Study on the effect of ion invasion on compressive strength, resistivity and polarizability of concrete

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Abstract. The structural safety of concrete has been attached great importance, especially in saline-alkali area. In order to better study the changes of physical parameters of concrete after corrosion in saline-alkali area, the soil quality in saline-alkali area was investigated and sampled to analyze the main ionic components of concrete corrosion environment. According to the corrosion ionic components, the concrete model was made by mixing carbonate and sulfate solutions with different concentrations. Resistivity method and induced polarization method were used to measure the resistivity and polarizability characterization of the model within the curing period (28d), and the compressive strength of the concrete model during the curing period was tested to study the correlation between the resistivity, polarizability and compressive strength of the concrete model. The results show that the resistivity, polarizability and compressive strength of concrete are closely related to the type and concentration of ions. There is a corresponding relationship between the polarizability and the bearing capacity of concrete test blocks mixed with the same solution. The larger the polarizability, the weaker the bearing capacity. There is no strong correlation between resistivity and bearing capacity. Polarizability data can reflect both ion invasion and strength change of concrete.

1. Introduction
Concrete building science is important composition of the material, the stability of the concrete due to the strong plasticity, are widely used in engineering construction, in recent years, more and more concrete because salt corrosion by coagulation micro pore structure and surface to the interior structure, produce certain physical and chemical reaction, the bearing capacity of structures, The bearing capacity is not only an important feature of rock and soil mechanics for structures, but also an important reflection in engineering technology. Due to the distribution of salt and alkali in Xinjiang and some areas in northern China and coastal areas, concrete is easily eroded in saline-alkali environment [1]. The erosion methods mainly include the following aspects: ① Direct chemical erosion [2]: It mainly refers to the chemical action of acidic components in the environment on the concrete protective layer. ② Alkali-base reaction. ③ concrete carbonization. ④ freeze-thaw damage [3]. ⑤ Sulfate erosion [4]. Land salinization in China covers a wide area, including the western, central and coastal areas, and the environment of ions in the ocean and saline-alkali areas are also similar. The results of salt-alkali sampling in Xinjiang show that there are a lot of SO₄²⁻, CO₃²⁻ and Cl⁻ ions in the anions, and the cations are mainly Na⁺, K⁺ and Ca²⁺.

Intrusion of ions corrodes concrete, causing corrosion of steel bars inside concrete and affecting concrete strength [5]. The main methods for detecting concrete corrosion and steel corrosion generally

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fall into the following categories: one is damage detection, which aims to observe the corrosion status of concrete by destroying the concrete surface [6]. One is nondestructive testing, mainly using analytical method, electrochemical method and physical analysis method [7].

Damage detection has been gradually replaced by nondestructive detection because of the damage to the concrete members and the damage to the active members. The analysis method is based on the comprehensive analysis of the environment where the concrete object is located, which needs the support of reasonable and reliable model. Electrochemical methods need to consider many factors, accuracy cannot be guaranteed, and data processing time is long [8]. Physical analysis methods, such as resistance probe method and infrared thermal imaging method, mainly reflect the corrosion conditions inside concrete through the changes of physical parameters, such as resistance value, magnetic permeability, resistivity and polarizability [9].

Induced polarization method is mainly used in geological survey [10], which is characterized by the observation of the ratio of the secondary field to the primary field, and can eliminate some interference factors. If used to observe concrete members, the effect of rebar in concrete can be eliminated [11]. The core of this study is whether the polarization can reflect the corrosion of concrete.

The concrete mixed with sodium sulfate and sodium bicarbonate solutions of different concentrations is used to simulate the state of concrete after erosion. In the eroded environment, the resistivity, polarizability and the change of compressive strength of the model test during the curing period are measured. Study the correspondence between parameters.

2. Concrete model

2.1. Matching ratio and raw materials

The proportion is calculated by 394 kg of cement, 185 kg of water, 571 kg of sand and 1250 kg of pebble to a cubic meter. The strength of concrete is C30, the particle size of stones is 5-20mm, the cement is P.O 42.5, and the sand is standard sand. Tap water is used, and the specific ratio is shown in Table 1.

| Group | Solute  | Solute /Kg | Water /Kg | Solution weight /Kg |
|-------|---------|------------|-----------|---------------------|
| 1     | 3%Na₂SO₄ | 0.0915     | 2.9585    | 3.05                |
| 2     | 6%Na₂SO₄ | 0.183      | 2.867     | 3.05                |
| 3     | Purified water | 0  | 3.05 | 3.05                |
| 4     | 3%NaHCO₃ | 0.0915     | 2.9585    | 3.05                |
| 5     | 6%NaHCO₃ | 0.183      | 2.867     | 3.05                |

2.2. Forming and curing of specimen

Pour cement, stone, sand into the mixing pot and stir it dry for 40s (cover of the mixer), then add 80% solution, stir it three times for 40s each time, and slowly pour the remaining solvent into the mixing pot while stirring. Remove the cover of the blender when the solvent is poured in. Close the lid again after pouring. Stir well. After the mixing is completed, the strength parts are formed and the mixture is built into the 100mm×100mm×100mm triple test die. Place the triplet test mold on the shaking table, turn on the magnetic suction, and vibrate for three times in numerical control, 60 seconds each. After forming, the specimens were put into the curing room for natural conservation, covered with wet towels, and moistened with water spray regularly. After 24H, the mold is removed and put into the room for maintenance to be measured.

3. Determination of concrete physical property parameters

3.1. Resistivity and polarizability test

The four-electrode method was used, the electrodes were uniformly arranged, and the pole distance was set at 2cm. The size of the model made is 100mm×100mm×100mm, which cannot be placed on
the rock specimen measurement rack. Four electrodes are placed manually. The power supply electrode AB at both ends is the iron clamp electrode, and the measuring electrode Mn is the calomel electrode. None of the four ABMN electrodes is connected to the fixed device circuit. Five groups were tested according to each concentration test block, and the average value was taken. This is shown in Figure 1.

![Figure 1. Four electrode measurements of resistivity and polarizability](image)

### 3.2 Concrete pressure test

Three good test blocks will be set according to each concentration to carry out pressure test, and the pressure value will be averaged for three times. For each group of test blocks with different concentrations, according to the production completion time, the curing time interval from the first group to the third group is 3, 7, 14, 21 and 28 days. The pressure test was carried out in groups 4 to 5 with curing intervals of 3, 6, 13, 20 and 28 days respectively.

### 4. Correlation analysis of physical parameters

#### 4.1 Concrete test block data collection

The concrete sample block was tested by using the four-electrode method, and the direct contact between the MN calomel electrode and the contact surface was measured. The calomel electrode contact surface is a circular surface with a certain area. In order to ensure good contact, drops of water are used during measurement to enhance the contact effect between concrete and calomel electrode. Try to ensure that the wetted area formed by each drop of water on the contact surface is consistent, but there is still a certain error due to human operation. In addition, the concrete test block is non-uniform body, and the conduction ability of electric signals to the current in the cement part and the sand part is different. Each time the measurement is selected for a fixed point, when placed, there will still be a small difference. Therefore, the measurement will cause the instability of the data, some of the data will be more fluctuation. Therefore, the experimental method of multiple measurements to take a stable value was adopted to reduce the error caused by this.
4.2 Resistivity comparison

As can be seen from Fig. 2 and 3, the resistivity of concrete increases significantly with the increase of curing time. The average resistivity of concrete test blocks mixed with clean water is 185.09 Ω·m, and the maximum value is 235.28 Ω·m after curing for 16 days. The average resistivity of concrete test blocks mixed with 6% sodium sulfate is 166.26 Ω·m, and the maximum value is 253.23 Ω·m on the 23rd day of curing. The average resistivity of the concrete test block mixed with 6% sodium bicarbonate is 161.40 Ω·m, and the maximum value is 198.65 Ω·m at the 21st day. The average resistivity of the concrete test block mixed with 3% sodium sulfate is 184.52 Ω·m, and the maximum value is the value of the 23rd day, and the resistivity is 284.77 Ω·m. The average resistivity of concrete test blocks mixed with 3% sodium bicarbonate is 184.45 Ω·m, and the maximum value is 230.14 Ω·m at the 25th day. From the average and overall trend, the resistivity of concrete test blocks mixed with purified water is higher than that of concrete test blocks mixed with 6% sodium sulfate and 6% sodium bicarbonate, the relative difference is about 10%. There is little difference between the resistivity of concrete samples mixed with purified water and that of concrete mixed with 3% sodium sulfate and 3% sodium bicarbonate, the relative difference is only about 0.5%. The resistivity of concrete test blocks is different with different ion concentrations in concrete, and the higher the concentration, the greater the influence on the resistivity is. For the existing observation means, more than 5% of the relative difference can be observed, from this point we know that the concentration of concrete internal ions need to reach a certain limit can be observed.

4.3 Polarizability comparison
It can be seen from Fig. 4 and Fig. 5 that the change of polarizability with curing time is not obvious. Comparing the polarizability of concrete mixed with sodium sulfate solution with that of purified water in the same period, the order of polarizability value from high to low is as follows: purified water, 3% sodium sulfate, 6% sodium sulfate; Compared with purified water test blocks, the polarizability of concrete mixed with sodium bicarbonate solution is in the order of 3% sodium bicarbonate, purified water and 6% sodium bicarbonate. The average polarizability of the concrete test block mixed with water is 1.70%, and the maximum value is the value of the fifth day, and the polarizability is 2.61%. The average polarizability of the concrete test block mixed with 6% sodium sulfate is 1.35%, and the maximum value is the value of the fifth day, and the polarizability is 1.80%. The average polarizability of the concrete test block mixed with 6% sodium bicarbonate is 1.54%, and the maximum value is the value on the 24th day, and the polarizability is 2.00%. The average polarizability of concrete test blocks mixed with 3% sodium sulfate is 1.48%, and the maximum value is 1.84% on the 11th day. The average polarizability of concrete test blocks mixed with 3% sodium bicarbonate is 1.85%, and the maximum value is the value on the 10th day, and the polarizability is 2.52%. From the relative difference of the mean polarizability, the difference between purified water and 3% sodium sulfate and 6% sodium sulfate is 12.9% and 20%, respectively. The relative difference of the mean polarizability between purified water and 3% sodium bicarbonate and 6% sodium bicarbonate was 8.4% and 9.8%, respectively. There are also observable differences in the values of polarizability with different ion types and concentrations.

4.4. Compressive strength comparison

As can be seen from Fig. 6, there are significant differences in the compressive strength of concrete test blocks mixed with purified water, 3% and 6% sodium sulfate solution, and 3% and 6% sodium bicarbonate at the age. The strength of concrete test blocks mixed with sodium sulfate solution is higher than that mixed with purified water, and the strength gradually increases with the increase of concentration. This phenomenon is related to the effect of concrete expansion caused by sulfate [12]. The compressive strength of concrete mixed with 6% sodium bicarbonate solution is higher than that of concrete mixed with 3% sodium bicarbonate solution, and the compressive strength of concrete mixed with 3% sodium bicarbonate solution is higher than that of concrete mixed with 3% sodium bicarbonate solution. After curing for 28 days, the compressive strength of concrete samples mixed with 6% sodium sulfate solution is 1.37 times that of concrete samples mixed with 3% sodium sulfate solution, 1.2 times that of concrete samples mixed with 3% sodium sulfate solution, and the compressive strength of concrete samples mixed with 6% sodium bicarbonate solution is 1.1 times that of concrete samples mixed with 6% sodium bicarbonate solution. As a whole, the strength of concrete mixed with sodium sulfate solution is greater.
4.5. Correlation between resistivity and compressive strength of test block
In terms of resistivity, the resistivity increases with the increase of curing time, and there is a certain difference in resistivity due to different ion concentrations and types, but there are also some ion concentrations with little differentiation. For example, compared with the concrete test blocks mixed with purified water solution and 3% sodium sulfate solution, the overall data maintained an increasing trend with the curing time. However, in the whole curing 28d, the resistivity of one solution was not significantly higher than that of the other solution for a long time. Another example is the comparison between the concrete test blocks mixed with purified water solution and those mixed with 6% sodium bicarbonate solution. After curing for 15 days, there is obvious differentiation. The resistivity of the concrete test blocks mixed with purified water solution is higher than that of the concrete test blocks mixed with 6% sodium bicarbonate solution. In several groups of data with large degree of differentiation, the resistivity of the test block mixed with purified water is higher than that of the test block mixed with 6% sodium sulfate solution and 6 sodium bicarbonate solution. The compressive strength of concrete test blocks mixed with three kinds of solutions varies from large to small: 6% sodium sulfate, 6% sodium bicarbonate and purified water. Such data cannot fully show the relationship between concrete resistivity and compressive strength. Different ion types and different resistivity characterization make the corresponding relationship between resistivity and compressive capacity weak.

4.6. Correlation between the test block's polarizability and compressive strength
From the overall data, the polarization rate changes relatively smoothly with the curing time, and the polarization rate has comparable characteristics. The order of the polarization rate from small to large is: 6% sodium sulfate, 3% sodium sulfate, 6% sodium bicarbonate, clean water, 3% sodium bicarbonate. Consistent with the order of compressive strength from large to small. In this experiment, it can be seen that the polarization rate has an anti-correspondence relationship with the degree of compression resistance, and the high polarization rate has a weak compression strength ability.

4.7. Correlation between resistivity and polarizability of test block
According to the comparison of resistivity and polarizability data, the resistivity of the concrete test block mixed with 6% sodium sulfate solution and the resistivity of concrete mixed with 6% sodium bicarbonate solution is lower than that of the concrete test block mixed with clear aqueous solution. The polarizability is also low; the resistivity of the concrete mixed with 3% sodium sulfate and sodium bicarbonate solution is not much different from that of the concrete test block mixed with water, but the polarizability is high or low. For the comparison between different ions and the same concentration, the resistivity cannot be distinguished from each other, but the polarizability has a more obvious degree of discrimination. There is no obvious correlation between the resistivity and polarizability of the test block.

5. conclusion
In the context of the diversified development of building science, the main body of buildings is still mostly constructed by concrete materials. The importance of concrete safety evaluation is well known. In this paper, some research rules can be found by selecting the resistivity, polarizability and compressive strength data of concrete models mixed with different ions and concentrations of solutions. In the above research results, there are still some deficiencies, such as the selection of invading ion species is less, the concentration gradient accuracy is not enough, it is suggested that the future scientific research can increase the species of invading ion concrete, and the ion concentration is fine, in order to find the correlation in the relevant engineering technology; In addition, the erosion of salt ions on concrete in engineering is the result of a variety of ions mixed together. With the conclusion of the study on the law of single ions, the influence of mixed ions on the compressive strength, resistivity and polarizability of concrete can be expanded and its correlation research can be carried out.
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