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Performance Evaluation of Lithium Nitrite-Based Gel against Corrosion of Rebar with Partial Short Cover Depth in Chloride Environment †

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Abstract: Surface coatings are widely used for preventive maintenance, as they prolong the durability of concrete structures. Partial short cover depth may result due to poor construction quality and uneven formwork. In this study, lithium nitrite-based gel was used as an anodic corrosion inhibitor coating material to investigate its influence on the corrosion of rebar embedded in a partial short cover depth in the presence of chloride. The specimens were cured at a temperature of 20 °C and a relative humidity of higher than 95%. (a) Macrocell corrosion current density, (b) microcell corrosion current, and (c) polarization curves were measured, and the results were compared with those of uncoated specimens after aging for 28 days. The results revealed that the corrosion rate was reduced considerably due to the application of the coating with the gel type.

Keywords: chloride attack; corrosion current densities; lithium nitrite-based gel; partial short cover depth; rebar corrosion

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1. Introduction

The corrosion of steel in concrete depends on cover depth, chloride environment, coarse and fine aggregate, and the water–cement (W/C) ratio of the concrete. The rebar is highly alkaline due to the large amount of calcium hydroxide contained in cement. Calcium hydroxide protects the rebar from external effects due to a protective coating effect of the passive film. This passive film is destroyed when the amount of chloride ions present in the concrete exceeds a certain level or threshold for corrosion. Sea sand, chloride ions from seawater, airborne chloride, and anti-freezing agents are the main sources of chlorides. A partial short cover depth results from the dealignment of spacers or poor construction quality. A rebar with an adequate cover depth significantly decreases the corrosion density by 50% compared to that with a low W/C mortar subjected to an aggressive chloride environment [1]. The gel contains lithium nitrite as an anodic corrosion inhibitor. Nitrite ions (NO_2^-) diffuse through the concrete surface and react with ferrous ions (Fe^{2+}) to form a passive film [2]. Lithium-ion gel has been used for the repair of ASR deterioration in the concrete and also as a rust inhibitor in solution form. The gel-type penetrant effectively delays the corrosion rate of rebar in concrete [3,4]. However, its influence on the corrosion of rebar embedded in partial short cover depth has not yet been investigated. Thus, we explored the effect of the nitrite-based gel-type surface penetrant against the corrosion of rebar with partial short cover depth in the presence of chlorides using quantitative electrochemical methods.

2. Materials and Methods

2.1. Specimen

The specimen is shown in Figure 1. For the measurement of corrosion current densities in the rebars, six (06) (D10, 295) steel elements [5] 25 mm in length were connected through the high-insulating epoxy resin to form a 180 mm long bar. The cover depth was 20 mm and 7.5 mm. Ordinary Portland Cement (OPC) was used with W/C = 0.50 for both the 20 mm and 7.5 mm cover depth. Chloride ions of 2.5 kg/m^3 were added to the mortar of the 7.5 mm cover depth portion only. The chloride ions were added by mixing sodium chloride (NaCl) in water at the kneading time.

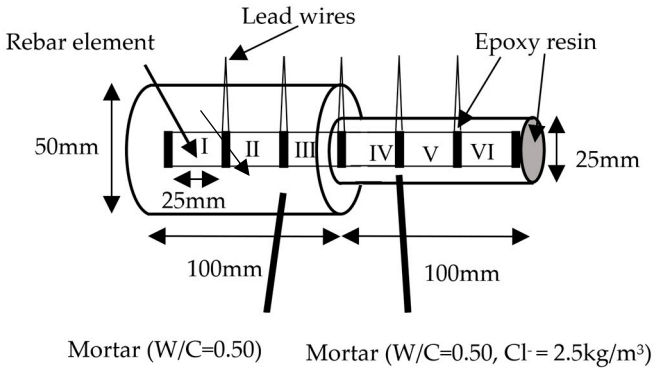


Figure 1. Partial short cover depth specimen with special divided bar.

The purpose of adding chloride ions was to simulate the penetration of chloride ions in short cover depth and to achieve a potential difference that enhances macrocell corrosion [6]. The mortar mix proportions are shown in Table 1. After casting, initial curing was completed in wet conditions at 20 °C and RH > 95% for 27 days, followed by 7 days of drying at 20 °C and RH = 60% to ensure that the surface moisture was less than 6%, as recommended by the manufacturer for coating. The gel-type coating was applied to the specimens at 1 kg/m^2 by using the brush. The antirust agent-mixed gel was an aqueous solution of lithium nitrite that was moderately thickened using a thickener. The amount of nitrite ions in the gel was 360 kg/m^3. The specimens were dried in dry conditions for 7 days and then cured in wet conditions for 27 days.

Table 1. Mortar mixture proportions.

W/C	S/C	Unit Weight (kg/m^3)		
		W	C	S
0.50	2.5	276	553	1384

2.2. Electrochemical Measurement

The current flowing between the steel elements was referred to as macrocell corrosion current density. The positive macrocell was anodic and the negative macrocell was cathodic in the macrocell corrosion current. However, the current flowing in the individual steel element was referred to as microcell corrosion current density. The summation of the anodic macrocell of an individual steel element and the microcell for that element was defined as total corrosion current density [7]. The polarization resistance was determined by the AC impedance method. Polarization curves were drawn in the three-electrode system. Ag/Agcl was used as a reference electrode. Potential at the rate of 1 mV/s was applied and the corresponding current was measured.

3. Results and Discussions

3.1. Corrosion Current Density

The graphs in Figure 2a,b show the variation in macrocell, microcell, and total corrosion current densities for all the steel elements along the rebar with cover depth and amount of chloride ion concentration for coated and uncoated specimens at the age of 28 days after coating. Figure 3 shows the result of the comparison of the average of the maximum total corrosion current densities of specimens that were coated and uncoated. The corrosion current densities for the coated specimen were lower than for the uncoated specimen. The average total corrosion current density for the specimen coated with the gel type was less than 0.1 μA/cm^2, which was a "Negligible corrosion level" as per RILEM recommendations [8].

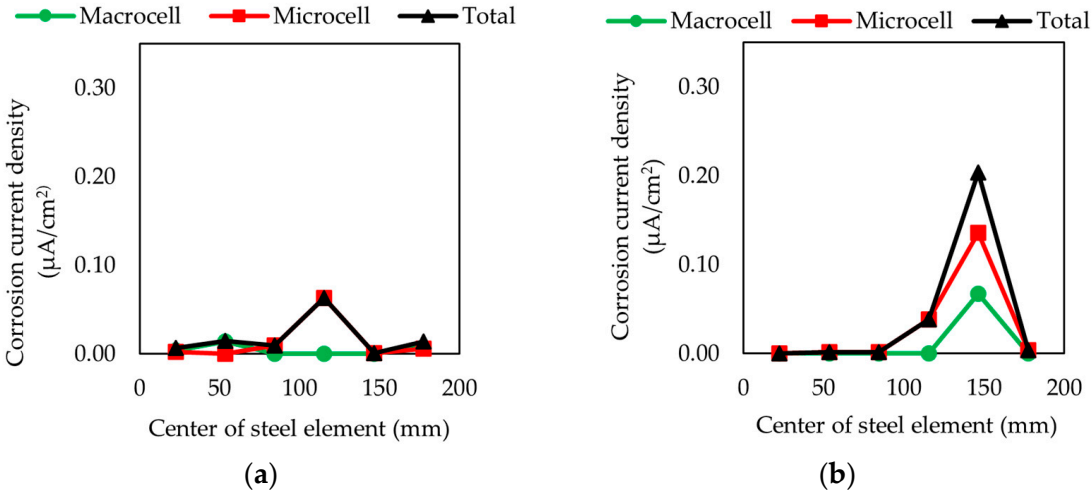


Figure 2. Showing comparison of macrocell, microcell, and total corrosion current densities of coated and uncoated specimens. (**a**) Variation in corrosion current densities along the length of rebar for specimen coated with nitrite-based gel; (**b**) variation in corrosion current densities along the length of rebar for the uncoated specimen.

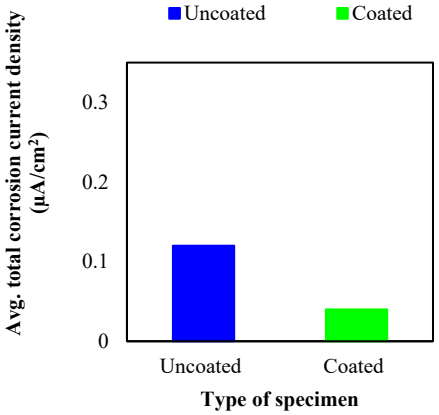


Figure 3. Comparison of avg. total corrosion current densities of coated and uncoated specimens.

3.2. Anodic Polarization Curves

Figure 4 shows the comparison of the anodic polarization curves at the age of 28 days after coating. The graph depicts that the current density at any potential difference is lower for coated specimens than the uncoated specimens. This confirmed the existence of lithium nitrite as an anodic corrosion inhibitor which reacted with the Fe^{2+} to regenerate the passive film and delay the corrosion reaction at the anode.

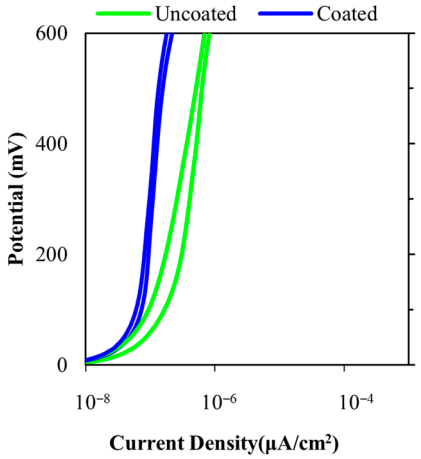


Figure 4. Anodic polarization curve of the coated specimen with anti-rust lithium nitrite gel type and uncoated specimen.

4. Conclusions

The performance of lithium nitrite-based gel as an anodic corrosion inhibitor was evaluated for the corrosion of rebar embedded in specimens with a partial short cover depth by using quantitative electrochemical measurements. The total corrosion current density for the coated specimen with the nitrite-based gel was less than that for the uncoated specimen for the partial short cover depth specimen. The magnitude of the current for the gel type was less than that of the uncoated specimen in the anodic polarization curves, indicating that the gel-type penetrant regenerated the passive film and delayed the initiation of corrosion. The application of the gel-type penetrant for partial short cover depth saves labor by delaying the corrosion that results in the spalling of concrete, thereby decreasing maintenance costs.

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References

1. Muhammad, A.K.; Miyazato, S.; Sugawara, N. Influence of Cover depth and mortar quality on Rebar corrosion under aggressive chloride environment. In Proceedings of the 4th Asian Concrete Federation Symposium on Emerging Technologies for Structural Longevity (ACF2023_ETSL), Shenzhen, China, 11–13 March 2023.
2. Lee, H.S.; An, J.M.; Shin, S.W. Study on the evaluation of corrosion protection effect with LiNO2, inhibitor. *J. Korea inst. Struct. Maint. Insp.* **2002**, *6*, 339–342.

3. Miyaguchi, K.; Takai, K.; Miyazato, S. Corrosion inhibition effects of reinforcing steel bars of reinforced concrete structures subjected to salt damage by Gel coating material containing Anti-corrosive. In Proceedings of the 77th Annual Lecture of Civil Engineering Society National Conference, Kyoto University Yoshida campus, Kyoto, Japan, 15–16 September 2022; Volume 548. (In Japanese)
4. Miyaguchi, K.; Takai, K.; Miyazato, S. Corrosion prevention effect of Reinforced concrete Using Gel composed Inhibitor against chloride attack, carbonation and composite deterioration. *Proc. Concr. Struct. Scenar. JSMS* **2022**, *22*, 1–6. Available online: https://cir.nii.ac.jp/crid/1520576137321497472 (accessed on 30 November 2023). (In Japanese).
5. Miyazato, S.; Otsuki, N. Steel corrosion induced by chloride or carbonation in mortar with bending cracks or joints. *J. Adv. Concr. Technol.* **2010**, *8*, 135–144. [CrossRef]
6. Hansson, C.M.; Poursaee, A.; Laurent, A. Macrocell and microcell corrosion of steel in ordinary Portland cement and high-performance concretes. *Cem. Concr. Res.* **2006**, *36*, 2098–2102. [CrossRef]
7. Miyazato, S.; Otsuki, N. Measurement Method for Macrocell Corrosion in Concrete Specimen using a Segmented Steel Bar. *J. Adv. Concr. Technol.* **2022**, *20*, 222–235. [CrossRef]
8. Andrade, C.; Alonso, C. Test methods for on-site corrosion rate measurement of steel reinforcement in concrete by means of the polarization resistance method. *Mater. Struct.* **2004**, *37*, 623–643. [CrossRef]

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