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Factors influencing half-cell potential measurement and its relationship with corrosion level

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ABSTRACT

The purpose of this research was to evaluate the influences of concrete cover, chloride content, compressive strength and moisture content on the half-cell potential measurement in reinforced concrete structure. The relationship between the level of corrosion and the half-cell potential value was also evaluated. Twenty one concrete slabs with the dimensions of $300 \times 300 \times 100\ mm^3$ and three concrete slabs with the dimensions of $300 \times 300 \times 125\ mm^3$ were prepared for various experimental cases; that is, three levels of cover (25, 50 and 100 mm), three levels of chloride content (0.6, 1.2 and 1.8% by weight of cement content) and two levels of compressive strength (17.65 and 20.59 MPa). After curing in water for 28 days, the half-cell potential was measured in accordance with the ASTM C879 every week to detect corrosion under wet-dry accelerated until 140 days. The specimens were then broken to observe the corrosion condition of reinforcement inside them. The results showed that the half-cell potential decreased (more negative value) with the increase of chloride content and moisture content but increased (less negative value) with the increase of compressive strength. The influence of concrete cover was still not definitive. The variation of half-cell potential decreased with the increase of concrete cover, chloride content and moisture content. On the other hand, the variation of half-cell potential increased with the increase of compressive strength. The relationship between the level of corrosion and the half-cell potential was found; that is, the level of corrosion increased with the decrease of the half-cell potential.

1. Introduction

Corrosion of steel bar in reinforced concrete structures is a significant problem in reinforced concrete structures as it decreases structural capacity and performance. The decrease of structural capacity is due to the reduction of bond strength between steel bar and concrete and the reduction of steel cross section. The decrease of performance is due to the cracking of concrete cover and the increase of deflection. Half-cell potential measurement has been recommended as a non-destructive method for assessing the probability of corrosion of reinforcing steel bar before the damage is evident on the surface of concrete structure. The half-cell potential measurement is currently well-known and is standardized in the ASTM C876 [1]. Its principle is simple and is fast for non-destructively detecting corrosion. However, the environmental aspects and the background in concrete behaviour must be considered in the interpretation of the test results. Several reports provided the background, application and guidelines for the interpretation of half-cell measurements in the reinforced concrete structures [2–4]. Assouli et al. [4] suggested that half-cell potential measurement should take into account various environmental parameters for interpreting the test results. Several researches attempted to use the half-cell potential measurement in investigating the corrosion of reinforced concrete. Leelalerkiet et al. [5] applied the Boundary Element Method (BEM) to the results of the half-cell potential measurement by analyzing the potential distributions and current flows in estimating the corrosion of reinforcing steel-bars in concrete slabs under the cyclic wet and dry conditions. They found that the half-cell potential measurement was marginally successful, compared with analytical results of potential distribution and current flow by BEM. Hussain [6] investigated the chloride induced corrosion potential in submerged reinforced concrete structures in comparison to various other relative humidity conditions. The results showed that the underwater half-cell measurements were not the true representative of corrosion rate and needed to be re-calibrated in light of bench mark measurement results obtained in his research. He stated that the result provided the basis for future calibration of under-water half-cell potential values of corroding steel in chloride contaminated concrete in a number of material and environmental

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Nomenclature

p_d	is the average half-cell potential value in one specimen in dry condition
p_e	is the average half-cell potential value in one specimen in wet condition
x_i	is the half-cell potential value of each point on the specimen surface
P_d	is the average half-cell potential value of three duplicate specimens in dry condition
P_e	is the average half-cell potential value of three duplicate specimens in wet condition
P_D	is the average half-cell potential value for total measurement period in dry condition
P_E	is the average half-cell potential value for total measurement period in wet condition
n_D	is the number of weeks for total measurement period in dry condition
n_E	is the number of weeks for total measurement period in wet condition
c_d	is the coefficient of variation of half-cell potential value in one specimen in dry condition
c_e	is the coefficient of variation of half-cell potential value in one specimen in wet condition
C_d	is the average of coefficient of variation of three duplicate specimens in dry condition
C_e	is the average of coefficient of variation of three duplicate specimens in wet condition
C_D	is the average coefficient of variation for total measurement period in dry condition
p_a	is the average half-cell potential value in anode side of one specimen
p_c	is the average half-cell potential value in cathode side of one specimen
x_{ai}	is the half-cell potential value of each point in anode side on specimen surface
x_{ci}	is the half-cell potential value of each point in cathode side on specimen surface
Δp	is the difference of potential between anode and cathode in one specimen
ΔP	is the average of difference of potential between anode and cathode of three duplicates specimens
ΔP_D	is the average of difference of potential between anode and cathode for total measurement period in dry condition

variables. Also, several researches used the half-cell potential measurement in experimental studies for evaluating corrosion potential [7–10].

In Thailand, the half-cell potential is widely used in evaluating the corrosion in existing reinforced concrete structures before maintenance measure was determined. It is also standardized in the DPT Standard 1506-51 (Standard Test for Non-destructive Inspection of Reinforced Concrete Structure: Test Method for Reinforcement Corrosion by Half-cell Potential Measurement) by the Department of Public Works and Town & Country Planning [11]. However, there are still few studies about the half-cell potential in Thailand, where the environmental condition is different from those in other researches. Therefore, the purpose of this study was to evaluate the impact of factors on the half-cell potential measurement and the relationship between the level of steel corrosion and the half-cell potential value. With the results of this research, the more precise interpretation of the half-cell measurement and the relationship between the half-cell potential and corrosion level were attained. This should substantially benefit the repair planning and management of existing reinforced concrete structures.

2. Materials and specimens preparation

Twenty one concrete slabs with the dimensions of $300 \times 300 \times 100\ mm^3$ and three concrete slabs with the dimensions of $300 \times 300 \times 125\ mm^3$ were prepared for determining the influence of concrete cover, chloride content, compressive strength and moisture content on the half-cell potential measurement. There were transverse and longitudinal deform bars embedded at 5 mm depth from each side surface and 25 mm, 50 mm and 100 mm from top surface for the case of varying concrete covers. All deformed bars (SD30) were 12 mm in diameter. Copper wire was joined to the steel in the concrete at the top-left corner for the half-cell potential measurement as shown in Fig. 1. The designed compressive strength of concrete of 20.59 MPa was used as it was normally used in reinforced concrete structures in Thailand. The concrete mix proportion with the water-cement ratio (w/c) of 0.57 is shown in Table 1. Ordinary Portland cement type I with $3.15\ g/cm^3$ was used. Fine aggregate was river sand with specific gravity of 2.60 and fineness modulus of 2.40. Coarse aggregate was crushed lime stone with the 20 mm maximum size and with specific gravity of 2.77. The chloride contaminated concrete was casted on the right side of the specimen, to be used as the anode side; tap water concrete was casted on the left side of the specimen, to be used as the cathode side. In the case of varying chloride content, the concrete at anode side was mixed with chloride solution. The chloride concentration used were 0.6, 1.2 and 1.8% by weight of cement. The experimental cases are shown in Table 2.

3. Half-cell potential measurement

Fig. 2 shows the process of curing and the half-cell potential measurement. After specimens were cured in fresh water for 28 days, they were kept in closed container with dry condition for 1 week. Then, the 3% of sodium chloride solution (artificial seawater) was poured into the container and the specimens were cured in wet condition for another 1 week. This process was simulated the sea water environment under the cycle of wet and dry [5]. The half-cell potential was first measured on the second cycle and it was alternating measured in wet and dry conditions until 140 days. The schematic of the half-cell potential measurement technique is shown in Fig. 3. The measurement was performed following the ASTM C876-09 [1]. The copper/copper sulphate was used for reference electrode. The potential were totally measured 25 points on top surface of the specimens as shown in Fig. 4. Three duplicate specimens were prepared and measured for each case of impact factors (three levels of concrete cover, three levels of chloride content and two levels of compressive strength). In case of different moisture contents, the specimens of 50 mm concrete cover were used to measure the half-cell potential in different moisture contents by varying the water immersion durations.