# EFFECTIVENESS OF SACRIFICIAL ANODE TO PROTECT EMBEDDED STEEL IN CRACKED CONCRETE

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## 1. Introduction

Extensive cracking in reinforced concrete structure is a major durability problem. Cracks reduce the service life of the structure by permitting more rapid access of moisture, chloride ion and oxygen to the reinforcement, thus accelerating the onset of corrosion. The use of cathodic protection for new constructions is relatively expensive and can be more advantageously applied to reinforced concrete structure as a rehabilitation technique. Moreover, prevention of deteriorated reinforced concrete structures from further corrosion can be competitively achieved through cathodic protection. This paper aims to evaluate the effectiveness of sacrificial anode to protect embedded steel in cracked concrete.

## 2. Experimental Outline

### 2.1 Materials and Mix Proportion

Ordinary Portland Cement (OPC) was used for concrete mixes. Tap water having a temperature of 20±2ºC was introduced as the mixing water. Sea sand as fine aggregate (S) with fineness modulus (FM) of 2.77 and the saturated surface dry density (SSD) of 2.58 g/cm$^3$ were used. The coarse aggregate (G) had a maximum size of 20 mm with saturated surface dry density (SSD) of 2.85 g/cm$^3$ were used. Further, plain steel bar with 13 mm in diameter was used. Also, sacrificial anode with 60 mm in diameter and 30 mm in thickness was used as shown in **Fig. 1**.

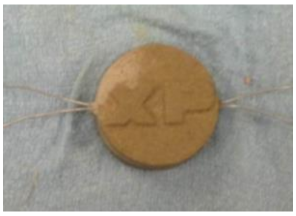

**Fig. 1 Sacrificial anode**

Concrete mix with water to cement ratio (W/C) of 40% was used throughout all specimens and mixture proportion of concrete is presented in **Table 2**. Both air-entraining agent and water-reducing admixture were used to obtain slump and air content in concrete mixes in the range of 10±2.5cm and 4.5±1% respectively.

### 2.2 Specimen Designs

Specimens were produced in the form of reinforced concrete prism with 150x150x500 mm in dimensions. The specimen had two plain steel bars of 13 mm diameter placed at the bottom with 30 mm clear cover from bottom surface. Each concrete specimen contained plain steel bar (PS) and plain steel bar with sacrificial anode (PSCP). Detail of specimens design is shown in **Fig. 2**. Before placing concrete in molds, sacrificial anode was installed on the steel bar and checked the maximum resistance of 0.3 Ω by using ampere meter, then concrete was placed and demolded after 24 hours. The specimens were cured under sealed condition in a wet towel for 28 days in constant room temperature at 20±2°C. After 28 days curing, all specimens were pre-cracked under one point flexural loading. One set of strain gauge was fixed in the bottom side of the specimen in order to check the crack width. Also, ten data were measured immediately for each side (bottom and lateral) as an average crack width.

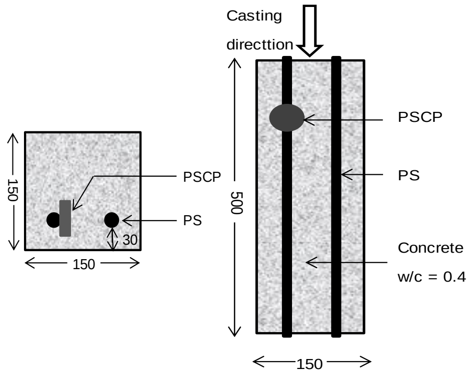


**Fig. 2 Detail of specimens**

**Table 2 Mix Proportion of concrete**

| Name | W/C (%) | s/a (%) | Unit content (kg/m$^3$) Water | Cement | Sand | Gravel |
|---|---|---|---|---|---|---|
| N40 | 40 | 41.5 | 161 | 403 | 680 | 1108 |

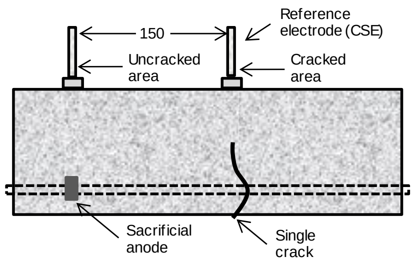


**Fig. 3 Potential mapping of specimens**

### 2.3 Experimental Method

In total, four specimens with different crack width were placed under dry/wet cyclic condition (2 days immersion in 3% NaCl solution & 5 days drying). Only 40 mm from bottom surface was immersed in 3% NaCl solution. **Table 3** summarizes the specimen used in this experiment.

**Table 3 Summary of specimen**

| Series | Crack Width (mm) | Crack Load (kN) | Exposure |
|---|---|---|---|
| C1 | 0.09 | 29.05 | Dry/wet Cyclic |
| C2 | 0.18 | 28.09 | |
| C3 | 0.29 | 31.04 | |
| C4 | 0.34 | 35.86 | |

The presence of corrosion in each bar was monitored by using half-cell potential measurement. Copper/copper sulphate electrode (CSE) was used as a reference electrode for measurement of potential. The potential evaluation of PS was based on ASTM C876-09 [1] and PSCP was according to JSCE Concrete Library 107 recommendation [2]. Sacrificial anode applied to steel in concrete is normally considered as effective if the potential difference between steel bar with and without sacrificial anode is more than 100 mV. The half-cell potential was measured in cracked and un-cracked area. The initial reading of the potential was taken immediately after pre-cracked.

**Fig. 3** illustrates the measurement mapping of specimen. In addition, anodic polarization curve of PS was measured both for uncracked and cracked area, and evaluated by using the passivity grade proposed by Otsuki [3]. When the current density becomes larger, the grade of passivation film of steel bar becomes worse.

## 3. Results and Discussion

### 3.1 Half-cell potential

The half-cell potential of PS under dry/wet cyclic at cracked and uncracked area are shown in **Fig. 4** and **Fig. 5**. In the cracked area, crack width of 0.09 mm shows the potential value around -350 mV at early age. After 12 weeks, the relationship between crack width and potential value changed by time. While larger crack widths shows more negative potential value less than -400 mV and categorized into the 90% probability of corrosion. Similar trend is found in uncracked area with potential value less than -350 mV. This is attributed to the effect of crack widths permitted easy access of chloride ions and oxygen to reach the steel bars and accelarated the onset of corrosion.

The half-cell potential value of PSCP at uncracked and cracked area under dry/wet cyclic are shown in **Fig. 6** and **Fig. 7**. The figures shows that both uncracked and cracked area achieved the half-cell potential values between -650 mV to -750 mV. The difference in potential value between PSCP and PS was more than 100 mV, which indicates that the sacrificial anode is effective to protect the steel bars. Also, the sacrificial anode is active an earlier time and have stable values after 12 weeks.

### 3.2 Anodic polarization curve

**Fig. 8** shows anodic polarization curve of the PS at uncracked and cracked regions, measured at the age of 36 weeks. PS embedded in concrete exhibited various polarization curve with potential between 0.2 and 0.6 V, and current density between 1 to 10 μA/cm$^2$, and 10 to 100 μA/cm$^2$. Besed on the criterion proposed by Otsuki, the conditions of PS under dry/wet cyclic is classified into Grade 4 (good condition) for crack width 0.09 mm. While for crack width of 0.18 mm, 0.29 mm and 0.34 mm were categorized Grade 3 (fair condition). It is also concluded that the specimen under dry/wet cycles exhibit higer corrosion rate in both uncracked and cracked area.

## 4. Conclusion

From the test results, following conclusions can be drawn:

1. Crack widths significantly affect corrosion of steel bars in concrete.
2. Sacrificial anode is effective to protect steel bars in cracked concrete and can fulfill the 100 mV potential difference of steel bar.
3. The passivitiy of PS under dry/wet cyclic becomes worse both uncracked and cracked area in larger crack width. This is attributed to the easy access of chloride ions and oxygen to the steel bars.

**Acknowledgment**

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## References

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[2] JSCE Concrete Library 107, "Recommendation for Disgn and Construction of Electrochemical Corrosion Control Method", November 2010.

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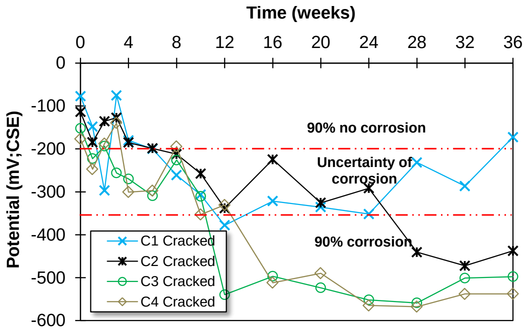


**Fig. 4 Half-cell potential of PS at cracked**

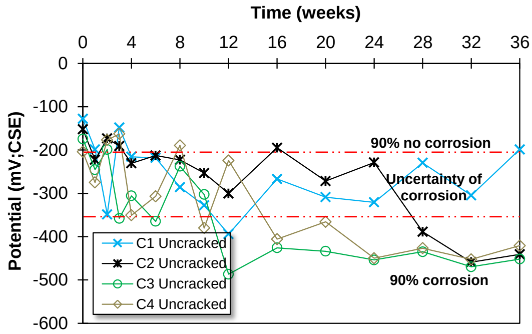


**Fig. 5 Half-cell potential of PS at uncracked area**

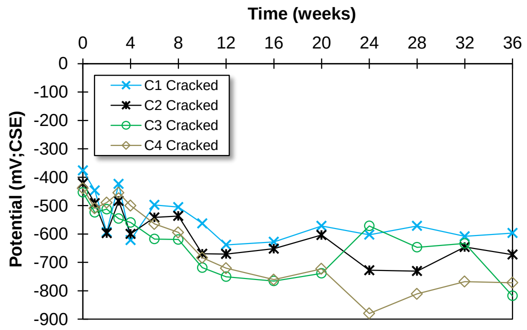


**Fig. 6 Half-cell potential of PSCP at cracked area**

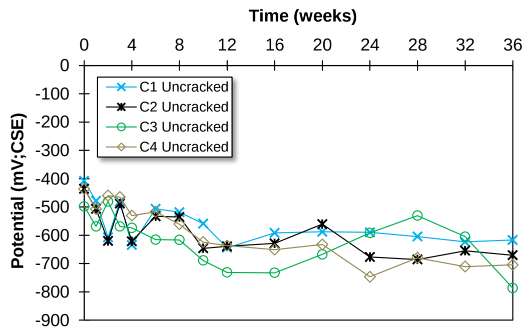


**Fig. 7 Half-cell potential of PSCP at uncracked area**

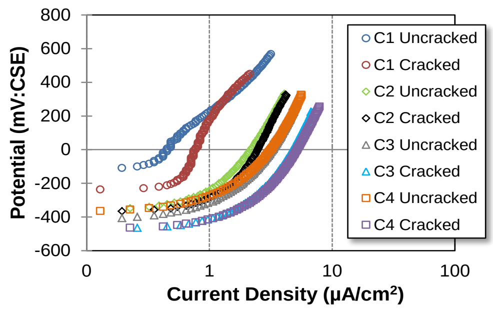


**Fig. 8 Anodic polarization curve of PS**