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Experimental study on solidification of high concentration desulfurization wastewater in power plants

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ABSTRACT

This paper proposes a technical route for the cementation of desulfurization wastewater in power plants after concentration with flue gas. The concentrated desulfurization wastewater is mixed with cement, fly ash and other materials to obtain a solidified body. The effects of different chlorine ion concentrations, high concentration brine water with different pH and coating treatment on the performance of the solidified body were explored. The results showed that the chemical bonding and physical adsorption of chlorine ions in the cement system could greatly improve the compressive strength of the solidified body. When the chlorine ion concentration was 70,000 mg/L, the compressive strength of the solidified body was the largest and the leaching rate of chlorine ion in the solidified body was below 16%; When the pH was 4, the compressive strength and chlorine ion leaching rate of the solidified body were the best. In the practical application, $Ca(OH)_2$ is added to the concentrated wastewater, and the pH is adjusted to 4.0–5.0; adding an epoxy resin coating on the surface of the solidified body greatly reduced the leaching rate of chlorine ion in the solidified body to less than 1%, but the disadvantage is that is decreased the compressive strength of the solidified body.

Keywords: Desulfurization wastewater; Cement solidification; Compressive strength; Leaching rate; Coating

1. Introduction

The limestone-gypsum wet desulfurization process is the most widely used desulfurization technology in coal-fired power plants [1]. In order to ensure the normal operation of the desulfurization system, the chlorine ion concentration in the circulating slurry should be controlled within 20,000 mg/L, so the desulfurization system can discharge a certain amount of desulfurization wastewater [2]. Affected by various factors such as pre-desulfurization and post-desulfurization conditions, the quality and quantity of desulfurization wastewater are diversified and changeable. As environmental protection policies become more and more stringent, desulfurization wastewater treatment has gradually become the focus of the industry [3,4]. According to typical steps of zero discharge treatment of desulfurization wastewater: pretreatment → concentration reduction → transfer and solidification [5–9]. The existing evaporation crystallization process converts the concentrated wastewater into crystallized salt with a low utilization value [10,11]; the bypass evaporation process transfers contaminants from concentrated wastewater into fly ash, which adversely affects boiler efficiency and fly ash quality [12,13]. According to the development trend of the desulfurization wastewater treatment process, this paper proposes a cement solidification desulfurization wastewater process and the whole process is shown in Fig. 1.

The process combines the advantages of cement fixing/stabilization technology with low-temperature flue gas

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evaporation concentration technology. 10%–15% of the hot flues gas extracted from the electrostatic precipitators and the liquid column of the desulfurization wastewater in the concentration tower perform cyclic heat exchange, the desulfurization wastewater can be reduced and concentrated by 5 ~ 10 times, the concentrated wastewater is mixed with cement, fly ash and other materials according to a mixing proportion, stirred by a mixing stirrer, placed in a molding apparatus, and then transferred to a constant temperature and humidity maintenance room. After qualified maintenance, it can be used as low-grade building materials such as plain concrete or kerbstone according to the properties of the solidified body. Low-temperature flue gas evaporation and concentration technology have low requirements on influent water quality, which is the reuse of waste heat resources of power plants, and it is in line with the future development trend of desulfurization wastewater concentration technology; the fixed/stabilization technology can greatly reduce the secondary pollution of desulfurization wastewater. Under the background of China's "Soil Pollution Prevention and Control Action Plan", the desulfurization wastewater is transformed into a solidified body that does not cause secondary pollution, thus can better meet the policy requirements.

In the fixed process of desulfurization wastewater, the fixation of heavy metal ions and chlorine ions is the focus of attention. For the fixation of heavy metal ions, it is mainly through the pozzolanic reaction of fly ash to fix the heavy metal ions, the amount of cement is less and the compressive strength of the prepared solidified body is poor [14]. Renew et al. [15] mixed desulfurization wastewater, fly ash and a small amount of cement to produce a solidified body, in which As^{5+}, Cd^{2+}, Hg^{2+} and Se^{4+} leaching rate is in 10% ~ 32%, thus had a good fixation effect on heavy metal ions. According to the moisture content of desulfurization sludge, Fei et al. [16] presented a new type of curing agent to reduce the leaching concentrations of heavy metals. Although there are already mature theories for the fixation of chlorine ions in the cement industry, there is few research on the fixation of chlorine ions in desulfurization wastewater.

The main forms of chlorine ions in cement system are bound chlorine ion and free chlorine ion, the bound chlorine ions include chemical bound chloride (which forms Friedel's salt by chemically combining with C_3A in cement) and physically bound chloride (which is physically adsorbed on the hydration product C-S-H gel) [17–19], Commonly, the ratio of combined state and free state chlorine ion is used to evaluate the existing form of chlorine ions in the cement system.

In the practical application, the concentration ratio of the concentration process, the pH of the concentrated wastewater and the surface coating of the solidified body have a great influence on the curing process and the performance of the solidified body. Therefore, the effects of different chlorine ion concentrations, different pH and coating treatments on the properties of the cemented body were investigated.

2. Experiments

2.1. Experimental materials

The cement used in the experiment is Portland Slag Cement; the sand and gravel used in the experiment is ordinary building river sand; fly ash from a thermal power plant in North China; the high concentration brine water is prepared in the laboratory. In order to verify the effect of chlorine ions on the solidification of cement, the laboratory prepared sodium chloride solution with different chlorine ion concentrations as simulated wastewater. In experiments with different pH and high concentration brine, diluted

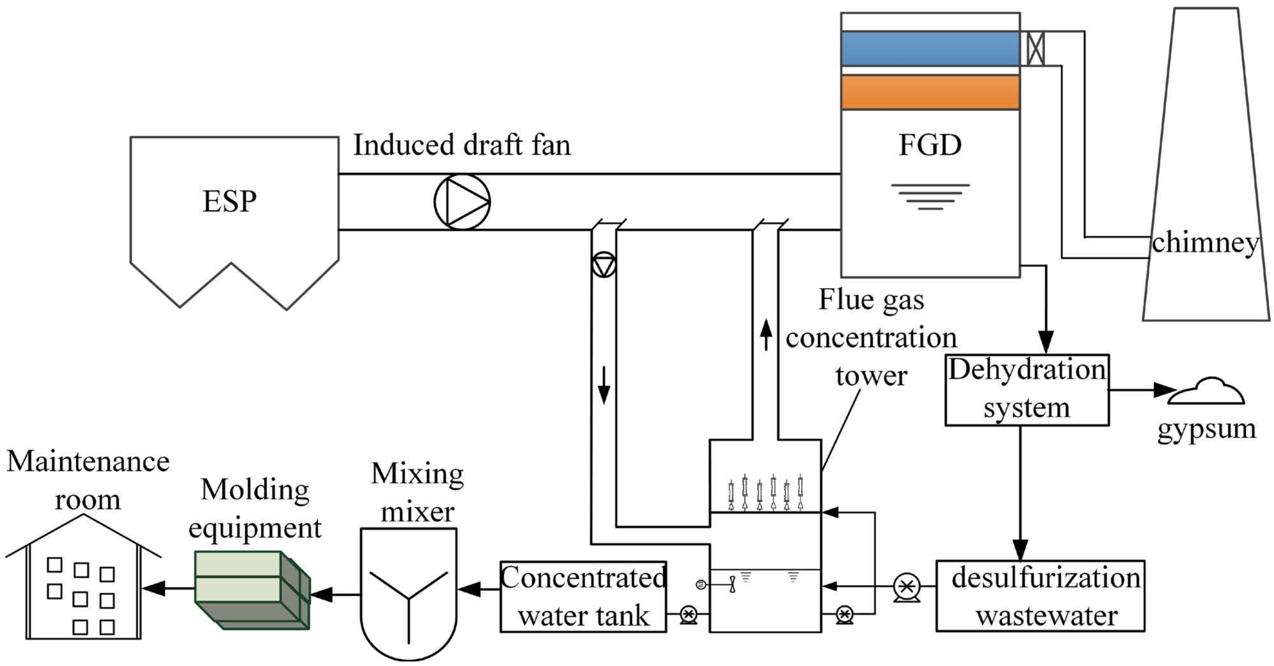

Fig. 1. Flue gas concentration and solidification with cement process of desulfurization wastewater.

HCl and diluted NaOH solutions were used to adjust the pH of the high concentration brine.

2.2. Fixing/stabilizing process

According to the experimental results in the literature [20], we concluded that the best mixing ratio for curing is 0.97:0.17:0.60:0.98 (cement: fly ash: concentration brine water: river sand). According to the design of mixture ratio, mixing cement (P·O42.5 ordinary Portland Cement), fly ash and river sand together, then added quantitative high concentration brine water, transferred it to the mold (40 mm × 40 mm × 40 mm six league quality mold steel) in time after fully mixing. Naturally placed for 24 h after covering with plastic wrap, the solidified body could be obtained by disassembling the mold, and after a prescribed period of time, the performance of the solidified body was detected.

2.3. Performance test of the solidified body

2.3.1. Compressive strength test

Compressive strength is an important property of a solidified body and an important indicator of the reuse of a solidified body. According to different testing ages, it can be expressed as compressive strength in n days, where n is curing age, and n values are generally recommended as 3, 7, 28 and 90, etc. After curing the solidified body to the specified age, the compressive strength of the solidified body was tested by a constant stress tester (Hebei Changji Instrument Co., Ltd., DYE-300B). The test machine moved at a constant speed, and when the solidified body reached the maximum endurance F_{max}, the machine stopped, then recorded F_{max}. The ratio of F_{max} to the cross-sectional area of the solidified body is defined as compressive strength. After all three parallel experiments of the compressive strength test; the average value is the compressive strength value of the current experiment.

2.3.2. Text of chlorine ion binding capacity

The ability to combine chlorine ions is an index for evaluating the ratio of combined chlorine ion to free chlorine ion in cement systems. Generally, it is represented by *R*. When the total amount of chlorine ion is the same, the larger the *R*-value, the more combined chlorine ion there is. The solidified powder was soaked with deionized water and nitric acid respectively after the solidified body was cured to 28 d. The concentration of chlorine ions in the nitric acid solution was measured by the Forhard method, and the total amount of chlorine ions in the slurry per unit mass P_t (mg/g) was obtained. The concentration of chlorine ion in an aqueous solution was measured by the Mohr method, and the free chlorine ion amount in the slurry per unit mass P_f (mg/g) was obtained [21,22].

Combined chlorine ion amount (P_b) – total chlorine ion amount (P_t) – free chlorine ion amount (P_f).

Ability to combine chlorine ions:

$$R = \frac{P_b}{P_f} = \frac{P_t - P_f}{P_f} = \frac{P_t}{P_f} - 1 \tag{1}$$

2.3.3. Chlorine ion leaching rate detection

The solidified body was cemented to the specified age and soaked in deionized water. After a period of time, chlorine ion concentration in leachate was detected, and the total amount of leached chlorine ion was calculated, the ratio of the leached chlorine ion to the total chlorine ion in the solidified body is the chlorine ion leaching rate.

2.4. Characterize the solidified product

In order to further explore the microstructure and chemical composition of the solidified body, the 28-d old solidified bodies were characterized. The microscopic morphology and elemental composition in the samples were characterized by scanning electron microscopy (SEM) [23] and the chemical composition of the product was detected by X-ray diffraction (XRD).

3. Results and discussions

3.1. Effect of brine with a high concentration of different chlorine ions on the performance of solidified body

In the practical process of desulfurization wastewater cement fixation, the idea of first concentration and then solidification is mainly adopted. In order to reduce the raw material cost in the later stage of curing, the wastewater needs to be concentrated and reduced as much as possible. The concentration process will increase the concentration of chlorine ions that are difficult to handle in desulfurization wastewater. In order to explore the effect of the concentration of desulfurization wastewater on the properties of the solidified body, experiments were designed to simulate the effects of different chlorine ion concentrations on the properties of the solidified body.

Keeping the optimal mixing ratio unchanged, that is, the amount of cement: the amount of fly ash blended: the amount of high concentration brine: the amount of river sand = 0.97:0.17:0.60:0.98, The chlorine ion concentration in simulated high concentration brine was changed to 30,000; 40,000; 50,000; 60,000; 70,000; 80,000; 90,000 and 100,000 mg/L, numbered L_3–L_{10}. At the same time, L_0 was set as a blank group, which is the control group to prepare the solidified body by mixing other materials with deionized water. The compressive strength of each group was measured at different ages under different conditions and the ability to combine chlorine ions in 28-d old solidified bodies was detected. Then the chlorine ion leaching rate was calculated.

3.1.1. Effect of brine with a high concentration of different chlorine ions on compressive strength of solidified body

The compressive strength of each group was tested when curing to the specified 7, 14 and 28 d ages, the results are shown in Table 1.

The compressive strength of each group was the average value of three parallel samples, according to Table 1, the trend chart of influence of different chlorine ion concentrations on the compressive strength of the solidified body can be obtained, as is shown in Fig. 2.

As can be seen from Fig. 2, the compressive strength of the solidified body increased with the increasing of curing age. The compressive strength of the solidified body mixed with deionized water (not mixed with sodium chloride) was the lowest at 3 ages and it was 32.945 MPa on day 28, which was lower than the compressive strength of the solidified body mixed with part of sodium chloride on day 14, indicating that the incorporation of sodium chloride could significantly improve the compressive strength of the solidified body. Concentration and reduction of high concentration brine can not only reduce the amount of treated water, but also improve the compressive strength of the solidified body at the curing stage.

From the overall trend, with the increase of chlorine ion concentration, the compressive strength of the solidified body does not continue to increase. The compressive strength of the solidified body increased at 7 d and 28 d with the increase of chlorine ion concentration when the chlorine ion concentration was less than 70,000 mg/L, whereas the compressive strength decreased with the increase of chlorine ion concentration when the chlorine ion concentration was more than 70,000 mg/L. At 14 d age, compressive strength was maintaining overall growth. However, when the chlorine ion concentration was 30,000–60,000 mg/L, the compressive strength decreased slightly, and then increased to 34.625 MPa at the concentration of 70,000 mg/L. The concentration continued to increase and the compressive strength changed a little and was stable at around 35 MPa.

On the one hand, chlorine ions can chemically react with the C_3A phase in the cement to form solid-phase Friedel's salt, which is filled in the pores of the cement material to improve the pore structure in the solidified body and increase the density of the slurry. On the other hand, chlorine ions are adsorbed by C-S-H gel (a typical hydration product after cement hydration), and its dispersion degree is increased, which can accelerate the hydration reaction. However, as is shown in Fig. 2, this combination of chemical bonding and physical adsorption has a limited

Table 1
Effect of brine with high concentration of different chloride ions on compressive strength of solidified body

Number	Chloride concentration (mg/L)	7 d compressive strength (MPa)	14 d compressive strength (MPa)	28 d compressive strength (MPa)
L0	0	22.725	28.945	32.945
L3	30,000	23.85	32.555	36.97
L4	40,000	25.53	32.45	40.36
L5	50,000	25.92	31.14	40.865
L6	60,000	25.78	31.76	40.5
L7	70,000	29.505	34.625	44.62
L8	80,000	27.99	34.09	42.05
L9	90,000	28.46	35.05	42.84
L10	100,000	26.255	34.615	42.17

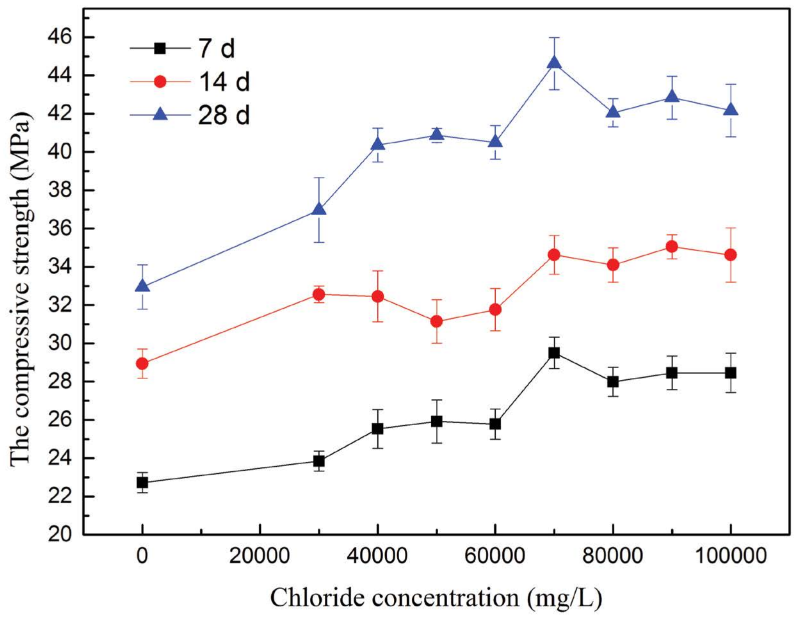

Fig. 2. Trend chart of the diagram of influence of different chlorine ion concentrations on compressive strength of the solidified body.

improvement in the compressive strength of the solidified body. As the concentration of chlorine ions increases, the hydration rate of cement will be faster, which will lead to uneven pore structure in the solidified body and will affect the compressive strength of the solidified body. Therefore, when the chlorine ion concentration is 70,000 mg/L, the solidified body has the best compressive strength.

3.1.2. Effect of brine with a high concentration of different chlorine ions on the chlorine ion binding capacity of the solidified body

Detect the combined chlorine ion capacity of each group of solidified bodies when the solidified body was cured to the specified 28 d age. Combine the amount of free chlorine ions with the total amount of chlorine ions in the detection process, the influence of high concentration brine with different chlorine ion concentrations on the combined capacity of the solidified body was obtained, as is shown in Fig. 3.

It can be seen from Fig. 3 that the amount of free chlorine ion and total chlorine ion of the solidified body increases with the increase of the chlorine ion concentration, and exhibits an overall linear growth trend. Chlorine ions in high brine enter into the solidified body slurry, and the higher the chlorine ion concentration in the high brine, the higher the amount of free chloride and total chlorine ions in the solidified body. The amount of combined chlorine ion increases with the increase of chlorine ion concentration from 30,000 mg/L to 60,000 mg/L. When the chlorine ion concentration is 70,000 mg/L, the amount of combined chlorine ion reaches the maximum at 28 d, and then it decreases.

3.1.3. Effect of brine with a high concentration of different chlorine ions on the leaching rate of the solidified body

After being cured for 28 d, the solidified body was immersed in deionized water for 42 d, and the chlorine ion leaching rate was detected to obtain a trend diagram of the effect of the brine with a high concentration of different chlorine ions on the leaching rate of the solidified body, as shown in Fig. 4.

As can be seen from Fig. 4 that the leaching rate of the solidified body decreases with the increase of the chlorine ion concentration, and the leaching rate of each group of solidified bodies is less than 16%, and the lowest leaching rate is 10.8%, the curing effect is good, and most of the chlorine ions are fixed in the solidified body by the cement, the leached chlorine ion is the surface chloride salt and the unfixed free chlorine ion in the thin layer close to the solidified body, and the chlorine in the deeper solidified body is bound by the dense structure in the solidified body slurry, and it is difficult to leach. There are two main reasons: on the one hand, as the concentration of chlorine ions increases, the compressive strength of the solidified body also increases, the density of the slurry increases, and the binding force of chlorine ions increases. On the other hand, the chlorine ion in the solidified body obtained by the high chlorine ion concentration has dissolution equilibrium after leaching, and the excessively high chlorine ion in the leaching solution can inhibit the continuous dissolution of the chlorine ion in the solidified body to certain extent.

3.2. Effect of high brine pH on properties of the solidified body

After the desulfurization wastewater is concentrated by the flue gas, the pH is greatly reduced, and the pH can

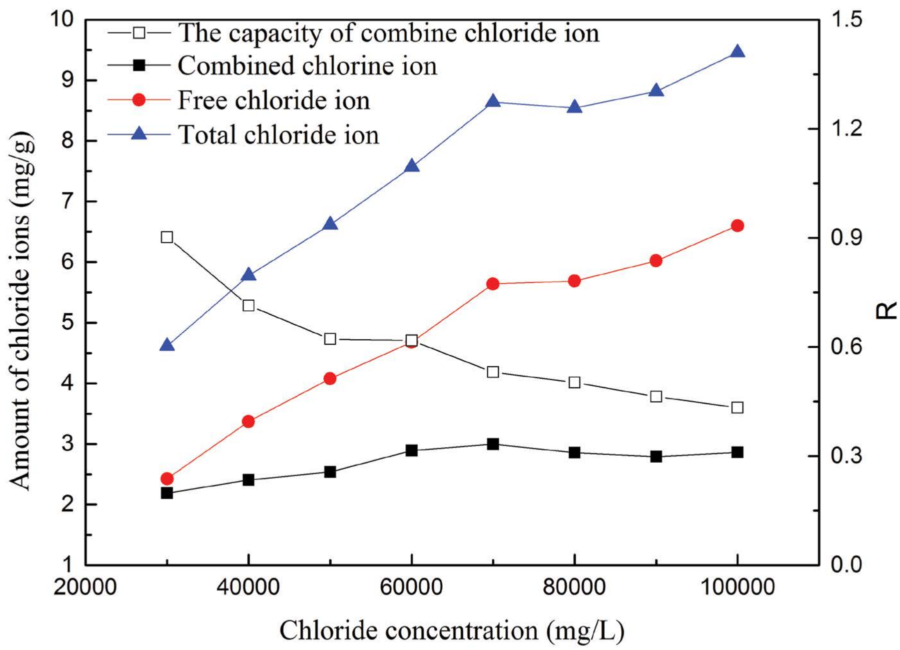

Fig. 3. The diagram of the effect of brine with a high concentration of different chlorine ions on the combined chlorine ion capacity of the solidified body.

be lowered to 2 as the concentration ratio increases, which will affect the performance of the solidified body if used directly in the cement curing process. Therefore, the appropriate pH of the concentrated desulfurization wastewater to be adjusted needs experimental demonstration, thus the experiments of the effect of high brines with different pH on the performance of the solidified body are designed.

Use the best mixing ratio and the constant proportion of materials of each component, prepare the NaCl high concentration brine water with a concentration of 30,000 mg/L. The pH of the high concentration brine water was adjusted to 2, 3, 4, 5, 6, 7 and 8, the components were mixed according to the optimum mixture ratio and cured for a predetermined period of time, the compressive strength of the solidified body and the chlorine ion leaching rate were detected. The effect of the high concentration of brine water with different pH on the compressive strength and chlorine ion leaching rate was obtained, as shown in Figs. 5 and 6.

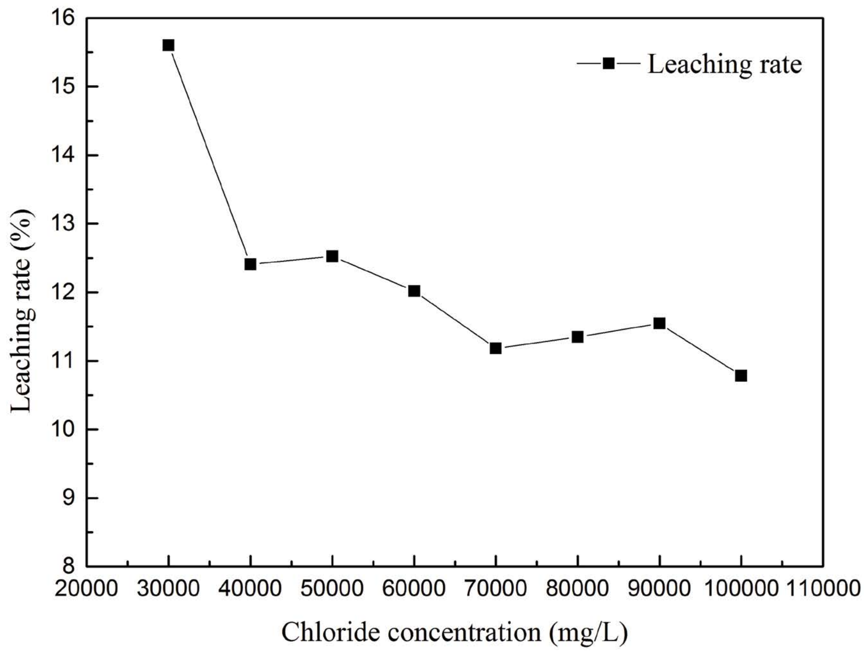

Fig. 4. The diagram of the effect of the brine with a high concentration of different chlorine ions on the leaching rate of the solidified body

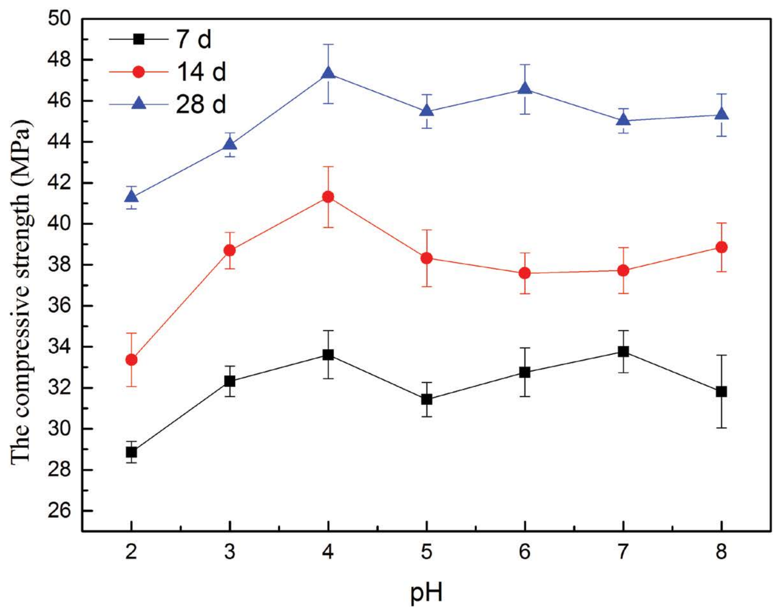

Fig. 5. Trend diagram of influence of the high concentration brine water with different pH on the compressive strength of the solidified body.

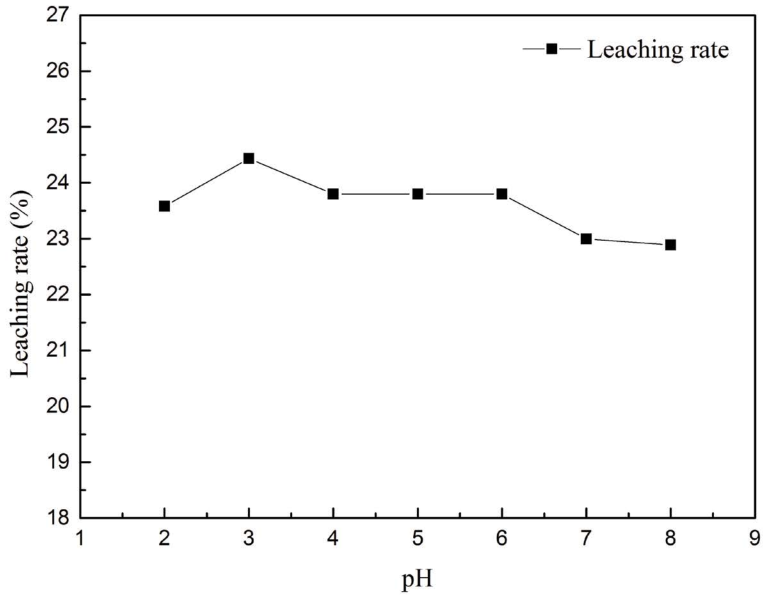

Fig. 6. Trend chart of influence of different pH high concentration brine water on chlorine ion leaching rate of the solidified body.

It can be seen from Fig. 5, as the curing age increases, the compressive strength of each group of solidified bodies increases. At three different ages, the compressive strength of solidified bodies of high brines with different pH shows the same growth trend: at a pH of 2–4, the compressive strength of the solidified body increases with the increase of pH; When the pH is 4, the compressive strength of the solidified body reaches a maximum value of 47.31 MPa; after the pH is greater than 4, the compressive strength of the solidified body decreases as a whole. At 28 d, the solidified body obtained from the high brines of pH 2 has the lowest compressive strength, which is only 87.2% of the maximum value. If compared with the compressive strength of the solidified body made of high brines with a pH greater than 5, the compressive strength of the solidified body is also much smaller, this is because the excessively high concentration of H^+ consumes too much cement hydration product $Ca(OH)_2$, which reduces the compactness of the solidified body, resulting in a large decrease in the compressive strength of the solidified body.

As can be seen from Fig. 6, the chlorine ion leaching rates of solidified bodies prepared with high brines of different pH at 28 d show a slight decline with the increase of pH of high brines after immersion in water for 42 d, but all maintain between 23%–25%, with a small change. The change of high brines pH only slightly decreases the chlorine ion leaching rate of the solidified body, that is, the closer the high brines is to neutral, the smaller the chlorine ion leaching rate, but the reduction is small.

Combining the trend of the performance of the solidified body in Fig. 5 with Fig. 6, it is recommended to adjust the pH of the concentrated desulfurization wastewater with $Ca(OH)_2$ to 4–5, then both the compressive strength and the chlorine ion leaching rate of the solidified body are good, and the added Ca^{2+} can further enhance the compressive strength of the solidified body.

3.3. Effect of coating treatment on the properties of the solidified body

In the above experiment, the chlorine ion leaching rate of the solidified body after immersion for 42 d was more than 10%, which was still high, and the chlorine ion leaching rate could be lowered by coating. Common coating materials are epoxy resin, polyurethane and acrylic resin. These coating materials can alleviate the leaching of chlorine ions in the solidified body. In the experiment, epoxy resin glue was used as the coating to reduce the chlorine ion leaching rate of the solidified body, and a blank group without coating was designed for comparison. At the same time, considering the epoxy resin itself as a curing agent, in order to verify its effect as a curing agent on improving the performance of the solidified body, the epoxy resin glue is added into the curing formulations by means of internal doping, that is, the epoxy resin is internally doped. The solidified body added to the resin glue was subjected to surface coating, and the experimental number setting is as shown in Table 2.

After the surface of the solidified body was coated with epoxy resin, the hydration process of the solidified body was inhibited by isolation from the wet environment. Therefore, after the curing of the solidified body for 21 d, the cement hydration has been basically completed, and the coating operation was performed at this time. The surface coating operation adopted the method of primer coating and top coating. Before the coating, the surface of the solidified body was treated to make the surface clean and free of clear water. Epoxy resin primer should be firstly stirred according to the mass ratio of epoxy resin: curing agent = 2:1, and then coated the entire surface of the solidified body. After the epoxy resin adhesive layer was completely solidified and not sticky, the surface coating operation could be carried out; the surface coating should be uniformly mixed according to the mass ratio of epoxy resin: curing agent = 1:1, and then the surface was evenly coated.

After curing to the specified age, the compressive strength and chlorine ion leaching rate of the four groups of the solidified body were tested, and the trend diagram of the influence of epoxy resin adhesive on the compressive strength and chlorine ion leaching rate of the solidified body was obtained, as shown in Figs. 7 and 8.

It can be seen from Fig. 7 that the compressive strength value of the blank group A is the highest, and the compressive strength value of the C group internally doped with epoxy resin glue and uncoated is only 86.6% of the blank group A, and the compressive strength drops significantly, this is because the epoxy resin adhesive fails to play a promoting role in the process of cement hydration. It only adheres to a small number of particles around it and fails to fully combine with the products in the cement hydration system, resulting in the increase of porosity in the cement system and the decrease of compressive strength. Compared with blank group A, the compressive strength of coated group B decreases significantly, but the difference is very small compared with that of group D with epoxy resin adhesive internal doping and coating. After the coating treatment, the compressive strength of the solidified body only shows the strength characteristics of the epoxy resin coating itself. The original strength characteristics of the cement system are masked, and the compressive strength of the solidified body after the coating treatment is less than that of the natural cement hydration.

It can be seen from Fig. 8 that in groups A and C without coating treatment, the chlorine ion leaching rate of group C is significantly higher than that of group A, which is due to the low compressive strength of the group C cement system, increased porosity of slurry and weak binding capacity of chlorine ions. The chlorine ion leaching rate of group B and group D after coating treatment decreases significantly, especially the chlorine ion leaching rate of group B after coating treatment was only 0.75%, which was 96.8% lower than that of blank group A. It shows that the epoxy resin coating can bind most of the free chlorine ions in the cement system inside the coating, which can greatly improve the performance of the solidified body.

In combination with Figs. 7 and 8, the epoxy resin coating can greatly reduce the chlorine ion leaching rate

Table 2
Epoxy resin test group description

Experiment number	A	B	C	D
Processing method	Blank	Coating	Internal doping	Internal doping + coating
Specific description	Simulated high brine to obtain a solidified body	Solidified body prepared by simulating high salt water is coated with epoxy resin coating after curing for a period of time	On the basis of the best formula, add 20 g of epoxy resin and stir to obtain a solidified body	Coated epoxy coating at the same time

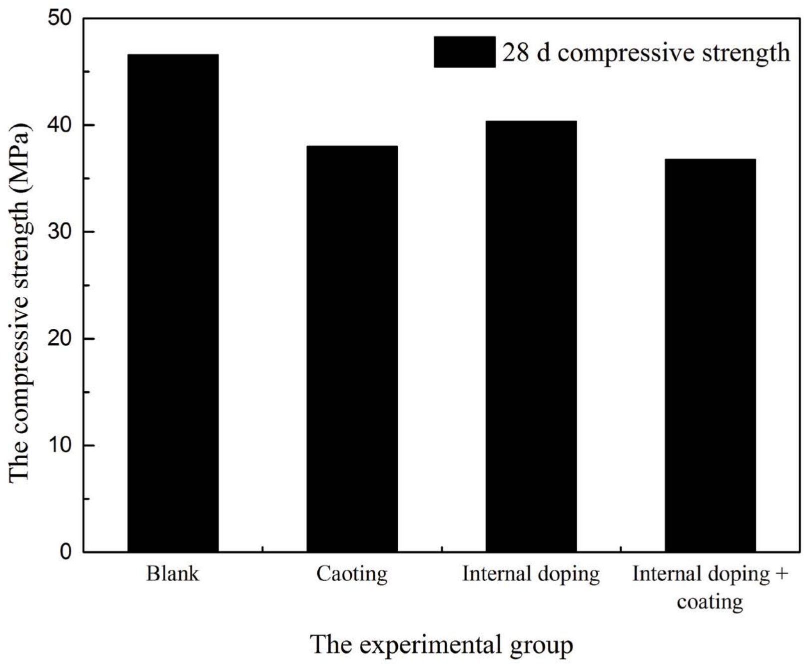

Fig. 7. Trend diagram of the effect of epoxy resin on the compressive strength of the solidified body.

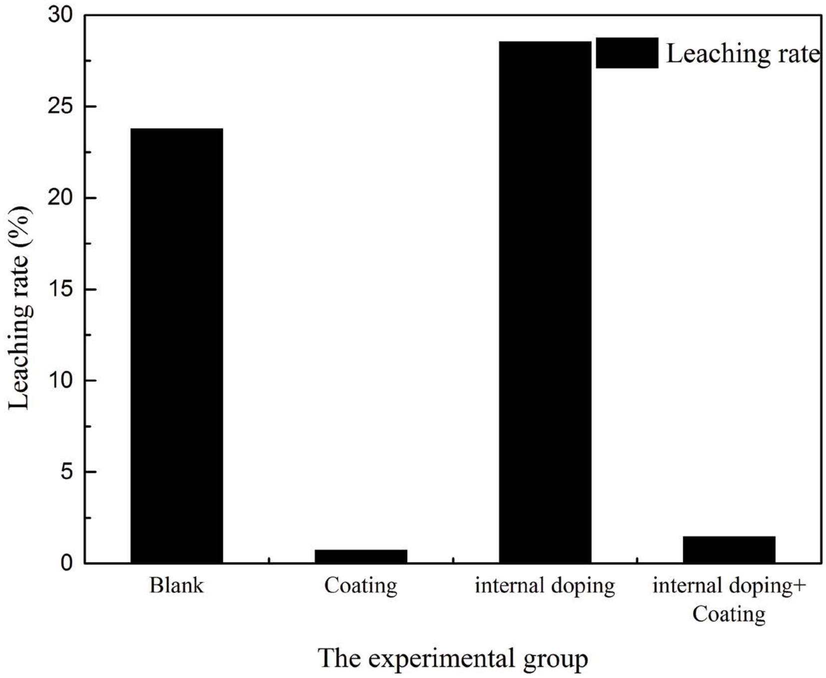

Fig. 8. Effect of epoxy resin on the chlorine ion leaching rate of solidified body.

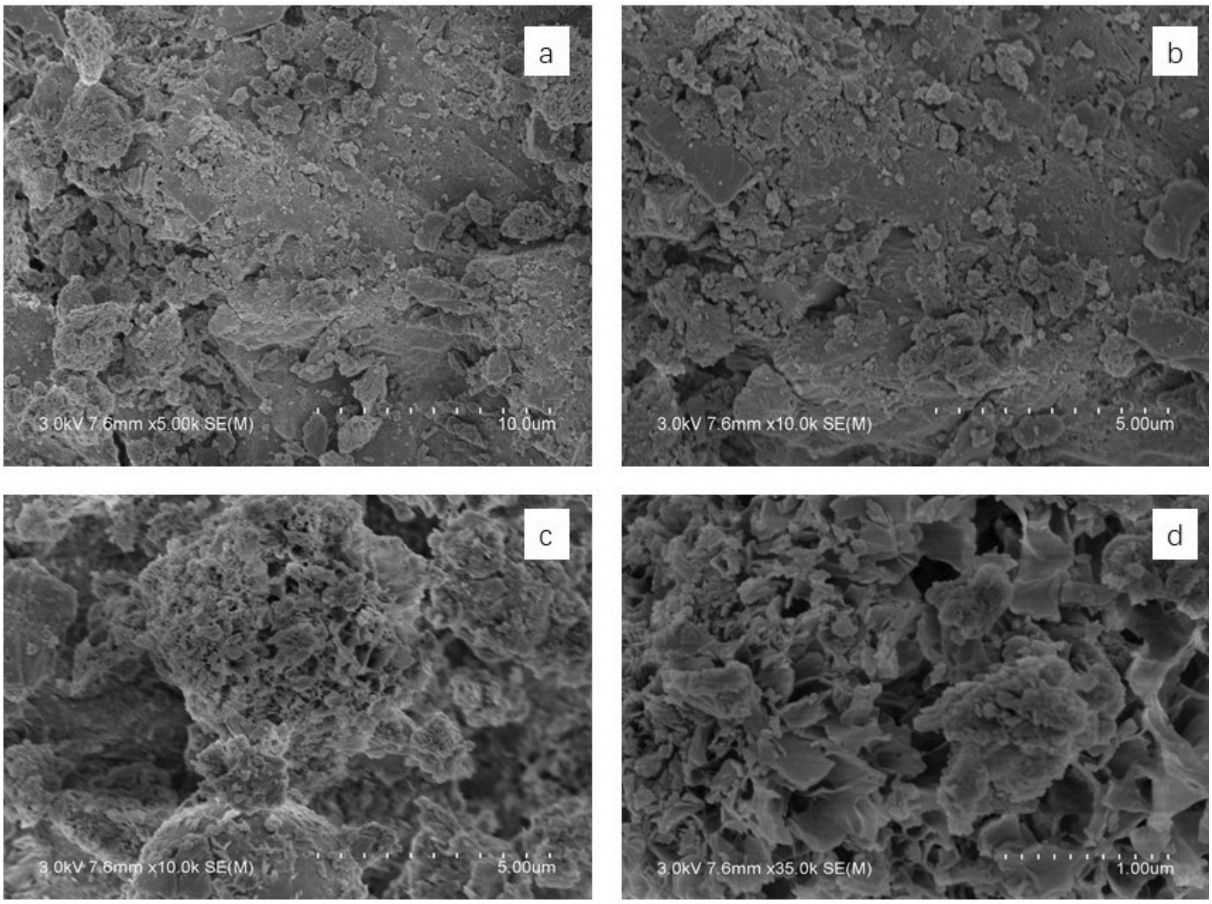

Fig. 9. SEM images of the solidified body with 70,000 mg/L chlorine ion concentration and the solidified body with pH = 4 (a,b) solidified body with 70,000 mg/L chlorine ion concentration and (c,d) solidified body with pH = 4.

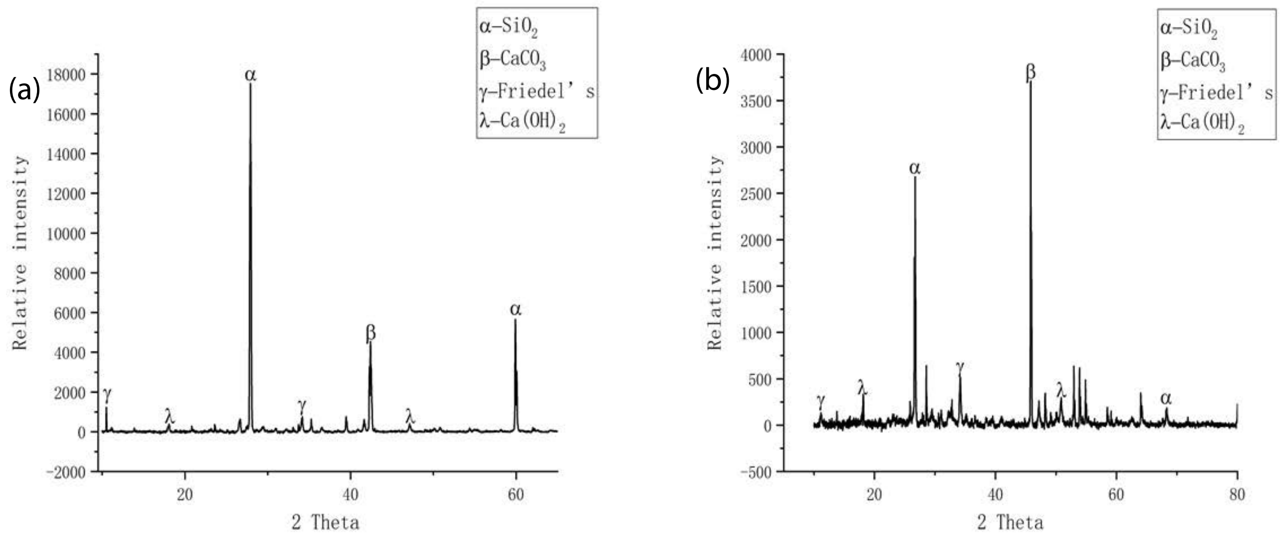

Fig. 10. X-ray diffraction spectral of solidified body: (a) solidified body with 70,000 mg/L chlorine ion concentration and (b) solidified body with pH = 4.

of the solidified body, and it can effectively isolate the free chlorine ions in the cement system. However, the coating masks the compressive strength property of the solidified body itself after hydration, so that the overall compressive strength value decreases. In the practical process, if the requirement for the compressive strength of the solidified body is not high, the coating treatment method can be used to reduce the chlorine ion leaching rate of the solidified body.

3.4. Products characterization results

3.4.1. SEM of the products

The morphologies of the solidified body with 70,000 mg/L chlorine ion concentration and the solidified body with pH = 4 were characterized by SEM, as shown in Fig. 9. It can be seen from Fig. 9a and b, the products are relatively dense and particles stack on top of each other. This is because chloride ions are closely combined with cement hydration products through chemical bonding and physical adsorption in the cement system. Friedel's salt formed by the chemical combination of chloride ions increases the particle size of the solidified body and improves the compressive strength of the solidified body. It can be further observed that there are two stacking forms of solidified particles, one is stacked by layers with irregular surfaces, and the other is stacked by layers with smooth surfaces and angular shape. This is also the main reason for the high compressive strength of the solidified body. In Fig. 9c and d there are some rod-shaped and plate-shaped crystals, forming a high bond strength. This is because the C-S-H gel interweaves with $Ca(OH)_2$ crystals and part of ettringite, the structure becomes denser, which also promotes the improvement of the compressive strength of the solidified body.

3.4.2. XRD spectrogram

The XRD patterns of the solidified body with 70,000 mg/L chlorine ion concentration and the solidified body with pH = 4 are presented in Fig. 10. It can be seen that the solidified body contains SiO_2, $CaCO_3$, Friedel's salt and $Ca(OH)_2$. The formation of Friedel's salt proves that the chloride ion of the high brines actually reacts with the C_3A phase in the cement. This is also the reason why the compressive strength of the solidified body is improved. At the same time, the XRD results verify the reason for the increase of solidified particles in SEM.

4. Conclusions

- The chemical bonding and physical adsorption of chlorine ions in high brines in cement system could greatly improve the compressive strength of the solidified body. The compressive strength of the solidified body was the highest when the chlorine ion concentration was 70,000 mg/L. When the concentration of chlorine ion was 30,000–100,000 mg/L, the leaching rate of chlorine ion in the solidified body was low (below 16%).
- When the pH was 4, the compressive strength and the chlorine ion leaching rate of the solidified body were the best. Therefore, in order not to affect the performance of the solidified body, $Ca(OH)_2$ was needed to adjust the pH value to 4.0–5.0 after concentration of desulfurization wastewater.
- The chlorine ion leaching rate of solidified body could be greatly reduced by epoxy resin coating treatment. Compared with the solidified body without coating treatment, the chlorine ion leaching rate was reduced by 96.8%. However, the compressive strength of the solidified body would be decreased by coating treatment.
- The formation of Friedel's salt is the key to improving the compressive strength of the solidified body. The SEM characterization results showed that the solidified body particles made of high brines were stacked in layers, and the XRD characterization results verified the existence of Friedel's salt.

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