Research on Salt Corrosion Resistance Design of Highway Concrete Structures

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Abstract. In response to the problem of salt corrosion on highway concrete structures in high-altitude areas, this article studies the effects of water cement ratio, admixtures, and admixtures on the salt corrosion resistance of concrete through salt freezing cycle tests and salt freezing erosion resistance tests. The results indicate that under the conditions of meeting the workability of concrete, when the water cement ratio is below 0.4, the resistance to salt freezing and erosion is excellent. When the air content of concrete is between 0 and 3.8%, the salt freezing resistance and corrosion resistance of concrete increase with the increase of air content. When the air content exceeds 3.8%, the impact of the increase of air content on its performance decreases. It is advisable to use silica fume as the active mineral admixture for concrete in the admixture. If fly ash or mineral powder is used as the mineral admixture, the curing period must be extended.

Keywords: Road Engineering · Salt Corrosion Resistance · Mineral Incorporation

1 Introduction

In the infrastructure construction of China in recent decades, cement concrete has become the most important building material in the world due to its low cost, easy to obtain materials locally, and good integrity and modelability [1, 2]. Small concrete components of road ancillary facilities such as curbs and anti-collision piers also use this material. This type of component does not withstand large loads such as vehicles, and therefore does not generate significant internal forces. Therefore, high-strength concrete is not required. However, due to the damage caused by freeze-thaw, salt corrosion, and other conditions, the surface peeling and other diseases of hydraulic concrete occur prematurely, resulting in a short service life and poor durability, resulting in an astonishing frequency of replacement of curbstones [3, 4]. Especially in high-altitude areas, during winter snowfall or freezing weather, deicing salt is usually sprayed for fast and open traffic. Coupled with factors such as freeze-thaw cycles and ultraviolet radiation, roadside structures are particularly corroded, and their appearance and functionality are far from reaching their lifespan [5].

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This article relies on the Sichuan Jiuma Expressway project, which is located in a high altitude area (over 3000 m) with a minimum temperature of −26.6 °C, an average annual temperature difference of 52.1 °C, and an average annual freeze-thaw cycle of 118 times. The concrete structure undergoes significant seasonal freeze-thaw cycles, with frequent alternations of positive and negative temperatures not only accelerating the freeze-thaw failure of concrete, but also leading to the superposition of freeze-thaw and shrinkage cracking damage, Further leading to difficulty in ensuring strength and durability. The article studies the effects of concrete water cement ratio, admixtures, and admixtures on the interface structure and pore structure of concrete, studies better corrosion resistance design of concrete, enhances its service life, and reduces later maintenance costs.

2 Raw Materials and Testing

2.1 Raw Materials

PO 42.5 cement is selected, and its technical performance is shown in Table 1.

Table 1. Physical and Mechanical Properties of Cement

project	Specific surface area m^2/kg	Standard consistency %	stability	setting time (min)		flexural tensile strength (MPa)		compressive strength (MPa)	
				Initial setting	Final set	3d	28d	3d	28d
Specification requirements	-	-		≥90	≤600	≥4.5	≥7.5	≥17	≥42.5
cement	353	27.6	合格	209	267	6.5	9.4	36.1	54.8

The fine aggregate is river sand, with a fineness modulus of 2.87 and a silt content of 0.9%. Which meets the requirements of Zone II grading in the national standard “Building Sand” (GB/T 14684-2001).

The coarse aggregate is 4.75–26.5 mm continuously graded limestone crushed ston.

Water reducing agent JG-2 is a high-efficiency water reducing agent, and the air entraining agent is a triterpenoid saponin air entraining agent.

The Class I fly ash used in the fly ash test meets the requirements of Class I fly ash. The physical properties and chemical composition of Class I fly ash are shown in Tables 2 and 3. The physical performance indicators of silicon powder are shown in Table 4.

2.2 Test Methods

According to the requirements of GB/T50080-2002 “Standard for Testing the Performance of Ordinary Concrete Mixtures” for air content testing, a direct reading air content tester is used for measurement.

This article considers the dual effects of plateau climate and deicing salt environment, and designs an indoor accelerated test (salt freezing test) for the coupling effect of

Table 2. Physical properties of fly ash

Density/(g*cm-3)	45um sieve residue/%	Water demand ratio/%	Loss on ignition/%	Moisture content/%	Mass fraction of sulfur trioxide/%
	≤12	≤1.0	≤5.0	≤95	≤3.0
2.8	10.8	0.1	2	94	0.3

Table 3. Chemical Composition of Fly Ash (Unit:%)

w(silica)	w(alumina)	w(iron oxide)	w(calcium oxide)	w(Sulfur Trioxide)	w(Potassium oxide)	w(Sodium oxide)	w(magnesium oxide)
52.54	33.62	7.05	3.56	0.68	0.5	0.31	0.36

Table 4. Physical Properties of Silicon Powder

45umsieve residue/%	Specific surface area/(m^2/kg)	activity index/%	loss on ignition/%	moisture content/%	silicon dioxide mass fraction/%
1	18000	121	1.6	0.7	92

corrosive salt and freeze-thaw cycles. At present, there are significant differences in the preparation of specimens, the contact method of salt solution, the selection of salt solution concentration, the setting of freeze-thaw system, and the evaluation parameters of salt freezing and erosion damage between domestic and foreign concrete salt freezing test methods. By comparing and studying domestic and international standards, it is summarized that there are several main ways of contact between specimens and salt solutions: (1) specimens are completely immersed in salt solutions for salt freezing cycles, such as the test specifications for harbor concrete; (2) The test piece was immersed in a salt solution for 4–6 mm on one side for salt freezing cycle testing. For example, the CDF test method was proposed by the TC117-FDC Professional Committee of the European International Federation of Materials Testing Laboratories (RILEM); (3) The surface of the test piece is covered with a 4-6mm thick salt solution for salt freezing cycle testing, such as the Swedish SS137244 (Boras) method and the American ASTM C672 method.

Considering the objective and reasonable simulation of the destructive effect of deicing salt on concrete structures, as well as the simple, accurate, and easy operation method, the salt freezing cycle test was carried out by immersing the specimen in a salt solution for 4–6 mm on one side. The specific schematic diagram and equipment are shown in Fig. 1. The solution is a 4% NaCl salt solution, and the computer control system can control the limit temperature (+20 °C ~ −40 °C) and the rate of temperature rise and fall (cooling rate greater than 10 °C/h) inside the chamber. At the same time, corresponding software is used to automatically collect the temperature of the test chamber and the surface of the specimen. Each freeze-thaw cycle of the specimen is 6 h, and the frozen specimen is 3.5 h. The melting time is 2.5 h, which means 4 cycles per day. The time required for the specimen to decrease from 15 °C to −20 °C shall not exceed 2 h, and the time required for −20 °C to rise to 15 °C shall not exceed 1.5 h. After freeze-thaw of the specimen, ultrasonic cleaning is used.

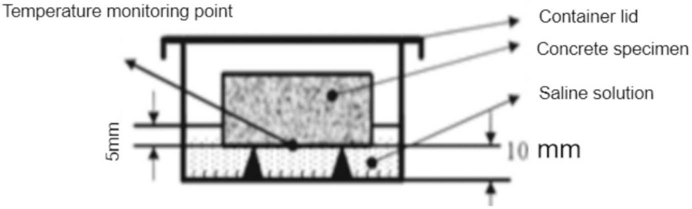


Fig. 1. Schematic diagram and equipment of salt freezing test method

The formed surface of highway concrete structures determines the key factor in their corrosion resistance. In order to better simulate and reflect the salt frost resistance characteristics of the road surface, this article chooses the formed surface as the salt frost test surface. At the same time, in order to reduce the boundary effect of the specimen during the salt freezing process, the test area of the specimen was appropriately enlarged during the testing process. The forming method and method of the test specimen are shown in Fig. 2. Place the newly mixed concrete into a trial mold (with a wooden bottom mold) made of PVC pipes with an inner diameter of 250 mm and a length of 75 mm, vibrate and compact it on a concrete vibration table, and treat the formed surface of the concrete with a wooden trowel. After 24 h, remove the wooden bottom mold and place the PVC material test mold and concrete together in the standard curing room for standard curing.

Fig. 2. Forming Method of Salt Frozen Specimens

3 Research on the Mix Design of Salt Resistant Cement Concrete

The water cement ratio is the most important parameter in concrete mix design. It directly affects the porosity and pore structure inside the concrete, and is an important parameter for measuring the compactness and permeability of concrete. It largely determines the strength and long-term durability of concrete. Five different water cement ratios were compared. Due to the fact that the main cause of concrete salt freezing and peeling is cement slurry, the mix design was based on a fixed volume of cement slurry. Five levels of water cement ratios, namely 0.36, 0.40, 0.44, 0.48, and 0.52, were used. After 28 days of curing, the salt freezing cycle test was conducted in a salt freezing testing machine, and the results are shown in Fig. 3.

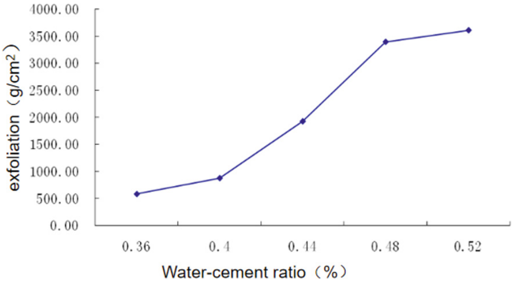


Fig. 3. Effect of water cement ratio on the resistance of concrete to salt freezing and erosion

From Fig. 3, it can be seen that as the water cement ratio gradually increases, the amount of concrete peeling gradually increases, and the salt frost resistance gradually decreases. When the water cement ratio is greater than 0.4, the resistance of concrete to salt freezing and erosion exceeds 1000 g/m^2, which exceeds the recognized and acceptable requirements for salt freezing damage. Therefore, in environments with salt freezing damage, such as non aerated concrete, it is recommended to control the water cement ratio of concrete below 0.4 in order to prevent salt freezing and erosion damage.

The slurry to aggregate ratio mainly affects the workability of concrete, which in turn affects its durability, and to a certain extent also affects its strength, elastic modulus, and dry shrinkage. Usually, in order to ensure the workability of concrete, a large amount of cementitious material is required. But as the slurry to aggregate ratio increases, the elastic modulus of concrete will decrease and the shrinkage of concrete will also increase. At the same time, due to the fact that the salt freezing damage of concrete is mainly caused by surface erosion, and the slurry content directly determines the amount (or degree) of concrete erosion, the slurry to aggregate ratio of concrete also greatly affects the salt freezing resistance of concrete. In order to ensure that concrete has good workability and excellent resistance to salt freezing and erosion, a reasonable range of slurry to aggregate ratio should be selected during mix design. The test results are shown in Fig. 4.

From Fig. 4, it can be seen that when the slurry to aggregate ratio fluctuates within the range of 258.6:741.4–287.4–712.6, there is an optimal range for the concrete's salt frost resistance performance as the slurry to aggregate ratio changes. That is, when the slurry to aggregate ratio is within the range of 265.8:734.2–280.2:719.8, the concrete's

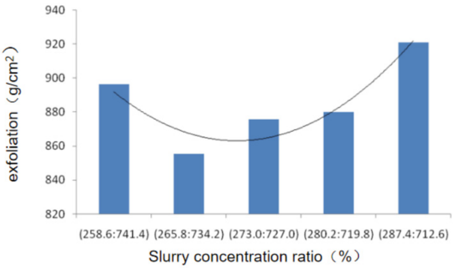


Fig. 4. Effect of Slurry to Aggregate Ratio on the Resistance of Concrete to Salt Freezing and Erosion

salt frost resistance performance is better. When the slurry to aggregate ratio exceeds this range, the amount of concrete peeling under salt freezing conditions increases due to the increase in slurry content in the concrete. When it falls below this range, it may be due to the low content of slurry in the concrete, resulting in a decrease in the compactness of the concrete and a slight increase in the amount of salt freezing and erosion of the concrete. However, the fluctuation of the slurry to aggregate ratio leads to a much smaller amplitude of change in the salt freezing and erosion damage of concrete compared to the fluctuation caused by changes in the water cement ratio. Therefore, it can be seen from the law of the influence of changes in the slurry to aggregate ratio on salt freezing and peeling damage that in order to improve the salt freezing and peeling resistance of concrete, the optimal range of slurry to aggregate ratio for concrete should be selected between 265:745 and 280:720.

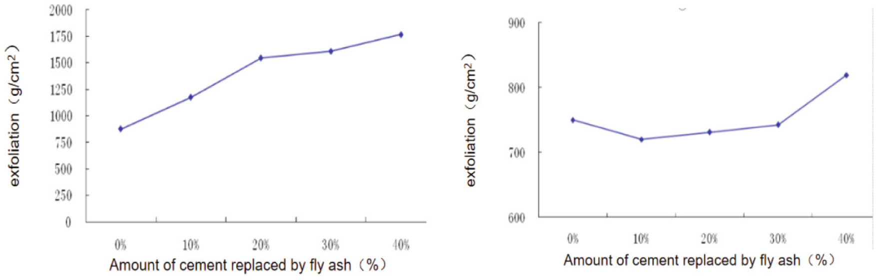
4 Research on the Influence of Admixtures on the Salt Corrosion Resistance of Concrete Surface

With the development of cement concrete technology, the addition of mineral admixtures in cement concrete is receiving increasing attention. The application of mineral admixtures can improve many properties of concrete and is also an important component material of green concrete in the 21st century.

4.1 Fly Ash

With the increasingly widespread application of fly ash in concrete, especially in the harsh climate and environment areas of northern China, the salt freezing durability of fly ash concrete has received widespread attention as an important indicator of concrete. The test results are shown in Fig. 5.

From Fig. 5, it can be seen that under the standard curing condition of fly ash concrete for 28 days, the salt freezing resistance of the concrete gradually decreases with the increase of fly ash content. The main reason may be that the activity of fly ash was not fully utilized in the early stage. When the replacement amount of fly ash is large, the strength of fly ash concrete is lower, the porosity is higher, and the salt freezing resistance of fly ash concrete is slightly worse. But when the concrete is cured



28d 180d

Fig. 5. Effect of fly ash content on the salt freezing resistance of concrete

to the age of 180 days, due to the sufficient secondary hydration of fly ash, the hardening structure of fly ash concrete is more dense, and the salt freezing resistance of fly ash concrete is significantly improved. Therefore, in the presence of salt freezing conditions, it is advisable to avoid using fly ash as a mineral admixture. If fly ash is added to the concrete, maintenance should be strengthened to ensure that the fly ash is fully hydrated.

4.2 Granulated Blast Furnace Slag Powder

Granulated blast furnace slag powder is a glassy substance formed by rapid cooling of blast furnace molten material. Its main components are calcium oxide, silicon oxide, and aluminum oxide, with a total content of about 95% or more. It has high activity and can generate hydraulic cementitious substances in the presence of an activator. The test results are shown in Fig. 6.

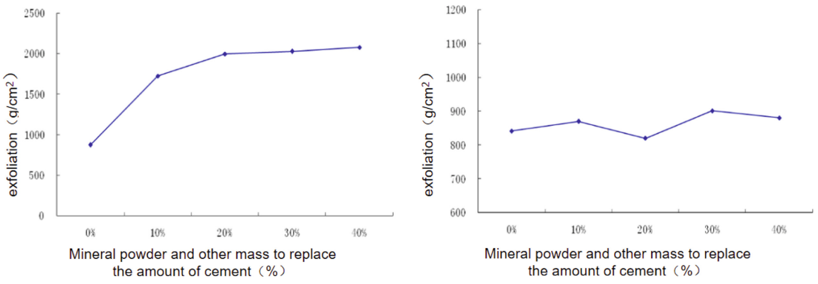


Fig. 6. Effect of Mineral Powder Content on the Salt Freezing Resistance of Concrete

From Fig. 6, it can be seen that the salt freezing resistance of mineral powder concrete is basically the same as that of fly ash. Under the 28 day standard curing test of mineral powder concrete, the salt freezing resistance of concrete gradually decreases with the increase of mineral powder content. When the concrete is cured to 180 days, the salt freezing resistance of mineral powder concrete is basically the same as that of the reference concrete.

4.3 Silica Ash

Silica fume, also known as silica micro powder, also known as micro silica powder or silica ultrafine powder, is generally referred to as silica fume. Silica ash is a ultrafine siliceous powder material formed by the rapid oxidation and condensation of SiO2 and Si gases generated during the smelting of ferrosilicon alloys and industrial silicon with oxygen in the air. The experimental results are shown in Fig. 7.

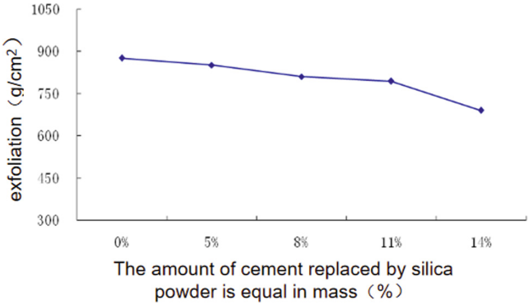


Fig. 7. Effect of silica fume on the salt freezing resistance of concrete

From Fig. 7, it can be seen that as the amount of silica fume gradually increases, the amount of concrete peeling gradually decreases and the salt frost resistance gradually increases. The main reason is that silica fume has a large specific surface area, high activity, and can quickly undergo secondary hydration reactions, improving the compactness of concrete and improving its salt freezing resistance. Therefore, when the road surface concrete requires salt freezing, if mineral admixtures are selected, silica fume should be selected as the active mineral admixture. If fly ash or mineral powder is selected, it is necessary to strengthen maintenance to avoid early damage to the concrete due to salt freezing.

5 Research on the Effect of Air Entraining Agent on the Salt Corrosion Resistance of Concrete Surface

Since the 1950s, foreign countries have generally required the addition of air entraining agents in the preparation of concrete in freeze-thaw environments, thus effectively solving the general problem of frost damage to concrete. In cold regions and concrete pavements that use deicing salts for deicing, air entrained concrete has been widely used to improve the durability of concrete against freezing and thawing. Adding a large number of uniform bubbles to concrete can cut off the pore channels inside the concrete, greatly reducing capillary action and improving impermeability. When water is filled into the capillary pores leading to the surface, the pores in the capillary pore pathway locally expand the capillary pores, which can buffer the ice crystal pressure when water freezes and significantly improve the frost resistance of concrete. The test results are shown in Fig. 8.

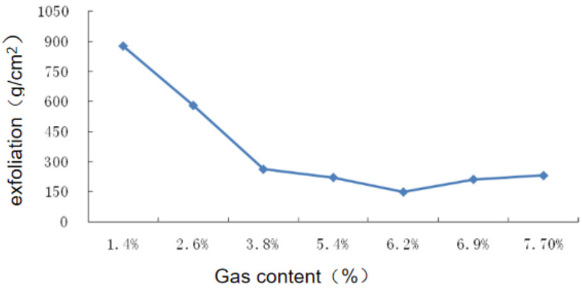


Fig. 8. Effect of Air Content in Concrete on Salt Freezing and Erosion Resistance

From Fig. 8, it can be seen that the introduction of bubbles in concrete can significantly reduce the amount of salt freezing and erosion of concrete, and improve its salt freezing resistance. And with the increase of air content in concrete, the salt frost resistance of concrete further improves. However, when the air content in concrete reaches 3.8%, further increase in air content no longer significantly improves the salt frost erosion resistance of concrete. Therefore, it is recommended to add an air entraining agent and control the air content above 4% when preparing salt frost resistant concrete.

6 Conclusion

(1) When preparing salt frost resistant road surface machine made sand concrete, it is necessary to strictly control the water cement ratio of the concrete, reasonably control the air content of the concrete, and try to choose a lower slurry aggregate ratio under the condition of meeting the workability of the concrete.
(2) When preparing salt frost resistant concrete, it is advisable to use silica fume as the active mineral admixture of the concrete. If fly ash or mineral powder is used as the mineral admixture, the curing period must be extended to prevent the concrete from bearing salt frost erosion damage too early.
(3) When preparing salt frost resistant concrete, when the water cement ratio is below 0.4, the salt frost resistance and peeling performance are excellent; When the air content in concrete is between 0 and 3.8%, the salt frost resistance increases with the increase of air content. When the air content exceeds 3.8%, the continuous increase in air content will no longer significantly improve the salt freezing and peeling resistance of concrete.

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