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Repair Performance of Re-Injecting of Lithium-Nitrite-Containing Solution and Grout on Corroded PC Tendons Due to Antifreeze Agents

Tomoshige Kamotani[1], Toshiyuki Aoyama[1*] and Hidenori Morikawa[2]

[1]*P.S. Mitsubishi Construction Co., Ltd., Japan*
[2]*Kobe University, Japan*
[*]*Harumi Center Bldg. 3F, 2-5-24, Harumi, Chuo-ku, Tokyo 104-8215, Japan*
kamotani-t@psmic.co.jp, t-aoyama@psmic.co.jp, morikawa@kobe-u.ac.jp

ABSTRACT

Prestressed tendons are designed for protection against steel-corrosion, where the protection is attributed to the high alkalinity of grout in post-tensioned PC structures. However, improper implementation of a design, such as incomplete grouting, may create voids in a post-tensioning duct. In such scenarios, the PC tendons may suffer from corrosion damage due to chloride ions that enter voids when structures are sprayed with antifreeze agents in the winter. One method to repair voids and mitigate corrosion is to re-grout using ordinary Portland cement. However, the prevention of corrosion of PC tendons by the re-grouting method has not yet been verified. This paper proposes a re-grouting method that re-injects a lithium nitrite ($LiNO_2$)-containing solution, and grout and validates its performance in repairing corrosion in concrete specimens.

Keywords. Repair, $LiNO_2$, Prestressed Concrete, Corrosion, Incomplete Grouting

1. INTRODUCTION

Prestressed tendons are designed for protection against steel corrosion, where the protection is attributed to the high alkalinity of grout in post-tensioned PC structures. However, improper implementation of a design, such as incomplete grouting, may create voids in a post-tensioning duct. In these instances, the PC tendons may suffer from corrosion damages due to chloride ions that enter voids when structures are sprayed with an antifreeze agent in the winter. Photo 1 shows one example of corroded PC tendons in an incomplete grouting area of a PCT bridge.

One method to repair voids and mitigate corrosion is to re-grout using ordinary Portland cement. However, prevention of corrosion of PC tendons by the re-grouting method has not yet been verified (Kondou et al., 2010).

Therefore, the authors propose a method that uses a $LiNO_2$-containing solution and grout, as illustrated in Figure 1, as a countermeasure. This paper compares the corrosion repair performance of the existing re-grouting method and the proposed method using concrete specimens.

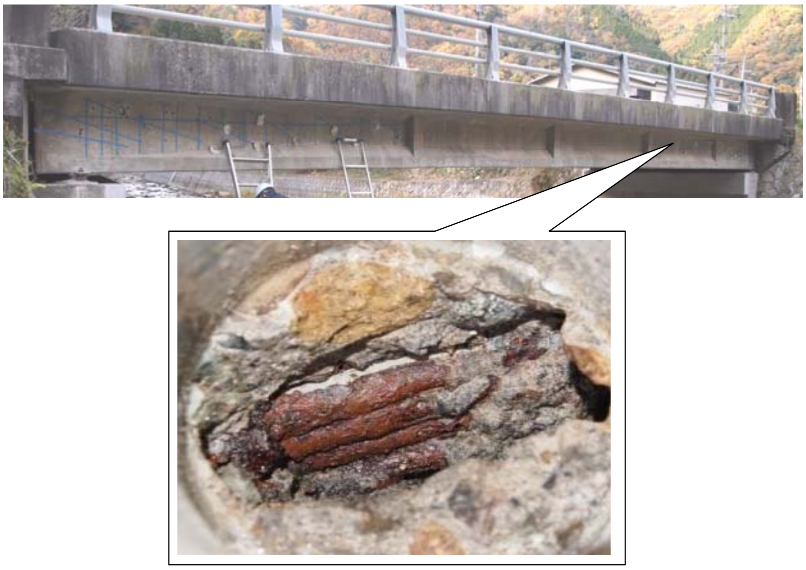

Photo 1. Example of corroded tendons in a real PC bridge

1. Injection of $LiNO_2$-containing solution into incomplete groutings area in sheath
2. Holding of $LiNO_2$-containing solution
3. Removing of $LiNO_2$-containing solution
4. Injection of $LiNO_2$-containing grout

Figure 1. Procedure of proposed method

2. EXPERIMENTAL METHODS

Test Piece. The test pieces consisted of round bars corroded by spraying of a solution containing 5% sodium chloride (NaCl). Both edges of each test piece were enclosed in a polyvinyl chloride pipe to prevent corrosion at the ends, with a measuring lead connected to one edge. Test pieces were sprayed twice per day for two months. Photo 2 shows the corrosion after two months of spraying NaCl solution twice per day. The average corrosion on three test pieces was 43.4 mg/cm^2.

Photo 2. Corrosion of test piece

Test Method (Sequence 1). The examination contained two sequences. Sequence 1 entailed the measure of a potential curve of a test piece in varying concentrations of $LiNO_2$-containing solution. The amounts of NO_2^- and Cl^- contained in the rust were also measured. Each test piece was dipped in a solution of saturated $Ca(OH)_2$, 6.5% $LiNO_2$, 13% $LiNO_2$, or 40% $LiNO_2$. The potential was continuously measured with a reference electrode and digital voltmeter (Figure 2).

A sample of rust was obtained from the test pieces injected into solutions of 13% $LiNO_2$ and 40% $LiNO_2$. The rust was dried and the sample was dipped in water. The amounts of NO_2^- and Cl^- dissolved in water were measured by ion chromatography analysis.

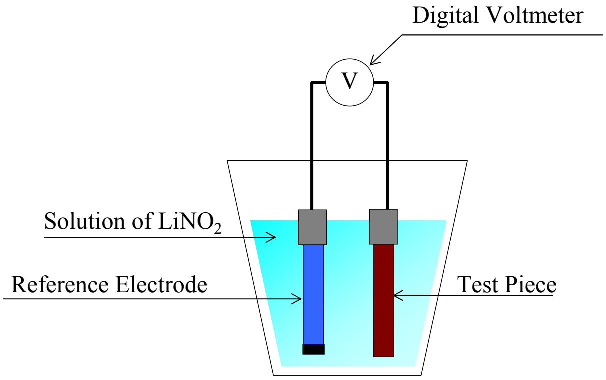

Figure 2. Experimental setup for potential measurement

Test Method (Sequence 2). Sequence 2 entailed using the experimental configuration shown in Figure 3 to calculate the corrosion rate in a repaired area. The test piece and counter electrode were sealed in a polyvinyl chloride pipe. A hole on the side of the apparatus provided access for measurement so that the cover of test piece is 10 mm.

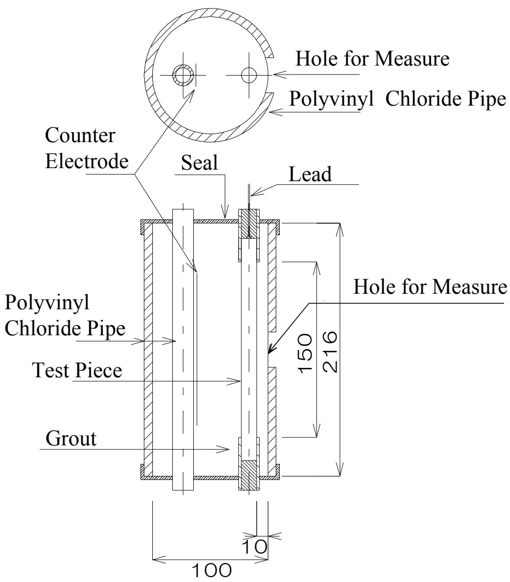

Figure 3. Experimental setup for Sequence 2

The parameters of Sequence 2 are listed in Table 1. The repair methods considered here included the re-injection of normal grout (Nor-G), re-injection of $LiNO_2$-containing grout (LN-G), and re-injection of both a $LiNO_2$-containing solution and $LiNO_2$-containing grout (LN-WG). The amount of $LiNO_2$ contained in the grout ranged from 6 kg/m^3 to 15 kg/m^3. The grout was made from high early strength Portland cement and a highly viscous admixture. The water/cement ratio was 45%. The test piece of LN-WG was dipped for 4 days based on the results of Sequence 1.

Table 1. Parameters of Sequence 2

No.	Repair Method ※)		Abbreviation
	(A)Dipped in $LiNO_2$-containing solution (Concentration of NO_2^- / Period)	(B)Re-grout (Amount of additonnal NO_2^-)	
sp-1	-	0kg/m^3	Nor-G
sp-2	-	6kg/m^3	LN-G
sp-3	-	9kg/m^3	LN-G
sp-4	-	15kg/m^3	LN-G
sp-5	6.5% / 4days	9kg/m^3	LN-WG

※) Procedure : the first is (A) and the second is (B)

In order to evaluate the performance of each repair method, all specimens were exposed to conditions of about 30°C and about 80% RH for 9 months. During this time, the polarization resistance of each test piece was continuously measured once per month by linear polarization resistance measurement, with a linear potential sweep rate ranging from 5 mV/min to 10 mV/min. After measurement, all test pieces were removed and the corrosion amount was measured.

3. TEST RESULTS AND DISCUSSION

Sequence 1

The potential curve of each test piece dipped in solution is shown in Figure 4.

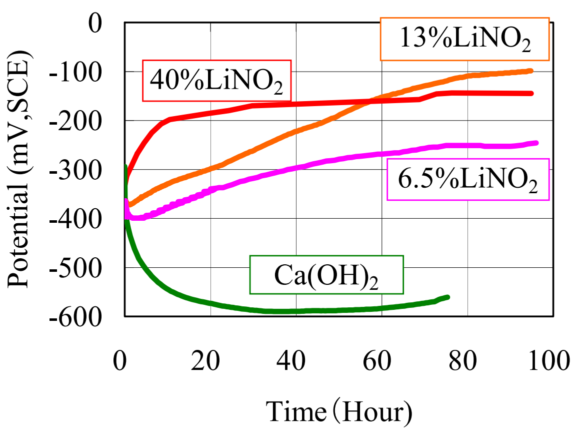

Figure 4. Potential of test pieces dipped in various solutions

The test pieced dipped in saturated $Ca(OH)_2$ decreased from -400 mV(SCE) to -600 mV(SCE). Conversely, the test pieces dipped in $LiNO_2$ increased to a range of -100 mV(SCE) to -250 mV(SCE). The slope of the curve depends on the concentration of $LiNO_2$ in solution. The higher the concentration of $LiNO_2$, the larger is the slope. The amounts of NO_2^- and Cl^- contained in the rust are given in Table 2. Penetration of NO_2^- into the rust and the amount of NO_2^- were confirmed to depend on the concentration of the solution. Diffusion of Cl^- into the solution was also confirmed. Considering previous knowledge that the rust of rebar is porous in structure and has microvoids (Kimura et al., 2004), the increase in potential is possibly caused by the penetration of NO_2^- and the diffusion of Cl^- in the $LiNO_2$ solution. As a result, the test pieces dipped in the $LiNO_2$ solution become passive because the ratio of Cl^- to NO_2^- decreased to below 1.25, which is reported as the threshold value of passivity (Hama et al., 2000).

Table 2. Results of ion analysis

No.	(A)Corroded due to Spray of 5%NaCl-containg solution (With or Without)	(B)Dipped in $LiNO_2$-containg Solution (With or Without / Concentration of NO_2^-)	(wt% in rust)		Cl^- / NO_2^-
			Cl^-	NO_2^-	
1	With	Without	4.1	—	—
2	With	With / 13%	0.23	3.2	0.072
3	With	With / 40%	0.53	5.1	0.104

※) Procedure : the first is (A) and the second is (B)

Polarization Resistance of Sequence 2

The polarization resistance for each specimen is shown in Figure 5. The polarization resistance of sp-1 (Nor-G) showed an increasing trend. After 180 days, the polarization resistance of sp-1 was greater than 130 $k\Omega cm^2$, which is the threshold value of passivity as given in Table 3. However, before 180 days, the value for sp-1 was consistently lower than 130 $k\Omega cm^2$, and sp-1 was therefore considered as not being passive. Considering the ion analysis result present in Table 2, if a certain amount of Cl^- is present in the rust, the corroded PC tendons are not passive following application of the existing re-grout method.

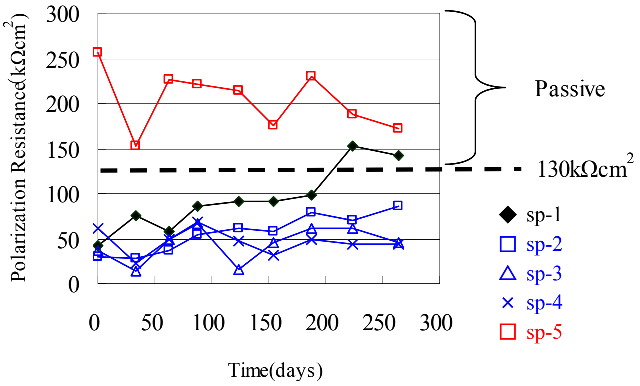

Figure 5. Polarization resistance of specimens

The polarization resistance values of sp-2, sp-3, and sp-4 (all LN-G) were consistently lower than 130 $k\Omega cm^2$ and therefore considered as not being passive. This is possibly because of the fact that penetration of NO_2^- present in grout into the rust was difficult, and the amount of NO_2^- in the rust was insufficient. The reason for the values of LN-G being lower than those of Nor-G is not clear. However, the results indicate that addition of $LiNO_2$ to grout without injection of a $LiNO_2$-containing solution can potentially have harmful effects.

The value of sp-5 (LN-WG) was consistently higher than 130 kΩcm^2 (JCI, 2001) and sp-5 was therefore considered passive. The repair performance of the proposed method was good and was an improvement over that of the existing method (Nor-G). Injection of the $LiNO_2$ solution is critical to the high repair performance of the proposed method.

Table 3. Relationship between polarization resistance and corrosion rate

Polarization Resistance(kΩcm^2)	Corrosion Rate
130< Rp ≤ 260	No cossosion or very low rate
52< Rp ≤ 130	Low ∼ middle rate
26< Rp ≤ 52	Middle ∼ high rate
Rp ≤ 26	Very high rate

Corrosion Amount of Sequence 2

The amount of corrosion for each test piece is shown in Figure 6. Both the actual measured amounts and the amounts estimated from equation (1) and the polarization resistance are shown in Figure 6.

$$G_h = 1/2 \times MK_v/F_a \times \sum(\Delta t/R_p) \quad (1)$$

where, G_h (g/cm^2) is the estimated amount of corrosion, K_v (mV) is 0.026, R_p (Ωcm^2) is the polarization resistance, M(g) is the atomic weight of Fe, F_a (coulombs) is the Faraday constant, and Δt (s) is time.

In this study, the amount of corrosion is defined as the gravimetric mass loss from the time at which each test piece is dipped in grout to the time at which the test piece is removed from the grout. Good correlation was observed between actual measured amounts and estimated amounts for all specimens except sp-4. Therefore, the approach of measurement of polarization resistance was validated.

The corrosion amount for sp-5 (LN-WG) was smaller than that of sp-1 (Nor-G). The amounts for sp-2, sp-3, and sp-4 (all LN-G) were larger than that of sp-1. This result indicates the same trend as that observed for polarization resistance (shown in Figure 5) and demonstrates the high repair performance of the proposed method.

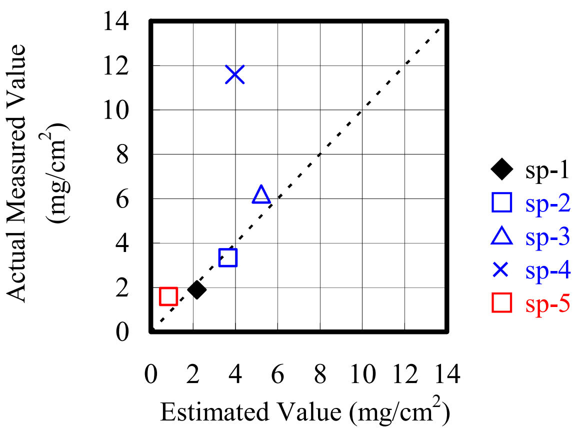

Figure 6. Corrosion amount for test pieces

4. CONCLUSION

In this paper, the authors proposed a new repair method that uses a $LiNO_2$-containing solution and grout as a countermeasure for PC tendons corroded by Cl^- in incomplete grouting areas. In order to verify the repair performance of this method, the potential of test pieces corroded by Cl^- in a $LiNO_2$ solution, the polarization resistance in grout, and corrosion amount were measured. Based on the measurement results, the repair performance of the proposed method was confirmed to be good and an improvement over that of the existing method.

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