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STUDY ON CHLORIDE MIGRATION IN CONCRETE UNDER PRESSURE

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This paper used self-designed equipment to carry out chloride migration test in concrete samples under the conditions imitating subsea tunnel environment. It determined the permeability characteristics of chloride ions in concrete under different water pressure, concentration and time, and analyzed the influence degree of various factors.

Keywords: chloride, migration, pressure, diffusion, permeability

INTRODUCTION

Reinforced concrete is widely used in subsea tunnel due to its local materials and good bearing capacity [1]. The service environment of subsea tunnel is complex and harsh. From an environment point of view, it is affected by dry and wet cycle of atmosphere, carbon dioxide, chloride sulfate ions and other aggressive ions. From the material point of view, it is effected by carbonize, alkali-aggregate reaction, biological degradation and splitting under high water pressure. These adverse factors make the durability of the underwater tunnel an urgent problem to be solved. In addition, the subsea tunnel is different from the normal highway and mountain tunnel in that it is used in high-pressure seawater environment. The combination of chloride and pressure should be considered together.

Scholars establish theoretical models of chloride migration in concrete based on Fick's second law [2-4]. However, the theoretical models have many uncertainties of parameters and lack comparison of corresponding tests. For the experimental study, the chloride migration rule is mostly considered with the coupling of carbonation, freeze-thaw, load and other factors[5-7], but lack of pressure. This paper carried out chloride migration test in concrete samples under the conditions imitating subsea tunnel environment. It determined the permeability characteristics of chloride ions in concrete under different water pressure, concentration and time, and analyzed the influence degree of various factors.

EXPERIMENT WORK

Different water pressure was applied to the specimens by using self-made equipment. The specimens were cut along the center after the specified pressure time, then took concrete samples at different positions along the infiltration direction, grinded the powder, and analyzed the content of chlorine concentration in each sample by chemical method. The relationships between chloride content and water pressure, concrete strength grade, water-cement ratio, diffusion coefficient, saturation degree, environmental chloride concentration and pressure time were obtained.

Self-made equipment was used to do pressure permeation experiment. The RCT instrument was used to determine chloride concentration. Chloride diffusion coefficient measuring instrument is used to measure the diffusion coefficient of chlorine ions in different water-cement ratio concrete. Chlorine ion diffusion coefficient tester was used to measure the chloride diffusion coefficient in different water-cement ratio concrete.

This self-made pressure infiltration device is consisted of nitrogen cylinder, stainless steel water storage device, pressure chamber, pressure regulating valve and pipeline, shown as Figure 1. Nitrogen cylinder provides pressure and adjusts it through pressure gauge and valve. Nitrogen enters the water reservoir through the pipeline, exerting pressure on the liquid, which flows into the concrete in the pressure chamber and exerts corresponding pressure on its side wall.

Figure 1 Water storage device

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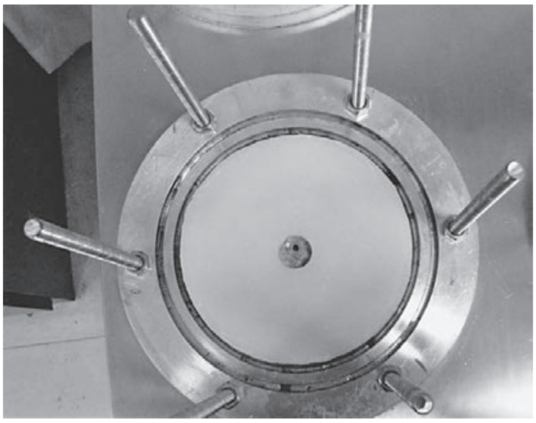

Figure 2 Pressure chamber

This set of equipment has 4 pressure Chambers, which can pressurize 4 test blocks at a time. Each pressure chamber has its own water inlet valve, which can be controlled separately. The specimens have perforated reserved holes in the middle. During the test, the hole is pointed at the hole at the bottom of the pressure chamber. The specimen has a silica gel gasket with a thickness of 1cm and a hole in the top and bottom respectively, which plays a sealing role. The upper part of the specimen is covered with stainless steel plate with a thickness of 2cm, which is fixed with six steel rods, as shown in Figure 2.

Three kinds of specimens were designed, such as truncated cone-shaped, cylinder and cube. The test mix ratio is as shown in Table 1.

Table 1 **Proportions of concrete mix**

w/c	The amount of material per unit volume/kg/m^3						Compressive Grade/ MPa
	Cement (c)	Fly ash	Water (w)	sand	pebble	admixture	
0,3	525,3	58,37	168,1	504,5	1 177,2	11,67	C50
0,34	468,2	52,02	168,1	519,4	1 211,9	10,4	
0,38	419,2	46,58	168,1	532,1	1 241,6	9,32	C45
0,42	379	42,1	168,1	542,8	1 266,5	8,42	
0,46	346,1	38,45	168,1	551,4	1 286,6	7,69	
0,5	318,4	35,4	168,1	595,6	1 265,7	7,08	C35

The permeability coefficients of various water-cement ratios are calculated based on the penetration depth obtained by soaking for a certain period of time in the state of natural immersion. When soaking, the upper and lower bottom surface and lateral side of the specimens are sealed with hot paraffin wax, leaving only the hole in the middle to serve as the interface for water entry. The values are in Table 2.

Table 2 **Permeability coefficient of different water-binder ratio concrete**

Water-binder ratio	0,34	0,38	0,42	0,46
Permeability coefficient×10^{-6}/m/s	1,05		1,23	1,43

The diffusion coefficient of chloride was determined by RCM. This test method can be used in the mix ratio design of concrete in chloride erosion environment.

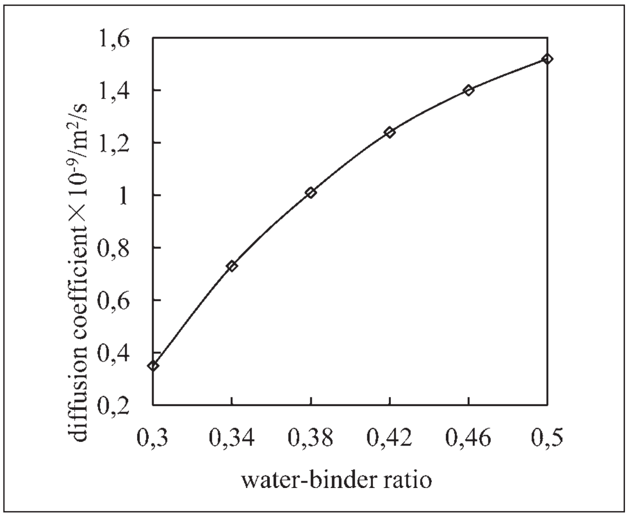

Figure 3 Distribution curve of chloride diffusion coefficient

It can be seen from the test analysis that the water-binder ratio is one of the influencing factors of the diffusion coefficient. Generally speaking, the diffusion coefficient increases with the water-binder ratio in Figure 3. In the range of 0,3~0,38, the diffusion coefficient increased greatly. The increase is small in the range from 0,38 to 0,5. The higher the water-binder ratio is, the more water is involved in the reaction during cement hydration and concrete mixing, and more channel pores are left behind, which is conducive to the diffusion and migration of chloride. The migration speed of water and ions increases, so that the diffusion coefficient is larger.

The experimental study on chlorine ion migration in concrete under pressure was divided into 9 working conditions according to water-glue ratio (0,34, 0,38, 0,42, 0,46, 0,5), pressure size(1,5 Mpa, 2 Mpa), pressurized time(3 days, 7 days) and NaCl solution concentration(3 %, 18 %).

RESULTS AND DISCUSSION

Figure 4 shows the chloride content test results of various parts of concrete with water-binder ratio of

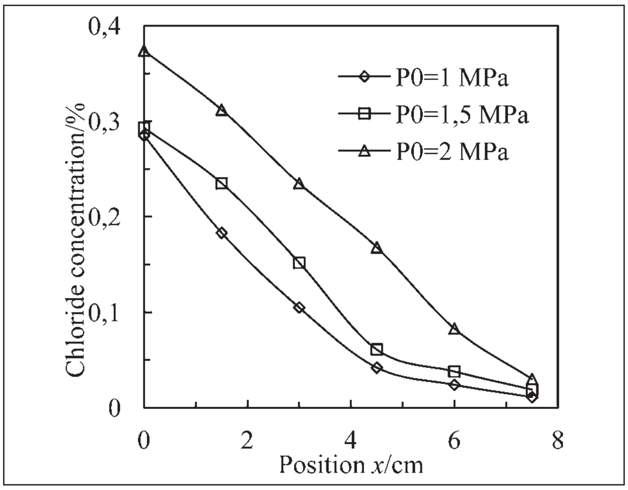

Figure 4 The influence diagram of pressure on chloride content

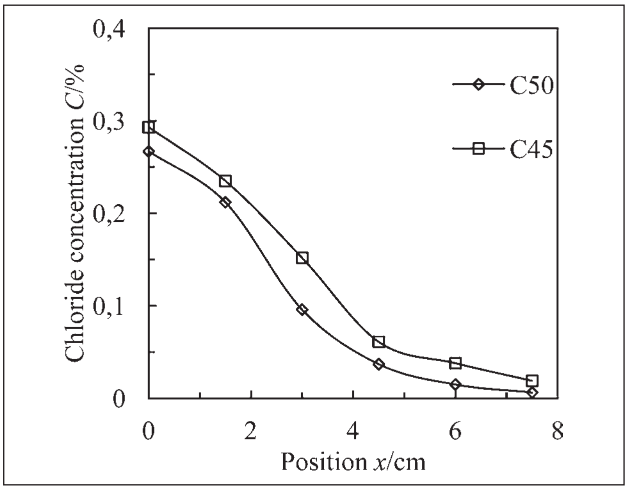

Figure 5 The influence diagram of compressive grade on chloride content

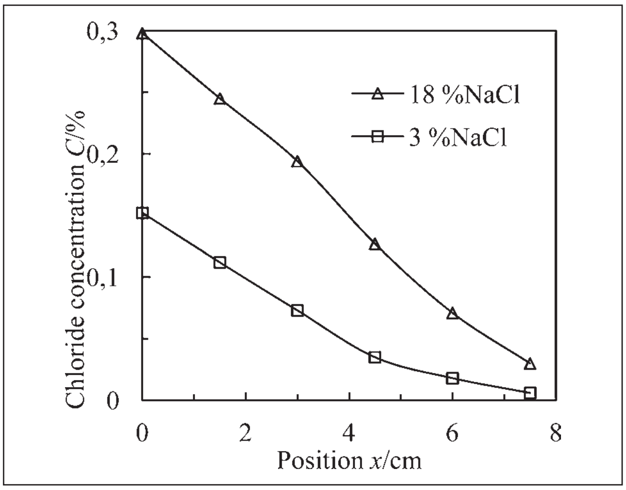

Figure 7 The influence diagram of NaCl concentration on chloride content

0,38 under different pressure heads. The chloride content increases with the increase of pressure at the same position. The chloride content decreases with depth under the same pressure. In the position range of 5cm~7,5 cm, the change range of concentration under pressure of 1 MPa and 1,5 Mpa is small and almost stable.

Figure 5 shows the effect of concrete compressive grade on the free chloride concentration. C50, C45 respectively correspond to the water-binder ratio of 0,38 and 0,34with the permeability coefficient of 1,05 × 10^{-6}/m/s, excluding the interference of other factors. The concentration of chloride at each position ranges from large to small, respectively: C45 > C50. Chloride permeates easily in low strength grade concrete. In concrete of the same strength grade, the chloride content decreases with the increase of distance, and decreases slowly in the shallow layer and the deep layer, while decreases greatly in the middle part.

Figure 6 shows the chloride content in concrete with different chloride diffusion coefficient under water pressure of 1,5 MPa. In concrete with high diffusion coefficient, the chloride content is higher than that of low diffusion coefficient. In the concrete with the same diffusion coefficient, the chloride content decreases with depth.

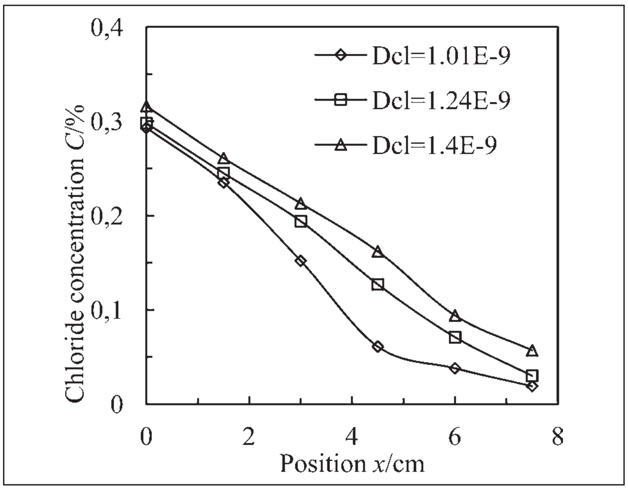

Figure 6 The influence diagram of diffusion coefficient on chloride content

Figure 7 shows the chloride distribution in different parts of the same concrete with different sodium chloride concentration. That is, the effect of chloride concentration on the surface is considered. The two curves are similar in shape. The chloride concentration at all parts of 18 % NaCl solution is higher than that at the same position in 3 % solution, and the chloride concentration increases by a large extent within a range of 0~25 mm.

CONCLUSIONS

(1) The diffusion coefficient of chloride ion increases with the increase of water-binder ratio. The diffusion coefficient increased greatly in the water-binder ratio range of 0,3~0,38, while that increased slightly in the water-binder ratio range of 0,38~0,5.

(2) The chloride content of each layer with the high-pressure was higher than that of the low-pressure under the same test condition. Because of the good compactness, the chloride content of each layer in low strength specimen is small. The diffusion coefficient of chloride determines the migration ability in concrete.

(3) Under the same test conditions, with the increase of the chloride concentration in the environment, the chloride content in each layer of concrete increases to different degrees, among which the chloride content in the range of 0~25 mm increases greatly.

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