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# Experimental study on corrosion induced cracking time of steel in concrete cover with initial middle defect

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**Abstract.** In this paper, based on the initial defects of different sizes in the middle of concrete cover, the corrosion cracking time of the steel with the initial defect in the middle part of the steel was studied by means of the method of electrified accelerated corrosion from an experimental point of view. The results show that the size of the actual initial defect in the concrete cover is the key factor to control the cracking time in chloride environment. Reducing the crack size is helpful to improve the durability of the whole structure. The severity of corrosion expansion and cracking time of concrete cover can be ranked as follows: thickness of concrete cover > diameter of steel > size of initial defect.

## 1. Introduction

In the marine environment, the corrosion of steel caused by chloride ion erosion is the main cause of durability failure of reinforced concrete structure [1, 2]. Due to the complexity of durability research, a large number of existing studies [3-6] mainly focused on the exploration of the process of rust expansion cracking in a single form, the experimental or theoretical study of other rust-expansion failure patterns induced by initial defects of different sizes was ignored, which was obviously far from the true derivative path of the rust expansion cracks. Zhang et al. [7, 8] shows that a large number of uniform critical cracking models are in poor agreement with each other in cross test. Therefore, it is very important for the establishment of rust expansion model in accordance with the natural actual corrosion state and the guidance of practical engineering practice. This paper aims at the corrosion cracking stage of concrete cover with initial defects, considering the size of actual initial defect, and scientifically recording the actual cracking time of concrete member with middle defect. It provides the experimental basis for verifying the actual initial defect concrete crack time prediction model.

## 2. Experimental investigation

### 2.1 Specimen preparation

As shown in Figure 1, the specimen with initial defect in the middle of the concrete cover. The cement was PO 42.5R, and the maximum diameter of fine aggregate was 3 mm, fineness modulus ( $M_x = 2.8$ ) and the coarse aggregate size was  $d = 2.8$  mm, and the fine aggregate was made of sand (apparent density is about  $2700 \text{ kg/m}^3$ ), concrete mix as shown in Table 1. The steel was HRB335. The defect was made by a 1.5 mm thick 304 stainless steel strip, as shown in Figure 1, with a width of 2 mm, prepositioned in the middle of concrete cover parallel to the direction of the steel, to simulate the initial defect. After 4 hours of concrete pouring, the strip was pulled out vertically to form the initial defect. After 24 hours, the mould could be cut open and marked with serial number. After grouping the



test blocks, the upper and lower surfaces of the specimens and the reserved external end ends of the steels were sealed with epoxy resin to prevent serious corrosion during the steam curing of concrete. The main factors of corrosion test were the thickness of concrete cover, the diameter of steel, the size of initial defect and so on. The design group was shown in Table 2.

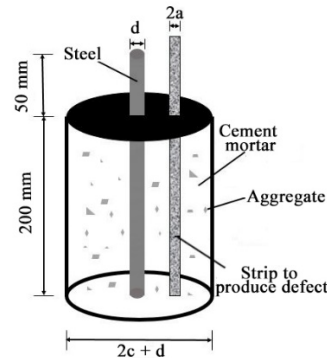


Figure 1. Schematic diagram of the middle defect specimen

Table 1. The proportion of the concrete  $\text{kg/m}^3$

Water cement ratio	Amount per cubic concrete material				Strength
	Water	Cement	Sand	Aggregate	
0.44	200	454	613	1133	C30

### 2.2 Accelerated corrosion process

After the pouring of the specimens standard curing for 28 days, electrified accelerated corrosion test performed, the operation method was shown in Figure 2. The test specimen was placed horizontally in each electrolytic cell by number, NaCl solution with a concentration of 15%. The current control value is 21 mA ( $d = 22 \text{ mm}$ ,  $I_{\text{corr}} = 150 \mu\text{A}/\text{cm}^2$ ), 16 mA ( $d = 25 \text{ mm}$ ,  $I_{\text{corr}} = 100 \mu\text{A}/\text{cm}^2$ ), 18 mA ( $d = 28 \text{ mm}$ ,  $I_{\text{corr}} = 100 \mu\text{A}/\text{cm}^2$ ). Finally, when the maximum crack width of the crack was arrived 0.1 mm, the actual cracking time of each specimens were recorded in time.

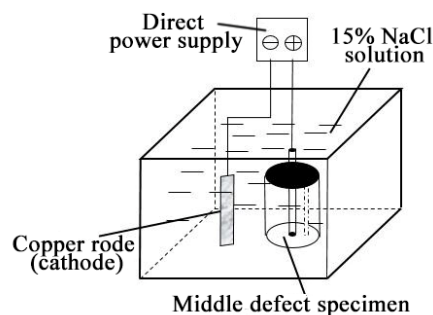


Figure 2. Schematic diagram of electrified accelerated corrosion test

## 3. Results and discussion

### 3.1 Corrosion cracking time

The crack time of each specimen is related to the thickness of the concrete cover, the diameter of the steel and the setting of different initial defects. The time of electrification accelerated corrosion varies from a few days to forty days, in general, the time of discovery of cracks and the time of cracking were inconsistent, often due to various factors leading to a certain delay. Therefore, in the test, when the crack width was arrived 0.1 mm, it was specified as the cracking time of the specimen. The relevant statistics of electrified accelerated corrosion were shown in Table 2.

Table 2. The cover cracking time for electrified accelerated corrosion

(a)						
Specimen#	c (mm)	d (mm)	2a (mm)	Cracking time (h)	crack width (mm)	Crack length (cm)
1	25		3	209	0.14	16
2	25		5	182.5	0.12	9
3	25		7	161.5	0.1	22
4	35		3	325.6	0.1	22
5	35	22	5	280.5	0.12	8
6	35		7	235.5	0.16	6.5
7	65		3	698.2	0.15	22
8	65		5	584.4	0.1	8
9	65		7	509	0.13	22
10	25		3	287.5	0.12	17.6
11	25		5	248	0.1	12.5
12	25		7	235	0.1	22
13	35		3	436	0.1	22
14	35	25	5	372.5	0.15	22
15	35		7	338	0.14	22
16	65		3	1115.5	0.1	8.7
17	65		5	917	0.18	22
18	65		7	792	0.12	8
(b)						
19	25		3	327.5	0.15	22
20	25		5	278	0.1	14.8
21	25		7	254.5	0.13	22
22	35		3	478.5	0.14	22
23	35	28	5	406	0.1	22
24	35		7	368	0.12	22
25	65		3	1161	0.16	22
26	65		5	958	0.1	10
27	65		7	832	0.1	6

Note: All electrification accelerated corrosion specimens were divided into three groups according to the diameter of the steels. The corrosion current density control values of I, II, and III were  $150 \mu\text{A}/\text{cm}^2$ ,  $100 \mu\text{A}/\text{cm}^2$ , and  $100 \mu\text{A}/\text{cm}^2$ , respectively.

### 3.2 Analysis of factors affecting cracking time

#### ① Initial defect size effect of concrete (single factor)

As shown in Figure 3, when the thickness of the concrete cover, the diameter of the steel and the initial were determined, the expansion cracking time of the concrete cover was shortened as the initial defect size of the concrete specimen increases. This is because the initial defect provides a certain release effect for the rust expansion stress in theory, which alleviates the development of the expansion stress. However, in fact, the size of the defect has a greater influence on the impermeability of the concrete, and has a non-negligible weakening effect on the macroscopic mechanical properties of the concrete. At the same concrete cover thickness, as the crack size increases, the stiffness of the surrounding concrete decreases. Correspondingly, the weaker the concrete cover is, the lower the amount of rust required for the specimen to cracking, and the shorter time for causing the rust and cracking in the defect position. Therefore, the initial crack has a significant effect on the rust expanding of the concrete structure. This issue should be fully considered in the design and evaluation of durability.

#### ② Effect of concrete cover thickness (single factor)

A vertical analysis of the data in Figure 3, under the same conditions (reinforcement diameter, size

of the defect), the thicker concrete cover is, the longer cracking time. This is because the increase in thickness prolongs the permeation path of the corrosive medium, which ultimately leads to an increase in corrosion resistance. The experimental results show that when the other conditions are the same, increasing the thickness of the concrete cover can effectively prolong the corrosion cracking time of concrete structure.

### ③ Effect of steel diameter change (single factor)

Horizontal analysis of the data in Figure 3, when the other conditions are the same, the law can be summarized: The greater the ratio ( $D/C$ ) of the diameter of the steel to the thickness of the concrete cover is, the longer the time required for the rust cracking of the concrete cover. This is due to the same thickness of the concrete cover, under the rust pressure, there should be the same amount of concrete radial displacement. The larger the diameter of the steel, the greater the thickness of the rust layer and the greater the amount of rust required, so the longer the rust cracking time.

### ④ Mix effect of common variations in defect size, concrete cover thickness and steel diameter

Diagonal analysis of the data of Figure 3, with the increase of three variables, the cracking time of the specimens is obviously prolonged, indicating that these three conditions have a great influence on the critical index of cracking. The severity of corrosion expansion and cracking time of concrete cover can be ranked as follows: thickness of concrete cover > diameter of steel > size of initial defect.

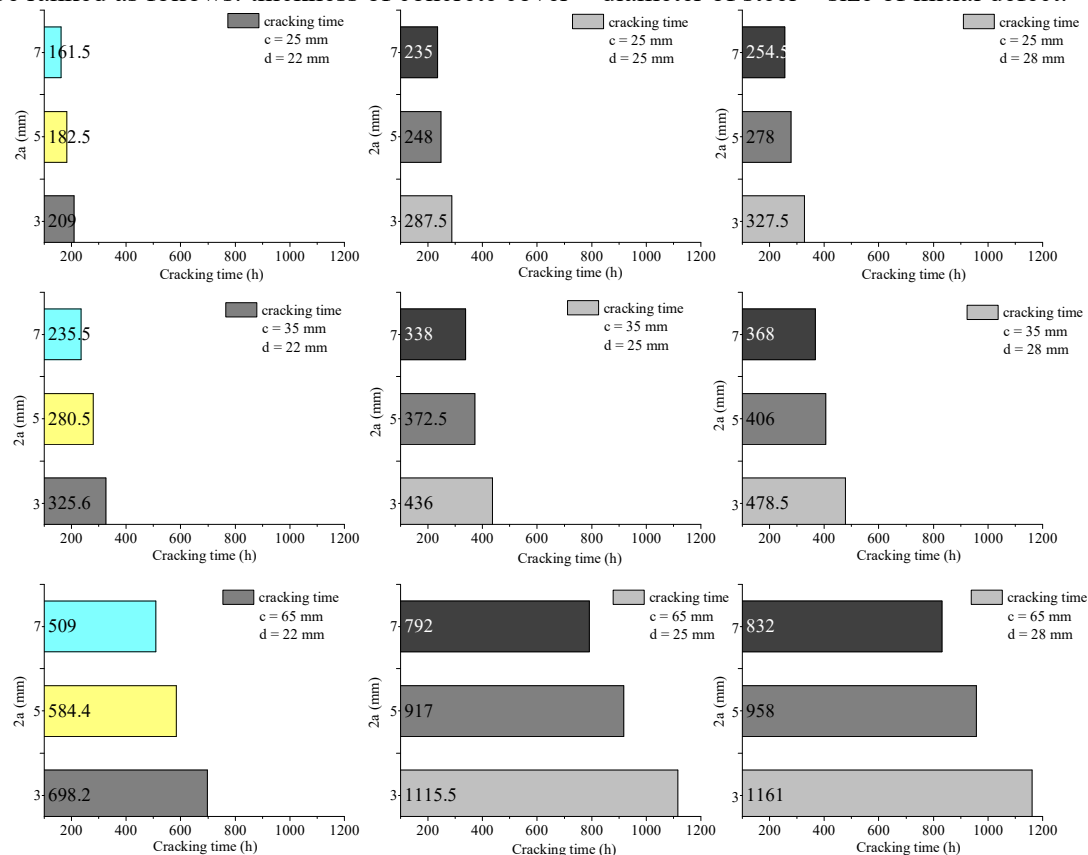


Figure 3. Influence factors of cracking time

## 4. Conclusion

The analysis of the factors influencing the cracking time shows that the cracking time is increasing with corrosion current density decreases, the diameter of steel increases and the thickness of the concrete cover increases. It decreases with the increase of actual preset crack size. According to the degree of influence, The severity of corrosion expansion and cracking time of concrete cover can be ranked as follows the concrete cover thickness > the diameter of steel > the initial defect size

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