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Study on Chloride Ion Transport Mechanism of Concrete under the Coupling Action of Carbonation and Erosion

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Abstract

Concrete durability has an important impact on the safety of concrete structures. Reinforcement corrosion is one of the main factors affecting the durability of concrete, and the de passivation of reinforcement caused by concrete carbonization and chloride ion corrosion is an important reason for reinforcement corrosion. Aiming at the theoretical problem of chloride ion transmission in concrete under the coupling action of carbonation and chloride salt erosion, the indoor test research method is adopted to measure the chloride ion concentration distribution and chloride ion diffusion coefficient of concrete under the coupling action of carbonation and erosion, different temperatures and different erosion time, and analyze the chloride ion transmission mechanism in concrete under the coupling action of carbonation and chloride salt. The results show that the chloride ion concentration shows a large growth trend within 20mm from the concrete surface, and the chloride ion concentration and diffusion coefficient increase with the increase of ambient temperature; The chloride diffusion coefficient of concrete shows an increasing trend with the increase of load level, and the larger the load proportion is, the more obvious the increasing trend of chloride diffusion coefficient is. The research results can provide prediction basis for the durability of concrete structures in such coastal areas in the future.

Keywords

Concrete; Carbonization; Erosion; Chloride Ion; Durability.

1. Introduction

Concrete durability has an important impact on the safety of concrete structures. The durability of concrete structure is closely related to the service environment. In the classification of the durability of the service environment of the structure, according to the traditional experience of various industries and different corrosion mechanism of reinforcement and concrete materials, the environment of the structure can be divided into five categories [1-2]: (1) the general environment corresponding to the corrosion of reinforcement caused by carbonization; (2) The environment of repeated freeze-thaw and freeze-corrosion of concrete; (3) Offshore or marine environment in which reinforcement corrosion is caused by seawater chloride; (4) Environment in which chloride other than ice salt causes reinforcement corrosion; (5) Environment where concrete corrosion is caused by other chemicals. Scholars at home and abroad have done a lot of research on the degradation mechanism of concrete durability under single factor [2-7]. The corrosive substances of concrete in sea, lake and cold areas are not single. Chloride ions, carbon dioxide, water and oxygen also penetrate into the reinforcement through the protective layer from the outside. At the same time, due to different concentrations, hydrogen and oxygen ions in concrete will also penetrate from the inside to the outside. The damage of external load to concrete will also affect the transmission of various ions in concrete.

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The initial corrosion of reinforcement is closely related to chloride ion content, oxygen supply and carbonation degree of pore fluid. It is obviously of great practical value to study the durability degradation mechanism under the action of multiple factors.

In order to determine the migration and diffusion mechanism of chloride ion in concrete, scholars at home and abroad mainly use numerical simulation, indoor test, field test and theoretical analysis to study the influence of carbonation on chloride ion erosion, and have achieved some research results. Chindaprasirt [8] found that carbonization can reduce the chloride ion diffusion performance. The research of Tumidajski [9] shows that CO2 gas can slow down and accelerate the chloride ion penetration in ordinary concrete and slag concrete respectively. Puatsananon et al[10] used numerical simulation to draw the conclusion that carbonation slows down the diffusion of chloride ions by reducing porosity. Yuan [11] obtained through experiments that carbonization increases the amount of chloride ions and reduces the attenuation rate of chloride ion concentration.

The research of Gong [12-13] shows that carbonization will release the originally solidified chloride ion. Xu [14] showed that carbonation has both positive and negative effects on chloride ion erosion. Zheng [15] and others found that carbonization reduced the diffusion coefficient of chloride ions. Pang [16] compared and analyzed the effects of natural immersion method, RCM method and permit method on chloride ion diffusion coefficient. The results show that in the process of natural immersion, carbonation reduces the concentration of chloride ions on the surface of concrete, the content of free chloride ions on the surface decreases significantly, the apparent chloride diffusion coefficient increases, and the chloride diffusion coefficient of concrete after carbonation decreases significantly.

Under the action of single factor, the chloride ion migration model in concrete can not be used to predict and evaluate the durability of this concrete structure. Considering that stress, carbonation and chloride action will affect the durability of concrete, the relevant research work is insufficient. In this paper, the indoor test method is mainly used to study the migration theory of chloride ion in concrete under the coupling effect of carbonation and chloride ion erosion.

2. Test Content

2.1 Specimen Preparation

The loading device can load up to 200 kn. In order to ensure at least 80% of the ultimate compressive strength, the strength grade of concrete is C25. Refer to specification [17] to determine three groups of concrete with different mix proportions as shown in Table 1.

Table 1. Concrete proportioning

Strength grade	Water cement ratio	Water / kg	Cement / kg	Sand / kg	Crushed stone / kg	Fly ash / kg
C25	0.63	182	231	676	1241	75
C25	0.64	182	284	700	1244	0
C25	0.64	160	250	722	1283	0

Combined with the actual size of power transmission and transformation infrastructure, considering the convenience of specimen fabrication and the limitation of test conditions, and in order to facilitate the application of continuous load and meet the requirements of bending strength test specified in the specification, two sizes of C20 concrete test blocks were used in the test-100×100×50 (mm) and 100×100×80(mm), all of which are poured at one time. Three 100×100×50 (mm) cube test block are reserved to determine the 28 day compressive strength of the concrete. The test piece is poured in the wood formwork, and the poured test block is shown in Figure 1. Remove the formwork after 24 hours, and then put it into the standard curing Laboratory for curing for 28 days; the strength grade of

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concrete is determined by 100×100×50 (mm) cube test block. The average compressive strength after 28 days of standard curing is 23MPa, and the coefficient of specimen size correction is k = 0.95. The strength grade C22 is multiplied by the two.

Figure 1. Concrete specimen

2.2 Rapid Carbonization Test

The size of concrete specimen is 100×100×50 (mm) cube concrete specimen, remove the formwork after curing for 24h, and then standard curing for 28d. After the curing time is reached, the accelerated carbonation test as shown in Figure 2 is carried out according to China's standard for test methods for long term performance and durability of ordinary concrete (GB / T50082-2009). The relative humidity in the carbonation box is 70%, the error is not more than 5%, the temperature is controlled at about 20 ℃, the error is not more than 5 ℃, the concentration is maintained at 20%, the error is not more than 3%, and the age is 0d, 3d, 7d, 14d and 28d respectively, the specimens carbonized to the specified age were tested for carbonization depth.

Figure 2. Rapid carbonization test

2.3 Chloride Ion Diffusion Coefficient Test

In this test, the chloride ion diffusion coefficient is measured by the chloride ion diffusion coefficient tester shown in Figure 3, and the permeability is measured by RCM method to study the water permeability, air permeability and chloride ion permeability of concrete under the coupling action of stress and carbonization.

Figure 3. RCM chloride ion diffusion coefficient tester

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The experimental temperature is controlled at about 20 ℃ with an error of 5 ℃. Under no-load condition, add 30V DC voltage with error no more than 0.2V at both ends of the sample, and synchronously measure the initial series current and initial temperature of the electrolyte. The test time is determined according to the measured initial current, as shown in Table 2.

Table 2. Relationship between initial current and test time

I0/mA	I0<5	5≤I0<10	10≤I0<30	30≤I0<60	60≤I0
Time / h	168	96	48	24	8

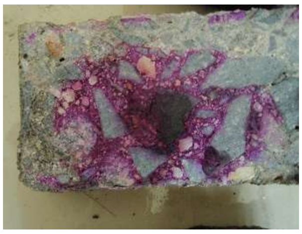
2.4 Determination of Flexural Tensile Strength

The continuous stress device in this test adopts the method of superposition of two test blocks and pressurization of screws. When stacking, the two test blocks are close to the outside. When loading the test piece, first fix a group of test pieces together with screw pressure gasket, and turn the nut with a wrench to apply the load, so as to make the test piece bend and produce bending tensile stress. A resistance strain gauge is pasted in the middle of each specimen to control the tensile strain produced by the concrete. In the process of tightening the nut, use a wrench to tighten the diagonal bolts at the same time, and pay attention to whether the readings of the strain gauges of the two specimens change evenly. The continuous loading device is shown in Figure 4.

Figure 4. Continuous loading device for bending tensile strength test

3. Analysis of Test Results

The rapid carbonation test was carried out on the cured samples, and the carbonation depth of C25 concrete at different carbonation ages was measured. Fig. 5 is a carbonation diagram for 7 and 14 days of the experiment.



a) 7d

b) 14d

Figure 5. Carbonization at 7 and 14 days of test

As shown in Figure 5, the carbonization depth and carbonization time are obviously non-linear and positively correlated. The carbonization is faster in the initial stage and slower over time. The carbonization depth was 60% and 67% higher in 7 days than in 3 days and 14 days than in 7 days, respectively. It was completely carbonized after 28 days.

3.1 Relationship between Chloride Concentration Distribution and Corrosion Time

Figure 6 shows the distribution curve of chloride ion concentration at different corrosion times. It can be seen from Figure 6 that the chloride ion concentration gradually decreases with the increase of penetration depth, which is basically in line with the chloride ion diffusion trend described by Fick's second diffusion law. With the extension of corrosion time, the concentration of free chloride ion in concrete at the same depth increases gradually. The chloride ion concentration shows a large growth trend in the range of 20mm from the concrete surface, while the growth trend of chloride ion concentration is not obvious in the range of 20mm-30mm.

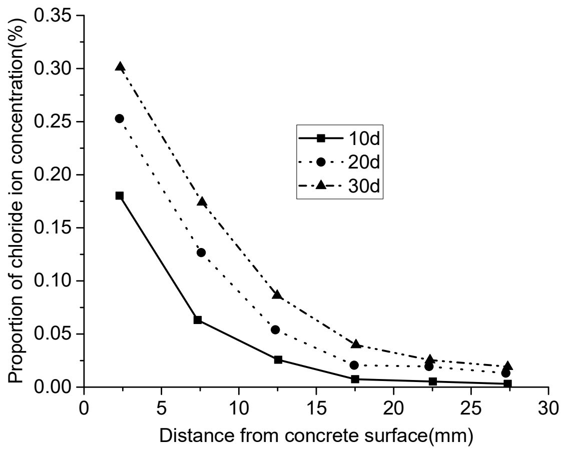


Figure 6. Chloride ion concentration distribution curve at different corrosion time

3.2 Effect of Solution Concentration on Chloride Concentration Distribution

Figure 7 shows the relationship between the concentration of different chloride ion solutions and the distribution of chloride ions in the test piece under the same ambient temperature. The ambient temperature of the test is 30 ℃, and the mass concentration of chloride ion solution is 6% and 9% respectively. It can be seen from Figure 7 that the chloride ion concentration in the concrete specimen with the concentration of sodium chloride solution of 9% is significantly higher than that of the concrete specimen with the concentration of sodium chloride solution of 6%. At the same time, the difference in chloride ion concentration in the concrete caused by the concentration of sodium chloride solution decreases with the increase of depth.

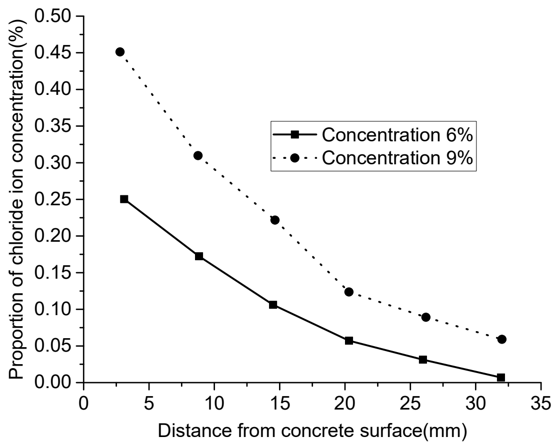


Figure 7. Chloride ion concentration distribution curve under different solution concentrations

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3.3 Effect of Temperature on Chloride Concentration Distribution

Fig. 8 shows the distribution curve of chloride ion concentration inside the concrete specimen when the concrete specimen is corroded for 30 days under different ambient temperatures of 20 °C, 35 °C and 50 °C and chloride ion solution concentration of 9%. It can be seen from figure 8 that the chloride ion concentration on the surface of concrete specimen and the chloride ion concentration at different depths increase with the increase of ambient temperature. According to the existing research [18-19], this phenomenon is due to the increase of porosity and permeability of concrete caused by the increase of temperature. At the same time, with the increase of permeability coefficient and temperature, the activity of ions increases and the diffusion ability of ions also increases. Therefore, when the temperature increases, the chloride ion diffusion coefficient increases accordingly, resulting in an increasing trend of chloride ion concentration in the specimen.

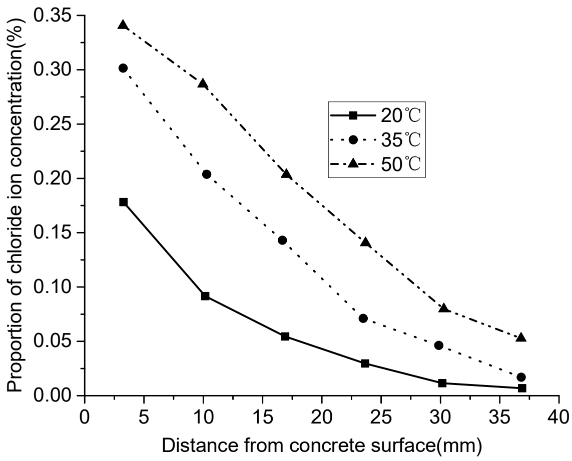

Figure 8. Chloride ion concentration distribution curve at different temperatures

3.4 Relationship between Chloride Diffusion Coefficient and Loading Ratio

Figure 9 shows the relationship between chloride ion diffusion coefficient D and concrete loading ratio. It can be seen from the figure that the chloride ion diffusion coefficient D increases with the increase of load level. The larger the loading ratio is, the steeper the diffusion coefficient curve is, and the more obvious the increasing trend of diffusion coefficient is.

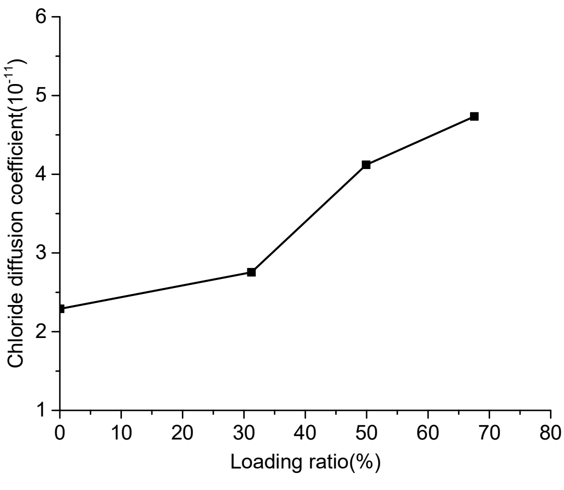

Figure 9. Relationship between chloride diffusion coefficient and loading ratio

3.5 Analysis of Bending Tensile Test

The ultimate load and ultimate tensile strain of concrete test block under two erosion environments are measured in the test, as shown in Table 3.

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Table 3. Ultimate load, bending moment and strain of concrete test block

Number	Temperature / °C	Solution concentration / %	Ultimate load / kN	Ultimate bending moment / kN·m	Ultimate strain / 10^{-6}
1	Room temperature	6	11.62	0.73	134
2	Room temperature	9	10.41	0.66	144

Figure 10 shows the relationship between the absolute change rate of flexural tensile strength and corrosion time. It can be seen from Figure 10 that the absolute change rate of flexural tensile strength of concrete increases slowly in the first 60 days, and then decreases gradually with the increase of corrosion time. This is because the strength of concrete specimens increases slowly at the initial stage of corrosion and the corrosion degree of chloride salt to concrete specimens is small, It has little effect on the strength of concrete. After 60 days of erosion, chloride salt crystallization appeared in the concrete, the reinforcement began to rust, and the ultimate flexural tensile strength of concrete showed an obvious attenuation trend.

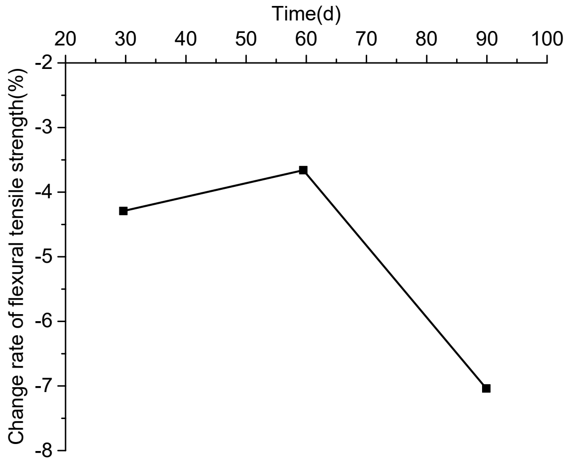

Figure 10. Relationship between absolute change rate of flexural tensile strength and corrosion time

4. Conclusion

This paper mainly studies the theoretical problem of chloride ion transmission in concrete under the coupling action of carbonization and chloride salt erosion. By measuring the chloride ion concentration distribution and chloride ion diffusion coefficient of concrete under the coupling action of carbonization and erosion, different temperatures and different erosion time, this paper studies the chloride ion transmission mechanism in concrete under the coupling action of carbonization and chloride salt, The main conclusions are as follows:

(1) With the increase of corrosion time, the chloride ion concentration shows a large growth trend in the range of 20mm from the concrete surface, while the growth trend of chloride ion concentration is not obvious in the range of 20mm-30mm.

(2) The chloride ion concentration on the surface of concrete specimen and the chloride ion concentration at different depths inside the specimen increase with the increase of ambient temperature. When the temperature increases, the chloride ion diffusion coefficient and chloride ion concentration also increase.

(3) At the same time, the difference of chloride ion concentration in concrete caused by the concentration of sodium chloride solution decreases with the increase of depth.

(4) The chloride diffusion coefficient D of concrete shows an increasing trend with the increase of load level, and the larger the load proportion is, the steeper the diffusion coefficient curve is, the more obvious the increasing trend of diffusion coefficient is.

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