Development of High Performance Grouting Method for PSC Strands

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Abstract. Prestressed concrete is very vulnerable to corrosion of strand because it has already been subjected to high tensile stress. The stability and durability of PSC have a very important relationship. In this study, many grouting specimens were made and the grouting performance used in the post tensioning construction fields were evaluated by the electrochemical method and weight loss measurement. The corrosion test was carried out in accordance with modification based on PTI M55.1-12 specification. Corrosion was activated by two types: corrosion by chloride ion (Cl⁻), and corrosion by chloride ion and dissolved oxygen (Cl⁻ + DO). The results showed that polymer is useful to maintain structural stability by reducing deterioration due to strands corrosion in PSC

1. Introduction
Corrosion-related failures of strand have been reported in the late 1990’s, USA. Strand failure was also examined in concrete viaduct in Republic of Korea as well. The normal causes have been attributed to development of bleed water during grouting and subsequent re-absorption or evaporation from the grout. Poor grouting during construction were of concern[1-3]. Corrosion failure of post-tensioned strands has been also identified to be related to grout segregation in Europe. Common main causes of premature prestressing strand corrosion are known as chloride or sulfate ions, microcracks, and voids due to insufficient cement grout, oxygen, and humidity[4]. The cement grout filled in the duct of bonded tendon forms a highly alkaline environment and corrosion resistant oxide layer on the surface of the prestressing strand. When the cement grout is exposed to salt water or CO₂ gas, corrosion can be initiated by chloride ions penetration or carbonation, as shown in Figure 1. After corrosion initiation, the rate of corrosion is governed by various factors such as oxygen inflow, water content, electrical resistance, and pH of cement grout[5]. The tendon at ions, galvanic interaction with the metal ducts and anchorages and possible enhanced macrowell corrosion.

According to the presence of corrosion of the prestressing tendon, the life cycle stages of prestressed concrete members have three life cycle stages, (1) crack initiation stage, (2) slow crack propagation stage, and (3) fast crack propagation stage, which induces a rapid brittle failure of prestressing strand by stress corrosion cracking. This is due to the stress corrosion phenomena and hydrogen embrittlement, which deteriorate metal structures. The higher the strength of prestressing strand, the more vulnerable to the brittle failure induced by hydrogen embrittlement. Higher degree corrosion coupled with higher levels of prestress leads to higher losses of prestress and this was accounted for as an additional loss at the design stage[6].

Based on the technical background above, strand corrosion is very important for durable prestressed concrete system, nevertheless, it has been rare to deal with this issue. This study is, therefore, devoted to examine the grouting performance of corrosion protective systems widely used in the multi-strand post-tension construction
fields. This work can provide us with how to make high performance grouting to make sure the best performance of corrosion protective systems.

2. Experiment overview

2.1 The Creation of Test Piece

Testing samples were casted with a circular cylinder pipe, placed on strands in the center. Seven strands with a nominal diameter of 16 mm were used. Mixing table is as shown in Table 1. Experimental variation is an amount of mineral admixture, anti-corrosion and polymer. Grouting was cured for 28 days, and then corrosion testing was carried out. Samples were sealed with epoxy at both ends.

Table 1. Grouting mixing table.

| Mixture symbol | Cement | Water | Blast furnace slag | Fly ash | Polymer | Anti-corrosion |
|----------------|--------|-------|--------------------|---------|---------|----------------|
| P0A0           | 1      | 0.27  | 0.4                | 0.1     | 0       | 0              |
| P7A0           | 1      | 0.27  | 0.4                | 0.1     | 0.07    | 0              |
| P15A0          | 1      | 0.27  | 0.4                | 0.1     | 0.15    | 0              |
| P0A5           | 1      | 0.27  | 0.4                | 0.1     | 0       | 0.05           |
| P0A10          | 1      | 0.27  | 0.4                | 0.1     | 0       | 0.1            |

P0A5 1. polymer 2. amount polymer 3. anti-corrosion 4. amount of anti-corrosion

To evaluate the corrosion resistance of each post-tensioning method, the experiment apparatus was designed as shown in Figure 1. The apparatus was slightly modified from the accelerated corrosion test (ACT) method specified in the Appendix B of PTI[7]. The chloride ion (Cl⁻) concentration in the corrosion cell was 5%, made by dissolving sodium chloride (NaCl) to distilled water. Two series of experiments were conducted with the type of corrosion activation; 1) only chloride ion, and 2) both chloride ion and dissolved oxygen. In order to evaluate corrosion by chloride ion and dissolved oxygen, the concentration of dissolved oxygen was 21 ppm which was measured by dissolved oxygen meter (DO meter).

2.2 Electrochemical Corrosion Assessment

The corrosion of prestressing strand specimens protected by each corrosion protection method was electrochemically estimated, based on polarization resistance method. The polarization resistance, \( R_p \), is defined as the ratio of the applied voltage, \( \Delta E \) (shift in potential from \( E_{corr} \)), to the step of current, \( \Delta I \), when the metal is slightly polarized (about 20 ~ 50 mV) from its free corrosion potential, \( E_{corr} \)[8]. In this study, the potentiostatic method was used for corrosion measurement based on the polarization
resistance method. A graphite rod was used as a counter electrode, and a saturated calomel electrode was used as a reference electrode. The working electrode was a prestressing strand specimen. The electrodes were connected to an electrostatic potential device, and the potential of the working electrode was measured as current applied for a short time period. The linear range of the current-potential curve is known to be linear in the range of 20 to 30 mV for the reinforcing steel. For the high corrosion rate, it is known to be linear in the range of 100 mV. Because there is a lack of research on the linear range of prestressing steel, a current corresponding to -10 to +10 mV, with respect to open-circuit potential, $E_{oc}$, was applied. The prestressing strand specimens were immersed in the corrosion solution for 60 days and the corrosion current density was measured every 15 days.

2.3 Weight Loss of Strands
To evaluate the degree of corrosion, the weight loss of prestressing strand due to corrosion was measured. The weight of strand was measured before and after the corrosion test. For the weighing, a precision balance with 0.1 mg of sensitivity was used to provide accurate measurement. After the ending of corrosion test, the prestressing strand in the specimen was taken and the impurities and corrosion products were removed. The prestressing strand was immersed in a cleaning solution and the corrosion product was removed using a resin brush. The cleaning solution was mixed with 20 g of antimony trioxide ($Sb_2O_3$) and 50 g of stannous chloride ($SnCl_2$) in 1 L of hydrochloric acid (HCl) solution. The cleaning procedure was referred to ASTM G1.

3. Experiment Results and Discussion
Figure 2 and Figure 3 represent corrosion current density of tendon protected by polymer, and anti-corrosion agent grouting with time, respectively. Grouting with polymer showed good performance to resist corrosion. This is proportional to the amount of polymer. For grouting with anti-corrosion agent, trend was not appeared. It should be noticed that the performance on corrosion had no relation with the amount of anti-corrosion agent.

Figure 4 shows the weight loss of the prestressing strand due to corrosion. The control specimens, which had no corrosion protection method, showed a very severe weight loss. The weight loss due to corrosion by chloride ion and dissolved oxygen was twice the weight loss by chloride ion solution. This has a good agreement with the result of corrosion current density. Likewise, the weight loss of the P7A0 P15A0 specimens showed a tendency similar to the measured corrosion current densities. Polymer can play a role of effective barrier to block the inflow of chloride ion or oxygen so that best corrosion protective performance was expected in the specimens. For the P0A0 specimens with no polymer and no anti-corrosion agent, the weight loss due to corrosion by chloride solution was similar to that of the P0A5 and P0A10 specimens. In a complex corrosive environment by combination of chloride ion and dissolved oxygen, however, the weight loss due to corrosion had increased significantly. It is concluded, therefore, that the corrosion protective performance of each corrosion protection method was consistent with the tendency found in the corrosion current density measurement. The corrosion resistivity was good in order of the P15A0, P7A0, P0A10, P0A5, P0A0, and the control.
Figure 2. Corrosion current density values according to the presence of oxygen (polymer)

(a) Polymer-growing without oxygen  
(b) Polymer-growing with oxygen

Figure 3. Corrosion current density values according to the presence of oxygen (anti-corrosion)

(a) Anti corrosion-growing without oxygen  
(b) Anti corrosion-growing with oxygen

Figure 4. Weight loss of strands
4. Conclusions
The purpose of this study is to provide fundamental data for the reliability of corrosion protective systems. In comparison of the performance of each corrosion protective system based on the measurement of corrosion current densities and weight loss of prestressing strands, methods contained with ad the best performance for corrosion protection. The tendon protected by grouting with polymer was found superior to others.

5. References
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