Advances in Frontier Research on Engineering Structures
A. Cheshmehzangi and H. Bilgin (Eds.)

doi:10.3233/ATDE230224

Investigating the Diffusion of Chloride Ions and Oxygen in Coral Concrete Under Stress

Hongbin TANG[1]
No.3 Engineering Company Ltd. of CCCC Second Harbor Engineering Company Ltd. Jiangsu 212000, China.

Abstract. In this study, the transport of chloride ions and oxygen in coral aggregate seawater concrete (CASC) was examined under realistic working conditions. The concrete specimens were subjected to pre-applied compressive strengths of 0%, 25%, 45%, and 65%. The diffusion coefficients of oxygen gas in the CASC were determined by different loads, and the diffusion of chloride ions was also analyzed. The concrete was subjected to continuous loads of 0%, 10%, and 20% of their maximum compressive strength and the chloride ion content was measured after being exposed to seawater erosion. The results showed that the diffusion of oxygen concentration follows the pattern of initial rapid and then gradual decline, the higher the load, the more microcracks are generated, resulting in a larger diffusion coefficient of oxygen. Chlorine ions and oxygen have similar diffusion patterns.

Keywords. CASC; Load; Oxygen diffusion law; Chloride ion diffusion coefficient

1. Introduction

Compared to the terrestrial environment, concrete structures subjected to seawater erosion will have a large accumulation of harmful ions, of which chloride ions are one of the important causes. When the chloride ion solubility on the surface of the reinforcement reaches its limit and causes corrosion of the reinforcement, it causes new cracks in the reinforced concrete, thus reducing its durability. Therefore. The study of chloride ion content within concrete is one of the key conditions regarding the enhancement of concrete durability [1]. Corrosion of steel bars must be carried out in the presence of oxygen, so oxygen is an essential factor in considering durability [2]. When changed from ordinary concrete to coral concrete, coral concrete contains high chloride ion content. It has a lower ultimate tensile strength. The material microstructural damage accumulates during its service. Cracks will transform the coral concrete from a continuous body to a discrete body. Although it does not directly affect the safety of the structure, it changes its transmission characteristics. There is a certain one-sidedness in ignoring the load effect to study the permeability of harmful substances. When we choose to use coral concrete, the issue of durability of coral concrete becomes a problem that we must go to consider [3-4].

[1] Corresponding Author: Hongbin TANG, No.3 Engineering Company Ltd. of CCCC Second Harbor Engineering Company Ltd. Jiangsu 212000, China; e-mail: 550918350@qq.com

The gas transport properties in concrete are represented by the diffusion coefficient. For example, Xu [5] found that with the gradual increase in stress, the surface chloride ion concentration gradually increases and the degree of decay of chloride ion diffusion coefficient gradually decreases; Kwon [6] derived the chloride ion diffusion coefficient in concrete structures of piers in service 7a and 11a by field observation and predicted their durability by Monte-Carlo method.

The continuous action of load will further coarsen the pore structure inside the concrete and cause cracking, thereby exacerbating chloride corrosion. At the same time, the presence of various ions in the pore fluid of concrete can also affect the transport of chloride ions. Hu [7] proposed a load multi ion transport coupling model validated by third-party experiments by comprehensively considering the combined effects of load induced concrete cracking and pore damage, as well as the electrochemical coupling effect between different ions. Research has found that changes in load size and load application method not only affect pore structure and crack morphology, but also cause differences in the distribution of electrostatic potential, thereby jointly affecting changes in ion concentration. The multi ion electrochemical coupling effect under load can significantly affect the ion transport law, and only considering a single ion can lead to a low prediction of chloride ion intake. The effect of load also amplifies the impact of environmental conditions such as salt solution concentration on chlorine transport.

In summary, although there are many studies by various scholars in the study of transport in ordinary concrete materials, there are fewer relevant studies for coral concrete. There are even fewer studies to study chloride ion and oxygen in CASC.

2. Test Materials and Methods

2.1. Test Materials

Cement adopts 42.5 ordinary silicate cement. The fine aggregate uses coral sand with good grading, which belongs to Zone II sand. Coarse aggregate adopts coral stone with particle size of 5-20mm, continuous gradation. The water reducing agent is high-efficiency water reducing agent with a water reduction rate of 25%. The mixing water is artificial seawater, prepared according to ASTM D1141-2013 [8]. The design strength grade of coral concrete in this test are C30, and the water-cement ratio is 0.35.

2.2. Preparation of Specimens

This article develops the test plan based on the SL352-2006 "Specification for Hydraulic Concrete Testing" and the GB/T 5008-2009 "Standard for Long term Performance and Durability Testing of Ordinary Concrete". The CASC cube specimens (with a side length of 100mm) were used in this experiment. Cut the pre loaded and dried specimens into thin slices (size 100mm × 100mm × 20mm) for testing. The details of the sample are shown in Figure 1.

Figure 1. Coral concrete specimen to be tested

A long-term erosion test was conducted on the specimens, with their ultimate loads applied at 0,0.1 and 0.2, respectively. Conduct concrete compressive strength test according to the "Standard for Testing Methods for Physical and Mechanical Properties of Concrete" (GBT50088-2019). The non eroding four sides shall be coated with wax before loading, and the two opposite sides shall be used as the erosion surface.

2.3. Test Method

When measuring the oxygen diffusion coefficient, the ultimate compressive strength is obtained first. Then pre apply 0, 0.25, 0.45, and 0.65 of the ultimate compressive strength to the samples. Continue for 120 seconds after the pressure reaches the design value, and then unload.

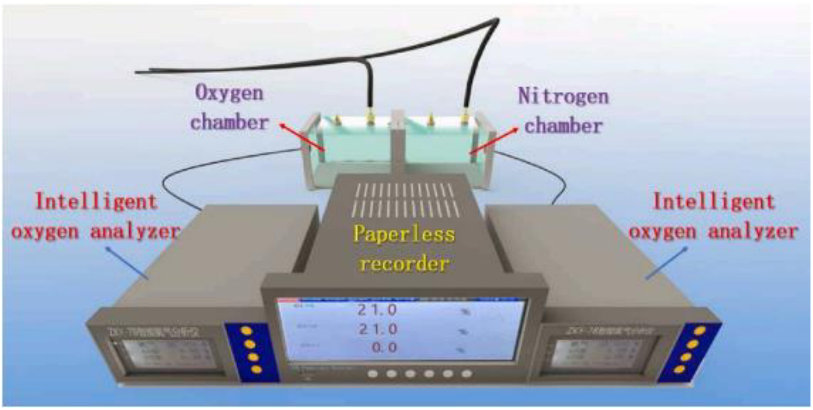

Figure 2. Test device for measuring oxygen diffusion coefficient in coral concrete

Conduct erosion and load coupling tests on the specimens using self-made equipment, and measure the chloride ion solubility of the specimens after continuous loading for 1, 2, 3, 4, and 6 months.

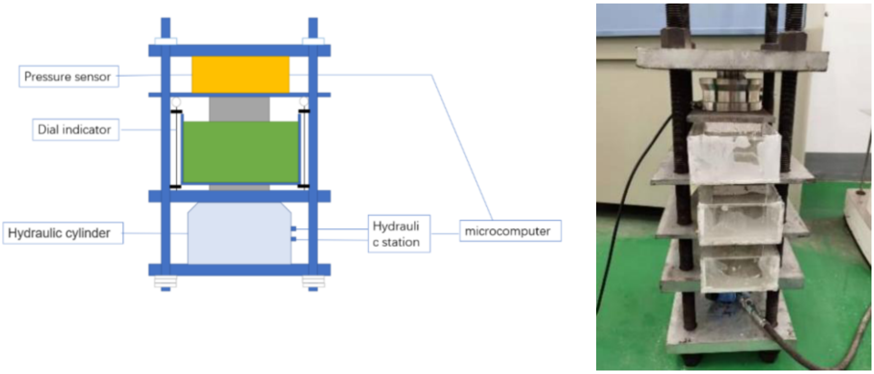

Figure 3. Continuous pressurized load and seawater joint action test equipment

2.4. Sampling Method

As shown in Figure 4, The drilling method was chosen to drill the powder at the midline of both sides of the specimen. the drilling tool was a hand drill with a drill diameter of 6 mm. the sampling depths were 15, 30, 45, 60 and 75 mm. after the powder was turned out at each depth, it was brushed out with a brush, and then a 100 mesh (0.15 mm) sieve was used to output the large particle size and only the powder below 100 mesh was retained. Then use the oven for drying process to avoid the original moisture on the test results. Then the powder is added with water, shaken thoroughly, and then heated for 6 minutes, then left to stand for 24 hours and filtered to obtain the finished solution.

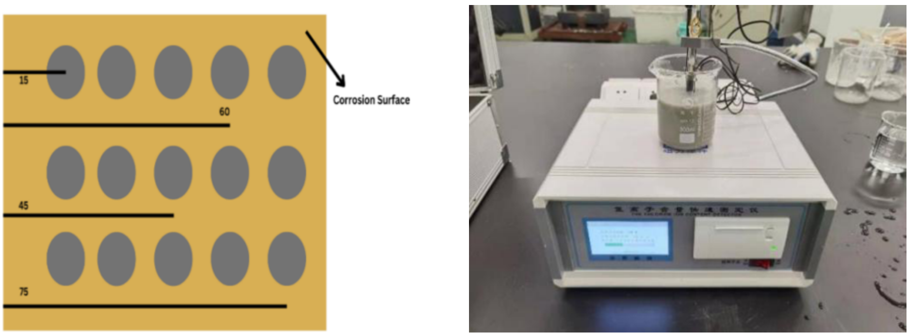

Figure 4. Drill hole for powder specimen

3. Results and Discussion

3.1. Ultimate Compressive Strength of Coral Concrete

The compressive strength values of coral concrete measured by the pressure testing machine in this test are shown in Table 1.

Table 1. Compressive strength of coral concrete

Specimen number	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Compressive strength /MPa	39.8	32.6	34.7	33.2	36.6	31.3	23.3	31	30.9

3.2. Oxygen Diffusion Coefficient of Coral Concrete under Different Loads under Dry Conditions

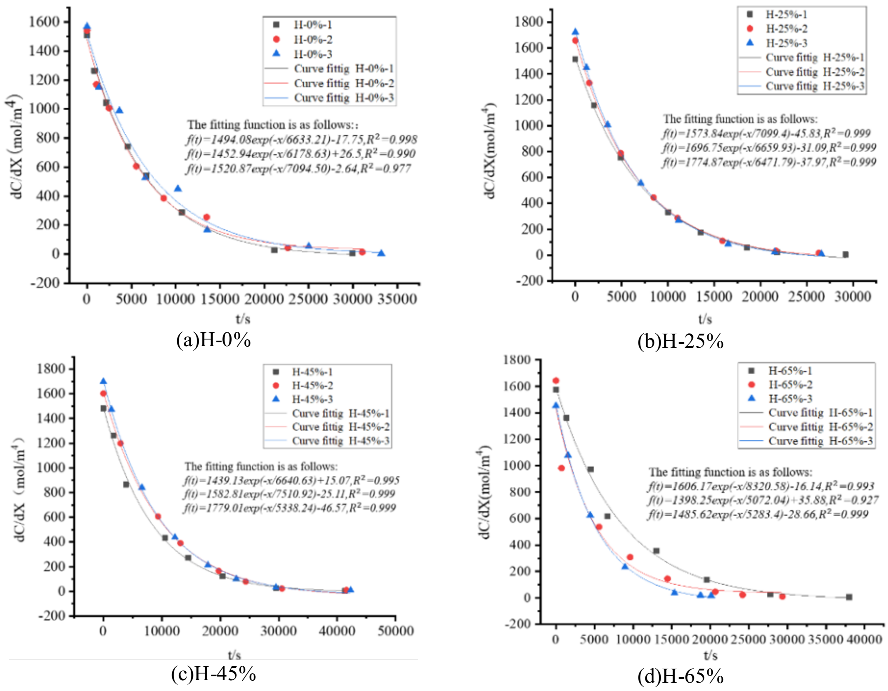

Figure 5. The relationship between the oxygen concentration gradient of coral concrete specimens and time under dry conditions

Also by observing the fitted curves in Figure 5, we can easily find that with the increase of applied load, the higher the degree of damage in the coral concrete, the oxygen diffusion coefficient dispersion gradually increases. The generation of microcracks reduces to some extent the porosity of the damaged coral concrete material as well as the curvature of the gas diffusion path. The increased dispersion is a visual representation of the above effect. In addition. Analysis from the above data shows that the solubility gradient of oxygen drops sharply in the first 1/3 time, dropping by about 80%. After that, in the 2/3 time, the decreasing rate of the solubility gradient of oxygen slows down and becomes stable. The oxygen only diffused from high concentration to low solubility and stopped after the solubility was consistent.

3.3. Chloride Ion Diffusion Coefficient

Based on C_f and C_S, the chloride ion diffusion coefficient D was calculated using Fick's second law.

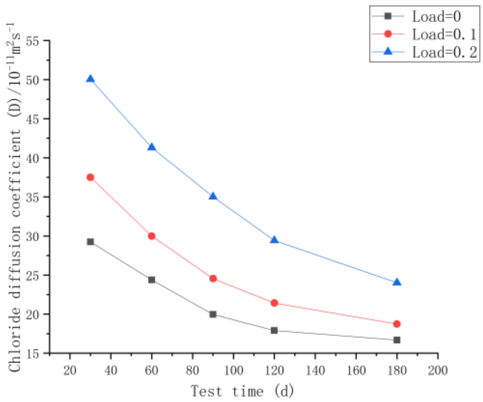

Figure 6. Relationship between *D* and time for different loads of CASC of 180d

From Figure 6, it can be seen that the diffusion coefficient of coral concrete decreases with the increase of erosion time. The diffusion coefficient decreased significantly in the early stage. As time increases, hydration proceeds further and the hydration products gradually increase. The diffusion is gradually stabilizing.

4. Conclusion

In this study, the following results were obtained through comparative analysis.

1.The effect of load on coral concrete was significant. The oxygen diffusion coefficient was 1.87 * 10^{-7} m^2s^{-1} when the load was 0, 1.93 * 10^{-7} m^2s^{-1} when the load was 0.25, 2.01 * 10^{-7} m^2s^{-1} when the load was 0.45, and 2.26 * 10^{-7} m^2s^{-1} when the load was 0.65. As the pre-applied load on coral concrete increased, the damage to the concrete specimens became more severe, leading to an increased number of micro cracks and a faster rate of oxygen transfer. This resulted in a higher final oxygen diffusion coefficient and the oxygen concentration changed in a pattern that started rapidly and then slowed down.

2.The chloride ion diffusion coefficient was 29.234 to 16.668 * 10^{-11} m^2s^{-1} when the load was 0, 37.501 to 18.740 * 10^{-11} m^2s^{-1} when the load was 0.1, and 50.059 to 24.023 * 10^{-11} m^2s^{-1} when the load was 0.2. As the applied load increased, the internal damage to the coral concrete increased, leading to an acceleration of chloride ion transport. During the diffusion process, the hydration within the coral concrete improved and the presence of various ions blocked the channels for chloride ion diffusion, causing the chloride ion diffusion coefficient to decrease gradually.

References

[1] Zuquan J, Xia Z, Tiejun Z, et al. Chloride ions transportation behavior and binding capacity of concrete exposed to different marine corrosion zones[J]. Construction and Building Materials, 2018, 177: 170-183. DOI: 10.1016/j.conbuildmat.2018.05.120

[2] Zheng H. Stochasticity and life prediction of concrete chloride ion erosion under natural environment[D]. Zhejiang University of Technology, 2009.(in Chinese) https://client.v.just.edu.cn/https/webvpn34dba54512b1dbccec764ab274be469e/kcms2/article/abstract?v

=3uoqIhG8C475KOm_zrgu4lQARvep2SAk0Wn9WGrcQB-qSRGXKNE7s9H-K4uzLQczxUsW1fprGNu8CVI_OnnsYaJam4dxJsTv&uniplatform=NZKPT

[3] Ju X, Wu L, Lin C, et al. Prediction of chloride concentration with elevation in concrete exposed to cyclic drying-wetting conditions in marine environments[J]. Construction and Building Materials, 2021, 278: 122370. DOI: 10.1016/J.CONBUILDMAT.2021.122370

[4] Pasupathy K, Sanjayan J, Rajeev P, et al. The effect of chloride ingress in reinforced geopolymer concrete exposed in the marine environment[J]. Journal of Building Engineering, 2021, 39: 102281. DOI: 10.1016/J.JOBE.2021.102281

[5] Xu J, Li F, Zhao J, et al. Model of time-dependent and stress-dependent chloride penetration of concrete under sustained axial pressure in the marine environment[J]. Construction and Building Materials, 2018, 170: 207-216. DOI: 10.1016/j.conbuildmat.2018.03.077

[6] Kwon S J, Na U J, Park S S, et al. Service life prediction of concrete wharves with early-aged crack: Probabilistic approach for chloride diffusion[J]. Structural Safety, 2009, 31(1): 75-83. DOI: 10.1016/j.strusafe.2008.03.004

[7] Hu Zhe, Liu Qingfeng. Numerical study of multi ion transport in cracked concrete under load [J/OL]. Materials Introduction, 2023 (09): 1-15. (in Chinese). http://kns.cnki.net/kcms/detail/50.1078.TB.20220223.1940.028.html.

[8] Ocean Water[J]. ASTMD.1141-2013. https://www.doc88.com/p-4834564165925.html