Salt Spray Testing on the Chloride Resistance of Jointed Concrete

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Abstract
Joints existing in segmental precast and pouring constructions have poorer performance than the monolithic parts in concrete structures, of which the mechanical behaviors have been studied by many researchers. However, studies related to the durability of concrete rarely focus on joints. The purpose of this study is to compare the chloride resistances between joints and the monolithic parts. Concrete structures are generally under a certain stress state, so unstressed specimens and specimens under compressive and tensile stresses were prepared. Salt spray tests on specimens with different stress states and different joint types were conducted. Based on the test results of chloride profiles, the chloride resistances of the specimens under different stress states were compared. The results indicate that the monolithic part has a better chloride resistance than the joint, no matter what the stress state is. Moreover, the chloride resistances of the different joints also differ greatly.

Keywords: wet joint; epoxied joint; roughened joint; stress state; chloride diffusion coefficient

1. Introduction
Chloride ingress is one of the main factors that lead to the durability deterioration of concrete structures. Chloride attack results in the depassivation of the reinforcing steel bars that are originally protected by the alkaline environment of the concrete. Steel corrosion leads to section loss and strength degradation of the steel bars. Meanwhile, steel rust expansion also results in cracking and spalling of the concrete cover (Zhang et al., 2010), eventually reducing the service life of concrete structures.

Because concrete is a porous material, the rate of chloride penetration is closely related to the state of the pores, which is influenced by the mix proportions (Shi, 2004), curing time (Ghanem et al., 2008; Hillier et al., 2000), saturation, supplementary cementing materials (Papadakis, 2000; Leng et al., 2000), etc. Moreover, Jau and Tsay (1998) indicated that the pore volume decreased as the concrete age increased, which means that the chloride diffusion coefficient of concrete gradually decreased with time. Mangat and Molloy (1994) considered the variation of the diffusion coefficient with time, and a good model was given to predict the long-term diffusion of chloride into concrete.

In addition, concrete structures usually work with cracks or under tensile stress. Most researchers (Djerbi et al., 2008; Boulfiza et al., 2003; Konin et al., 1998) believe that cracks or tensile stress accelerates the chloride transport process in concrete. Moreover, the influence of compressive stress on the chloride penetration process was also studied (Satio and Ishimori, 1995; Samaha and Hover, 1992; Zhang et al., 2014). Gowripalan et al. (2000) pointed out that proper compressive stress slows down the chloride penetration process. However, Samaha and Hover (1992) reported that low compressive loads had very little influence on the chloride penetration process and that an obvious influence appeared only when the load exceeded 75% of the peak value. Studies (Hoseini et al., 2009; Kermani, 1991) on the permeability of concrete also show that a threshold value for a rapid increase in the permeability of concrete with the increase of compressive stress exists. The threshold value varies from approximately 30% to approximately 80% of the ultimate strength according to different studies.

Joints widely exist in segmental precast and pouring constructions. In segmental concrete bridges, the wet joint, epoxied joint and dry joint are commonly adopted. The wet and epoxied joints have better durability performance, so they are recommended for adoption in aggressive environments rather than the dry joint. Moreover, the joint surface of a wet joint may be roughened to make the joint surface tighter. To understand the chloride resistances of the above joints (wet joint, roughened joint and epoxied joint), the corresponding specimens were cast and the salt spray

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tests were carried out on the stressed and unstressed specimens. The influence of the stress state and joint type on the chloride resistance was studied based on the data analysis of the measured chloride profiles.

2. Experimental Program

2.1 Preparation of the Specimens

Two types of concrete, C40 and C60, were used in the test. Their cubic compressive strengths are 40 and 60 MPa, respectively. In order to produce the two types of concrete, two types of ordinary Portland cement with the strength grades of 32.5 and 52.5 MPa were used for C40 and C60 concrete, respectively. The cement used for C60 concrete had a higher strength grade, which made the compressive strength of C60 concrete higher than C40 concrete. River sand was used as fine aggregate. The course aggregate was crushed limestone with one continuous gradation, and the grain size was in the range of 5 to 25 mm. No cement replacement materials were added to the mix. However, a polycarboxylate superplasticizer was used as the water reducer. Table 1. presents the detailed mix proportions of the concrete. According to Chinese code (MTPRC, 2004), the axial compressive strength $f_{ck}$ and the axial tensile strength $f_{tk}$ of C40 concrete are 26.8 MPa and 2.40 MPa, respectively, while the values of C60 concrete are 38.5 MPa and 2.85 MPa, respectively.

Unstressed specimens and specimens under axial compression, axial tension and flexural tension were studied in the test, as shown in Fig.1. The sizes of an axial compression specimen and an unstressed specimen were roughly the same (100 × 100 × 900 mm$^3$), while a circular hole (Φ32 mm) was made in the middle of the axial compression specimen for the tensioning of the prestressing tendon. The total length of an axial tension specimen was 1300 mm, with two screw sleeves set at the ends of the specimen. Two flexural tension specimens were set as a pair, and the size of each specimen was 100 × 100 × 400 mm$^3$, with two circular holes (Φ26 mm) reserved to apply the bending moment.

The flexural tension specimens were integrally cast, while the other specimens were segmentally cast. The casting processes of the specimens with wet joints (unstressed, axial compression, axial tension) were

![Fig.1. Sizes of the Specimens (unit: mm)](image)

![Fig.2. Casting Methods of the Specimens with Wet Joints](image)
very similar (Fig.2.), and the differences were mainly embodied in the different templates used for different types of specimens. The concreting process of a typical specimen with wet joints was divided into the following processes:

1) The template was made. Compared with the unstressed specimen, the axial compression specimen had an extra plastic pipe. As for the tension specimen, a plastic pipe, four steel bars (Φ8 mm) and two screw sleeves were set;

2) The side segments of the specimen were cast;

3) After two days, the inner templates were removed, and the middle segment was cast;

4) One day later, the specimen was de-molded.

In addition, unstressed specimens with roughened joints and epoxied joints were also cast. The sizes of the specimens with roughened joints and epoxied joints were also 100 × 100 × 900 mm³. For the specimen with roughened joints, the joint surfaces between two segments were roughened to expose the aggregate during the casting process. The specimen with epoxied joints had each segment cast separately and connected by epoxy resin after curing. After the casting process, all specimens were placed into a curing room at 20±2 °C and 95% RH for 28 days.

Low compressive stress has little effect on the chloride penetration process; thus, a proper stress of 0.5f₅ₙ was used for the axial compression specimens. Furthermore, this stress state is also the maximum compressive stress allowed for the normal use of prestressed concrete structures. Generally, the tensile stress does not exceed the tensile strength for prestressed concrete structures, so three levels of tensile stresses (0.3fₜₖ, 0.5fₜₖ and 0.7fₜₖ) were applied to the tension specimens in the test. Details of all the specimens are given in Table 2. In the "Type" column of the table, U, AC, AT and FT represent unstressed, axial compression, axial tension and flexural tension, respectively.

Table 2. Details of the Specimens

<table>
<thead>
<tr>
<th>Group</th>
<th>Item</th>
<th>Type</th>
<th>Concrete</th>
<th>Stress level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A1</td>
<td>U</td>
<td>C40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>U</td>
<td>C60</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>B1</td>
<td>AC</td>
<td>C40</td>
<td>0.5f₅ₙ</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>AC</td>
<td>C60</td>
<td>0.5f₅ₙ</td>
</tr>
<tr>
<td>C</td>
<td>C1</td>
<td>AT</td>
<td>C40</td>
<td>0.3fₜₖ</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>AT</td>
<td>C40</td>
<td>0.5fₜₖ</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>AT</td>
<td>C40</td>
<td>0.7fₜₖ</td>
</tr>
<tr>
<td>D</td>
<td>D1</td>
<td>FT</td>
<td>C40</td>
<td>0.3fₜₖ</td>
</tr>
<tr>
<td></td>
<td>D2</td>
<td>FT</td>
<td>C40</td>
<td>0.5fₜₖ</td>
</tr>
<tr>
<td></td>
<td>D3</td>
<td>FT</td>
<td>C40</td>
<td>0.7fₜₖ</td>
</tr>
<tr>
<td>E</td>
<td>E1</td>
<td>Roughened</td>
<td>C40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E2</td>
<td>Epoxied</td>
<td>C40</td>
<td></td>
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<tr>
<td></td>
<td>E3</td>
<td>Roughened</td>
<td>C60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E4</td>
<td>Epoxied</td>
<td>C60</td>
<td></td>
</tr>
</tbody>
</table>

2.2 Loading Methods

It was a key problem to produce the required stresses, and different loading methods were adopted to apply loads on different types of specimens. During the loading process, strain sensors were used to identify different stress levels. The loading methods are shown in Fig.3.

Fig.3.(a) shows the loading method of an axial compression specimen. Compressive stress was applied to the axial compression specimen by stretching a prestressing tendon. After installation of the loading device, tensile stress was applied to the tendon by a hydraulic jack. The jacking force and the sensor output were both recorded during the stretching process to ensure the accuracy of the applied stress.

Fig.3.(b) shows the loading method of an axial tension specimen. Tensile stress was applied to the axial tension specimen by compressing two prestressing tendons. First, two tendons were put into the hole of the specimen, and one was fixed by the pre-buried screw sleeve at one end of the specimen when the two tendons touched. Then, the tendon at the other end was tightened by a spanner to compress the tendons, which in turn made the specimen under tension. The value of the strain tensor was recorded during this process until the desired value was obtained.

Fig.3.(c) shows the loading method of a pair of flexural tension specimens. Two back-to-back specimens were loaded together to apply flexural stress on the specimens. First, the end without the spring was fixed. Then, the spring was compressed while the value of the strain tensor was recorded. Finally, the screw cap was tightened when the desired stress was obtained.

2.3 Salt Spray Tests

The salt spray tests were conducted in a salt spray chamber, where a 5% NaCl solution was atomized by means of a nozzle. The specimen surfaces were
smoothed by a polisher after loading and sealed with epoxy resin, leaving only one surface uncovered to ensure the one-dimensional chloride diffusion. The chamber temperature was kept at 35±5 °C by a heater to accelerate the chloride penetration process. The specimens were removed from the salt spray chamber after 40 days. They were kept at room temperature for 1 day before unloading. The exposure surfaces of the specimens were smoothed by 0.5 mm to eliminate the effect of surface salt. Concrete samples at different depths (0~3, 3~8, 8~13, 13~18, 18~23, 23~28 and 28~33 mm) were obtained by drilling and sampling perpendicular to the exposure surface. All samples were ground into powders and bagged for further chloride content determination. The chloride contents of the samples were determined by the chloride extraction liquid, and the standard process is described as follows:

1. The sample powders were put into the oven at 105±5 °C for 2 hours and then cooled to room temperature in a dryer. Then, samples of 1.5±0.001 g were taken by an analytical balance;
2. The samples were mixed with the extraction liquid (10 ml) in a special bottle and stirred for 5 minutes;
3. The bottle was incubated for 24 hours to ensure full dissolution of chloride ions;
4. Three concentrations of standard NaCl solutions were prepared, and their solution voltages were measured. The relation between the solution voltage and the concentration of standard solution was plotted as the calibration curve;
5. The voltage of the sample solution was measured, and the chloride concentration was finally determined by the calibration curve.

### 3. Results and Discussion
#### 3.1 Results of the Chloride Concentrations
From the test results of the powder samples, the chloride concentration (percentage of the total concrete mass) profiles of the specimens were obtained, which are shown in Fig.4. To compare the chloride concentrations of different specimens, the average chloride concentrations were also calculated by the following equation:

\[
C_a = \frac{\sum_{i=1}^{7} C_i h_i}{\sum_{i=1}^{7} h_i}
\]

where \(C_a\) is the average chloride concentration, and \(C_i\) and \(h_i\) represent the measured chloride concentration and the sampling thickness at the \(i\)th sampling depth, respectively.

Fig.4.(a) and Fig.4.(b) show the chloride concentration profiles of the unstressed specimens and axial compression specimens with wet joints, respectively. Compared with those at the monolithic parts, the average chloride concentrations at the joints increase by 24.65% and 28.31% for A1 and A2, respectively. However, the average chloride concentration at the joint only increases by 13.73% for B1 and decreases by 9.40% for B2. The results imply that compressive stress reduced the difference in chloride concentrations between the joints and the monolithic parts.

The chloride concentration profiles of the axial tension specimens with wet joints are shown in Fig.4.(c). An increase in chloride concentration with the increase in stress level at both the monolithic part and the joint is observed. Moreover, the average chloride concentrations at the joints are significantly higher than those of the monolithic parts. Compared with those at the monolithic parts, the average chloride concentrations at the joints increase by 34.19%, 37.67% and 41.26% for C1 (0.3f_ck), C2 (0.5f_ck) and C3 (0.7f_ck), respectively. At sampling depths of 13~18, 18~23, 23~28 and 28~33 mm, the chloride concentrations at the monolithic parts are close to 0, while those at the joints are still approximately 0.1%. This case implies that micro cracks mainly appeared and propagated inside the joint rather than in the monolithic part when tensile stress was applied to the specimen.

The chloride concentration profiles of the flexural tension specimens are plotted in Fig.4.(d). For the flexural tension specimens, an increase in tensile stress results in an increase in the chloride concentration, which is the same as that found in the axial tension specimens. However, the chloride concentrations of the flexural tension specimens are much lower than those of the axial tension specimens. The average chloride concentrations of the flexural tension specimens are only 57.54%, 76.31% and 83.31% of the axial tension specimens at three stress levels of 0.3f_ck, 0.5f_ck and 0.7f_ck, respectively. These results occur because the lateral faces of the flexural tension specimens were exposed to the salt fog, while the top faces of the axial tension specimens were exposed to the salt fog. Therefore, it was easier for the chloride ions to condense on the faces of the axial tension specimens, which resulted in higher chloride contents. Only the surface stress of a flexural tension specimen reached the designed stress, while the tensile stresses at different depths of an axial tension specimen remained relatively equal. Thus, the influence of tensile stress on the flexural tension specimens was smaller.

The test results of the specimens with roughened joints and epoxied joints are shown in Fig.4.(e). The average chloride concentration of the epoxied joint is higher than the roughened joint, regardless of the concrete grade. Moreover, the average chloride concentration of C40 concrete (E1 and E2) is higher than C60 concrete (E3 and E4) when the joint type is the same. For the roughened joint and the epoxied joint, the values of C60 concrete are only 85.78% and 93.19% of C40 concrete, respectively.
3.2 Calculation of the Diffusion Parameters

One-dimensional diffusion was assumed during the test. According to Fick’s second law, the diffusion process is given by the following expression:

\[ \frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} \]  

(2)

where \( C(x, t) \) is the chloride concentration at depth \( x \) from the surface at time \( t \), and \( D \) is the chloride diffusion coefficient.

The solution of this equation is:

\[ C(x,t) = C_s \left[ 1 - \text{erf} \left( \frac{x}{2 \sqrt{D t}} \right) \right] \]  

(3)

where \( C_s \) is the surface chloride concentration, and \( \text{erf} \) is the error function. For fixed time \( t \) (40 days in the test), Eq. (3) is determined by two parameters \( C_s \) and \( D \).

A nonlinear least squares regression method was used to perform the nonlinear regression analysis of the experimental data. According to the measured chloride concentration versus depth for each group of powder samples, the diffusion parameters were obtained, as listed in Table 3. In the table, MP refers to the monolithic part. The conditions of the specimens were not identical, so the surface chloride concentration \( C_s \) is not constant. However, the average surface chloride concentration is approximately 0.61, and relatively most of the data are close to this value. Different stress states, concrete grades, locations (monolithic part versus joint) and joint types have a great influence on the chloride diffusion coefficient and further affect the chloride resistance of the concrete. The influence of these factors is analyzed in detail below.

Fig. 4. Measured Chloride Concentration Profiles
Table 3. Results of the Chloride Diffusion Parameters

<table>
<thead>
<tr>
<th>Item</th>
<th>Position</th>
<th>$C_i$ (%)</th>
<th>$D$ ($10^{-12}$ m$^2$/s)</th>
<th>Item</th>
<th>Position</th>
<th>$C_i$ (%)</th>
<th>$D$ ($10^{-12}$ m$^2$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>MP</td>
<td>0.57</td>
<td>5.97</td>
<td>C2</td>
<td>Joint</td>
<td>0.51</td>
<td>24.85</td>
</tr>
<tr>
<td></td>
<td>Joint</td>
<td>0.65</td>
<td>7.83</td>
<td>C3</td>
<td>MP</td>
<td>0.67</td>
<td>9.18</td>
</tr>
<tr>
<td>A2</td>
<td>MP</td>
<td>0.68</td>
<td>5.76</td>
<td></td>
<td>Joint</td>
<td>0.53</td>
<td>27.48</td>
</tr>
<tr>
<td></td>
<td>Joint</td>
<td>0.66</td>
<td>9.21</td>
<td>D1</td>
<td>MP</td>
<td>0.38</td>
<td>6.01</td>
</tr>
<tr>
<td>B1</td>
<td>MP</td>
<td>0.62</td>
<td>10.14</td>
<td>D2</td>
<td>MP</td>
<td>0.51</td>
<td>7.46</td>
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<tr>
<td></td>
<td>Joint</td>
<td>0.69</td>
<td>11.52</td>
<td>D3</td>
<td>MP</td>
<td>0.58</td>
<td>7.76</td>
</tr>
<tr>
<td>B2</td>
<td>MP</td>
<td>0.71</td>
<td>7.10</td>
<td></td>
<td>E1 Joint</td>
<td>0.58</td>
<td>10.18</td>
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<tr>
<td></td>
<td>Joint</td>
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<td>7.34</td>
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<td>Joint</td>
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<td>12.79</td>
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<tr>
<td>C1</td>
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<td>7.36</td>
<td>E3</td>
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<td>Joint</td>
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<td>E4</td>
<td>Joint</td>
<td>0.81</td>
<td>7.41</td>
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<td>C2</td>
<td>MP</td>
<td>0.66</td>
<td>8.60</td>
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</tr>
</tbody>
</table>

3.3 Effect of Compressive Stress

The chloride diffusion coefficients of the unstressed specimens (A1, A2) and the axial compression specimens (B1, B2) are compared in Fig.5. The chloride diffusion coefficient at the joint is larger than that of the monolithic part for every specimen. The ratios of the chloride diffusion coefficients between the joints and the monolithic parts of A1, B1, A2 and B2 are 1.31, 1.14, 1.60 and 1.03, respectively. This clearly indicates that the joint has a poorer chloride resistance than the monolithic part. Furthermore, the ratios of the compression specimens are smaller than those of the unstressed specimens, so compressive stress does not worsen the chloride resistance of the joint when compared to the monolithic part.

3.4 Effect of Tensile Stress

The chloride diffusion coefficients of the axial tension specimens and the flexural tension specimens are plotted against the stress level in Fig.6. When tensile stress is applied to the specimens, the chloride diffusion coefficients of the axial tension and the flexural tension specimens both increase with the tensile stress due to micro crack development in the concrete with the tensile stress increase (Konin et al., 1998; Gowripalan et al., 2000).

At the monolithic parts, the chloride diffusion coefficients of the flexural tension specimens are only 81.66%, 86.74% and 84.53% of the axial tension specimens at three stress levels of 0.3$f_{ct}$, 0.5$f_{ct}$ and 0.7$f_{ct}$, respectively. This is because the tensile stresses at different depths of an axial tension specimen are relatively equal, but the stress of a flexural tension specimen decreases with the depth increase. The average stress of a flexural tension specimen is smaller than that of an axial tension specimen under the same stress level, so the diffusion coefficient is smaller.

At the monolithic part, the chloride diffusion coefficient of the unstressed specimen is smaller than that of the compression specimen, regardless of the concrete grade. In fact, micro cracks begin to propagate in the concrete when the compressive stress reaches 20%~30% of the ultimate strength (Zhang et al., 2014). This implies that 0.5$f_{ct}$ is large enough to cause concrete damage and further decrease the chloride resistance of the specimen. However, at the C60 concrete joint, the chloride diffusion coefficient of the unstressed specimen is larger than that of the compressive specimen (comparison between A2 and B2). The chloride diffusion coefficient at the joint of A2 is much larger than expected, which may be caused by the poor bond between the two joint surfaces during the casting process.

Moreover, if the chloride diffusion coefficient at the joint of A2 is not considered, the chloride diffusion coefficient of C60 concrete is smaller than C40 concrete under the same conditions. The chloride resistance of C60 concrete is better than C40 concrete because of the higher compactness.

Fig.5. Chloride Diffusion Coefficients of the Unstressed Specimens and Axial Compression Specimens

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The chloride diffusion coefficients at the joints of the axial tension specimens are extremely high; the values are 2.38, 2.89 and 2.99 times those at the monolithic parts at three stress levels of 0.3$f_{ct}$, 0.5$f_{ct}$ and 0.7$f_{ct}$, respectively. Compared with the unstressed and axial compression specimens, the chloride resistances at the joints of the axial tension specimens are much worse than the monolithic parts. This is likely because the tensile strength of concrete is much lower than its compressive strength. It is much easier for the defect of the joint to develop under tensile stress. Therefore, micro cracks first propagate at the joint rather than the monolithic part when tensile stress is applied to the specimen. The ultimate tensile strength of the joint is smaller than the monolithic part; thus, more serious damage to the joint
than the monolithic part is caused by the same stress. It is not recommended to use jointed concrete under tensile stress in a serious chloride environment.

**3.5 Effect of Joint Type**

To compare the chloride resistances of monolithic concrete and different types of joints, the chloride diffusion coefficients of the specimens in Group A and Group E are plotted in Fig. 7. On average, the chloride diffusion coefficient of C60 concrete is smaller than C40 concrete because of the greater compactness of C60 concrete. No matter what the concrete grade is, the monolithic part has a smaller diffusion coefficient than almost all of the joints. The results are in line with the expectation because more initial defects existing at the joint decrease the chloride resistance of the concrete. When the diffusion coefficients of different types of joints are compared, the results of C40 concrete and C60 concrete are different. For C40 concrete, the wet joint and the epoxied joint have the smallest and largest chloride diffusion coefficients, respectively, while the diffusion coefficient of the roughened joint is in the middle. However, joints of C60 concrete with the smallest and the largest chloride diffusion coefficients are the roughened joint and the wet joint, respectively, while the diffusion coefficient of the epoxied joint is in the middle. In practice, the joint surface is roughened to have a better bond effect between two segments, so the roughened joint is expected to have a smaller diffusion coefficient than the wet joint. However, the result of C40 concrete is not in accord with the expectation. The chloride resistances of the joints may decrease because of various uncertain factors such as the compactness of the epoxy-bond, the concreting quality of the wet joint and the roughened joint, etc.

To analyze quantitatively the effect of the joint on the chloride resistance of concrete, the influence coefficient \( K_{j} \) is defined by the following equation:

\[
K_{j} = \frac{D_{j}}{D_{m}}
\]

where \( D_{j} \) is the chloride diffusion coefficient of the joint, and \( D_{m} \) is the chloride diffusion coefficient of the monolithic part. Based on Eq. (4), the influence coefficients of all of the joints are calculated and presented in Table 4. On average, the influence coefficients of C40 concrete and C60 concrete are 1.72 and 1.29, respectively. Research (Chen and Mahadevan, 2008; Shi et al., 2012) on the durability of concrete structures in chloride environments shows that when the chloride content at the reinforcement bar reaches a threshold value, the corrosion phase of the steel bar begins. After steel corrosion, the structural performance drops rapidly in a very short time because of the steel rust expansion. Based on Eq. (3), if the surface chloride concentrations of the joint and the monolithic part are identical, and the critical moment of the steel corrosion at the monolithic part is 50 years, then averages of only 29.1 years and 38.7 years at the joints for C40 and C60 concrete structures are needed. The durability of the joint is much worse than that of the monolithic part. Moreover, further research on the durability of the joint in other aggressive environments is also needed to predict the service life of concrete structures.

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Wet Joint</th>
<th>Roughened Joint</th>
<th>Epoxied Joint</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>C40</td>
<td>1.31</td>
<td>1.70</td>
<td>2.14</td>
<td>1.72</td>
</tr>
<tr>
<td>C60</td>
<td>1.60</td>
<td>0.99</td>
<td>1.29</td>
<td>1.29</td>
</tr>
</tbody>
</table>

4. Conclusions

Salt spray tests were conducted on specimens with different stress states and different joint types. From the results and discussion, the following conclusions are drawn:

1. At the monolithic parts, the chloride diffusion coefficients of the compressive specimens \((0.5f_{ck})\) are larger than the coefficients of the unstressed specimens. \(0.5f_{ck}\) is large enough to cause the chloride resistance degradation of the specimens, so compressive stress should be considered in the practical durability design of concrete structures in chloride environments. Moreover, the ratios of the chloride diffusion coefficients between the joints and the monolithic parts of the compressive specimens are smaller than those of
the unstressed specimens, so compressive stress does not decrease the chloride resistances of the joints any more than in monolithic parts.

(2) The chloride diffusion coefficient increases with the increase in tensile stress. Compared with that of a flexural tension specimen, the chloride diffusion coefficient of an axial tension specimen is larger at the same stress level. Moreover, the chloride diffusion coefficients at the joints of the axial tension specimens are much larger than those of the monolithic parts. Tensile stress greatly decreases the chloride resistances of the joints, so the joints are not recommended for use in the tension region of concrete structures.

(3) The chloride resistances of the wet joint, roughened joint, and epoxied joint are compared with the value of the monolithic part. Basically, the chloride resistance of the monolithic part is better than the results found in the joints. On average, the chloride diffusion coefficients of the joints are 1.72 and 1.29 times those of the monolithic parts for C40 and C60 concrete, respectively.

(4) The chloride resistance of C60 concrete is better than that of C40 concrete, whether at the joint or the monolithic part, because of the greater compactness of C60 concrete.

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References