HALF-CELL POTENTIAL OF STEEL BAR IN MORTAR DUE TO CHLORIDE ION CONTENT AT AGE OF 6 YEARS

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1. Introduction

Half-cell potential is one of electrochemical methods used for corrosion evaluation among non-destructive test methods. Simple and easy measuring system is a main advantage of half-cell potential to evaluate an environmental condition of steel bars in concrete. However, test data vary widely and results do not correspond with actual corrosion condition of steel bar because electrochemical properties are affected by several factors. Estimation of the onset of corrosion by half-cell potential is very important from the view point of preventive maintenance. Therefore, data on electrochemical characteristics of steel in concrete chloride content around the corrosion threshold chloride level still need further necessary. The objective of this paper is to understand electrochemical characteristics of steel bars in mortar with chloride content (threshold chloride content). In addition, this paper also discusses differences due to water to cement ratio affected to corrosion of steel bar.

2. Outline of Experiment

2.1 Materials and Mix Proportion

The specimens were exposed for almost 6 years in atmosphere condition in the laboratory. Mortar cubic specimens with the dimensions of 135 x 135 x 120 mm were prepared, and used Ordinary Portland Cement (OPC) as cement and washed sea sand as fine aggregate. Two plain steel bars with 13 mm in diameter and 135 mm in length were embedded in each mortar specimens. Cover depth was 50 mm from measuring surface (**Fig.1**). Three types of water to cement ratios (W/C=40%, 50%, and 60%) were set for mixing mortar with parameter on fixed weight of fine aggregate. The physical properties of material, mix proportion of mortar were shown in **Table 1** and **Table 2**, respectively.

Corrosion evaluation of steel embedded in sodium chloride (NaCl) contaminated mortar was conducted by electrochemical method. Two influencing parameters of chloride content in mortar were used: chloride content interpreted in %-cement (mass ratio of cement) and in kg/m^3 (total chloride weight in mortar). **Table 3** presents all cases of chloride content in each mix. Water to cement ratio (W/C) of 50% was selected as reference. In this reference, chloride content in mortar are 2.18kg/m^3 and 2.91kg/m^3 in accordance to 0.43%-cement and 0.57%-cement, respectively. In mix series of D and F, chloride content is fixed in kg/m^3. Then mix series of C and E, chloride content is fixed in %-cement.

2.2 Method of Evaluation

After 6 years exposed in atmosphere condition, the specimens were investigated by half-cell potential. The half-cell potential was measured by using the silver/silver chloride reference electrode (Ag/AgCl) after one-hour pre-wetting. Then, potential value is converted to the value against copper/copper sulfate reference electrode (CSE) according to ASTM C876.

3. Results and Discussion

Fig. 2 shows the half-cell potential for each mix series after 6 years. From this figure, half-cell potential of all specimens shows less than -350 mV. The potential crossed a threshold value based on the ASTM C876 standard. The potential categorize as 90% of probability corrosion. In

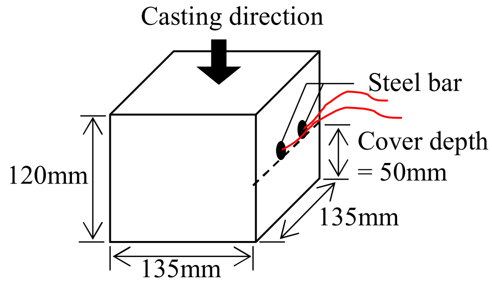

Fig. 1 Shape and size of specimen

Table 1. Physical properties of material

Material	Type	Description
Cement	OPC	Density = 3.16 g/cm^3, SSA= 3250 cm^2/g
Sand	Washed sea sand	Density = 2.49 g/cm^3, Absorption = 1.42%
Steel	Round bar SR235	ϕ13mm

Table 2. Mix proportions

W/C (%)	Unit weight (kg/m^3)		
	Water	Cement	Sand
40	232	581	1508
50	255	510	1508
60	272	454	1508

Table 3. Chloride content in each mix

Mix	W/C (%)	Chloride content	
		Total content in mortar (kg/m^3)	Weight ratio of cement (%-cement)
C	40	2.49	0.43
	50	2.18	
	60	1.94	
D	40	2.18	0.38
	50		0.43
	60		0.48
E	40	3.32	0.57
	50	2.91	
	60	2.59	
F	40	2.91	0.50
	50		0.57
	60		0.64

addition, the potential toward to more negative value as increasing of water to cement ratio. The similar trend also observed on chloride content in mortar. The potential move to more negative value as increasing of chloride content contaminated in mortar (i.e., chloride content interpreted in %-cement and in kg/m^3).

Fig. 3 shows the relationship between chloride content and half-cell potential at 6 years. Chloride content is interpreted in mass percent versus unit cement mass shown in **Fig. 3(a)**. Chloride content is interpreted total weight in unit mortar volume **Fig. 3(b)**. From these figures, half-cell potential shows linear relationship with chloride content. The relationship is interpreted with following equations (1) to (6).

$y= -182x - 339$	(W/C=40%)	(1)
$y= -260x - 355$	(W/C=50%)	(2)
$y= -388x - 305$	(W/C=60%)	(3)
$y= -31x - 341$	(W/C=40%)	(4)
$y= -50x - 358$	(W/C=50%)	(5)
$y= -84x - 308$	(W/C=60%)	(6)

Where variable y and x represents half-cell potential value (mV) and chloride content (%-cement and kg/m^3), respectively. Moreover, higher water to cement ratio shows lower half cell potential. Also, different propensity confirmed between two different chloride content interpretation. The difference due to water to cement ratio becomes easy to evaluate when the chloride content is interpreted in total chloride weight in mortar.

The figures show similar potential trend between the 16 weeks (Hamada et al., 2014) and 6 year's result. Both influencing interpretation (i.e., chloride content based on mass ratio of cement and total content in mortar) shows potential move to more negative value as increasing of chloride content. Further, water to cement ratio showed has intense influence also. In both influencing interpretation, the potential became more negative as increasing of water to cement ratio. Also, after 6 years, the potential dropped around from -200 mV to less than -350 mV. In the early age of 16 weeks, the potential was around about -200 mV. However, after 6 years the potential become around about -400 mV. In addition, after 6 years, the sensitivity of chloride content effect (Cl^-) tend to decreased.

4. Conclusion

In this study, water to cement ratio, chloride content in mortar were set as an experimental parameter. And, effectiveness of these experimental parameters on electrochemical measurements, such as half-cell potential was experimentally discussed. Following conclusions were obtained.

- Half-cell potential showed a good correlation with chloride content in mortar.
- Chloride content around steel bar surface strongly affects the result of half-cell potential.
- It is suggested that chloride content interpreted in total weight per unit mortar volume is easy to evaluate using electrochemical method compared to chloride content interpreted in percentage of cement.
- At the age of 6 years, according to electrochemical characteristic, steel bar in all specimens are estimated to be already corroded. Also, the potential move to more negative value was dropped about -200mV compared to 16 weeks result.

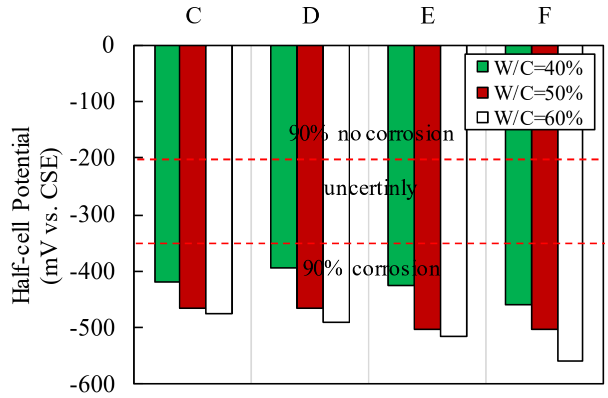

Fig. 2 Half-cell potential and chloride content at 6 years (mass ratio of cement)

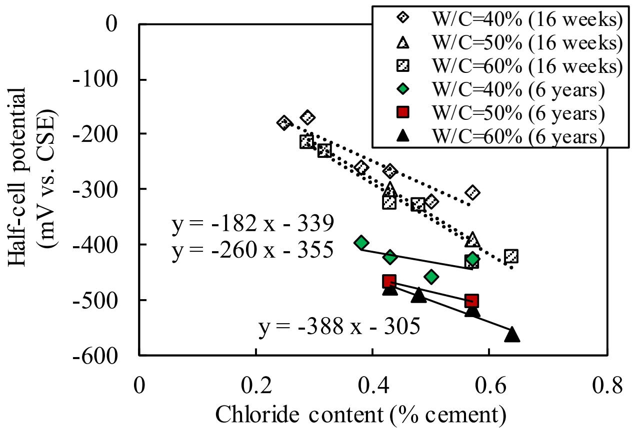

Fig. 3(a) Half-cell potential and chloride content at 6 years (mass ratio of cement)

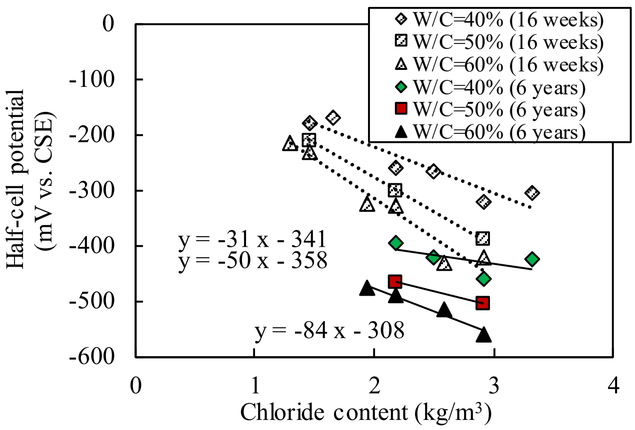

Fig. 3(b) Half-cell potential and chloride content at 6 years (total content in mortar)

- At the age of 6 years, the sensitivity of chloride content effect (Cl^-) tend to decreased.

References

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