

# Research and performance analysis of water-resistant phosphogypsum masonry materials

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**Abstract.** Phosphogypsum is a solid waste produced by the phosphoric acid industry. With the development of the phosphoric acid industry, the emissions of phosphogypsum are increasing year by year and its recycling rate is low. The environmental problems caused by tailings storage are becoming increasingly serious. The chemical formula of the main component of phosphogypsum is  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ . its performance is similar to that of natural gypsum. Using phosphogypsum as a raw material to produce phosphorus building gypsum is one of the main ways to utilize phosphogypsum resources. However, phosphogypsum building materials have poor water resistance and low strength, which greatly limits their application. Based on the analysis of the poor resistance mechanism of phosphogypsum, this paper analyzed and studied the mechanical and water resistance properties of phosphorus building gypsum by separately adding different amounts of polyvinyl alcohol and silane emulsion and mixing polyvinyl alcohol and silane emulsion. The conclusion is that adding waterproofing agents and water-reducing agents can greatly improve the water resistance of phosphogypsum building materials.

**Keywords:** Phosphogypsum, Water Resistance, Compressive Strength, Water Absorption, Softening Coefficient

## 1. Preface

With the development of urbanization and the increasing shortage of land resources, the environmental problems caused by the extensive management of phosphogypsum, a solid waste of the phosphoric acid industry, have become more and more acute due to the tailings stockpile. The resource utilization of phosphogypsum has gradually been adopted in various places. The government included it in the regional development plan list. Currently, phosphorus building materials products on the market mainly include phosphogypsum blocks, lightweight partition boards, phosphogypsum ceilings, cementitious materials, floor mortars, etc. Limited by the low strength and poor water resistance of phosphogypsum, the promotion of phosphogypsum as a building material has been slow.

Li Long et al. <sup>[1]</sup> comparatively studied the effects of polycarboxylic acid, citric acid, and polyvinyl alcohol on the density, bonding strength, and water retention properties of phosphorus building gypsum. Polycarboxylic acid can effectively improve the density of the material, but it will leave behind in the hardened body. Cavities, adversely affecting strength. Chen Yayun et al. <sup>[2]</sup> comparatively studied the effects of three additives: polycarboxylic acid, formaldehyde-resistant sulfonate, and sulfonated melamine formaldehyde on the fluidity, water retention, and hydration properties of materials. Polycarboxylic acid and sulfonated melamine formaldehyde will hinder the development of calcium sulfate crystals affects the hydration process. Pan Zude et al. <sup>[3]</sup> used red mud as an activator and used filling methods to study the improvement of the mechanical properties and water resistance of the material. Wang Dong <sup>[4]</sup> used different brands of hydrophobic agents at home and abroad to influence the water absorption properties and softening coefficient of the material. The results show that The water resistance effects of different brands vary greatly.

Based on the above analysis, this article studied the effects on the mechanical properties and water retention of phosphorus building materials by separately adding different ingredients of

waterproofing agent silane emulsion and water-reducing agent polyvinyl alcohol, and by compounding different ingredients of silane emulsion and polyvinyl alcohol.

## **2. Reasons for poor water resistance of phosphorus building materials and improvement measures**

Phosphorus building materials themselves have defects such as gaps and tiny holes, and there will be certain stress in local locations during the tissue formation process. These factors lead to low strength of phosphorus building materials; the contact angle between calcium sulfate dihydrate and water is less than  $90^\circ$ , and it is hydrophilic. Excellent performance leads to poor water resistance [5].

Based on the characteristics of phosphorus building materials, inorganic materials such as silica fume and kaolin can be added to fill cracks and holes; water-reducing agents are added to reduce water consumption, making the structure porosity lower and denser; waterproofing agents are added to increase the hydrophobicity of pores and reduce the material's Water absorption and other methods can improve the water resistance of materials.

## **3. experiment method**

### **3.1 Experimental group design**

(1) Test group with polyvinyl alcohol added alone: Weigh 120g of polyvinyl alcohol raw material, and set the experimental group to a blank group with polyvinyl alcohol content of 0.1%, 0.3%, 0.5%, 0.7%, 1.0%, and 1.5% in total 7 Group experimental group.

(2) Individually added silane emulsion test group: Measure 120 mL of silane emulsion, and set up a blank group and a total of 7 experimental groups with silane emulsion content of 0.1%, 0.5%, 1.0%, 1.5%, 1.7%, and 2.0%.

(3) Polyvinyl alcohol and silane emulsion composite addition group: Weigh 120g of polyvinyl alcohol and 120mL of silane emulsion. According to the blank group, add 0.1%, 0.1%, 0.3% and 0.5 of polyvinyl alcohol and silane emulsion respectively. %, 0.5%, 1.0%, 0.7%, 1.5%, 1.0%, 1.7%, 1.5%, 2.0% to prepare 7 experimental groups.

### **3.2 Specimen preparation**

When preparing the specimens, each experimental group weighed 1,400g of phosphogypsum mortar, and prepared blank groups [6], separate mixing groups with different amounts, and composite mixing groups to make specimens according to the experimental groups. The overall dimensions of each group were 70.7 There are 6 cubic test blocks of  $70.7 \times 70.7 \times 70.7$ mm, 3 of which are divided into one group for soaking and drying comparison. The reagent and the required water are added to the phosphogypsum. Use a hand-held electric mixer to fully stir until it is gelled. Then pour it into a test mold of  $70.7 \times 70.7 \times 70.7$ mm. After final setting, remove the mold and mark it. The temperature is  $20 \pm 2^\circ\text{C}$ , humidity  $\geq 95\%$  standard curing room for 7 days. [7] The drying group of qualified specimens is placed in a drying box for drying, and the soaking group is placed in a soaking box for a soaking treatment of not less than 24 hours.

### **3.3 Performance index determination**

Mechanical property measurement: Refer to the national standard "Determination of the Mechanical Properties of Building Gypsum" (GB/T17669.3-1999) [8] to conduct flexural and compressive strength tests of the test block.

Determination of water absorption rate: After soaking for 24 hours in the soaking group, use paper towels to wipe off the moisture on the surface of the specimen, then weigh the mass of the specimen, and use the following formula to calculate the water absorption rate:

$$w = \frac{m_1 - m_0}{m_0}$$

In the formula: w-water absorption rate

m1 - wetted mass

m0 - absolute dry mass

Determination of softening coefficient: Determine the compressive strength of the dried specimen and the compressive strength of the soaked specimen, recorded as F and f respectively. Use the following formula to calculate the softening coefficient K:

$$K = \frac{f}{F}$$

## 4. Experimental results and analysis

### 4.1 Effect of polyvinyl alcohol alone on the properties of phosphogypsum

#### (1) Impact and analysis on mechanical properties

1 group of blank and 6 groups of test comparison groups were tested for mechanical properties in accordance with relevant specifications to explore the effects of different amounts of polyvinyl alcohol alone on the mechanical properties of phosphorus building gypsum. The test results are as follows:

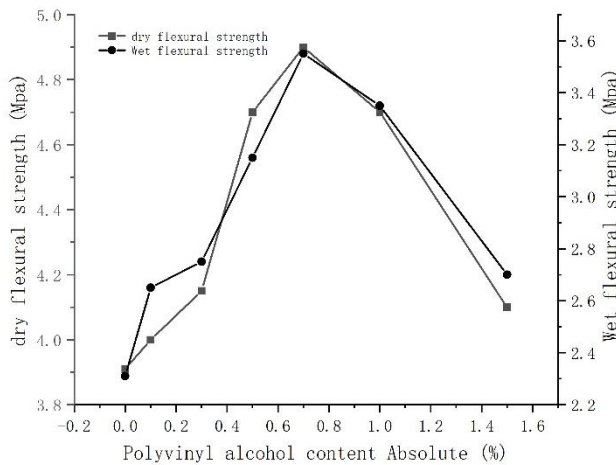


Fig. 3-1 Flexural strength

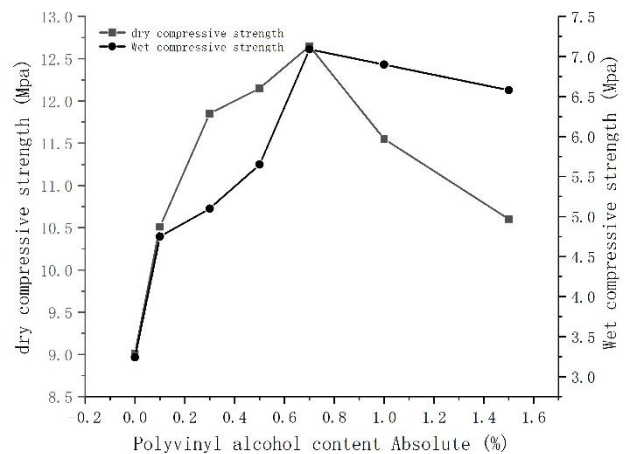


Fig. 3-2 Compressive strength

By studying the effect of polyvinyl alcohol content (0% to 1.5%) on mechanical properties, it can be concluded that as the polyvinyl alcohol content gradually increases, the absolute dry, wet flexural strength and compressive strength of phosphorus building gypsum are the same. It shows a trend of rising first and then falling, but the strength growth of the absolutely dry group is not obvious, while the strength growth of the wet group is relatively obvious. When the dosage is 0.7%, the flexural strength of the wet group and absolute dry group are 3.55Mpa and 4.90Mpa respectively. Compared with the blank group, the strength increases by 53.6% and 25.1% respectively. The compressive strength of the soaked group and absolutely dry group were 7.09Mpa and 12.65Mpa respectively. Compared with the blank group, the strength increased by 60.1% and 26.5% respectively.

The main reason is that polyvinyl alcohol increases the contact angle between calcium sulfate dihydrate and water, reduces its hydrophilicity, and reduces the amount of water used for mixing, making the structure porosity lower and the structure denser. However, starting from the addition amount of 1.0%, as the addition amount increases, the viscosity of the specimen increases significantly and is difficult to stir. The reduced fluidity leads to pores inside the specimen, resulting in a decrease in strength.

#### (2) Impact and analysis on water resistance

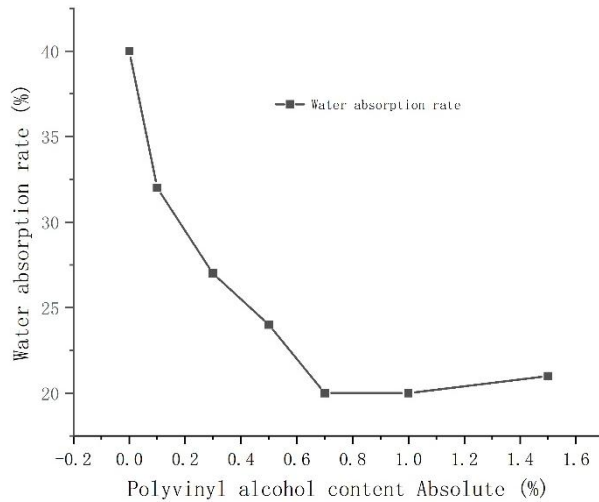


Fig. 3-3 Water absorption

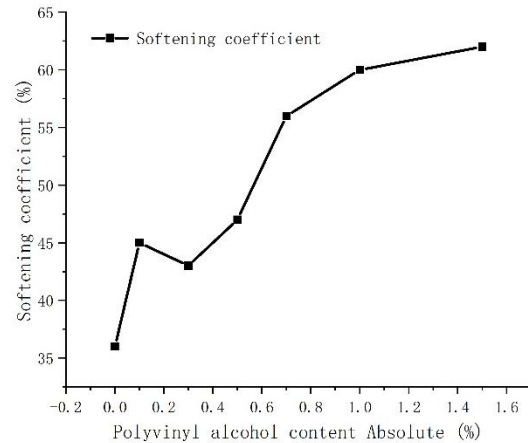


Fig. 3-4 Softening coefficient

By studying the effect of polyvinyl alcohol content (0% to 1.5%) on water resistance, it can be concluded that as the polyvinyl alcohol content gradually increases, the water absorption rate of phosphorus building gypsum shows a downward trend and the softening rate shows an upward trend. When the dosage is 0.7%, the water absorption rate and softening coefficient are 20% and 0.56 respectively. Compared with the blank group, the water absorption rate and softening coefficient decrease by 20% and increase by 20% respectively. The softening coefficient of the 1.0% and 1.5% groups still increased slowly, but the water absorption rate increased by 1% from the 0.7% to 1.5% group .

The main reason is that the addition of polyvinyl alcohol increases the structural density, but when the dosage reaches 1.0%, the viscosity begins to increase, and pores appear inside the configured specimen, resulting in enhanced water absorption performance of the specimen.

## 4.2 Effect of single-doped silane emulsion on the properties of phosphogypsum

### (1) Impact and analysis on mechanical properties

1 group of blank and 6 groups of test comparison groups were tested for mechanical properties in accordance with relevant specifications to explore the impact of different dosages of single-doped silane emulsion on the mechanical properties of phosphorus building gypsum. The test results are as follows:

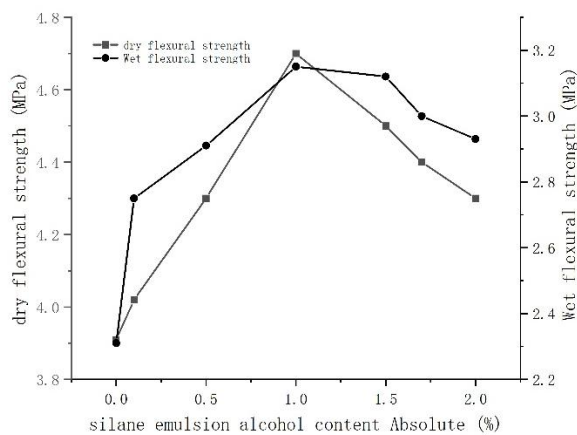


Fig. 3-5 Flexural strength

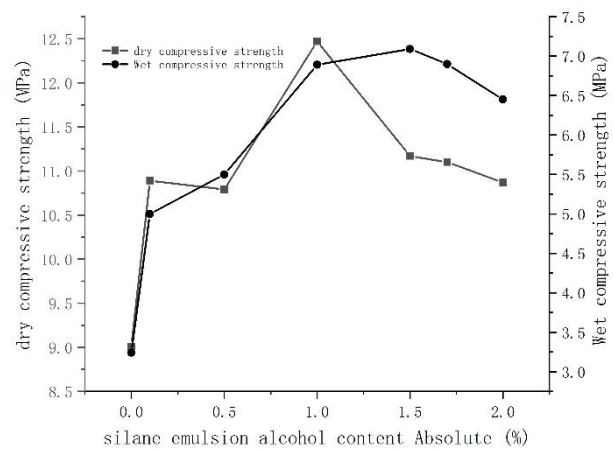


Fig. 3-6 Compressive strength

By studying the effect of silane emulsion content (0% ~ 2.0%) on mechanical properties, it can be concluded that as the silane emulsion content gradually increases, the absolute dry, wet flexural strength and compressive strength of phosphorus building gypsum all show an improvement. There is a downward trend after rising, but the strength increase of the absolutely dry group is not obvious, while the strength increase of the wet group is relatively obvious. When the dosage is 1.0%, the

flexural strength of the wet group and absolute dry group are 3.15Mpa and 4.70Mpa respectively. Compared with the blank group, the strength increases by 36.4% and 20.2%. The compressive strength of the soaked group and absolutely dry group were 6.89Mpa and 12.47Mpa respectively. Compared with the blank group, the strength increased by 50.2% and 22.5% respectively.

The main reason is that the infiltration of silane emulsion will form a hydrophobic film attached to the surface of the calcium sulfate dihydrate crystal, which will affect the overlapping mechanism of the crystal, resulting in incomplete crystal development and insignificant strength growth.

#### (2) Impact and analysis on water resistance

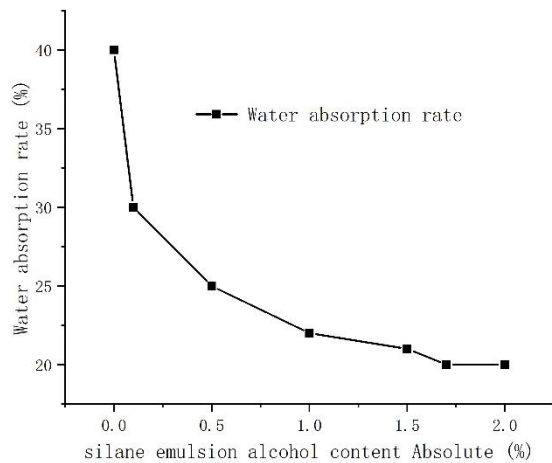


Fig. 3-7 Water absorption

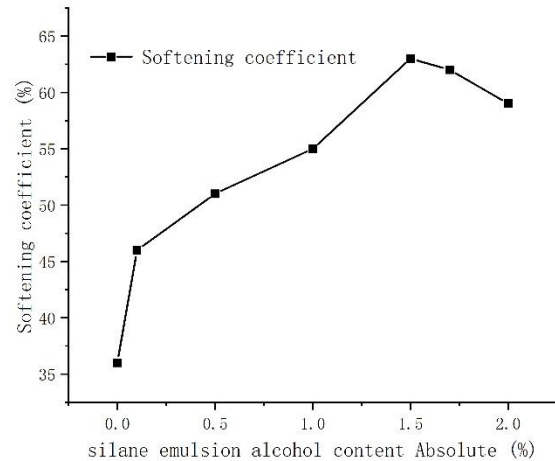


Fig. 3-8 Softening coefficient

By studying the effect of polyvinyl alcohol content (0% to 2.0%) on water resistance, it can be concluded that as the silane emulsion content gradually increases, the water absorption rate of phosphorus building gypsum shows a downward trend and the softening rate shows an upward trend. When the dosage is 1.0%, the water absorption and softening coefficient are 22% and 0.55 respectively. Compared with the blank group, the water absorption and softening coefficient decrease by 18% and increase by 19% respectively.

The main reason is that the silane emulsion increases the hydrophobicity of the pores, reduces the water absorption rate of the material, and has the effect of "locking water" through surface tension<sup>[9]</sup>, blocking external moisture from penetrating into the structure.

### 4.3 Effect of compound addition of polyvinyl alcohol and silane emulsion on the properties of phosphogypsum

#### (1) Impact and analysis on mechanical properties

One blank group and six experimental control groups were subjected to mechanical property tests according to relevant specifications to explore the effects of different dosages of composite polyvinyl alcohol + silane emulsion (polyvinyl alcohol, silane emulsion content 0.1%, 0.1%, 0.3%, 0.5%, 0.5%, 1.0%, 0.7%, 1.5%, 1.0%, 1.7%, 1.5%, 2.0%) on the mechanical properties of phosphorus building gypsum. The test results are as follows:

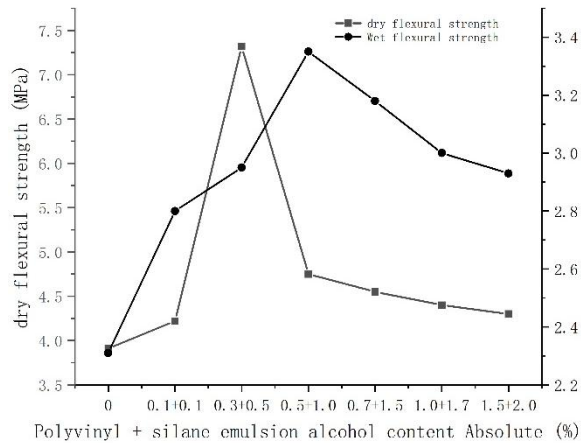


Fig. 3-9 Flexural strength

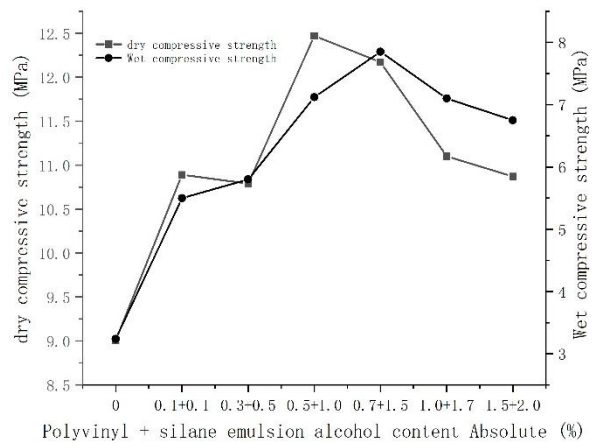


Fig. 3-10 Compressive strength

By studying the effects of the combination of polyvinyl alcohol content (0% ~ 1.5%) and silane emulsion content (0% ~ 2.0%) on mechanical properties, it can be concluded that as the combination content gradually increases, the absolute performance of phosphorus building gypsum will increase. The dry and wet flexural strength and compressive strength both showed an increase first and then a downward trend. Similar to the case of single doping, the strength increase of the absolute dry group was not obvious, while the strength increase of the wet group was relatively obvious. The combined flexural strength of the wet group and absolute dry group with a polyvinyl alcohol content of 0.5% and a silane emulsion content of 1.0% were 3.18Mpa and 4.55Mpa respectively. Compared with the blank group, the strength increased by 45.1% and 21.5%. The compressive strength of the soaked group and absolutely dry group were 7.12Mpa and 12.47Mpa respectively. Compared with the blank group, the strength increased by 58.1% and 25.5% respectively.

The main reason is that polyvinyl alcohol and silane emulsion increase the contact angle between calcium sulfate dihydrate and water and reduce its hydrophilicity. [10] Reducing the amount of mixing water makes the structural porosity lower and the structure denser, while improving the material's durability. Hydrophobicity.

## (2) Impact and analysis on water resistance

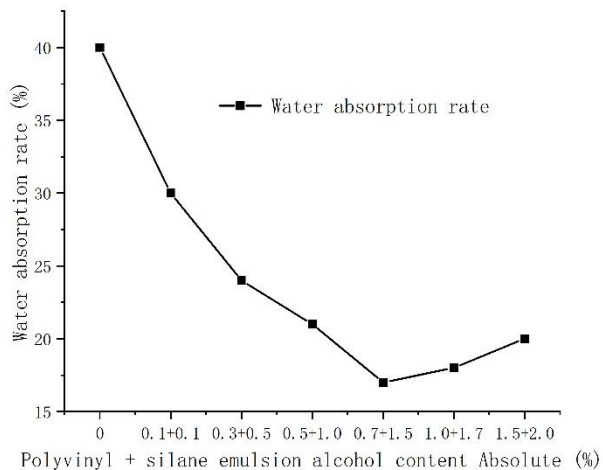


Fig. 3-11 Water absorption

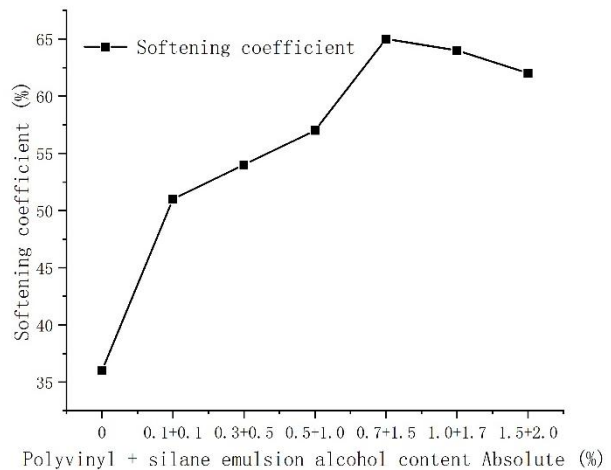


Fig. 3-12 Softening coefficient

By studying the effect of the combination of polyvinyl alcohol content (0% ~ 1.5%) and silane emulsion content (0% ~ 2.0%) on water resistance, it can be concluded that as the content gradually increases, the water absorption rate of phosphorus building gypsum It shows a downward trend and the softening rate shows an upward trend. When the polyvinyl alcohol content is 0.7% + the silane emulsion content is 1.5%, the water absorption rate and softening coefficient are 17% and 0.65 respectively, which are 23% lower and 20% higher than the blank group respectively.

## 5. Conclusion

At present, the utilization rate of phosphogypsum resources underground in the world basically adopts the extensive management of tailings stockpiling. The environmental problems caused by it are becoming increasingly severe, and the resource utilization of phosphogypsum has gradually been included in the regional development planning list by local governments. Currently, phosphorus building materials products on the market mainly include phosphogypsum blocks, lightweight partition boards, phosphogypsum ceilings, cementitious materials, floor mortars, etc. Due to the strong hydrophilicity and large porosity of the phosphogypsum material itself, it has low strength and poor water resistance. Based on the analysis of the mechanism of poor resistance of phosphogypsum, this paper uses different amounts of polyvinyl alcohol and silane emulsion separately and mixed blending of polyvinyl alcohol and silane emulsion to analyze the mechanical and water resistance properties of phosphogypsum building gypsum and draw the following conclusions:

(1) Use the water-reducing agent polyvinyl alcohol to increase the contact angle between calcium sulfate dihydrate and water, reduce its hydrophilicity, reduce the amount of mixing water, and make the structural porosity lower and the structure denser. The recommended dosage is 0.5%-1.0%. The flexural strength of the wet group and absolute dry group can reach 3.55Mpa and 4.90Mpa respectively. Compared with the blank group, the strength increases by 53.6% and 25.1% respectively. The compressive strength of the soaked group and absolutely dry group can reach 7.09Mpa and 12.65Mpa respectively. Compared with the blank group, the strength increases by 60.1% and 26.5% respectively. The water absorption rate and softening coefficient were 20% and 0.56 respectively. Compared with the blank group, the water absorption rate and softening coefficient decreased by 20% and increased by 20% respectively.

(2) The use of waterproofing agent silane emulsion increases the hydrophobicity of the pores and reduces the water absorption rate of the material. The recommended dosage is 1.0%-1.5%. The flexural strength of the wet group and absolute dry group can reach 3.15Mpa and 4.70Mpa respectively. Compared with the blank group, the strength increases by 36.4% and 20.2% respectively. The compressive strength of the soaked group and absolutely dry group can reach 6.89Mpa and 12.47Mpa respectively. Compared with the blank group, the strength increases by 50.2% and 22.5% respectively. The water absorption rate and softening coefficient were 22% and 0.55 respectively. Compared with the blank group, the water absorption rate and softening coefficient decreased by 18% and increased by 19% respectively.

(3) The water-reducing agent polyvinyl alcohol + waterproofing agent silane emulsion is mixed to reduce the hydrophilicity of phosphorus building gypsum, improve the structural compactness, and increase the hydrophobicity of the pores. The recommended dosage is a combination of 0.5% polyvinyl alcohol and 1.0% silane emulsion. The flexural strength of the wet group and absolute dry group can reach 3.18Mpa and 4.55Mpa respectively. Compared with the blank group, the strength increases by 45.1% and 21.5% respectively. The compressive strength of the soaked group and absolutely dry group can reach 7.12Mpa and 12.47Mpa respectively. Compared with the blank group, the strength increases by 58.1% and 25.5% respectively. When the polyvinyl alcohol content is 0.7% + the silane emulsion content is 1.5%, the water absorption rate and softening coefficient can reach 17% and 0.56 respectively. Compared with the blank group, the water absorption rate and softening coefficient decreased by 23% and increased by 20% respectively.

the composite dosage group is basically the same as that of the single dosage group, and the water absorption rate is reduced by 3% and 1% respectively compared with the single addition of polyvinyl alcohol and silane emulsion. The softening coefficient increases by 0% and 1% respectively compared with adding polyvinyl alcohol and silane emulsion alone.

This research has excellent results under laboratory conditions, but there are many uncontrollable and unpredictable factors in actual construction in the construction industry. In actual engineering, certain improvement measures still need to be taken on the basis of considering economic costs, construction efficiency, and quality.



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