Permeability of Concrete Chloride Under Carbonization and Flexural-Tensile Load

Xiaoyan Yang and Jiaying Sun

ABSTRACT

In order to study the transmit problem of chloride in concrete under the coupling of carbonization and flexural-tensile load. Grade C30 concrete as the research object, loading test and rapid carbonization test were used to study the penetrating quality of chloride migration in concrete. The electric flux method was used to measure the electric flux of concrete in different carbonization time under the multifactor coupling. The chloride permeability coefficient of concrete was calculated and its relationship with concrete carbonization time was analyzed. The results showed that, the protective layer of concrete is completely carbonized about 28d. The carbonization depth is exponential growth with carbonization time before the completely carbonated through the test data and theoretical calculation. The chloride diffusion coefficient of concrete is described by a cubic polynomial function with carbonization time under the coupled of carbonization and flexural-tensile load, and the change rule becomes more obvious with the crease of flexural-tensile load.1

INTRODUCTION

For concrete structures in the marine and northern deicing salt environments, the durability problems are mainly caused by the combination of load factors and environmental factors such as chloride, carbon dioxide, temperature, humidity and oxygen. Among them, the damage degree of chloride salt to concrete structure is much greater than the influence of carbon dioxide on concrete carbonization. In the past, the model of concrete chloride transport have been ignored the carbonation,

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while the concrete in the atmosphere is subject to carbon dioxide, thus the carbonation of concrete is unavoidable. Especially in the concrete structure of the deicing salt environment in the atmospheric area are not negligible the influence of carbonization, e.g., [1] and [2]. In addition, the actual concrete structure under a certain load, and the load will change the pore structure and micro cracks in the concrete structure. Especially in fatigue load, flexural-tensile load and a certain degree of compressive load (generally 80% of ultimate strength) will produce different degrees of microscopic cracks in the concrete. These all provide a shortcut for the erosion of concrete by harmful media, which has an important impact on the chloride penetration and carbonization process of concrete structures.

At present, many scholars in domestic and abroad have studied the chloride permeability of concrete under the single action of chloride salt, carbonization or load. A sample of listing are provided for journal paper [3], [4] and [5] studied the chloride permeability of concrete under load, which showed that chloride permeability of concrete are different by forms of load. References [6] and [7] studied the effect of carbonation on the permeability of concrete and found that carbonization reduced the permeability coefficient of chloride. However, due to the various loads and complex environments in the actual service process, the chloride transport model in concrete under the single factor are not satisfied the prediction and evaluation of structural durability. This paper uses the self-made flexural-tensile device to test the electric flux of concrete specimens under carbonization and flexural-tensile load by means of experimental means, and establishes the relationship between concrete carbonization time and chloride permeability coefficient. Study the affect the chloride permeability of concrete by coupling with carbonization and flexural-tensile load.

MECHANICAL PROPERTIES TESTS OF CONCRETE MATRIX

Test Mix Proportion of Concrete

This paper design the grade C30 concrete, a total of 24(4×2×3) specimens were produced by the standard test method [8], in which 4 represents the test scheme of concrete mix proportion, 2 represents the methods of compression and flexural tests, and 3 represents specimens in each group test. The specimens used in the compression strength test are 150mm × 150mm × 150mm. The flexural strength test specimen is a prismatic specimen of 150mm × 150mm × 550mm. Through integrated into account the compressive and flexural strength, economic rationality, and durability, the ordinary Portland cement (P.O 42.5) was used in the test, natural river sand by fineness modulus was 2.58, the water-cement ratio of concrete was 0.52. The mixture ratio of concrete is cement: gravel: sand: water = 1: 3.20: 1.72: 0.52. The average value of compression strength and flexural strength of concrete are 41.1MPa and 5.41MPa, respectively.
Coupling Test of Carbonization and Flexural-Tensile Load

![Molding specimens](image)

![Device schematic diagram](image)

Figure 1. Test of flexural-tensile loading.

The coupling tests with carbonization and flexural-tensile load were carried out by standard test method [9]. The test specimens of flexural-tensile load with a size of 300 mm × 50 mm × 100 mm were divided into 21 groups, as shown in Figure 1. The carbonation depth test mainly selects the middle area of the concrete specimen, so it is not sealed. The 3 specimens were used to determine the ultimate bending strength of concrete, results shown that average ultimate flexural-tensile strength for 28 days is 11.03kN. That another 18 specimens were loaded flexural-tensile at 0, 0.3, and 0.6 times of the ultimate flexural-tensile strength, respectively. That is to say, the torque load for concrete specimens is 0, 3.15N·m and 6.29N·m, respectively. The self-made flexural-tensile loading device is based on the three-point bending self-anchoring loading principle. The torque is tightened by the torque wrench to tighten the nut at both ends of the bolted rod to make the bolt with the pulling force, and the torque value required for the torque control is preset by the torque wrench. In order to reduce the looseness of the nut during the handling of the test piece, this test uses a double-nut anchor bolt to prevent it. In addition, the test piece can be placed in a normal carbonization box for rapid carbonization test while being continuously loaded, and can be subjected to rapid chloride penetration test after carbonization. The schematic diagram of flexural-tensile device is shown in Figure 1.

**CHLORIDE PENETRATION OF CONCRETE UNDER MULTIFACTOR COUPLING**

**Effect of Concrete Carbonation Time on Carbonation Depth**

In order to study the chloride permeability of concrete under different load levels and carbonization times. The self-made flexural-tensile device was used to apply
torques of 0, 3.15N·m and 6.29N·m to the concrete specimens for 28 days, and then the test specimens were placed in a carbonization test chamber for accelerated carbonization test. The carbonization depth of the test piece was measured by a phenolphthalein coloring method. After the concrete specimens were loaded, put them into the HTX-12X microcomputer concrete carbonization box. The concrete carbonization box maintains a CO2 concentration of (20±3) %, a relative humidity of (70±5) %, a temperature of (20±2) ℃, and the carbonization depth of concrete specimens with the carbonization times of 0, 3d, 7d, 14d, 28d and 56d were measured by phenolphthalein coloring method. The concrete carbonization depth measured by the test is shown in Figure 2.

It can be seen from Figure 2 that the concrete carbonization depth increases with the increase of the flexural-tensile load, it is indicated that the flexural-tensile load has weakened the carbonation resistance of the concrete. Accelerated carbonized concrete specimens can reach full carbonization in about 28 days. Therefore, for the carbonization time 0~28 days corresponds to carbonization depth of concrete, least square estimation approach is adopted to fit the parameters in Eqs. (1) and (2). The fitting results are shown in TABLE I, and the comparison with the measured results is shown in Figure 3.

\[ X = \alpha \sqrt{T} \]  \hspace{1cm} (1)

Where, \( X \) is the carbonization depth of concrete (mm); \( \alpha \) is the coefficient; \( T \) is the carbonization time of concrete (d).

\[ X = X_0 + a \cdot \exp \left( -\frac{T}{b} \right) \]  \hspace{1cm} (2)

Where, \( X_0 \) is the carbonization depth corresponding to the complete carbonization of concrete (mm); \( a \) and \( b \) are the carbonization coefficient.
### Table I. Fitting Parameters of Concrete Carbonation Depth.

<table>
<thead>
<tr>
<th>$T/\text{N} \cdot \text{m}$</th>
<th>$a$</th>
<th>$r$</th>
<th>$X_0$</th>
<th>$a$</th>
<th>$b$</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.627</td>
<td>0.9970</td>
<td>27.86</td>
<td>-27.35</td>
<td>13.26</td>
<td>0.9982</td>
</tr>
<tr>
<td>3.15</td>
<td>5.613</td>
<td>0.9521</td>
<td>28.43</td>
<td>-28.22</td>
<td>8.21</td>
<td>0.9813</td>
</tr>
<tr>
<td>6.29</td>
<td>6.202</td>
<td>0.8983</td>
<td>27.82</td>
<td>-27.60</td>
<td>5.02</td>
<td>0.9833</td>
</tr>
</tbody>
</table>

Figure 3. Fitting curve of concrete carbonation depth with time.

It can be seen from Figure 3 that the early stage of concrete carbonation develops faster and the later stage is slower; the exponential carbonization model of Eq. (2) can better reflect the carbonation law of concrete.

### Permeability Coefficient of Concrete Chloride under Multifactor Coupling

This paper uses the electric flux method to determine the chloride content of concrete, that is to say, the negatively charged chlorides in the solution can quickly move through the pre-vacuum-saturated concrete under the action of an external electric field to positive electrode direction, and the electric flux $Q$ passing through a certain period of time is measured. During the test, NaCl solution having a mass concentration of 3.0% was injected into the negative electrode tank, and a positive electrode tank was injected with NaOH solution having a concentration of 0.3 mol/L, and a direct current constant voltage of $(60 \pm 0.1)$ V was applied. The current data is automatically collected every 5 minutes. The electric flux $Q$ with the carbonation times of 0, 3d, 7d, 14d, 28d and 56d was determined, shown in Table II.

### Table II. Electric Flux of Concrete in Different Carbonation and Loading.

<table>
<thead>
<tr>
<th>$T/\text{N} \cdot \text{m}$</th>
<th>0</th>
<th>0.3</th>
<th>0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Flux Time/d</td>
<td>$Q/C$</td>
<td>$D/10^7 \text{cm}^2/\text{s}$</td>
<td>$Q/C$</td>
</tr>
<tr>
<td>0</td>
<td>2827</td>
<td>0.1649</td>
<td>2956</td>
</tr>
<tr>
<td>7</td>
<td>2529</td>
<td>0.1502</td>
<td>2465</td>
</tr>
<tr>
<td>14</td>
<td>2038</td>
<td>0.1261</td>
<td>2006</td>
</tr>
<tr>
<td>28</td>
<td>2233</td>
<td>0.1356</td>
<td>2364</td>
</tr>
<tr>
<td>56</td>
<td>2707</td>
<td>0.1590</td>
<td>2866</td>
</tr>
</tbody>
</table>
The relationship between the coefficient of chloride permeability of concrete and the electric flux is seen in Eq. (3) by reference [10].

\[ D = 2.57765 + 0.00492Q \]  \hspace{1cm} (3)

Where, \( Q \) is the electric flux through concrete (C); \( D \) is the coefficient of chloride permeability of concrete, accurate to 0.1×10^{-7} cm²/s.

The chloride coefficient of concrete under multifactor coupling is calculated by least squares method. The chloride permeability coefficient and the carbonization time of the concrete change in a cubic polynomial law and the flexural-tensile load increases, the law of change becomes more obvious, as shown in Figure 4.

Figure 4 summaries that: (1) the concrete carbonization time is 0~14 days, and its chloride permeability coefficient shows a sharp downward trend. The reason is that the early carbonization of the concrete produces CaCO₃, so that the voids and micro-cracks inside the concrete are filled, and chlorides are adsorbed to form Friedel's salt. (2) After 14 days of concrete carbonization time, the chloride permeability coefficient gradually increases due to the decomposition and carbonization of some Friedel's salts, and the load causes the internal pores and micro-cracks of the concrete to be further aggravated.

**CONCLUSIONS**

(1) The carbonation depth and carbonization time of the concrete change exponentially before it reaches full carbonization.

(2) When the flexural-tensile load ratio is 0, 0.3 and 0.6, the concrete carbonization time is 14 days, the flexural-tensile load has a great influence on the concrete carbonation depth, and the carbonization rate increases rapidly with the increase of the load ratio.

(3) Under the coupling of carbonization and flexural-tensile load, the chloride permeability coefficient and carbonization time of concrete show a cubic polynomial law, and the variation law becomes more obvious with the increase of flexural-tensile load.
(4) Under the coupling of carbonization and flexural-tensile load, if the concrete carbonization time is 28~56 days, whether the penetration coefficient will still have an inflection point still needs further experimental research.

REFERENCES