DEMONSTRATION OF REBAR CORROSION MITIGATION WITH EMBEDDED DISTRIBUTED GALVANIC ANODES

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Introduction

Corrosion of steel embedded in concrete structures and bridges can be prevented by using cathodic protection. Among the various corrosion control methods available, cathodic protection is a major technique adopted to control the corrosion of steel embedded in concrete. Cathodic protection system is aimed to shift the potential of the steel to the least probable range for corrosion.

This study has been carried out with a view to analyse the use of sacrificial anodes and electric current for the cathodic protection of steel embedded in concrete.

Objective

This research introduces electrochemical corrosion protection and basic experiment to develop embedded distributed sacrificial anodes for concrete structures. Then the few weeks of monitoring data is presented. Lastly, further research plan is briefly discussed. In this study it was decided to measure potential shift. Because the simplicity of instrumentation with data interpretation was appropriate for the further investigation and to define an appropriate electric current density range that can almost prevent the steel bar not to get corroded.

Testing practice

The corrosion process involved in typical chloride-induced steel corrosion is numerically simulated by employing the various kinds of element method.

In practice, the applied cathodic current density varies from 100-500mA/m^2 for passive steel not to corrode in order to achieve the more than 100mV potential decay criterion. The 100mV depolarization criterion specifies that the potential shift induced by the applied cathodic current should be larger than 100mV to prevent the corrosion.

< Preliminary water tank tests >

In this work, chloride and applied electric current worked as a simple factor which is suitable for water tank to operate continuous monitoring of corrosion were designed and tested in saturated Ca(OH)$_2$ condition. Using potentiostat which is called IviumStat, constant current was applied to the steel bar. Monitoring had started from July of 2017. Due to lack of previous data, there were many changes of setting while operating testing practice.
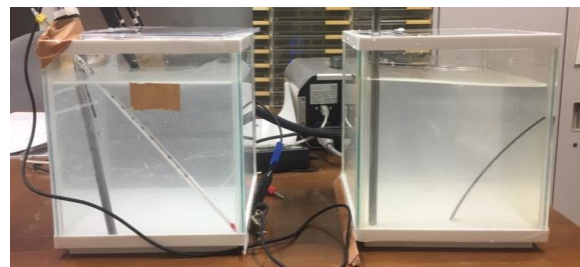
< Experiment model >　　< Comparable model >

Picture 1. Water tank test

A sample on the right side (**Picture 1**) which is named as comparable model is for checking the experimental condition that we set without applying electric current. During monitoring there were lots of changes in settings which were arranged in **Table 1**.

Table 1. Changes of setting during monitoring

Date	Settings	Input current
06/07/2017	5L of 3% brine	-4μA
11/07/2017	5L of 3% brine	-20μA
18/07/2017	5L of 0.2% brine	-20μA
20/07/2017	5L of 0.2% brine	-40μA
01/09/2017	5L of 0.2% brine $Ca(OH)_2$ Saturated	-100μA
29/09/2017	5L of 2% brine $Ca(OH)_2$ Saturated	-100μA
16/10/2017	5L of 2% brine $Ca(OH)_2$ Saturated	-500μA
17/10/2017	5L of 2% brine $Ca(OH)_2$ Saturated	-100μA
23/10/2017	5L of 1.5% brine $Ca(OH)_2$ Saturated	-100μA
01/11/2017	5L of 1.5% brine $Ca(OH)_2$ Saturated	-230μA

This One-week cycle monitoring has been operating with few facts and rules.

(a) The 100mV potential decay criterion specifies that a polarization decay of at least. 100mV from the "instant-off potential" is achieved within 48hours following the shutdown of the protection current.

(b) Electric potential at 3 points which are before disconnect, instant off, 48 hour shift is being checked through reference electrode (Ag/AgCl).

<Results from water tank tests>

Total seven session was held for monitoring data and the data that fits to our assumption was given and discussed in **Figure 1**.

- 7th Session < 2017.12.13-2017.12.20 >

- Right before disconnect : -0.7716V

- Right after disconnect : -0.7626V

- 48hour after disconnect (48hour shift): -0.6442V

- Depolarization : 118.4mV (0.7626V – 0.6442V)

Over 100mV of shift was measured in 7th session. The flow of electric potential was stably downward through a week.
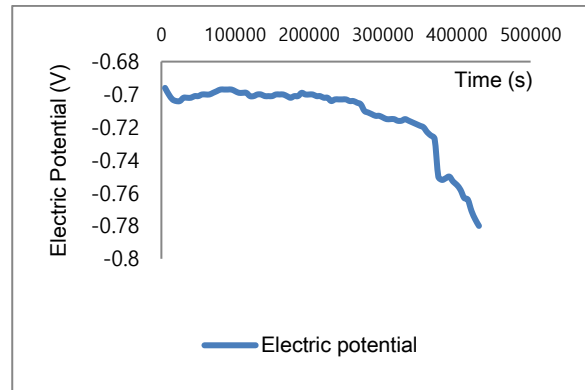

Figure 1. The flow of electric potential in 7th session

In the case of testing practice, the current distribution becomes much more complex than for concrete case. Generally, when a low cathodic current is applied, the protection current tends to flow more. In order to make it stable, much higher cathodic current should be applied. Various factor that could affect electric potential will be further demonstrated by the numerical case studies later in this paper.

< Main testing practice >

In this work, various kinds of cathodic protection was applied to chloride contaminated reinforced concrete in laboratory conditions in order to determine the minimum current that may be achieved with a smaller cathodic current than the ordinary cathodic protection criteria. In this case the protective effects of a negative potential shift may be small since such changes occur slowly and do not give the instantaneous protection offered by a large negative potential shift.

< Fabrication of Test Specimens >

All the specimens were contaminated with 6kg/m^3 of chloride. 21 reinforced concrete beams in size of 100 x 100 x 250 mm were made using one concrete mix. Total 7 types of specimen containing a centrally located 13mm diameter mild steel bar with an exposed length of 150mm, a titanium mesh counter electrode located close to the concrete surface of the specimens for
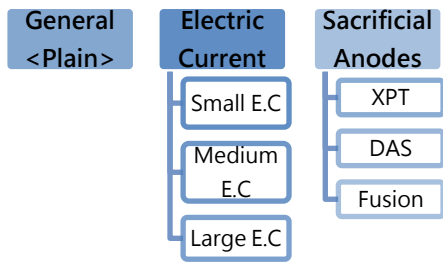
which the galvanic current is applied.

Figure 2. Type of main testing specimens

Designs of specimens are given in **Picture 3**. In the specimens in which sacrificial anodes are embedded, the following 3 types of sacrificial anodes were used.

- XPT is alkali-activated to keep the zinc active over the life of the anode and are non-corrosive to reinforcing steel (**Picture 2**).

- DAS is classified as alkali- activated anodes for corrosion control in concrete. Zinc anode core is surrounded by cement-based mortar (**Picture 2**).

- Fusion is an advanced system that combines the power of impressed current cathodic protection from embedded battery (**Picture 2**).

<XPT>   <DAS>   <FUSION>

Picture 2. Sacrificial anodes that are used
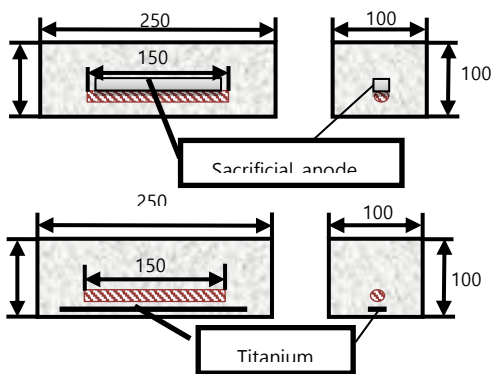
Picture 3. Design of testing specimens

An examination of main experiment in this study suggests that the range of applied current to achieve 100mV potential shift and the workability of sacrificial anode products. Changes in applied electric current of E.C specimens are arranged in **Table 2**.

Table 2. Changes in applied electric current of E.C specimens

Session	Applied electric current (A / µA/m²)		
	E.C Small	E.C Medium	E.C Large
1	0.1 / 16.3	0.2 / 32.6	0.4 / 65.2
2	0.1 / 16.3	0.2 / 32.6	0.4 / 65.2
3	0.05/8.15	0.1 / 16.3	0.2 / 32.6
4	0.05 / 8.15	0.1 / 16.3	0.15/24.45
5	0.05 / 8.15	0.1 / 16.3	0.15 / 24.45
6	0.01 / 1.63	0.05 / 8.15	0.1 / 16.3

It should be emphasised that monitoring the current density without controlling voltage during this period allows changes in the cathodic protection with time to be determined. One of the data from 6th session is indicated in Figure 3 - 4.
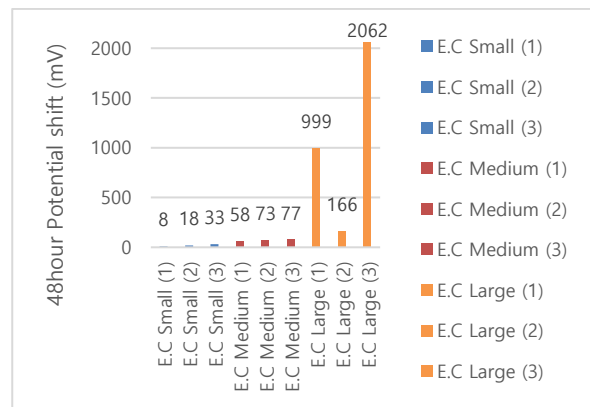

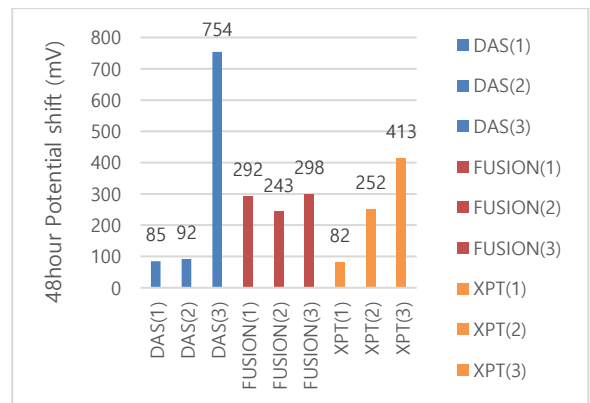Figure 3. 48hour potential shift of E.C specimen

Figure 4. 48hour potential shift of S.A specimen

Additional examination

After finished monitoring, embedded steel bars were collected and examined in two ways. Firstly steel bars were scanned divided into 2 sides as a front and back. Secondly corroded surface area was calculated each (**Figure 5-6**).
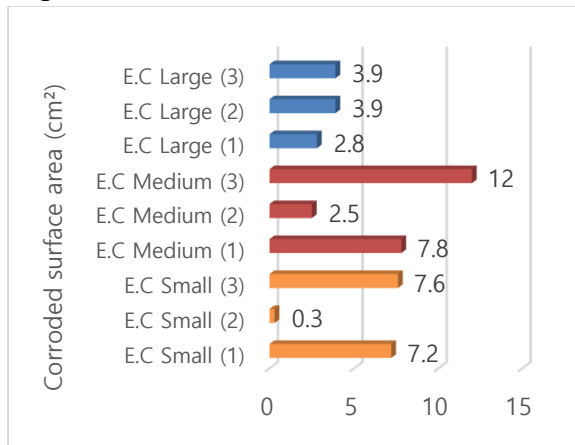

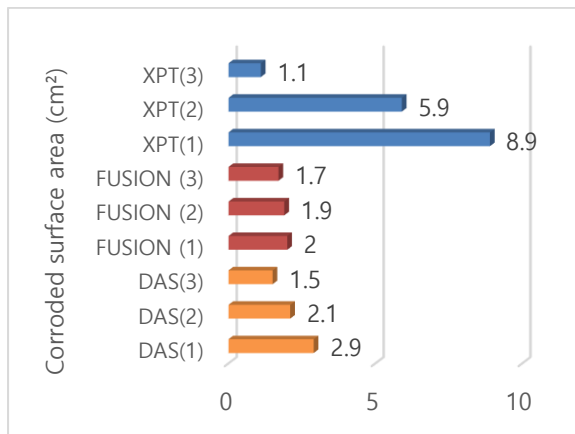**Figure 5. Corroded surface area of E.C specimens**

Figure 6. Corroded surface area of S.A specimens

Discussions

< Phase 1: Preliminary water tank tests >

An applied current of -230 A/ m², which is normally the upper limit for practical cathodic protection design, induced around 90-120mV of potential shift. The -100mV potential shift is really difficult to achieve at the water tank condition, even when the applied current is as large as -230 A/ m². The simulation results show that the impressed cathodic current required to arrest localized steel corrosion in water tank is much larger than in common concrete specimens.

< Phase 2: Application to concrete specimens >

This study investigates the application of cathodic protection to chloride-contaminated RC structures controlling in lab condition.

Cathodic methods that containing sacrificial anodes have been found to be rather effective than E.C specimens. In the 3 different sacrificial anodes analysed above, S.A FUSION presented the best stabled status with minimum deviation.

Conclusions & Recommended Considerations

This study can be concluded in 2 sides. Firstly at the point of comparing Plain specimens to E.C and S.A specimens. From this monitoring, because of short term of time, plain specimens were not corroded much than they expected. The effectiveness of cathodic protection did not proved well through comparison of E.C and S.A specimens to plain specimens.

Secondly, it can be relatively discussed about the methods that we used which are E.C and S.A. From the numerical figure, it is evident that S.A specimens worked better than E.C specimens in this study.

However, we shouldn't overlook the difference in condition. E.C specimens were connected in series order to the machine and even the applied electric current was keep changed to find the ideal amount of potential shift for best fit to cathodic protection.

Still the achievement of this criterion can provide the theoretical basis for the commonly adopted cathodic protection criterion. It also indicates ways in which such a criterion maybe developed.

However, the long-term beneficial effects of cathodic protection have not been considered, and future work should address the time-dependent changes of cathodic protection