Study on the Effect of Silane-silica Sol Hybrid Material on the Properties of Cement-based Materials

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Abstract—This article analyzes the preparation of cement-based materials and the preparation of silane-silica sol hybrid materials. The author studied the effects of materials on the water permeability, gas permeability, ion permeability, freeze-thaw resistance, material mechanism and other properties of cement-based materials. The purpose of this article is to improve the performance stability of cement-based materials and extend the service life of cement-based materials.

1. INTRODUCTION
Cement materials are widely used as building materials during construction work, and their performance stability will also directly affect the service life of construction projects. Based on this, how to improve the performance, reliability and durability of cement-based materials has also become a key focus of construction units. The application of silane-silica sol hybrid material to the protection of cement-based materials can not only optimize the application performance of the material, but also has a positive significance for extending the application effect of the material.

2. TEST MATERIALS AND METHODS
2.1. Cement-based Material Preparation
2.1.1. Raw Material Preparation
The cement-based materials used in the specific test process include concrete, cement mortar and cement paste. The stones used in the experiment are basalt with a particle size between 5mm-25mm. The cement uses P·O·42.5 Portland cement, and the cement composition is shown in Table 1. The sand adopts Qingdao river sand with a particle size below 5mm. The detailed indicators are shown in Table 2. The water reducing agent used in this test is a polycarboxylic acid water reducing agent.

| Chemical Composition (%) | SiO2 | Fe2O3 | CaO | MgO | SO3 | K2O | Na2O | TiO2 | Al2O3 |
|--------------------------|------|-------|-----|-----|-----|-----|------|------|-------|
| P-O-42.5                 | 3.10 | 3.67  | 57.59 | 2.18 | 2.65 | 0.72 | 0.18  | 0.34 | 7.10  |

| Type | Specification | Fineness | Mud Content | Gradation |
|------|---------------|----------|-------------|-----------|

TABLE 1. BASIC CHEMICAL COMPOSITION OF CEMENT

TABLE 2. SAND INDEX
2.1.2. Test Block Preparation
We can prepare various experimental materials according to the corresponding materials prepared in advance and the proportions that have been drawn up. The preparation of concrete is based on the Standard for Test Methods of Mechanical Properties of Common Concrete (GB/T50081). Pour the required raw materials into a concrete mixer and mix evenly, dissolve the water reducing agent in water, then slowly add it to the mixer, and then mix for 2-3 minutes. Then stop mixing, put the well-mixed concrete into a 100mm × 100mm × 100mm concrete mold, then place it on a vibrating table and vibrate, remove the excess concrete with a spatula, and smooth the surface of the concrete. When the test block is formed then stop vibrating, then put the concrete mold into the concrete curing room, remove the mold after 24h, and put the molded concrete test block in the concrete curing room (temperature=21℃, relative humidity RH>95%) for curing.

The preparation standard of mortar test block refers to "Mortar, Concrete Waterproofing Agent" (JC474-2008). Pour the weighed cement into a cement mortar mixer. Add water during the mixing process, and add sand after mixing for 60 seconds. Then, stir for 180 seconds, stop the machine, and put the mixed mortar into a 25mm × 40mm × 160mm mold equipped with steel bars (for capillary water absorption test with cracks), and a 40mm × 40mm × 160mm mold (for capillary water absorption test); Ф100×50mm mold (for RCM test). After that, place the mold on the vibrating table and vibrate to ensure that the vibrating time is not less than 30s. Then, put the vibrated mortar into the molding room, remove the mold after 24 hours, and put the mortar into the curing room for curing.

The preparation standard of cement paste refers to "Mortar, Concrete Waterproofing Agent" (JC474-2008). In the specific operation process, we need to put the cement material into the pure slurry mixer and slowly add the mixing water to it. After stirring it for 240s, put the obtained mixed material into a mold of 40mm × 40mm × 160mm. Subsequently, it was placed on a vibrating table for vibrating treatment, and the time was maintained at about 20s. After that, put the mixed materials directly into the molding room for placement. After waiting for 24 hours, the mold can be demolished. At the same time, the test block is put into the curing room for curing as required.

### Table: Modulus (%) of River Sand and Nakasago

| Material       | Modulus (%) | ≤5mm |
|----------------|-------------|------|
| River Sand Nakasago | 2.6         | 1.9  |

2.2. Preparation of Silane-silica Sol Hybrid Material

#### 2.2.1. Raw Material Preparation
The raw materials that need to be prepared in the course of this experiment mainly include silane materials, emulsifiers, and distilled water for the mixing treatment of hybrid materials in order to obtain reliable mixing materials. Among them, the commonly used monomer material for silane materials is isobutyl triethoxy silane, which has good waterproof genes and penetration depth. Emulsifiers are used to improve the application effect of silane materials. Commonly used emulsifiers are Span80 and PPG O.

#### 2.2.2. Preparation Process
In the specific material preparation process, the following application steps need to be paid attention to. In the first step, the oil phase is prepared, and a certain proportion of silane monomer and PPG O are thoroughly mixed together. Afterwards, put it into a homogenizer and stir it. The rotation speed during mechanical operation should be controlled at 10000-20000r/min, and the time should be controlled at 5-15min. This can ensure the uniformity of the prepared materials. The second step is to prepare the water phase. Mix a certain proportion of Span80 and dispersant together. Then, put it into the homogenizer and stir it. During mechanical operation, the speed should be controlled at 10000-20000r/min, and the time should be controlled at 5-15min. In this way, a mixed solution with higher uniformity can be obtained. In the third step, the first two solutions are evenly mixed together.

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Afterwards, put it into a mixer for processing, the initial rotation speed is 10000-20000r/min. Then, slowly add the oil phase to it, keep a constant speed for uniform mixing. In this way, the required preparation materials can be obtained and the reliability of the preparation results can be improved.

3. ANALYSIS OF THE INFLUENCE OF MATERIALS ON THE PERFORMANCE OF CEMENT-BASED MATERIALS

3.1. Water Permeability

3.1.1. Water Penetration Test

During the test, the silane-silica sol hybrid material was coated on the surface of the material, and the control group was the cement block in the initial state. We need to add distilled water in the sealed water storage tank, the water volume is controlled at about 80%, and the corresponding gap is reserved. Subsequently, we should use a syringe to inject gas into it. When the gas pressure in the enclosed space reaches 500 mbar, the flow regulating valve in the water storage tank is closed, and the water seepage volume of the concrete material at different times is recorded. According to the experimental data, it can be understood that compared with the concrete test block of the blank control group, the test block coated with silane-silica sol hybrid material. Its average water permeability index is around 55.3, and the coefficient has dropped by 45.6%. Moreover, its effect will increase with the increase of cement strength, which has strong applicability.

3.1.2. Capillary Water Absorption Test

During the test, it is also necessary to coat the silane-silica sol hybrid material on one surface of the material, and seal the other surface with epoxy resin. The control group is the cement block in the initial state, and the same treatment is carried out to ensure the orderliness of the experiment. Add distilled water to the water tank, the amount of water is controlled at about 50%, and the corresponding gap is reserved. Then, the cement block coated with the silane-silica sol hybrid material was brought into contact with the water surface of the sink with a depth of 5 mm, and the mass of the material was weighed at two-hour intervals. In this way, the capillary coefficient of the coated material can be calculated. According to the experimental data, the capillary water of the test block coated with the silane-silica sol hybrid material decreased by 85.6% compared with the concrete test block of the blank control group. Moreover, the effect will increase with the increase of cement strength, which has strong use value.

3.1.3. Capillary Water Absorption Test of Damaged Cement-based Materials

During the test, the silane-silica sol hybrid material needs to be coated on one surface of the material, and the other surface is sealed with epoxy resin. The control group is the cement block in the initial state, and the same treatment is carried out to ensure the orderliness of the experiment. The experimental procedure of capillary water absorption is the same as above. But in the treatment of experimental variables, we need to use polishing equipment. The surface layer is polished 1mm each time, and then immersed in the water tank, and the material quality is weighed at two-hour intervals. In this way, the capillary coefficient of the coated material can be calculated, and the sanding operation can be repeated multiple times to obtain the changing law of the material’s capillary water absorption under different damage conditions. According to the experimental data, it can be understood that in the 1~5mm wear test, the coefficient changes are 33.%, 72.5%, 195.2%, 243.7% and 303.2%, respectively. This also shows that the material has good protective properties and can be used for material protection.
3.2. Gas Permeability

3.2.1. Gas Penetration Test
During the test, the silane-silica sol hybrid material was coated on the surface of the material, and the control group was the cement block in the initial state. During the experiment, we need to use a syringe to inject gas into the sealed storage. When the gas pressure in the closed space reaches 500mbar, the flow regulating valve in the storage is closed. The entire test process time is controlled above 6, and the air pressure attenuation value of the concrete material at different times is recorded. According to the experimental data, it can be understood that the gas penetration test is similar to the concrete test block of the blank control group, which is coated with a silane-silica sol hybrid material. The air pressure attenuation value is in a state of decline, and the air permeability index has also declined, but the value has been in the range of 0.1ln/min. This indicates that the material has good air permeability and will not interfere with the air permeability of the material in its initial state.

3.2.2. Accelerated Carbonization Test
During this test, we need to coat the silane-silica sol hybrid material on one side of the material and cover the other side with epoxy resin. Subsequently, we should put the material in a closed space with a humidity of 70±5%, an ambient temperature of 20±2℃, and no carbon dioxide inside, and then pass carbon dioxide into it after the basic indicators meet the requirements. Then, we took out the materials under different experimental days and split them. Meanwhile, we need to use phenolphthalein reagent to treat the cleavage surface, and the pink part indicates that it has not been carbonized. The non-discoloring part indicates that it is carbonized. A number of detection points are randomly selected, and the distance between it and the coverage surface is measured to calculate the carbonization depth. As shown in Figure 1, according to the experimental data, it can be understood that the carbonization depth of the test block coated with the silane-silica sol hybrid material is reduced by 35.8% compared with the concrete test block of the blank control group. It can be seen that the material has strong carbonization resistance, which can protect the material to a certain extent.

3.3. Ion Permeability

3.3.1. Capillary Salt Absorption Test
During this test, we need to coat the silane-silica sol hybrid material on one side of the material. The other surfaces are sealed with epoxy resin. The control group is the cement block in the initial state. We
need to treat it in the same way to ensure the order of the experiment. We need to add 10% sodium chloride solution in the sink, reserve the corresponding gap, and contact the cement block coated with the silane-silica sol hybrid material to the surface of the sink. The depth is 5mm, and the data is collected at 14d intervals. The sampling needs to be dried in a 50℃ constant temperature box. Two days later, we need to sample the powder from the surface of the test block to obtain the chloride ion change curve. According to the experimental data, it can be understood that the chloride ion migration speed and depth of the test block coated with the silane-silica sol hybrid material decreased by 65.3% compared with the concrete test block of the blank control group. Moreover, it reaches a stable state at the position of 5mm, which has strong stability [1].

3.3.2. Chloride Ion Migration Test
During the experiment, the basic processing content was consistent with the marked content in the previous article. In order to accelerate the chloride ion migration rate experiment, we will put the processed cement block into 0.3mol/L NaOH solution. It serves as the anode of the electrolyte, while the cathode uses a 10% sodium chloride solution. After completing the electrolysis experiment, we will take out the test block for splitting, and at the same time use silver nitrate solution to treat the splitting surface, and the white part indicates penetration. The non-discoloring part indicates that it has not been penetrated. A number of detection points are randomly selected, and the distance between it and the coverage surface is measured to calculate the penetration depth. According to the experimental data, the penetration depth of the test block coated with the silane-silica sol hybrid material decreased by 25.8% compared with the blank control group. Moreover, its diffusion coefficient has also decreased, which has a good protective effect for the material [2].

3.4. Freeze-thaw Resistance
During the test, the researcher will put the cured test block into distilled water and soak it until the material mass increase is less than 1mg, then take the test block out to complete the overall coating work of the material. Then, put it into the freeze-thaw cylinder, put the test block into it, pour clean water into it, and start the quick freeze-thaw experiment. The freezing time is controlled at 120min and the thawing time is controlled at 80min. Repeat this operation several times. After waiting for the material mass loss to exceed 5%, stop the experiment, and then calculate the cycle loss rate, and then analyze the relevant parameter information. According to the experimental data, it can be understood that the test block coated with the silane-silica sol hybrid material has a strong freeze-thaw performance. In 150 repeated experiments, the elastic modulus of ordinary materials has dropped by 60%, while the modulus of concrete blocks of coated materials has only dropped by 0.6%. This has a good protective effect for the material [3].

3.5. Material Mechanism Analysis
3.5.1. Infrared Spectrum Test
During the test, the researcher will dry the cured material first. Subsequently, the researchers will apply the silane-silica sol hybrid material on the surface of the material, wait for it to be completely absorbed, scrape the 2mm powder from the cement block, and divide it into several groups after sieving. Researchers need to use Fourier infrared spectrometer to illuminate and collect corresponding data information. As shown in Figure 2, according to the feedback map data, it can be understood that the test block coated with the silane-silica sol hybrid material has two characteristic peaks at a wavelength of 300 microns, namely the absorption peak of the alkyl group. This also shows that the material has good hydrophobicity after application, which can reduce water erosion [4].
3.5.2. Surface Microscopic Observation
During the test, a silane-silica sol hybrid material was applied on the surface of the material. Researchers will wait for it to be completely absorbed before spraying gold on the surface of the material. Subsequently, researchers need to observe under an electron microscope to determine the nature of the elements inside the material. The specific graphics are shown in Figure 3. It can be seen from the figure that white crystalline material has appeared on the surface of the material, and the foggy material indicates that the material has formed a protective layer on the surface of the concrete, and its properties are relatively stable [5].

3.5.3. X-diffraction Test
In the test process, the researchers need to dry the curing material, and then apply the silane-silica sol hybrid material on the surface of the material. After waiting for it to be completely absorbed, scrape the 2mm powder from the cement block and divide it into several groups after sieving. Researchers need to use X-ray diffractometer to irradiate and collect corresponding data information. According to the feedback map data, it can be understood that the SiO2 peak value of the test block coated with the silane-silica sol hybrid material has increased significantly. This shows that the material and concrete have a secondary reaction, which improves the material properties [6].
3.5.4. Comprehensive Thermal Analysis Test
During the test, the pre-processing content was consistent with the above steps. After obtaining the required samples, the researchers will place them in an environment of 0-1400°C for comprehensive thermal analysis, calculate the heat loss at different temperatures, draw the corresponding curves after summarizing, and then check the fusion between the materials. According to the relevant data, it can be understood that when the temperature is lower than 600°C, the heat loss fluctuates little, and the heat loss after the temperature exceeds this temperature is basically the same as the ordinary test block. It can be seen that the application of materials has also improved the heat resistance of concrete [7].

4. CONCLUSION
In summary, combining the relevant data and information obtained above, it can be understood that the application of silane-silica sol hybrid materials to cement-based materials has good promotion value. It can not only effectively improve the initial performance of the material, but also improve the durability of the material.

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