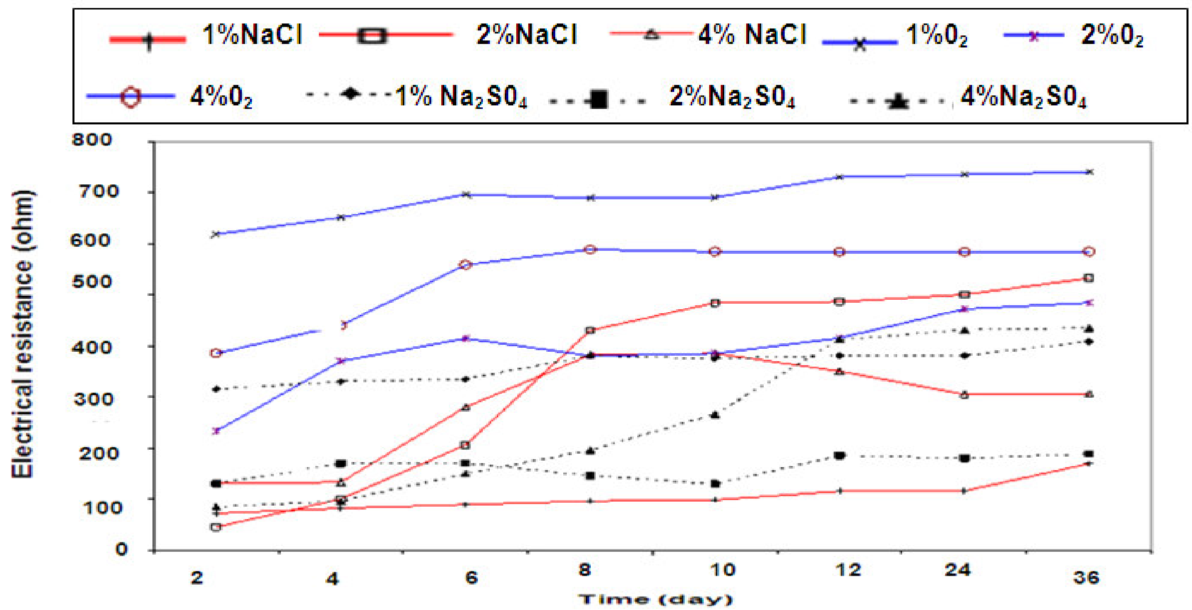

Figure 4. Variation of electrical resistance with time for the first series in aggressive solutions under cathodic protection.

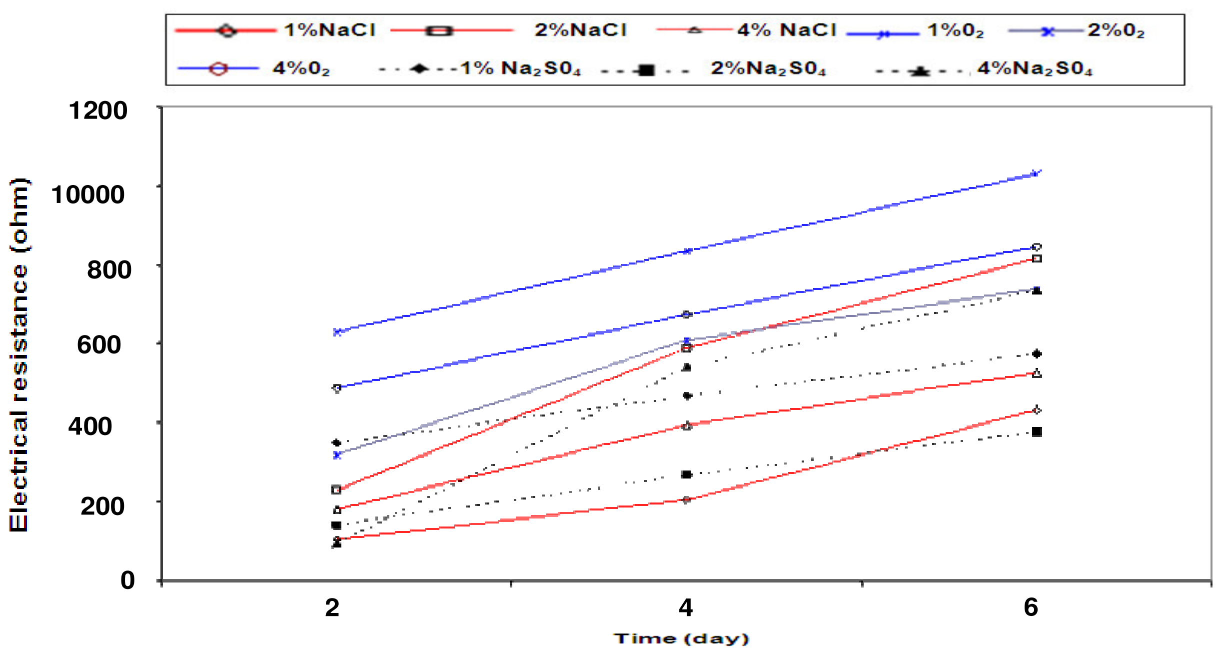

Figure 5. Variation of electrical resistance with time for the second series in aggressive solutions with no protection.

solutions. As shown in the figure, the electrical resistance gradually increases with time. On the other hand, as one expects, the electrical resistance increases more rapidly in the second series, which had no protection (Figure 5). As Figure 4 shows the corrosion rate is relatively higher for the oxygen solutions in comparison to the other two solutions. The variation in the electrical resistance after two weeks is very small for all groups under cathodic protection. Protection is displayed in Figure 6. In general, the cathodic protection generated relatively lower electrical resistance which means lower corrosions at the binding points.

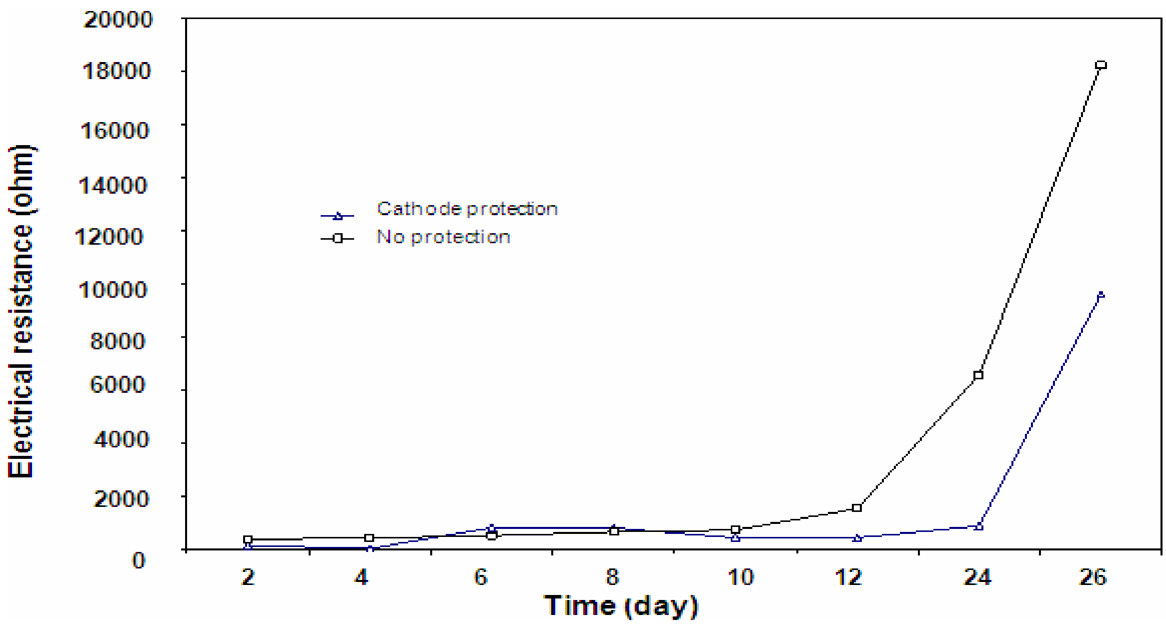

Figure 6. Variation of electrical resistance with time for the groups in waste coal powder with and without cathodic protection.

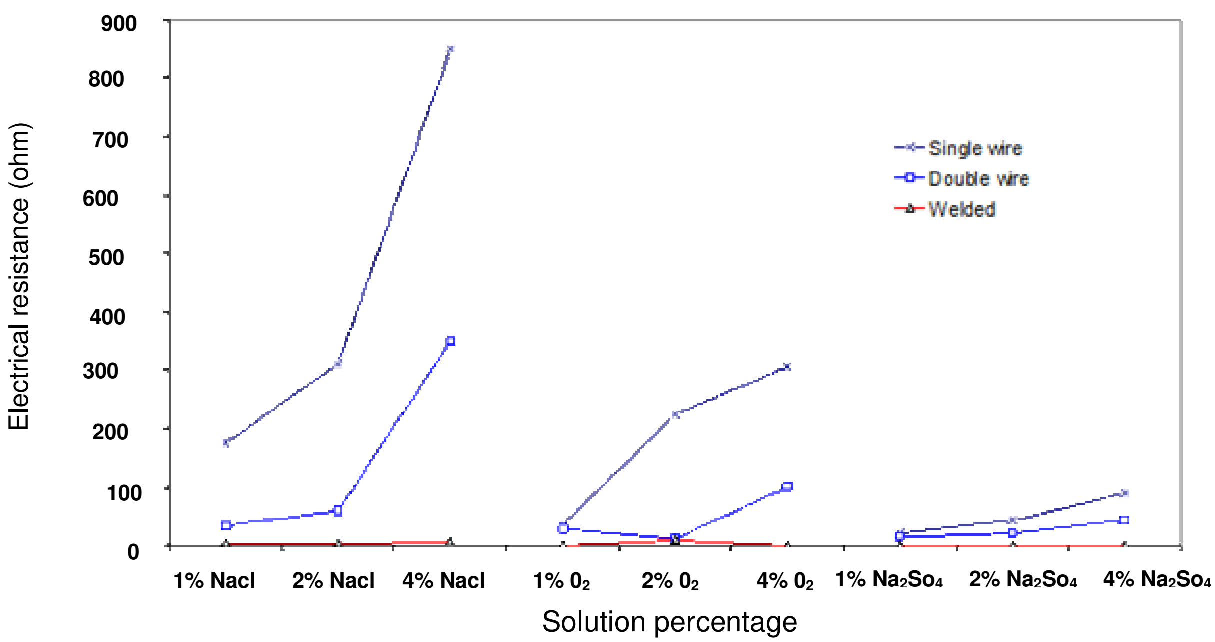

Figure 7. Comparison of electrical resistance values measured on the second day for different binding types under cathodic protection

The variation of electrical resistance for different binding types under cathodic protection was compared in Figure 7 where only the second day measurements were shown. As the figure indicates the corrosion rate is relatively higher for the single wire binding than the others. This is due mainly to loose contact between the steel rebars. On the other, negligible electrical resistance or corrosion rate is observed for the welded binding. Overall, this figure exposes the importance of binding of steel rebars if they are subjected to cathodic protection. The same figure also reveals that as the concentration of aggressive solution increases the corrosion rate also increases.

The evaluation of experimental results indicates that the cathodic protection for reinforced concrete structures may be very useful if carried out properly. The durability of such structures depends mainly on the protection of reinforcement against corrosion. As this study showed the type of binding and the amount of corrosives play a significant role in reinforcement corrosion.

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