論 文

[2139] CORROSION OF REBARS UNDER DIFFERENT CONDITIONS

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1. INTRODUCTION

Reinforcement corrosion involves the setting up electrical potential differences between anodic (corroding) and cathodic sites, followed by the passage of electric current between them with the concrete serving as "electrolyte". Though, in almost all concrete structures, the reinforcement in its various forms, bars, tendons, stirrups, chairs, etc. constitutes an electrically continuous system, for various reasons, most of the research work carried out so far has been done by exposing the entire reinforcement of laboratory size specimens in more or less uniform exposure conditions. Thus, the effect of the simultaneous existence of different exposure conditions with respect to different segments of the reinforcement system, on the susceptibility of these different parts to corrosion has not been fully understood.

This study was carried out to obtain a clearer understanding as to the part(s) of a structural element which is most susceptible to corrosion under simultaneous diverse exposure conditions and whether the corrosion activity can still be meaningfully monitored using natural potential measurements [1].

2. DETAILS OF SPECIMENS AND EXPERIMENTAL CONDITIONS

Two series of experiments were carried out with specimens cast using concrete having a water-cement ratio of 70%, s/a 52% and unit water content of 209 kgs/m^3. Whereas concrete for Series I did not have any initially added chlorides, 0.4% of chlorides (as NaCl, by wt. of cement) were added to the mixing water for specimens of Series II. All other experimental conditions were similar for the two series of experiments, which were carried out at room temperature. Deformed bars of 13 mm diameter were used and were provided with a lead wire coming out of the concrete to facilitate the measurement of natural potentials from time to time.

The exposure conditions for both series of experiments were chosen to represent those of actual structures and are schematically represented in Figure 1. The portions marked "spray" were sprayed once everyday with 3.3% NaCl solution using a spray bottle.

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Whereas, specimens No. 1, 2 and 5 have their entire reinforcement system in uniform environment, the conditions for specimens No. 3, 4 and 6 represent a combination of conditions occurring together.

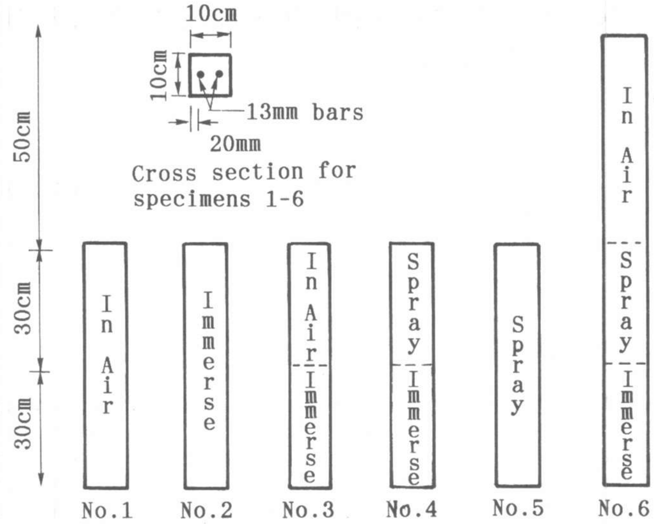


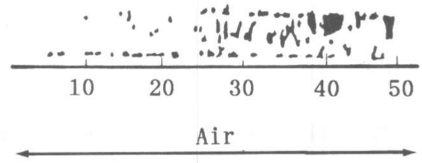
Fig. 1 Representation of exposure conditions

3. RESULTS & DISCUSSION

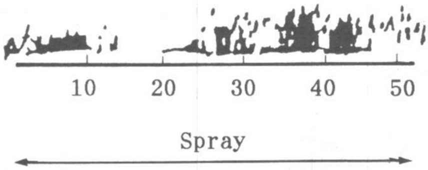
3.1 Observed corrosion

The corroded portions observed in the steel bars extracted from specimens at the end of the exposure period (6 and 8 months for Series II and I, respectively) were traced out and some of these tracings have been reproduced in Figures 2 and 3, where the darkened portions show the corroded portions of the bars.

<u>Uniform</u> <u>conditions:</u> As far as the corrosion in specimens exposed in air is concerned, no corrosion was observed in Series I, whereas similar conditions in Series II led to some corrosion all across the length of the bar as shown in Figure 2a. Therefore, it can be said that at least some of the chlorides initially mixed in the concrete remain available to initiate accelerated corrosion in reinforcing bars.

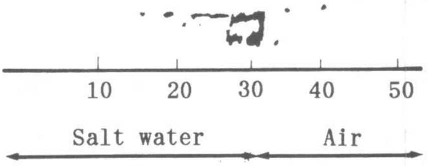


a) Specimen No. 1
(Series II, Air)

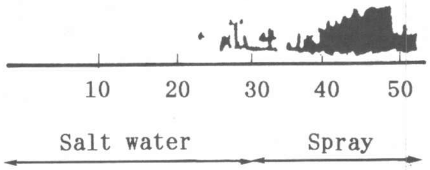


b) Specimen No. 5
(Series I, Spray)

Fig. 2 Observed corrosion under uniform conditions



a) Specimen No. 3
(Series I, Salt water and air)



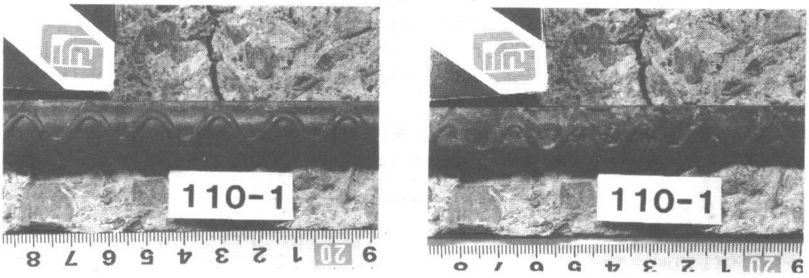
b) Specimen No. 4
(Series I, Salt water and spray)

Fig. 3 Observed corrosion under non-uniform conditions

It is believed that after the chlorides have depassivated the reinforcement, the initiation and propagation of corrosion is controlled by the availability of oxygen, which should be in the form of dissolved oxygen [2]. Now though no corrosion was observed in the specimens which were kept immersed in salt water [3], the corrosion observed in specimen No. 5 (spray, Figure 2b) extends all along the length of the bars. These results suggest that whereas dissolved oxygen (DO) alone does not induce visible corrosion (immersed condition), if its supply is replenished from the air, significant amounts of corrosion could be observed in the same time frame.

Non-uniform conditions: Typical corrosion patterns observed in the specimens exposed under non-uniform conditions are shown in Figures 3a and 3b. As we can see, in the case of specimen No. 3, whereas from the results discussed above no corrosion is observed in the two conditions (air and salt water) independently, a combination of these conditions at the interface, leads to corrosion in that area and the corroded area ranges from a little above to a little below the water-line. This corrosion at the interface can be imagined to be arising from the upwards movement of salt-water by capillary action, and the downward movement of oxygen from the air as dissolved oxygen. The corrosion observed in specimen 4 extending to a certain depth below the water-line, also supports the above hypothesis that replenishment of DO from air is important to sustain corrosion.

It is also of interest to note that the observed corrosion in all specimens was limited to the "underside" of the reinforcing bars [4]. Figure 4 points this out very clearly as Figures 4a and 4b are photographs taken at identical positions of the bars by just turning them through 180°.



a) Top of the bar

b) Bottom of the bar

Fig. 4 Corrosion is observed only on the bottom of the bar

Accumulation of bleeding water under the bars at the time of casting and it's subsequent drying gives rise to a void just below the bar and also leaves the underside without any sizable lime rich protective film, making the "belly" more susceptible to corrosion.

3.2 Capillary rise of salt water

As can be seen from Figure 1, some of the specimens are only partly immersed in salt water and the remaining part is exposed to air or is sprayed with salt water. Some white deposits were observed to have formed on the surface of such specimens at locations much higher than the water-line. Upon analyzing this white powder using X-Ray diffraction, it was found to be almost pure crystalline sodium chloride as can be seen from

Figure 5, which shows the diffraction patterns of pure NaCl and that of 2 samples of the powder collected from the surface of specimen No. 3 (Series I). Also, concrete samples were taken from varying depths from locations as high as 20cm above the water-line and analysed for chloride content. Though the results are not discussed here in detail, even parts of specimens that were exposed in air were found to have a significant chloride concentration. These observations show that movement of water within the pore structure of the concrete, in this case by capillary suction, plays a vital role in the transport of chlorides within concrete. Also the occurrence of crystalline NaCl at the surface under certain conditions, suggests a strong possibility of existence of chlorides in this form even within the concrete matrix. These findings add a new dimension to studies concerning chloride penetration in concrete.

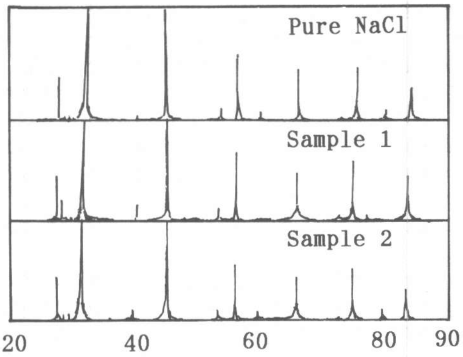


Fig. 5 Patterns of X-ray diffraction for pure NaCl and collected samples

3.3 Monitoring using natural potentials

In this study the natural potential of the bars was measured at a spacing of 5cm in accordance with the provisions of ASTM [1] at regular intervals of time to determine whether the occurrence of corrosion in the areas described above can be monitored using this method. At the start of the experiments, the potentials for all the specimens over their lengths are relatively uniform and in the "no-corrosion" region as per ASTM standards.

The typical variation of the potentials for some of the specimens exposed under uniform conditions over time is shown in Figures 6 and 7.

From Figures 2 and 3 it is known that no corrosion occurs in specimens left totally in air and immersed completely in salt water. However the behaviour of the natural potentials as monitored over time is quite different in the two cases. Whereas, the potentials for specimens totally in air remain in the "no corrosion" zone, almost in

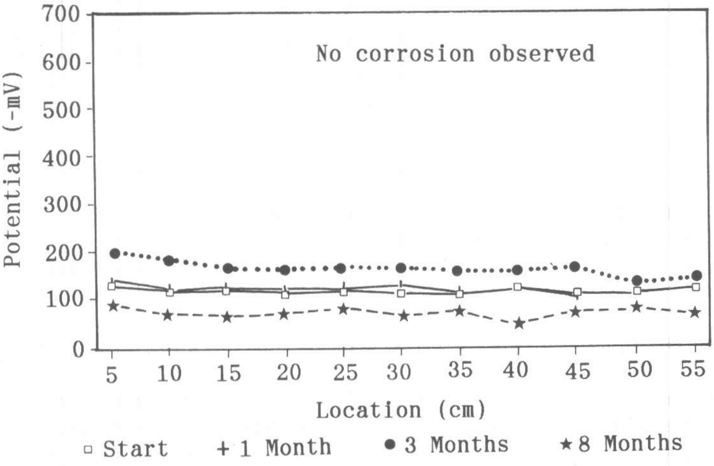


Fig. 6 Observed natural potentials for specimen exposed in air

all cases for the portions immersed in water the potentials "jump" to a very "active" value (more than -400mV) within one month of exposure.

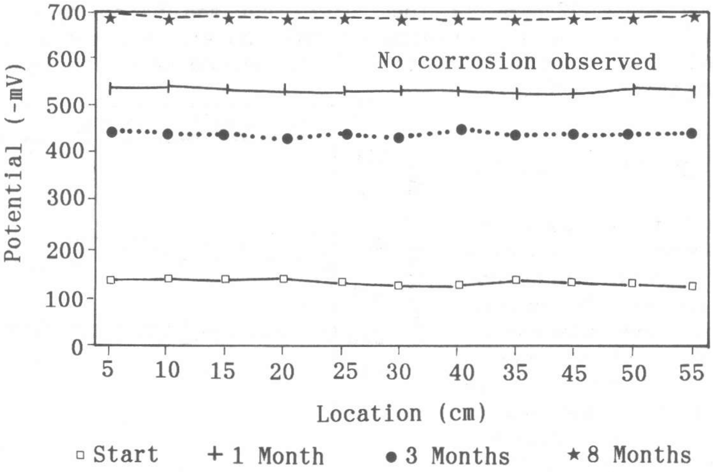


Fig. 7 Observed natural potentials for immersed specimen

A typical plot potentials for specimens under diverse exposure conditions for is shown in Figure 8 (for Specimen 4). The corroded portion in this specimen as shown in Figure 3b is also reproduced for easy reference. A plot for the 110cm long specimen (No. 6) is also shown in Figure 9 for completeness. We can see that the difference between the submerged portions and the portion being sprayed is lost rapidly within only a month as in the case of 60cm long specimens with no discernible difference in portions where corrosion was later found. It thus emerges that under certain conditions,

a) very active potentials could be obtained (Fig. 7) even without any observed corrosion, and

b) no difference between corroding and non-corroding sites may be observed (Fig. 8).

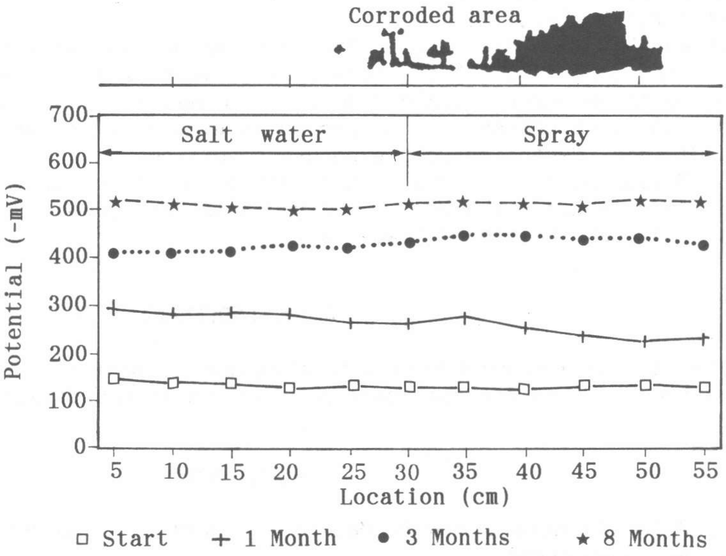


Fig. 8 Natural potential variation under non-uniform conditions

It can, thus, be said that whatever difference caused by the occurrence of corrosion is suppressed by some other affect. Whether this change in the natural potentials of the bars is attributed to the decrease in resistance of the cover concrete on account of saturation of the matrix with water [2,5,6] or the steel surface being deprived of oxygen is a matter outside the purview of this paper, but these results cast serious doubts on the applicability of the method in a straight-forward manner for corrosion diagnosis.

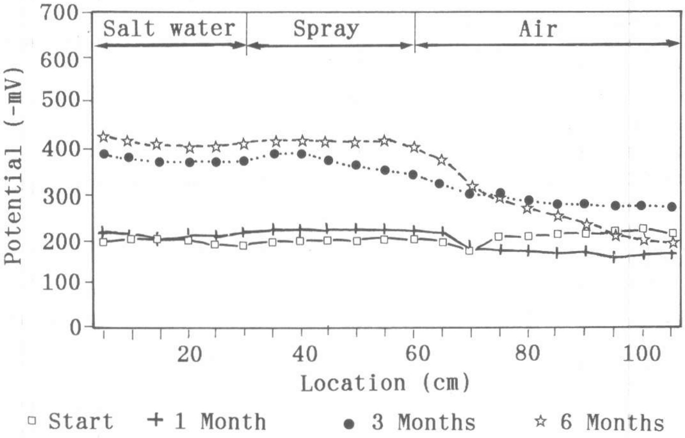


Fig. 9 Natural potentials for 110 cm specimen

4 CONCLUDING REMARKS

1. Not all parts of a member are equally vulnerable to corrosion and the corrosion characteristics under actual conditions cannot be clarified by studying them independently under different conditions.
2. Corrosion was found only in portions that were subjected to cyclic wetting and drying, or were at the interface of the immersed and aerial portions.
3. The "underside" of the bars is more vulnerable to corrosion.
4. Water movement within the matrix plays a crucial role in determining the chloride concentration and could even lead to deposits of crystalline NaCl, etc. depending upon exposure conditions.
5. Measurement of natural potentials alone may be grossly misleading under certain conditions and the saturation of the cover concrete is identified as one such interfering factors.

ACKNOWLEDGEMENT

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