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Article

Experimental Study on Anode Life and Effective Distance of Sacrificial Cathodic Protection in Reinforced Concrete

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Abstract. The purposes of this study were to examine influences of concrete quality and environmental severity on anode life and to determine effective distance of sacrificial cathodic protection in reinforced concrete. 100 x 100 x 400 mm^3 concrete beams embedded with a reinforcement at distance of 25 mm from top surface were prepared and sacrificial zinc anode plates were attached on top surface of specimens. 700 x 700 x 75 mm^3 concrete slabs embedded with reinforcement mesh of 150 mm spacing were prepared and sacrificial anode were attached on top surface of concrete slabs at lower-left corner. The concrete beams and slabs were then exposed to wet-dry cycle and impressed voltage corrosion accelerations. The anode life was determined by time taken for total consumption of anode in concrete beams and the effective distance was determined by distance influenced by polarization effect of sacrificial anode in concrete slabs. Time taken for total consumption of anode and polarization effect were interpreted from corrosion potential data conducted in accordance with the ASTM C876. As a result, the anode life increased with increasing of concrete quality and decreased with increasing of the environmental severity. The effective distance was approximately 500-600 mm from the anode-installed position.

Keywords: Reinforcement, corrosion, cathodic protection, reinforced concrete, chlorides.

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1. Introduction

Reinforcement in concrete is naturally protected from corrosion by the high alkalinity of pore solution which enables the formation of a passive film on the steel surface. This passive film prevents the development of an active corrosion process. However, this protection can be destroyed by chloride ions or by the acidification of the environment in the vicinity of the rebar with carbonation [1]. Chloride-induced corrosion of steel bars is the primary cause of the deterioration of reinforced concrete structures in onshore and offshore marine environments. The depassivation occured when a certain amount of chlorides reaches the permissible chloride content which has been commonly limited at 0.4% (acid-soluble) or 0.15% (water-soluble) by mass of cementitious material in Europe and North America, respectively [2]. There are three well-known electrochemical methods for rehabilitation of the reinforced concrete structures deteriorated by chloride-induced corrosion, i.e. cathodic protection, electro-deposition and electrochemical chloride removal [3]. The principle of cathodic protection is the control of corrosion of the reinforcement by applying a cathodic current to the reinforcement such that the reinforcement is cathodically polarized and the anodic reaction is inhibited [4]. There are two main systems of cathodic protection, i.e. impressed current cathodic protection and sacrificial cathodic protection. The principle of impressed current system is the protection of reinforcement by applying electrical current from an external power source connected between an anode and reinforcement [5]. The principle of sacrificial anode system is electrical coupling of reinforcement to a sacrificial anode. It has been reported that both the sacrificial anode cathodic protection system and the impressed current cathodic protection system are appropriate repair options that can be used in the right circumstances [6]. The cathodic protection was also used to combined with the structural strengthening; combined impressed current cathodic protection-structural strengthening (ICCP-SS), to repair the reinforced concrete structures which was reported by Su et al. [7]. This technique was able to provide effective cathodic protection as well as shear stress transfer behavior to RC structures, leading to an improvement with respect to structural durability. The ICCP-SS was also used to rehabilitate sea-sand concrete column and the results showed that the loading capacities of the columns retrofitted by the ICCP-SS method were up to 40% greater than those of the corroded columns without any protection [8]. For the impressed current cathodic protection, regular monitoring in order to assess the levels of cathodic protection being afforded to the structure is required. In addition, cabling and control boxes associated with the impressed current cathodic protection are required to be strategically placed in order to avoid the risk vandalism. Therefore, the impressed current cathodic protection system may still not be appropriate in repairing small infrastructures in local areas where the security system is not good enough. The sacrificial anode cathodic protection is one of the most attractive alternative for repairing. Zinc and its alloys have been studied mostly among the sacrificial anode materials; however, the zinc alloys is limited in term of protection capability and anode implementation has evolved to promote sustained metal activity [9]. Zinc-hyrogel; a zinc sheet embedded in ionically conductive adhesive, was developed and the improved performance was reported [10]. Zinc mesh embedded in a Portland cement mortar cover has been used in concrete patch repair and effective extension of service life was also reported [11]. Aluminum sacrificial has been used and it has been found that the reinforcing steel was protected and no crack was observed [12]. Khomwan and Mungsantisuk [13] performed the experimental study of the performance of the sacrifincial anode cathodic protection system installed in the concrete prims, slabs and concrete water tanks. They found that the anode polarized the rebar at a significant potential and there was a good agreement with enhance the structural durability. The study of Astuti et al. [14] monitored the effectiveness of rusted and non-rusted reinforcing bar protected by sacrificial anode cathodic protection in repaired patch concrete and the result indicated that the non-rusted rebar condition is the most desirable initial condition when the sacrificial anode was applied on it in existing concrete.

The sacrificial anode cathodic protection system is suitable for small infrastructures and limited budget cost repair. In Thailand, the Southern and Eastern parts have long coastlines which concrete structures located in a hot and humid climate zone tends to deteriorate from the corrosion of the reinforcement by airborne chloride [15]. Therefore, a lot of small infrastructures deteriorated and the repair is required. Even the sacrificial cathodic protection is considered as the most effective and widely used in controlling chloride-induced reinforcement corrosion [16-18]; however, the sacrificial cathodic protection can lose its effectiveness with time due to the consumption of the anode. This effective period or the anode life is dependent on the average current output of the anodes. It has been reported that various factors affect the amount of current output of the anode system, such as temperature, oxygen content, humidity and also chloride content [19]. For the patch repaired concrete, it was reported that the sacrificial zinc anode had a profound effect on polarizing the potential of reinforcement in the substrate concrete and no significant protection in patch repair section [20]. However, this problem could be solve by adding the sacrificial anode in the patch repair section as Cheung and Cao [21] reported that the patch repair containing zinc sacrificial anodes was rather effective in inhibiting the corrosion effect around the substrate-patch interface. In order to achieve more accurate design of sacrificial cathodic protection, various factors affecting on anode life should be clarified. Concrete quality and environmental severity are factors of importance in the designing of sacrificial anode protection system. In another aspect, the effectiveness of the cathodic protection depends on adequate current distribution in concrete. The distance between the reinforcement and the installation position of sacrificial anode is an important factor for considering its effectiveness. It has been reported that the first row closest to the anode-installed point takes up to 90% of protective current in the case of slabs having two or more rows of reinforcement [4]. In new concrete structures or existing structures that the sacrificial anode can be installed at any location, anode installation is possible. However, the accessibility for installation of the anode may not be possible in some existing structures leading to the inevitability of installing sacrificial anodes far away from the reinforcement. Therefore, it is necessary to determine effective protection distance. This study tried to examine the influence of concrete quality and severity of environment on anode life and to determine the effective distance of the sacrificial cathodic protection in reinforced concrete. The result of this research will provide information for better understanding of sacrificial cathodic protection performance in term of influence of concrete quality and environmental severity on anode life. This will improve the design practice of sacrificial cathodic protection. The effective distance is useful for specifying appropriate installation position of anode to attain high efficiency of corrosion protection, in particular for the reinforcement at the position where the accessibility is not possible.

2. Materials and Method

2.1 Specimens Preparation

Concrete beams with dimension of 100 x 100 x 400 mm^3 were prepared for determining the influence of concrete quality and severity of environment on the anode life. A 12 mm round bar (SR24) was embedded at 25 mm from top surface as shown in Fig. 1. The properties of the rebar used in this study complied with the Thai Industrial Standard (TIS20-2543: Standard for Round Bar) [22] with the yield strength not less than 235 MPa. The steel was clean, without rust and other extraneous matters attached to the surface. 240 x 50 mm^2 sacrificial zinc anode plates (MAPESHIELD) with 99.9% pure zinc having 25 μm thickness were attached on top surface of concrete beams using electrically-conductive adhesive. The reason for not embedded the anode in the concrete because it was easy to confirm the complete consumption of the sacrificial anodes. Figure 2 shows the figures of the concrete beams. Three duplicates of specimens were prepared for each case of study. Three levels of designed compressive strengths of concrete were considered. 17.65 MPa designed compressive strength was represented for low quality concrete, the most commonly used in small infrastructure construction of local government organizations in Thailand. 24.52 MPa and 34.32 MPa designed compressive strengths represented middle and high qualities concrete,specified as the C25/30 and C35/40 concrete classes in accordance with the Thai Industrial Standard (TIS213-2552: Standard for Ready-Mixed Concrete) of the Thailand Industrial Standard Institute [23]. The concrete mix proportion is shown in Table 1, water-cement ratio (w/c) of low, middle and high qualities were 0.7, 0.6 and 0.4 respectively. Ordinary Portland cement type I with 3.15 g/cm^3 was used. Fine aggregate was river sand with 2.60 specific gravity and 2.40 fineness modulus. Coarse aggregate was crushed lime stone with 19-mm maximum size and with 2.77 specific gravity.

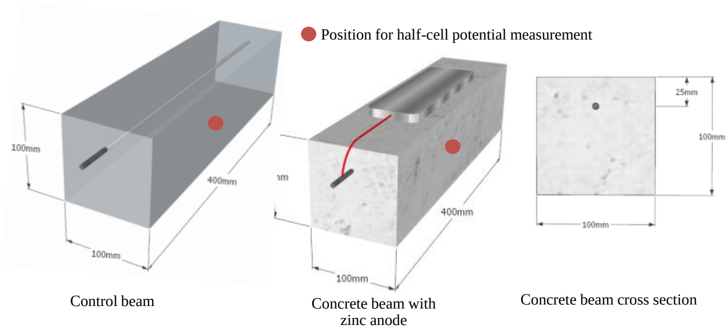

Fig. 1. Configuration of concrete beams.

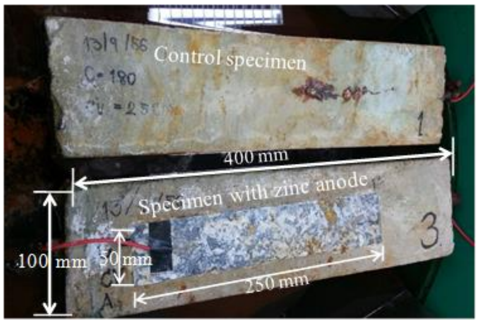

Fig. 2. Figures of concrete beams.

700 x 700 x 75 mm^3 concrete slabs embedded with reinforcement mesh with 30-mm covering were prepared for examining effective distance of the sacrificial cathodic protection. The reinforcement mesh was composed of ten round bars with 12-mm diameter (SR24) (five each for longitudinal and transverse directions) tied using the steel binding wire into a mesh with 150-mm spacing as shown in Fig. 3. The reinforced concrete slab preparation followed the previous study of the first authors [24]. The sacrificial zinc anode plate was installed on top surface of concrete slab at lower-left corner. Two duplicates of specimens were prepared for each case of study. The 24.52 MPa designed compressive strength was used.

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Table 1. Concrete mix proportion.

Concrete Class[a]	Designed Strenght [MPa]	Tested Strength [MPa]	Cement [kg m-3]	Water [kg m-3]	Fine Aggregate [kg m-3]	Coarse Aggregate [kg m-3]
-	17.65	18.79	320	225	1030	715
C25/30	24.52	24.69	365	225	990	715
C35/40	34.32	35.72	470	190	885	715

[a] According to Standard for ready-mixed concrete, TIS213-2557 [23]

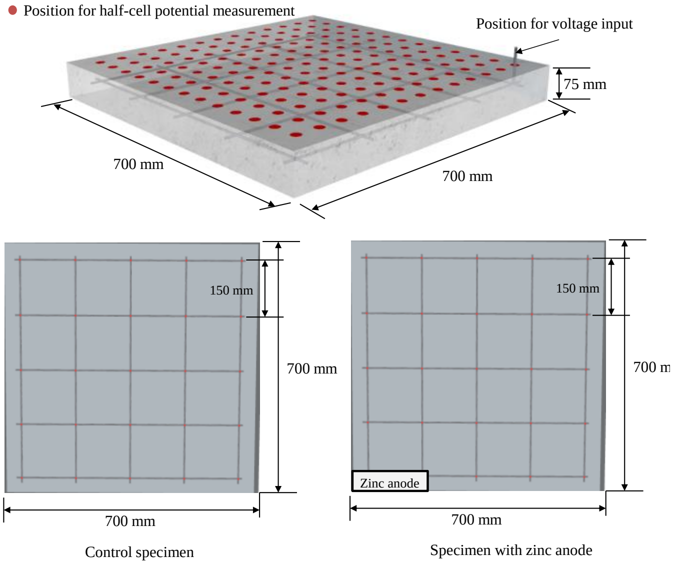

Fig. 3. Configuration of concrete slabs.

2.2 Corrosion Acceleration

Two methods of corrosion acceleration; the wet-dry cycle and the impressed voltage, were conducted. The wet-dry cycle corrosion acceleration was conducted by storing the specimens in the 5% of sodium chloride solutions for 3 days and then storing in the dry condition for another 3 days. It was conducted for totally 168 days. During storing in the solution, the specimens was not completely immersed in the solution because the zinc sheet was prevented from directly contacting the solution. The impressed voltage corrosion acceleration was conducted by applying the direct electric potential of 6 V between reinforcement and external electrode by using a regulated power supply which converts AC into a constant DC. Also, the specimens were not completely immersed in the solution due to the prevention of the zinc sheet to contact directly to the solution. Aluminum plate was used as the external electrode and 5% of sodium chloride solution was used as the electrolyte. The outline of wet-dry cycle and impressed voltage corrosion accelerations are shown in Figs. 4 and 5. In order to examine the influence of environmental severity, the 24.52 MPa designed compressive strength of concrete was used and chloride content of electrolyte was varied from 3% to 5% by weight. The chloride content of 3% was specified following the salt pounding test according with the AASHTO T259 [25]. In order to represent a more severe condition, the 5% chloride content were used.

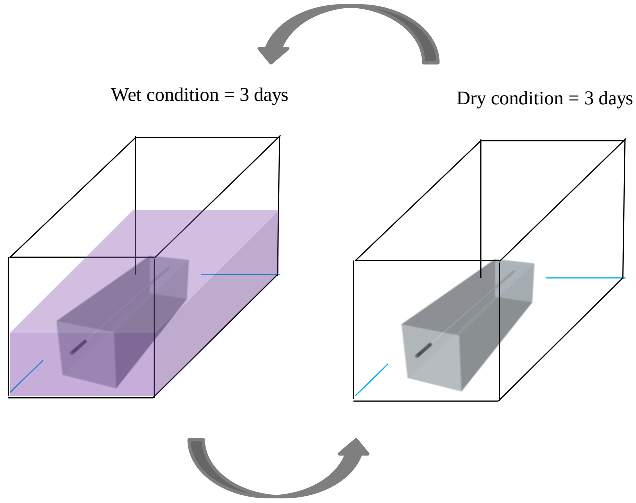

Fig. 4. Wet-dry cycle corrosion acceleration.

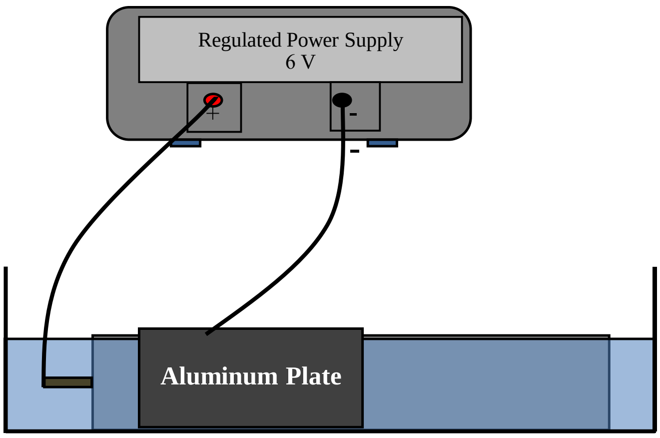

Fig. 5. Impressed voltage corrosion acceleration.

2.3 Half-cell Potential Measurement

The half-cell potential measurement was performed in accordance with the ASTM-C876 standard [26]. This method is well established as non-destructive corrosion monitor technique [27-28] and has been used in various studied [29-34]. The procedure for measuring the half-cell potential basically consists of an external copper/copper sulphate ($Cu/CuSO_4$) electrode, connecting wires and a high impedance voltmeter as shown in Fig. 6 [35]. The equipment having measurement range of ±999 mV, resolution of 1 mV and impedance of 10 MΩ was used. In concrete beams, the measurement was conducted at side surface of the specimens every 14 days for the wet-dry cycle corrosion acceleration and every day for the impressed voltage corrosion acceleration. In concrete slabs, the measurement was conducted on top surface with uniform grid of 50 mm. The potentials were plotted into the equi-potential contours (potential mapping) to interpret the corrosion potentials. For the impressed voltage corrosion acceleration, the specimens were taken off the accelerating voltage 30 minutes before the corrosion potential measurements were taken [36].

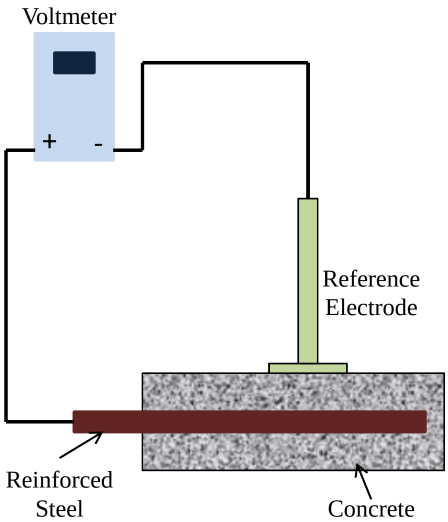

Fig. 6. Schematic of the half-cell potential measurement technique [35].

2.4 Loss of Reinforcement Cross Section

After the completion of corrosion acceleration, concrete beams were broken and the corroded reinforcement was taken off and immersed in the 12% by volume of HCl solution for 30 minutes. Then, the corroded bar was immersed in the 5% NaOH solution for 5 minutes and was cleaned by the water [37]. The weight of the corroded bars was measured and the loss of cross section was calculated using Eq. (1).

$$\eta_s = \frac{m_0 - m_c}{m_0} \times 100 \quad (1)$$

where
ηs = Loss of reinforcement cross section (%)
mo= Initial weight of reinforcement before corrosion (g)
mc= Weight after the corrosion acceleration (g)

3. Results and Discussion

3.1. Influence of Concrete Quality on Anode Life

Figure 7 shows potentials of concrete beams with and without sacrificial anode exposed to wet-dry cycle corrosion acceleration. The potentials of concrete beams without anodes decreased (more negative value) with time and with decreasing of designed strength. The potential lower than -350 mV was a benchmark for 90% probability of active corrosion, according to the ASTM C876. The time taken to reach -350 mV increased with increasing of concrete quality. For concrete beams with anodes, the measured potentials were the potentials of the sacrificial anode couple with the steel, which were approximately -700 mV. It has been reported by Mouanga et. al. [38] that the potential was around -1,000 mV for zinc, around -500 mV for steel and around -800 mV for the zinc couple with the steel. Various studies reported similar value of the potential of the zinc couple with the steel [29-33]. Almost no difference of sacrificial anode potentials with different designed concrete strengths was found as the anodes were exposed directly to the environment. The potentials of the sacrificial increased with time, implying that the anode was consumed. Figure 8 shows the potentials of concrete beams without anodes exposed to the impressed voltage corrosion acceleration. The potentials decreased with time and the time taken to reach -350 mV increased with increasing of concrete quality. This agreed with the previous study [35], which found that corrosion level of the reinforcement increased with decreasing of concrete strength. Figure 9 shows the potentials of concrete beams with anodes exposed to the impressed voltage corrosion acceleration. It should be noted that the potentials shown in figure were recorded during the switched off current. The potentials (potential of zinc couple with reinforcement) of the sacrificial anodes increased with time; however, after reaching the peak the potentials started to decrease. The anode service life is defined as the point of decrease of the potentials after reaching the peak. The increase in potentials were from the potential of zinc couple with steel reinforcement. The potentials after the peak were solely from the potentials of the reinforcement. The anode life increased with the increase in concrete quality; in other words, the sacrificial anode consumption was slower with the higher quality (compressive strength) concrete. This was because the higher compressive strength of concrete was accompanied by higher resistivity [39-40]. The higher resistivity of concrete decreased the flow of ionic current through the pores of the concrete surrounding the steel. The corrosion reaction was therefore slower. Figure 10 shows the relationship between loss of reinforcement cross section and concrete compressive strength of concrete beams exposed to the impressed voltage corrosion acceleration. The concrete beams with anodes yielded lower loss of reinforcement cross section than the concrete beams without anodes. The loss of reinforcement cross section was affected by the concrete quality as the lower concrete quality lost the higher cross section. For higher compressive strength concrete, the weight loss was varied between 7-9% with only 10 days of corrosion acceleration. This was agreed with study of Maaddawy and Soudi [41] which 7.27% steel weight loss was obtained with the corrosion acceleration for 306 hours duration. However, for the lower compressive strength weight loss was quite higher than other studies [41-42], this may be due to the compressive strength in this study was quite low (17.65 MPa) compared to other studies (38-46 MPa). The higher compressive

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strength led to the increase of the resistivity value and then the higher the possibility of the corrosion in the reinforcement [38].

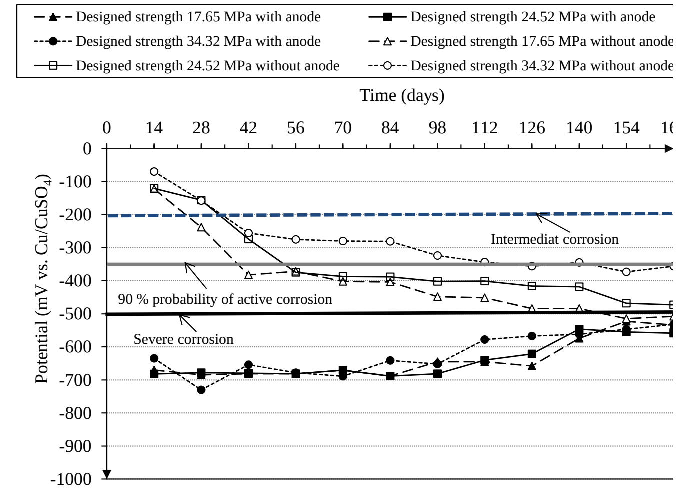

Fig. 7. Potentials of concrete beams exposed to wet-dry cycle corrosion acceleration.

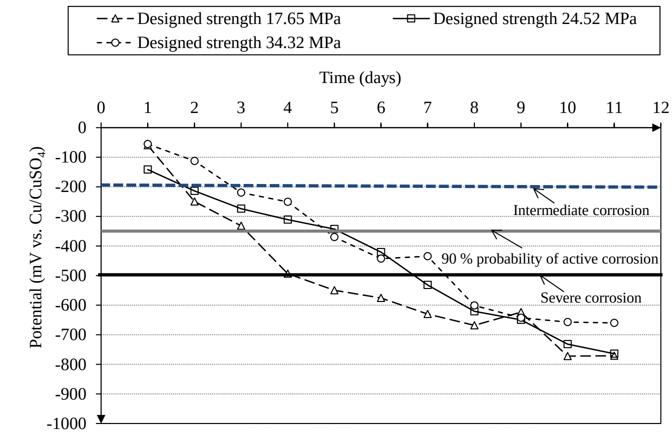

Fig. 8. Potentials of concrete beams without anode exposed to impressed voltage corrosion acceleration.

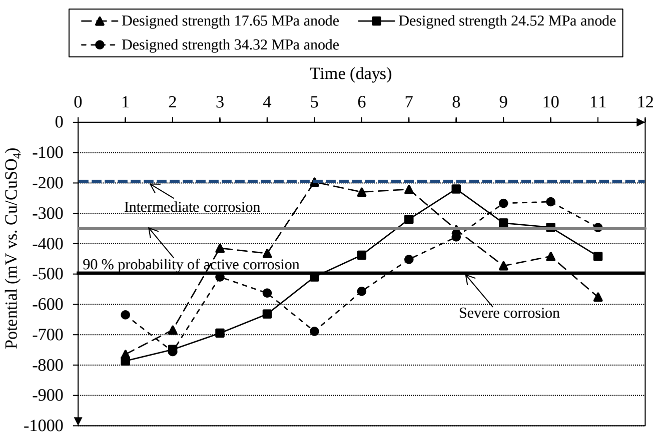

Fig. 9. Potentials of concrete beams with anode exposed to impressed voltage corrosion acceleration.

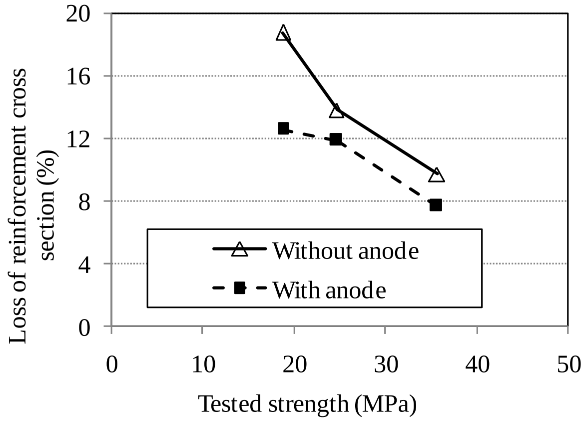

Fig. 10. Relationship between loss of reinforcement cross section and tested compressive strength.

3.2. Influence of Environmental Severity on Anode Life

Figure 11 compares the potentials of concrete beams with and without sacrificial anodes exposed to the wet-dry cycle corrosion acceleration between 3% and 5% chloride contents of soaking solutions. The potentials of the concrete beams without anodes decreased (more negative value) with time. In concrete beams with anodes, the potentials of the sacrificial anode were approximately -700 to -800 mV and increased with time. This implied that the anode was consumed during the corrosion acceleration. It was interesting to note that to the potentials of 3% chloride content with anode was less than that of 5% chloride content. The electrically-conductive adhesive used to glue the anode to the concrete top surface may be affected by the NaCl solution. The higher the concentration of NaCl was, the more effect to the bond between the anode and the concrete. This could lead to the lower potentials of 3% chloride than that of the 5% chloride. Figure 12 shows the potentials of specimens without anodes exposed to the impressed voltage corrosion acceleration comparing between 3% and 5% chloride contents of electrolyte. The potentials decreased with time and the time taken to reach -350 mV decreased with increasing of chloride content. It has been reported by Güneyisi et al. [43] that the chloride penetration depth varied from 3 to 20 mm within the immersion period of 14 week. In this study, the chloride affected the corrosion of the reinforcement in the beam specimens with 25-mm concrete cover especially in case of the wet-dry cycle and impressed voltage corrosion accelerations. This agreed with the previous study [38], which found that the corrosion potential of reinforcement decreased with increasing of chloride content. Hussain [44] reported that the corrosion potential decreased with the increase of chloride content and temperature. Pradhan [45] also reported that the potential values mostly decreased with the increase in sodium chloride concentration for both of ordinary Portland cement concrete and Portland pozzolan concrete. Figure 13 shows the potentials of concrete beams with anodes exposed to the impressed voltage corrosion acceleration comparing between 3% and 5%

chloride contents of electrolyte. The potentials of the sacrificial anodes increased with time and started to decrease after reaching the peak due to the loss of the polarization effect. The anode life decreased with the increase in chloride content. This was because the higher diffusion of the chloride ion into concrete resulted in of the decrease in concrete resistivity [46]. The lower concrete resistivity led to the faster corrosion reaction, which then reduced the anode life. Figure 14 shows the relationship between loss of reinforcement cross section and chloride content of electrolyte of the concrete beams exposed to the impressed voltage corrosion acceleration. The concrete beams with anodes yielded lower loss of reinforcement cross section than concrete beams without anodes. The loss of reinforcement cross section was influenced by the chloride content of electrolyte; the higher chloride content was the higher loss of reinforcement cross section.

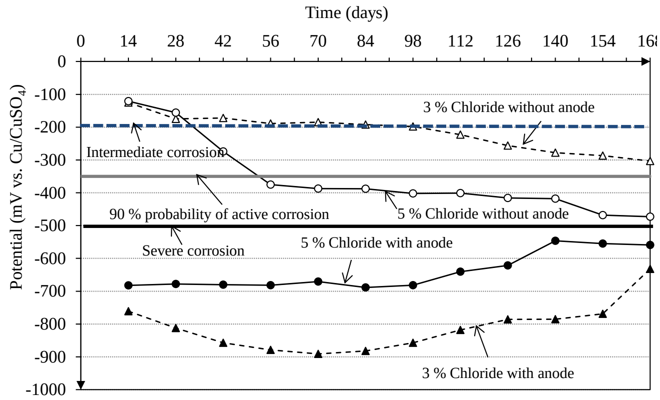

Fig. 11. Potentials of concrete beams exposed to wet-dry cycle corrosion acceleration with different concentrations of chloride solution.

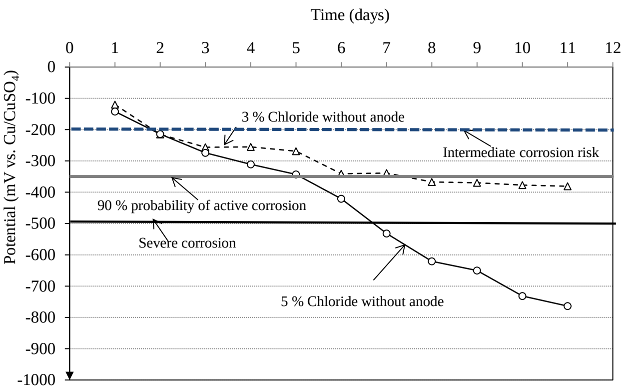

Fig. 12. Potentials of concrete beams without anode exposed to impressed voltage corrosion acceleration.

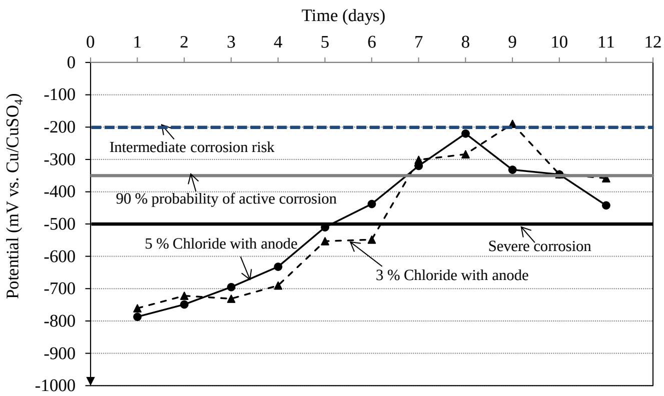

Fig. 13. Potentials of concrete beams with anode exposed to impressed voltage corrosion acceleration.

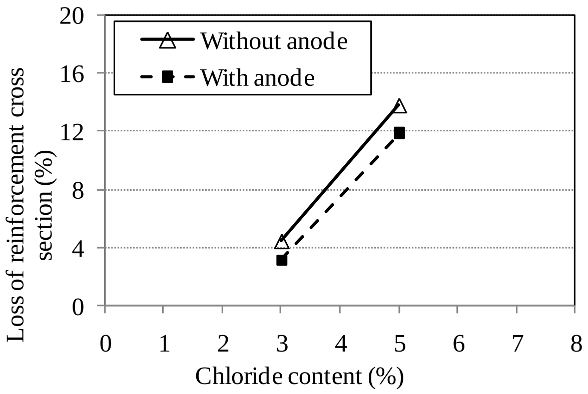

Fig. 14. Relationship between loss of reinforcement cross section and chloride content.

3.3. Effective Distance of Sacrificial Cathodic Protection

Figure 15 shows the potentials mapping of concrete slabs with and without anode exposed to the wet-dry cycle corrosion acceleration. Before corrosion acceleration, the potentials of both concrete slabs with and without anode were higher than -350 mV entirely (Figs. 15(a)) and 15(b). At 14 days, the potentials of concrete slabs without anode (Fig. 15(c)) were still higher than -350 mV, which agreed with the result of the concrete beams (Fig. 7), i.e. the reinforcement corrosion still did not occur. In concrete slabs with anode (Fig. 15(d)), the potentials of the sacrificial anode were lower than -350 mV at area near the anode-installed position. This implied that the nearer the anode installed position was the higher the polarization effect. At 168 days, the potential of concrete slabs without anode (Figure 15(e)) were entirely lower than -350 mV. The concrete slabs with anode (Fig. 15(f)) yielded opposite results from those of at 14 days; that is, the potentials at the remote area were lower than -350 m V, but those of at the area near the anode-installed position were higher than -350 mV. This was because the effectiveness of the sacrificial anode could not reach the remote area; therefore, the reinforcement started to corrode. At the area near anode-installed position, the reinforcement still was protected from the polarization effect of the sacrificial anode. This agreed with result from the concrete beams which the potentials of concrete beams without anode

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started corroding at 53 days. However, the concrete beams with anode were still be protected even at 168 days (Fig. 7). To determine the effective distance of the sacrificial anode, the potentials of sacrificial anode at 14 day were plotted with different radial distance from the anode-installed position as shown in Fig. 16. The potentials were from both the test data and the data interpreted from the potential mapping. The potentials of sacrificial anode increased with the distance from the anode-installed position. The effective distance specified by the sudden change of potentials, was approximately 500-600 mm.

Figure 17 shows the potentials mapping of concrete slabs with and without anode exposed to impressed voltage corrosion acceleration. Before corrosion acceleration, there was no difference between the concrete slabs with and without anode. The potentials were higher than -350 mV entirely for both slabs (Figs. 17(a) and 17(b)). At 3 days, the potentials of the concrete slabs without anode (Fig. 17(c)) decreased but still did not reach -350 mV. This agreed with the result from concrete beams (Fig. 8), implying that the reinforcement corrosion still did not occur. In concrete slabs with anode (Fig. 17(d)), the potentials of the sacrificial anode were lower than -350 mV at the area near the anode installed position. This implied that the nearer the anode-installed position was the higher the polarization effect. At 10 days, the potentials of the concrete slabs without anode (Fig. 17(e)) were entirely lower than -350 mV. The concrete slabs with anode (Fig. 17(f)) yielded opposite results from those of at 3 days; that is, the potentials at the remote area were lower than -350 mV, but those of at near the anode installed position was higher than -350 mV. This was because the effectiveness of the sacrificial anode could not reach to the remote area; therefore, the reinforcement started to corrode. At the area near anode-installed position; nevertheless, the reinforcement still was protected from the polarization effect of the sacrificial anode. This agreed with result from the concrete beams which the reinforcement of the concrete beams without anode started corroding at 5 days (Fig. 8). However, reinforcement of concrete beams with anode was still be protected even at 10 days (Fig. 9). To determine the effective distance of the sacrificial anode, the potentials of the sacrificial anode at 1 day were plotted with different radial distance from the anode-installed position as shown in Fig. 18. The potentials were from both the tested data and the data interpreted from the potential mapping. The potentials of sacrificial anode increased with of the increase in the radial distance from the anode-installed position. The effective distance specified by the sudden change of potential, was approximately 500-600 mm. The effective distance evaluated from the impressed voltage corrosion acceleration agreed with the result from the concrete slabs exposed to the wet-dry cycle corrosion acceleration. This was due to the same configuration of concrete slab having the same amount of the reinforcement and same concrete properties. Therefore, it could be said that even different method of corrosion acceleration gave the same result for evaluating the effective distance for the same amount of the reinforcement and the concrete properties. The effective distance may change if the concrete resistivity is different as an increase in concrete resistivity reduced the protection current output of a galvanic anode with limits the protection delivered and the effective distance may increase as the current distribution is better due to the larger area of zinc anodes [34]. The reinforcement density was also affected to the effective distance. The study of Christodoulou et al. found that the effective distance was approximately 600 mm for the multi-storey car park with steel mesh reinforcement only; however, the effective distance was reduced to approximate 400 mm for the bridge structure with the higher amount of reinforcing steel. This was indicated that the beneficial effects of the sacrificial anode reduced with the increase of the density of reinforcement [35].

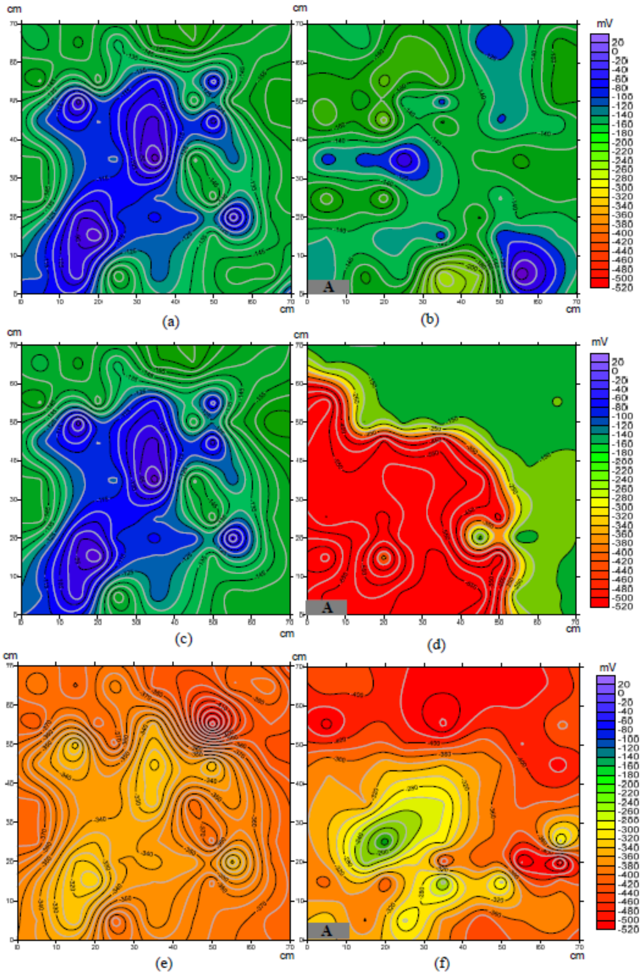

Fig. 15. Potentials mapping of concrete slabs (a) without anode before wet-dry cycle corrosion acceleration (b) with anode before wet-dry cycle corrosion acceleration before connecting anode to the reinforcement (c) without anode exposed to wet-dry cycle corrosion acceleration for 14 days (d) with anode exposed to wet-dry cycle corrosion acceleration for 14 days (e) without anode exposed to wet-dry cycle corrosion acceleration for 168 days (f) with anode exposed to wet-dry cycle corrosion acceleration for 168 days.

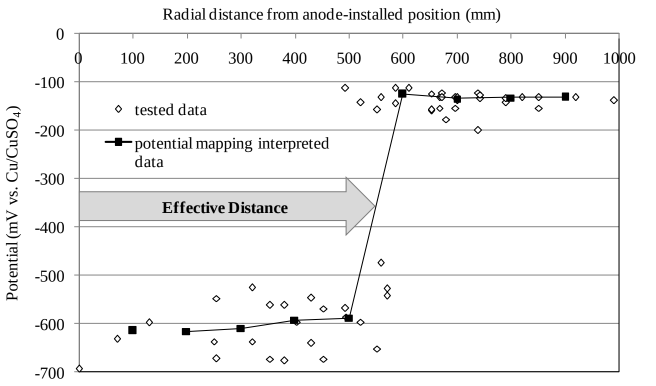

Fig. 16. Potentials of sacrificial anode with different radial distance from anode-installed position.

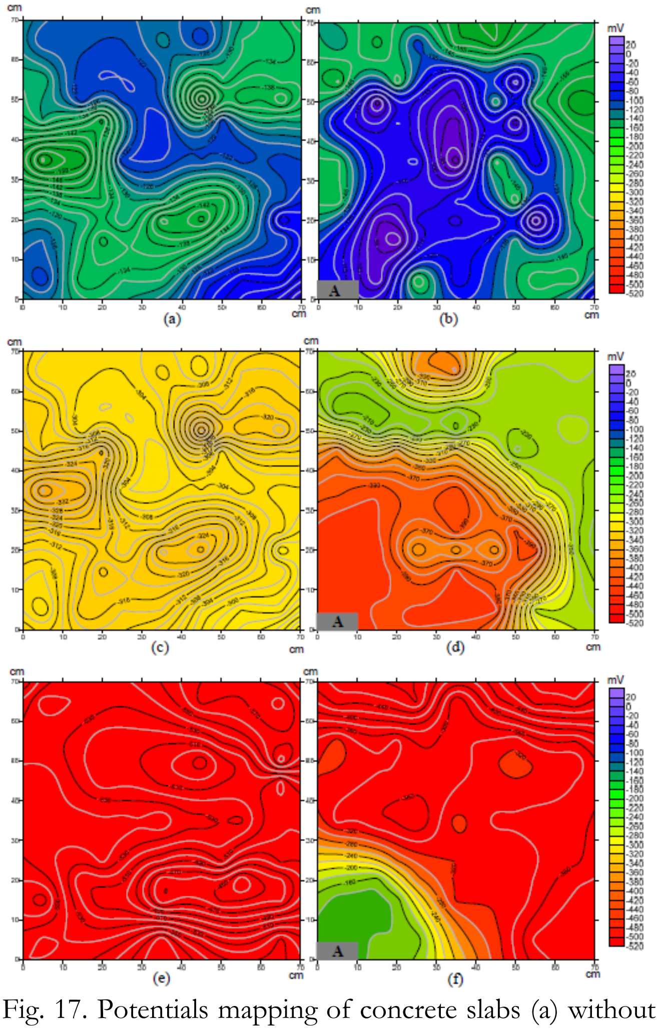

Fig. 17. Potentials mapping of concrete slabs (a) without anode before impressed voltage corrosion acceleration; (b) with anode before impressed voltage corrosion acceleration before connecting anode to reinforcement; (c) without anode exposed to impressed voltage corrosion acceleration for 3 days; (d) with anode exposed to impressed voltage corrosion acceleration for 3 days; (e) without anode exposed to impressed voltage corrosion acceleration for 10 days; (f) with anode exposed to impressed voltage corrosion acceleration for 10 days.

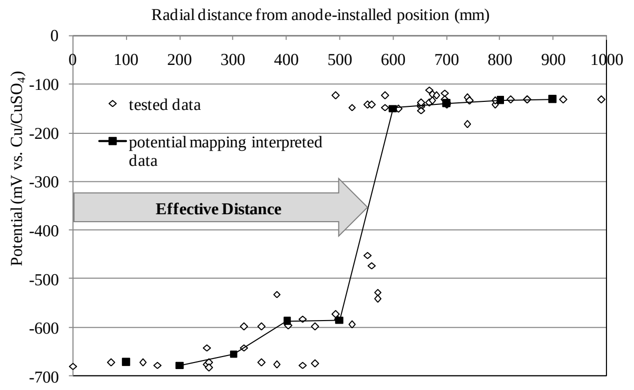

Fig. 18. Potentials of sacrificial anode with different radial distance from anode-installed position.

4. Conclusion

The conclusions could be drawn as follows.

1. Higher concrete quality yielded longer sacrificial anode life and lower loss of reinforcement cross section and more severity of environment yielded shorter sacrificial anode life and higher loss of reinforcement cross section.

2. With the given sacrificial anode size and type, concrete mix proportion and corrosion acceleration condition, the effective distance of the sacrificial anode was approximately 500-600 mm.

3. The effective distance evaluated from the impressed voltage corrosion acceleration agreed with the result from the concrete slabs exposed to the wet-dry cycle corrosion acceleration. It other words, method of corrosion acceleration did not influenced on the effective distance of the sacrificial anode.

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