

Chloride ion erosion experiment research in cracked concrete

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Abstract:For the study of chloride ion erosion in cracked concrete, this essay tries to take advantages of relevant trails to build up concrete chloride ion diffusion model based on the Fick's second law. The parameter of this model is easy to be set, and many factors such as the effect of cracks are taken into consideration in this experiment. The concept of "chloride ion diffusion coefficient of equivalent apparent" is introduced to simplify the calculation. It can help simplify the calculation process, and get a more accurate test result, as well as facilitating the practical application of this parameter.

1. Introduction

Concrete has low tensile strength. It will inevitably produce cracks in the process of service, and the existence of these cracks will accelerate the corrosion of reinforcement in concrete. Most scholars have done lots of researches, and they found that once the concrete cracking phenomenon occurs, the mode of chlorine ion erosion in concrete becomes very complicated. The appearance of cracks not only destroys the integrity of the concrete, but also offers chloride ion some small resistances, short paths of the ideal channel, making it smooth for chloride to reach the surface of the steel. On the other hand, the transport rule of chloride ions which gave priority to diffusion before changes into comprehensive invasion approaches, including diffusion, osmosis, wool stoma siphon and migration, and this change is resulted from the circumstances the concrete belongs to and the crack width and so on.

2. Existed calculation models for chloride ion diffusion coefficient in cracked concrete

2.1. Dispersion crack method

This method aims at reducing the ability to resist chloride ion erosion of concrete in cracks-influenced areas, and it always takes the influence of crack width and crack-spacing into consideration. In simple terms, cracks will be considered as a part of the pore, dispersing the volume of cracks to the whole volume of the concrete evenly.

2.2. Discrete fracture method

The premise of the discrete crack model is to identify that the crack and the concrete are two distinctive medias, and the chloride's transmission mechanisms in the the crack and concrete are quite different. It is more applicable to situations with less and distributed cracks because it can help us get more accurate results.

2.3. Double-porosity model

Dispersion crack method greatly simplifies the calculation, but the problem is the low level of exactness. On the contrary, discrete crack model can help us get more accurate results, but the



calculation process is complex because of the complexity of the crack path and the transmission mechanism of chloride in cracks. Based on these analyses, students introduced the double-porosity model which had been widely used in rock-mass seepage engineering and dual porosity reservoir engineering. As shown in figure 1, in this model, not only concrete itself is regarded as a continuous porous medium, the crack is also viewed as an equivalent continuous porous media. We can calculate the chloride ion erosion in cracks according to the transmission equation of solution in porous media (Fick's second law under saturated condition). Lu Chunhua et al [1] proposed that there exists a direct relationship between the cracking factor and the crack width, both of which are equivalent to reflect the chloride ion diffusion coefficient, and then they set up the adjusted Fick's law for the chloride ion diffusion model.

$$D(w) = k_w \cdot D_m = (47.18w^2 - 8.18w + 1)D_m \quad (w > 0.1\text{mm}) \quad (1)$$

$D_{(w)}$ -equivalent chloride ion diffusion model of cracked concrete; w -crack width; D_m -average chloride ion diffusion coefficient during a certain period of time

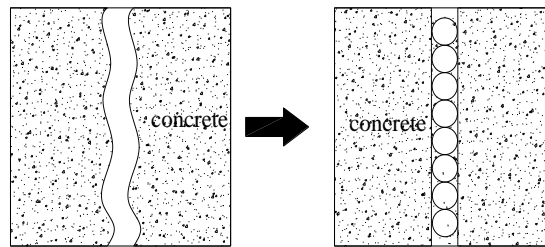


Figure 1 Principle of double porosity medium model

According to literature [1, 2], this paper will adopt the double porosity medium model to analyze the transmitting procedure of chloride ion in cracked concrete, and we introduce the equivalent apparent chloride ion diffusion coefficient $D_{(w)}$ to simplify the analysis. A degradation effect function will be used to describe the influence that the crack width can act on the performance of chloride ion diffusion. The $D_{(w)}$ can be expressed as:

$$D(w) = f(w) \cdot D_0 \quad (2)$$

$D_{(w)}$ -equivalent apparent chloride ion diffusion coefficient of a cracked concrete; w - crack width;

D_0 -chloride ion diffusion coefficient of a integral concrete

On this basis, we also need to consider other parameters comprehensively. The final chloride diffusion model is shown like this.

$$C(x, t) = C_0 + (C_s - C_0) \left[1 - \operatorname{erf} \left(\frac{x}{2 \sqrt{\frac{K_e f(w) D_0 t_0^\alpha}{1 - \alpha}} t^{1-\alpha}} \right) \right] \quad (3)$$

3. Experiment

3.1. Method and process of the experiment

The way of producing initial transverse cracks: First the concrete should be poured into the model, and a sheet of steel which has a same thickness with the preset crack should be inserted to ensure a required initial crack width, and then the sheet should be pulled out the at the first set moment of the concrete. The details of initial preset crack width plan shows in table 1.

Table 1 list of the test program

specimen number	A1	A2	B1	B2	C1	C2	D1	D2	E
preset crack	0.25	0.25	0.5	0.5	0.75	0.75	1.0	1.0	0

In order to transport the chloride into the concrete, the non-erosion surfaces of specimens should be coated with epoxy resin glue. Then the whole specimens should be put into a pool with NaCl solution (mass fraction, 3.5%). The soaking period is 70 days. The solution should be change half a month to ensure a stable solution concentration.

After the scheduled soaking time, the specimen should be removed from the solution, and powder extraction work should be started after two days' dry sediment. A 10 mm diameter churn drill should be used to drill specimen A1 and the drilling powder should be collected. Fracture cross-sections as well as cross-sections 20 mm, 40 mm, 60 mm and 80 mm away from the fracture should be chosen as detection objects. Each section was three holes drilled. The powder should be took every 5 mm in depth direction for every section, but the maximum sampling depth is 45 mm. The rest of these specimens should be drilled using a drilling bit with small aperture on one side of the fracture in the positions which are 5mm, 10mm, 20mm, 30mm, 40mm and 50mm away from it and another side of the fracture symmetrical to them, and every specimen in the positions which are 5 mm, 10 mm, 15 mm, 20 mm, 35 mm and 50 mm away from fracture in the depth direction should be drilled at every position on the cross-section. The powder should be collected with a self-styled bag. The free chloride ion concentration should be measured through the sieve, drying and a series of processes and it can be expressed in a percentage term.

After the powder extraction, the concrete cover should be chiseled up. The steel bar should be get out and the length of the corrosion areas should be measured with a Vernier caliper.

3.2. Test data collection and processing

In an actual operation process, the self-healing capacity of the concrete and the artificial errors can influence the actual value of crack width when the steel is pulled out. Therefore, it is necessary to measure the crack width for a second time. The result is shown in table 2.

Table 2 group of measured lateral crack

Specimen number	The initial default cracks width/mm	The measured crack width/mm
A1	0.25	0.22
A2	0.25	0.27
B1	0.50	0.54
B2	0.50	0.45
C1	0.75	0.51
C2	0.75	0.84
D1	1.0	0.87
D2	1.0	-
E	0	0

“-”Means the next step will not be taken because the gap between the measured value and the preset cracks value is too large to be accepted

4. Transmission rule of chloride ion in cracked concrete

4.1. Chloride ion concentration analysis around fractures

Specimen A1 should be drill and drilling powder should be collected. Ion selective electrode method should be used to detect the content of chloride ion around fractures. The distribution of chloride ions of the test beam A1 is shown in figure 2.

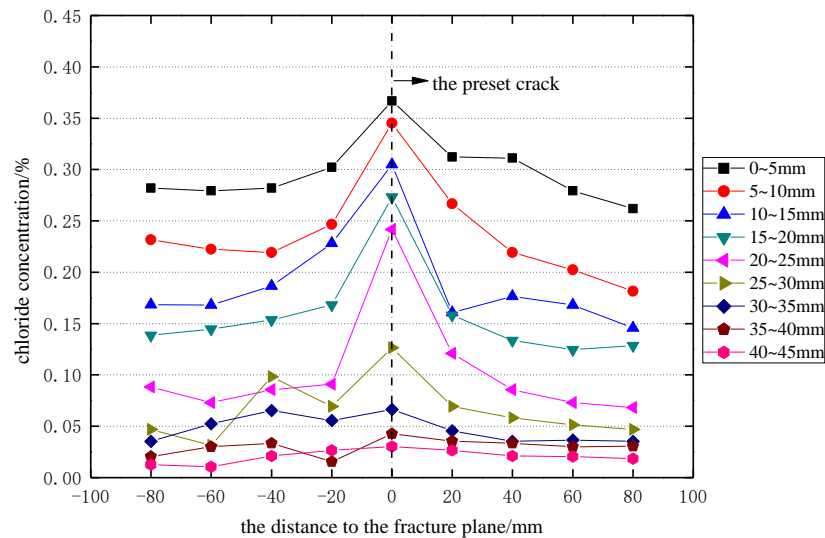


Figure 2 Relationships between the content of chloride ion and the distance to the fracture cross-section in different depth of beam A1.

As it can be seen from the picture, (1)The chloride ion content in fracture cross-section is far higher than other sections and as the distance from cracks becomes larger, the concentration of chloride ions decreases. In the position of the reinforcement, the chloride ion content on the crack face is respectively 1.99, 2.82, 3.31, and 3.54 times higher than the content of 20 mm, 40 mm, 60 mm and 80 mm away from the cross-section. There are two main reasons for these results. One is that the presence of cracks accelerates the chloride ion erosion, and there exists an obvious two-dimensional diffusion when compared with other completed cross-sections. Secondly, in the test, a very large crack width is prefabricated and the lateral diffusions which were perpendicular to the fracture cross-section occurred, resulting in a high content of chloride ions near cracks in concrete. (2)The chloride ion content is almost the same where the distance to the fracture cross-section is over 40mm in completed cross-sections. It means that the existence of cracks has no influence on chloride ion erosion in the surroundings of cross-sections. It also shows that under the action of soaking the concrete in 3.5% NaCl solution about 70 days, the maximum crack width which is stipulated in the current specification will influence the content of concrete chloride ion that - 40 ~ 40 mm around the cross-sections.

In the symmetry position from the crack, the chloride ion content is almost the same. So, for the rest of the specimen crack, the powder should be obtained symmetrically on both sides of the crack (5 mm, 10mm, 20mm, 30mm, 40 mm, and 50 mm) along the erosion surface. So it's convenient for data comparison because the fracture width is the only one variable. The final measured results of chloride ion content are shown in figure 3.

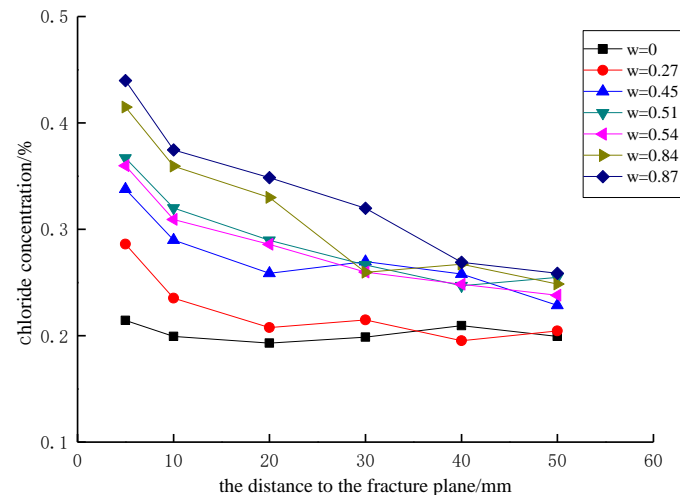


Figure 3 Chloride ion content in surrounding areas of concrete cracks

Figure 3 shows that the content of chlorine ion in the cracks' surrounding areas is much higher than integrated sections, and in the position where there is the same distance to the cracks, the content of chloride ions shows an increasing trend as the crack width expands. As for intact concrete, chloride ion can take advantage of the concentration difference to diffuse into concrete. Therefore, the concentration of chloride ion moves quite gently since it not change with the distance. But for the cracked concrete, specimens' erosion surface is enlarged due to the large crack width. Chloride ions can diffuse through the concrete from the side of fracture plugging as it could only penetrate the concrete from the erosion surface before. The diagram also shows us, for the concrete beam of which the crack width is within the scope of 0.2 ~ 0.6 mm, the chloride ion concentration which is about 20 ~ 30mm away from cracks is basically in a state of balance. So, the effect depth of unilateral diffusion is about 20 ~ 30 mm in cracks and diffusion depth of chloride ion is about 40 ~ 60 mm around the cracked area. For the concrete beam of which the crack width is within the scope of 0.6~1.0mm, the chloride ion concentration which is about 30~40mm away from cracks is basically in a state of balance, and the diffusion depth of chloride ion is about 60 ~ 80 mm around the fractured area.

4.2. Chloride ion concentration analysis of different depth

Powder should be took down through the crack (5 mm, 10 mm, 15 mm, 20 mm, 35 mm, and 50 mm) and the concentration of chloride ion of different depth of cracks should be detected with ion selective electrode method. The results are shown in figure 4.

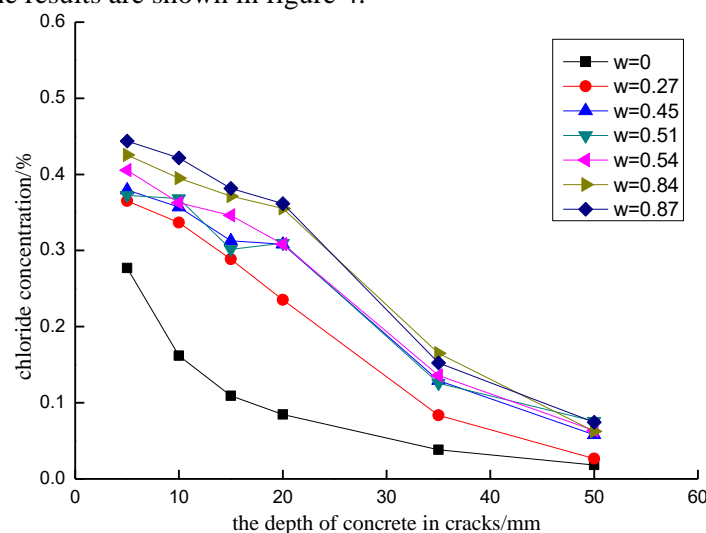


Figure 4 Concentration of chloride ion of different depth of cracks

Figure 4 shows that the content of chloride ion in completed concrete is significantly lower than other cracked concrete. As the crack width expands, the content of chloride ions in the position where there is the same distance to the cracks shows an increasing trend. The content of chloride ions in fractured sections gradually declines as erosion depth deepens. Within depth of 20 mm, the content of chloride ions in concrete does not decline dramatically, and the concentration in cracked section is about 3.5 ~ 4.5 times than the intact concrete. When the depth is over 20 mm, there is an apparent decrease trend of chloride ion content as the crack width expands, especially at a reinforced location (25 mm), and the chloride ion concentration in cracked concrete is 4 ~ 6 times of intact concrete. The chloride ion concentration which is over 35mm away from cracks is basically in a state of balance, and it increases with the expanding of crack width in this balanced stage; Secondly, for specimens with a relatively large crack width, the down trend of chloride ion content at the end of fracture location (steel) appear to be something like "bulge" as erosion depth changes, then it falls sharply with erosion depth deepening. There are some possible reasons for these results.

(1) Crack depth which preset by sheet steel is all about 25 mm (reinforced location), so it is easy for the chloride to infiltrate into root areas of cracks. After that the transport rule of chloride ion erosion changes into diffusion, and the "bulge" phenomenon appears. When the crack width is relatively large, the chloride ion diffusion inside is equivalent to the outside. In other words, in 25 mm depth of the cracks, the chloride ion diffusion inside is equivalent to the outside, as long as there is sufficient chlorine in cracks.

(2) Different degrees of hydration happen inside the crack after pulling out sheet steel, resulting in a rough and relatively small root surface in the crack. However, when chloride infiltrates into the root of cracks smoothly, the root of fracture will have a strong adsorption to the chloride ion, and the chloride ion content will also increase as the crack width expands.

(3) It takes a long time to reach saturation because of the compactness of concrete [3], and the short test cycle makes it difficult for the specimen to reach saturation. However, for unsaturated concrete, hydraulic gradient exists because of the capillary action and the action of pressure, adding a convective way of internal transportation as well as the diffused way. It can be inferred that the convection exists in the experiment, and the existence of cracks exacerbates the convective process.

5. Summary

Through the experiment, we can get the following conclusions.

(1) Under the effect of soaking in chlorine solution, the content of chlorine ion in the surrounding areas of cracks is much higher than integrated sections and in the position where there is the same distance to the cracks, the content of chloride ions shows an increasing trend as the crack width expands. As the fracture section spacing expands, the content of chloride ions shows a decreasing trend in each section.

(2) The experimental results show that the chloride ion presents different degrees of two-dimensional diffusion. As the crack width increase, the two-dimensional diffusion effect in cracks is more apparent. The chloride ion concentration which is over 35mm away from cracks is basically in a state of balance, and it increases with the expanding of crack width in this balanced stage.

(3) The double-porosity model is adopted to simplify of transmission of chloride ions in the analysis of cracked concrete, we can conclude that the crack has a significant effect on the "equivalent apparent chloride ion diffusion coefficient". But when the crack width expands to a certain value (0.45 mm), the expanding of the crack width will have no influence on the transportation of chloride ion in cracked concrete.

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