Effect of Surface Defects of Reinforced Concrete Cover on Corrosion Expansion Cracking

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Abstract. The effect of initial defects on the surface of concrete cover with different sizes on the corrosion cracking time of steel bars was studied by electrochemical acceleration method. The results show that the initial defects on the surface of the concrete cover will significantly shorten the cracking time of the cover and have a strong induction effect on the cracking direction. The degree of cracking time reduction is positively correlated with the length of surface defects. At the engineering site, attention should be paid to the surface quality of the concrete structure. Then, the paper also evaluated the effect of the thickness of the sheath and the diameter of the steel bar on the cracking time of the cover.

Introduction

In the coastal corrosive environment, the failure of reinforced concrete structures is mostly caused by the rust of steel bars caused by chloride ion erosion [1, 2]. However, due to the complexity of concrete materials and reinforced concrete structures, most of the theoretical and experimental research on the rust cracking of reinforced concrete covers is based on the assumption that the concrete is uniform and compact, and the reinforced concrete specimens are assumed to be regular geometric shapes [3-7]. The influence of the complex surface damage of the real reinforced concrete members on the cracking time and mechanism of the components is neglected. Therefore, it is necessary to carry out experimental exploration and establish a theoretical model to reflect the actual boundary conditions of real engineering and simulate natural corrosion. The research results of zhang et al. [8] also prove this. Therefore, in view of the phenomenon that the surface of the cover contains initial defects, which is inevitable in practical engineering, this paper carried out an experiment on the corrosion cracking time of reinforced concrete specimens with initial defects of different sizes. It provides the experimental basis for establishing and verifying the model of corrosion expansion and cracking of structures with initial surface defects.

Experimental Details

Specimen preparation

In this experiment, HRB335 steel, PC32.5 cement, IOS standard sand and stone with a particle size of 5-20mm were used for the preparation of the initial surface defect test piece and the non-defective test piece. The concrete mix ratio is cement:water:sand:aggregate=1:0.38:1.11:2.72, and the water cement ratio is 0.38. The defects were made of 304 stainless steel sheets with a thickness of 1.5 mm and lengths of 5 mm and 10 mm, respectively. The steel sheet is fixed radially to the inner surface of the mold before casting. After pouring for 24 hours, the mold was removed and the steel sheets were pulled out to form initial surface defects. The dimensions of the specimens are shown in Fig. 1. After the wires are bundled on the upper steel bars, the steel bars exposed at both ends of the test piece are sealed with epoxy resin to prevent unnecessary corrosion. In this experiment, 27 cylindrical
reinforced concrete specimens were prepared, and three kinds of diameter steel bars were selected, which were 22mm, 25mm and 28mm respectively. Three kinds of cover thicknesses are arranged, which are 25mm, 40mm and 65mm respectively. Surface defects are classified into non-defect, 5mm defects, and 10mm defects. The grouping of the specimens is shown in Table 1.

![Figure 1. Dimensions of the specimens.](image1)

Accelerated corrosion process

After the standard curing of specimens for 28 days, electrification accelerated corrosion test was carried out. As shown in fig. 2, this experiment adopts semi-immersion electrification acceleration experiment. The distance between steel bar and NaCl solution is 10 mm, which can effectively reduce the loss of corrosion products, so as to ensure better accumulation of corrosion products and continuous increase of rust swelling pressure. The defect direction of the specimen was immersed in NaCl solution with a concentration of 5%, and the steel reinforcement was connected to the positive pole of the power supply, while the copper sheet was connected to the negative pole of the power supply.

The current density is $i_{\text{corr}}=100\mu\text{A/ cm}^2$. The corresponding current of 22mm, 25mm and 28mm rebar is 13.8ma, 15.7ma and 17.6ma respectively. Finally, when the crack width reaches 0.1mm, the specimen is considered to have cracked and the crack time is recorded.

![Figure 2. Schematic diagram of electrification accelerated corrosion.](image2)

Result and Discussion

Cover cracking time

In the initial stage of electrified accelerated corrosion, gas is continuously generated on the surface of the electrode, and the electrolyte is clarified. Over time, tiny cracks appeared on the surface of the
test piece, and a small amount of rust products appeared at the crack, and the solution gradually began
to change from clarification to turbidity. As time continues to develop, the crack width gradually
increases until it reaches the limit of 0.1mm. In general, the time of finding tiny cracks on the surface
of specimen is not the same as the time of cracking.

By comparing the specimen without defects with the specimen with initial surface defects, it can be
clearly found that the first crack in the specimen with surface defects always develops in the direction
of initial defects and runs through the initial defects, while the crack in the specimen without defects
always develops in an irregular and random direction. There may be the following reasons: first of all,
the surface defect causes obvious stress concentration in its direction [8], making it easier to achieve
failure. Secondly, surface defects can significantly increase the rate of chloride ion erosion [9],
making the corrosion speed of defect direction much higher than that of other directions, thus
generating more concentrated corrosion expansion pressure. The cracking time obtained from the
electrification acceleration test are shown in table 1.

Table 1. Group of specimens and cracking time.

| specimen | c [mm] | d [mm] | cracking time [day] | specimen | c [mm] | d [mm] | a [mm] | cracking time [day] |
|----------|--------|--------|---------------------|----------|--------|--------|--------|---------------------|
| AA1      | 25     | 22     | 28.3                | AAA2     | 22     | 5      | 26.6               |
|          |        |        |                     | AAC2     |        | 10     | 24.5               |
| AB1      | 25     | 22     | 31.5                | ABA2     | 25     | 5      | 28.7               |
|          |        |        |                     | ABC2     |        | 10     | 25                 |
| AC1      | 28     | 22     | 31.5                | ACA2     | 28     | 5      | 30.5               |
|          |        |        |                     | ACC2     |        | 10     | 29.9               |
| BA1      | 40     | 22     | 30.8                | BAA2     | 40     | 22     | 5                  |
|          |        |        |                     | BAC2     |        | 10     | 27.5               |
| BB1      | 25     | 22     | 34.4                | BBA2     | 25     | 5      | 32.8               |
|          |        |        |                     | BBC2     |        | 10     | 30.6               |
| BC1      | 28     | 22     | 35                  | BCA2     | 28     | 5      | 33.5               |
|          |        |        |                     | BCC2     |        | 10     | 31.8               |
| CA1      | 65     | 22     | 33.6                | CAA2     | 65     | 22     | 5                  |
|          |        |        |                     | CAC2     |        | 10     | 31.5               |
| CB1      | 65     | 22     | 36                  | CBA2     | 65     | 25     | 5                  |
|          |        |        |                     | CBC2     |        | 10     | 35.5               |
| CC1      | 28     | 22     | 38.4                | CCA2     | 28     | 5      | 36.4               |
|          |        |        |                     | CCC2     |        | 10     | 35.3               |

Analysis of Factors Affecting Cracking Time

In the cracking time data obtained in this experiment, the cracking time of BAA2 specimens with
a=5, d=22, and c=40 is abnormal. The cracking time of BAA2 specimen is obviously too early, which
may be caused by measurement error. The cracking time of BAA2 specimen will not be taken as a
reference again.

As shown in the 9 broken lines in Fig. 3, under the same other conditions, the larger the diameter of
reinforcement, the later the cracking time. This is because for the same thickness of the cover, the
radial displacement distance required for cracking is the same, that is, the thickness of the outer rust
layer of the steel bar is the same. The larger the diameter of the steel bar, the larger the area of the rust
layer of the same thickness on the steel surface, and the greater the required corrosion rate.

By comparing three solid lines, long dotted lines and short dotted lines, it can be clearly observed
that the thicker the cover is, the longer the cracking time is. Because the thicker the cover, the longer
it takes for the erosive medium to reach the surface of the steel bar, and the later the steel bar begins to
corrode. Moreover, the thicker the cover of concrete is, the greater the radial displacement of the
cover, i.e. the thickness of the rust layer, is required when cracking, which means the greater the
amount of corrosion is required, thus delaying the cracking time of the cover.
By comparing the three black lines, red lines and blue lines, it is obvious that the cracking time of the defective specimens is significantly lower than that of the non-defective specimens. In the defective specimens, the longer the defect, the sooner the crack. This is because obvious stress concentration effect can be produced at the defect, which reduces the critical corrosion amount of cracking. At the same time, the defect can weaken the thickness of the cover, making it easier for the corrosive medium to reach the surface of the steel bar, making the corrosion occur earlier and the corrosion rate faster.

Meanwhile, the coupling effect between the thickness of the protective layer and the length of the defect can be observed. For the specimens with thicker protective layer, the gap between the cracking time of the three defect sizes is smaller. This is because for the same defect length, the ratio a/c of the defect length to the thickness of the protective layer is smaller with the thicker the protective layer, and the weakening effect of the defect on the protective layer is lower, thus reducing the gap in cracking time.

**Conclusion**

Based on the data obtained from the experiment, the influencing factors of rust swelling and cracking of the protective layer of reinforced concrete structures with initial defects on the surface of the protective layer are analyzed. The influence of defect length and protective layer thickness on cracking time is most significant. At the same time, it is found that the initial surface defect can significantly induce and restrict the direction of the first crack.

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