

EFFECT OF ENVIRONMENTAL NON-HOMOGENEITY ON MACRO-CELL CORROSION IN REINFORCED BAR

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1. Introduction

Pore solution in concrete is highly alkaline (high pH), therefore, a thin passive film is formed spontaneously on the reinforcement bar. Passive film protects the re-bar even if sufficient moisture and oxygen are available. However, due to ingress of sufficient Cl⁻ ions into concrete destroy the protective passive film; hence corrosion starts. The corrosion of steel is essentially an electrochemical process producing a ‘corrosion cell’ which is a combination of the anode and cathode. According to the ‘cell’ size (how apart the anode and cathode) corrosion of steel basically in two forms ^[1]; Micro-cell (cell size in ~μm) and Macro-cell (cell size in ~mm to ~m). Both forms of corrosion may occur at the same time, however, macro-cell corrosion is more detrimental to the structure since it rapidly decreases the re-bar diameter producing more rusts locally.

Therefore, the main objective of this study is to partially clarify the macro-cell corrosion mechanism considering how the environmental non-homogeneity by chloride ions affects on macro-cell corrosion in re-bar.

2. Macro-cell corrosion current measurement ^[2]

The rate of corrosion (current density; calculated as in the equation 1) is estimated by measuring the macro-cell corrosion current. Providing a divided steel bar helps to measure the current passing through a given steel element. Schematic view of the current measurement set up is shown in the figure 1.

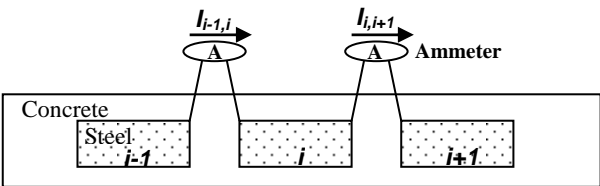


Fig.1. Measurement of macro-cell corrosion current

$$I_{macro} = \frac{I_{i,i+1} - I_{i-1,i}}{S_i} \text{ (}\mu\text{A/cm}^2\text{)}$$

..... (1)

I_{macro} – Macro-cell corrosion current density (μA/cm²)

$I_{i-1,i}$, $I_{i,i+1}$ – Corrosion current (μA) flow from element $i-1$ to i and i to $i+1$ respectively

S_i – Surface area (cm²) of the steel element i

3. Experimental program

3.1 Materials

Specimens were cast using concrete of W/C 0.55. Fine aggregate of fineness modulus is 2.69 and 15mm coarse aggregate were used keeping the s/a ratio as 45%. The slump and the air content were in the range of (12±2.5)cm and (5±1)% respectively. Cl⁻ ions were deliberately added to concrete during mixing (as in the Table 1) to represent chloride attacked structural elements.

Table 1. Variation of chloride ion contents (in kg/m³)

No	1	2	3	4	5	6	7
Side A	0	0	0.6	0.6	1.2	1.2	2.4
Side B	1.2	2.4	2.4	4.8	2.4	4.8	4.8
B-A	1.2	2.4	1.8	4.2	1.2	3.6	2.4

3.2 Preparation and test method

Side A and B of 100x100x400mm specimen were cast in consecutive days so that the common face (the centre) contacts each other. 400mm length, 10mm diameter divided (as shown in the figure 2 with the individual steel element name) and undivided round steel bars were placed at bottom with the cover 20mm. Clear spacing between two steel bars were 40mm. All faces were epoxy coated except the bottom face after sealed curing for first 7 days.

Specimens were subjected to cyclic wet (Relative Humidity-90%, Temperature-60C, 3 days) and dry (RH-65%, T-15C, 4 days) exposure condition starting from the end of sealed curing.

Using the divided steel bar, macro-cell current flowing from particular steel element to the neighbor element was measured at each connection periodically. Undivided steel bar was used to measure the half cell potential values.

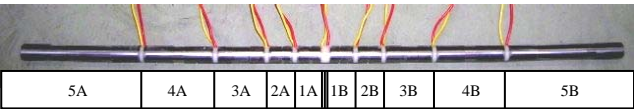


Fig.2. Divided steel bar

4. Results and Discussion

Variation of macro-cell corrosion current density along the specimen is shown in figure 3 as an example. Specimen (No

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6) contains chloride ion content 1.2kg/m^3 and 4.8kg/m^3 in side A and B respectively. Comparatively low current density curves are not shown for the clarity. It can be seen that the anodic corrosion current density drastically increases in the middle of the specimen. Steel element in the side B and adjacent to the centre (i.e. element 1B as in Fig. 2) is subject to highest electrochemical potential difference which becomes more active and therefore rapid corrosion occurs.

Current density values are converted to the 'Average rate of weight loss' using the Faraday's law and it is shown in the figure 4. Related to the current density variation, highest rate of weight loss occur in the element 1B as expected theoretically. Element 2B also corrodes slightly due to the effect of potential difference. However, the corrosion of element 5B is out of the theoretical background.

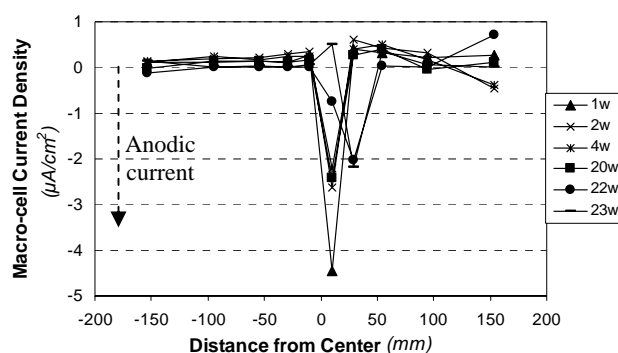


Fig. 3. Macro-cell corrosion current density variation

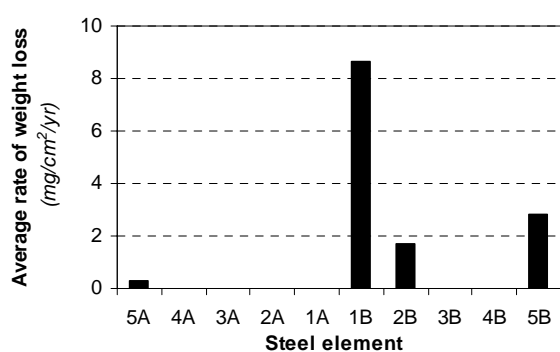


Fig. 4. Average rate of weight loss of steel elements

Half cell potential technique is also a widely used method to measure corrosion risk. In the figure 5, values show a clear variation at the middle of the specimen pointing out more negative half cell potential values in the high chloride content side. This fact indirectly confirms the theoretical background of the macro-cell corrosion.

Figure 6 shows the results of average weight loss against the chloride content difference. It can be noted that, when the chloride content difference is increased keeping the side A chloride content constant, the macro-cell corrosion

effect is increasing (Figure 6: Angled solid lines). This is due to the increment of potential difference caused by side A and B chloride contents. Also, each case shows that the gradient is decreasing with the increasing of side A chloride content. It is also noted here that, even if the difference is the same, higher chloride contents in both side A and B individually shows higher weight loss (Figure 6: Vertical arrows).

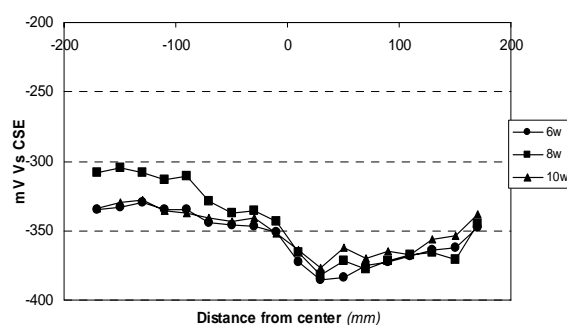


Fig. 5. Half cell potential variation in undivided bar

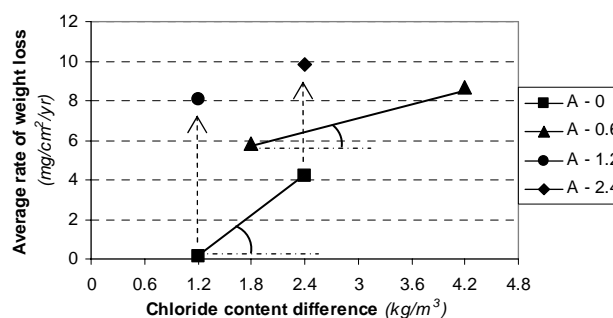


Fig. 6. Effect of chloride content difference

5. Conclusions

Macro-cell corrosion mainly occurs in the middle region high chloride content side of specimens which has the highest electrochemical potential difference.

Half cell potential values show a similar trend to the corrosion current density values. Hence, careful observation of results of half cell measurements may identify the occurrence of macro-cell corrosion.

When the chloride content difference increases, the macro-cell corrosion become more active and it causes the structure deteriorated rapidly.

6. References

- [1]. Elsener B, Macrocell corrosion of steel in concrete—implications for corrosion monitoring, Cement and Concrete Composites 24, pp 65-72, 2002.
- [2]. Miyazato Shin-ichi, Nobuaki Otsuki, Hiyato Kimura, Steel Corrosion Induced by Chloride ions and Carbonation in Mortar with Bending Cracks and Joints, Second International Conference on Engineering Materials, pp 531-542, 2001.