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Properties of Mineral Powders Modified Foamed Concrete

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Abstract. *In order to improve the stability of lightweight foamed concrete, the particle-stabilized foam (PSF) has been proposed because of its high stability. However, most PSFs added particles to foams, and few researchers have investigated whether the stabilization effect exists when particles are added to the paste. In this study, a new type of foamed concrete was prepared by adding different kinds of mineral powders to cement and using ionic surfactants to prepare foam. The influence of different mineral powders on the mechanical properties and durability of foamed concrete was investigated. Results showed that mineral powders decreased the drainage and disproportionation of foam, which stabilizes the foam. The excellent stability is attributed to the interaction between the mineral powders and ionic surfactants, which allows the mineral powders to adhere to the foam surface and form a dense granular film layer. Moreover, due to the interaction between mineral powders and ionic surfactants, hardened foamed concrete has a robust pore structure, which improves its properties.*

Keywords: *mineral powders, foamed concrete, particle stabilize foam.*

1 Introduction

Foam concrete is a kind of lightweight porous insulation material, which has the advantages of low density, good flow, low thermal conductivity and good fire resistance. It has been widely used in the field of construction materials (Shi et al. 2022, Ramamurthy et al. 2009, Zhang et al. 2022). The properties of foam concrete are affected by its unique pore structure, so the foam properties have a greater impact on foam concrete properties (Nambiar et al. 2007). Foam is an unstable system composed of a large number of bubbles, and its destruction includes the discharge of liquid, the rupture of liquid film, and Oswald ripening (Koehler et al. 2004). The instability of the foam can lead to the collapse of the foam concrete and adversely affect the performance of the material (Cilek et al. 2015, Dhasindrakrishna et al. 2020). The instability of foam seriously affects the application of foam concrete in practical engineering (Jones et al. 2016).

Particle-stabilized foam is the traditional Solid-gas-liquid three-phase foam by introducing a solid substance on the surface to achieve the effect of bubble stabilization, this kind of stable foam has been widely used in the chemical industry, food and oil fields (Murray and Ettelaie 2004). Adding nano or micron scale particles to the foam system can create more stable foam

(Vijayaraghavan 2006). The main mechanism of particle-stabilized foam is that particles gather at the gas-liquid interface and reduce the contact area between bubbles. The dense particle film formed can inhibit the coalescence and disproportionation of bubbles. At the same time, a three-dimensional network structure is formed between the foam surface and the continuous phase, and the liquid film's discharge time is prolonged (Dandamudi et al. 2018, Horozov 2008). Many studies have been carried out on the effect of particles as a stabilizer on foam stability (Binks and Lumsdon 2006). Unlike surfactants, desorption is difficult once solid particles are adsorbed at the gas-liquid interface, which significantly increases the stability of the foam. The following are the research results of different scholars on the stability of solid particles on foam.

Xiong et al. (2021) showed that the stability, density and viscosity of foams prepared by plant protein-based surfactants (PS), animal protein-based surfactants (AS) and synthetic surfactants (SS) with similar functional groups, density and stability can be enhanced by the addition of NA. There are still many scientific problems in the application of solid particle-stabilized foam (PSF) in the field of foamed concrete, such as the matching rule and interaction mechanism between other solid particles and surfactants, and the influence mechanism of different environments on the interaction between solid particles and surfactants. The research and application of solid particle stabilized foam in the field of building materials is still in its infancy, and there are some problems such as high solid particle consumption, high foam density, low foaming amount and high cost, which still need further research and exploration.
In this paper, different kinds of minerals such as calcite, montmorillonite, kaolinite and muscovite were mixed with cement respectively to prepare cement paste, and foam prepared by SDS and DTAB was added into the cement paste to prepare foamed concrete. The effects of different mineral powders on foam stability and cement paste were studied. The effects of different mineral powders on the properties of foamed concrete are also studied. In addition, SDS and DTAB are oppositely charged surfactants, and their interaction with different types of minerals on the performance of foam concrete is worth studying.

2 Materials and Methods

2.1 Materials

Ordinary Portland cement P.O 42.5 was used in this work. The physical properties of cement are listed in Table 1. Calcite, Montmorillonite, Kaolinite and Muscovite used in the study were obtained from Shanlinshiyu Mineral Products Co., LTD. (Hunan, China). The particle size distributions of the mineral powders are shown in Fig. 1.

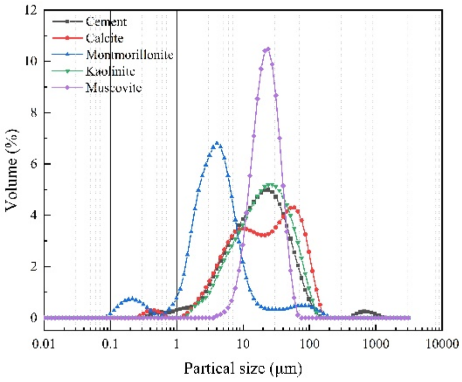

Figure 1. Particle size distributions of raw materials.

Two foaming agents were used in this study. Sodium dodecyl sulfate SDS was selected as an anionic surfactant. Dodecyl trimethyl ammonium bromide DTAB was selected as a cationic surfactant. SDS and DTAB are common surfactants.The water used in the experiment was tap water. In this study, the concentration of foaming agents was controlled at 10 g/L to reduce concentration interference (Hou et al. 2021). The settling distance and bleeding capacity of prefabricated foam are important performance indexes for evaluating prefabricated foam. The two foaming agents were foamed by F80 portable bubbler. The density of DTAB and SDS is 22.38 Kg/m^3 and 37.77 Kg/m^3. The changes in settling distance and water secretion of prefabricated foam within 1 h were measured with reference to Chinese standard "Foaming agents for foamed concrete" JCT2199-2013, and the results are shown in Figure 2.

2.2 Preparation of Sample

2.2.1 Preparation of foamed concrete

Cement paste specimens were produced from cement, water and mineral powders. The mix proportions of cement paste are summarized in Table 2. For each mixture, three 100 × 100 × 100 mm prisms were prepared and covered with plastic film and left in the casting room at 23 ± 2 °C for 24 h. The specimens were then demolded and cured in water at 23 ± 2 °C until the time of testing.

Table 1. Physical properties of cement.

Loss-on-Ignition (%)	SO_3 (%)	MgO (%)	Specific Surface (m^2/kg)	Initial Setting Times (min)	Final Setting Times (min)	Invariabilit y	Chloride lon Content (%)
3.54	1.85	0.76	337	197	247	Pass	0.015

2.2.2 *Preparation of cement paste*

Cement paste specimens were produced from cement, water and mineral powders. The mix proportions of cement paste are summarized in Table 2 and without adding foam.

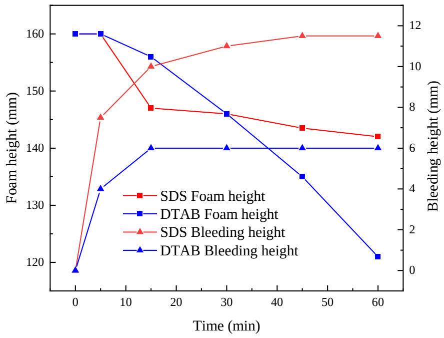

Figure 2. Sedimentation rate and bleeding rate of prefabricated foams.

2.3 Test Methods

2.3.1 *Properties of cement paste*

The fluidity of each cement paste was measured using a clean and dry truncated conical die placed on a horizontal board. The cone was held by hand to steady it on the plate while prepared foam concrete was poured into the die. The overflow was cut off with a scraper. Then, the die was gently lifted vertically to allow the slurry to spread freely. After 60 s, the diameter of the slurry was recorded as the fluidity of the foamed concrete.

Compressive and flexural strength was measured according to the Chinese standard "Test method for strength of cement mortar" (GB/T 17671-2021).

Table 2. Compositions of foamed concrete with different mineral powders.

Mix	Target density (kg/m^3)	Cement (kg)	Mineral powders (kg)	Water (kg)	W/C	Foam (m^3)
S	800	666.7	0	333	0.5	0.72
S-Cal	800	660	6.7	333	0.5	0.72
S-Mon	800	660	6.7	333	0.5	0.72
S-Kao	800	660	6.7	333	0.5	0.72
S-Mus	800	660	6.7	333	0.5	0.72
D	800	666.7	0	333	0.5	0.72
D-Cal	800	660	6.7	333	0.5	0.72
D-Mon	800	660	6.7	333	0.5	0.72
D-Kao	800	660	6.7	333	0.5	0.72

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S-Mon	800	660	6.7	333	0.5	0.72
S-Kao	800	660	6.7	333	0.5	0.72
S-Mus	800	660	6.7	333	0.5	0.72
D-Mus	800	660	6.7	333	0.5	0.72

2.3.2 Fluidity of fresh foamed concrete

The fluidity of the foam concrete paste was test with a hollow cylinder. The prepared foam concrete was poured into the hollow cylinder, and scraped flat with a scraper. Then the hollow cylinder was lifted vertically. After 30 s, the maximum diameter of slurry flow is the fluidity of foamed concrete. The above process was repeated three times, and the fluidity of fresh foamed concrete slurry was taken as the average of the three experimental results.

2.3.3 Properties of hardened foamed concrete

Compressive strength was measured according to the Chinese standard “Foamed concrete” (JG/T 266–2011) First, cubic specimens (100 mm × 100 mm × 100 mm) were dried in an oven at 60 ◦C for 24 h to reach a constant weight. Then, the compressive strength of the samples was measured using an electro-hydraulic servo rock multifunctional testing machine with a loading rate at 1.0 kN/s.

Dry density and water absorption tests were conducted following the Chinese standard ‘‘Foamed concrete” (JG/T 266–2011). First, 28-day cured specimens were dried at 60 ◦C until they lost less than 1 g per 4 h, and their weight at this time was taken as their actual dry weight (m_d). Subsequently, the sample was soaked in a tank of wood on the bottom. The increase in the mass (m_w) of the specimens immersed in water for minutes was measured, and the water absorption rate (W_a, %) of the specimens was calculated according to Equation (1), as follows:

$$w_a = \frac{m_w}{m_d} \times 100\% \quad (1)$$

The microstructures and morphologies of the foamed concrete were observed digital camera. Three parallel specimens were set up for each group of hardened foam concrete performance tests to eliminate the influence of experimental equipment errors.

3 Results and Discussion

3.1 Properties of Cement Paste

In order to study the effect of mineral powders on foam, the effect of mineral on cement paste should be studied first. The influence of different minerals on the fluidity of fresh cement slurry is shown in Table 4. The addition of calcite has little influence on the fluidity, while other minerals will reduce the fluidity, indicating that montmorillonite, kaolinite and Muscovite influence the fluidity of the fresh cement paste. The influence of different minerals on the mechanical properties of cement paste is shown in Figures 3 (a) and (b). The compressive and flexural strength of all specimens increased with time. After adding different mineral powders, the compressive and flexural strength of cement paste changed little. This may be because the content of mineral powders in this study is relatively small, which has little influence on cement hydration. It was concluded that a small number of mineral powders substituted into cement has little effect on cement hydration.

3.2 Properties of Foamed Concrete

3.2.1 Fluidity of fresh foamed concrete

In order to study the influence of different mineral powders on the fluidity of fresh foamed concrete, the influence of different mineral powders on the fluidity of fresh foamed concrete is shown in Table 4. Compared with the results in Table 4, it was found that the fluidity of the fresh slurry increased after the addition of foam. The two foaming agents have little effect on the fluidity of fresh foamed concrete. The different mineral powders have little influence on the fluidity of fresh foamed concrete. It can be seen that adding a small number of mineral powders has little effect on the fluidity of the fresh foamed concrete.

3.2.2 Properties of hardened foamed concrete

The effect of different mineral powders on the effect of different types of minerals on the dry density and porosity of 28 d foamed concrete are shown in Table 6. The dry density and porosity are inversely proportional. The higher the dry density, the lower the porosity. The reason why the dry density of S-Mus is lower than that of S and the porosity does not increase will be explained below.

The effect of different mineral powders on the compressive strength of the foam concrete is shown in Fig 4. From Fig. 4, it can be seen that the strength of all specimens increased with time. When the blowing agent is SDS, the results are shown in Fig. 4 (a), the strength of the foam concrete with the added minerals are all increased, the compressive strength is S-Mon > S-Kao > S-Mus > S-Cal > S. When the blowing agent is DTAB, the results are shown in Fig. 4 (b), the compressive strength is D-Kao > D-Mon > D-Cal > D > D-Mus, the addition of minerals has some effect on the compressive strength of the foam concrete. influence. Combined with the conclusion of 3.1, it can be known that the effect of minerals on the foam concrete is because of the action between different minerals and different charged foaming agents. The addition of minerals has an effect on the pores of the foam concrete, the closed pores increase and the open pores decrease, which in turn increases the compressive strength.

The effect of different mineral powders on the water absorption of foam concrete at 28 days is shown in Fig. 5, where the water absorption increases with the increase of time. Fig 5(a) shows that the magnitude of water absorption is S = S-Mus > S-Kao > S-Mon > S-Mus, and Fig 5(b) shows that the magnitude of water absorption is D > D-Mus > D-Mon. The addition of minerals optimizes the pore structure of the foam concrete and the number of closed pores increases, which in turn reduces the water absorption.

Table 3. Fluidity of cement paste.

Mix	Blank	Cal	Mon	Kao	Mus
Fluidity (mm)	151	150	125	134	128

The pore distribution of 28d foam concrete is shown in Figure 6. The pores of S, S-Mus and S-Cal are mainly distributed between 100-200um and the pore size of S-Mon, S-Kao is mainly distributed at 300um.The results of porosity in Table 6 are explained. S-Mus has a large proportion of small pores, so it has a greater number of pores with smaller porosity. The addition of minerals leads to a change in the pore structure distribution of the foam concrete with more small pores and narrower pore distribution for S-Mus. The pore size distribution is wider for S-Cal, S-Mon, and S-Kao. However, the strength and durability of the foam concrete increased by adding minerals. It may be that the enhancement mechanism of different minerals on the foam concrete is different, which is still to be further studied.

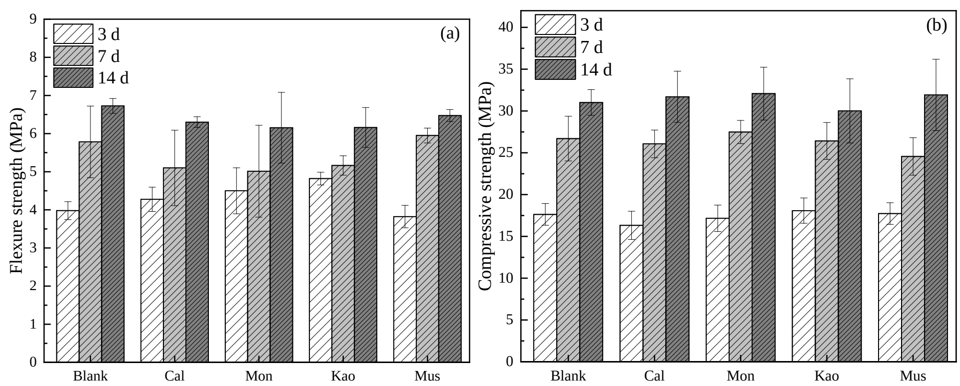

Figure 3. Properties of cement paste with different mineral powders

4 Conclusions

This study presents a new method to modify foamed concrete using mineral powders. Here are the results of foamed concrete prepared by this method:

- Adding mineral powders to foamed concrete can improve its compressive strength and reduce its water absorption. In this paper, the foaming agent is DTAB, the compressive strength of montmorillonite was the best, and the water absorption of calcite was the lowest. The foaming agent is DTAB, the compressive strength of kaolinite is the best, and the water absorption of montmorillonite is the lowest.

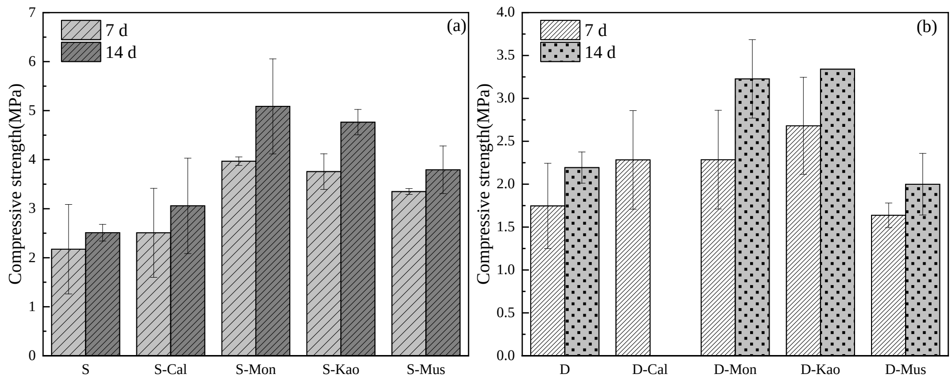

Figure 4. Compressive strength of foamed concrete with different mineral powders

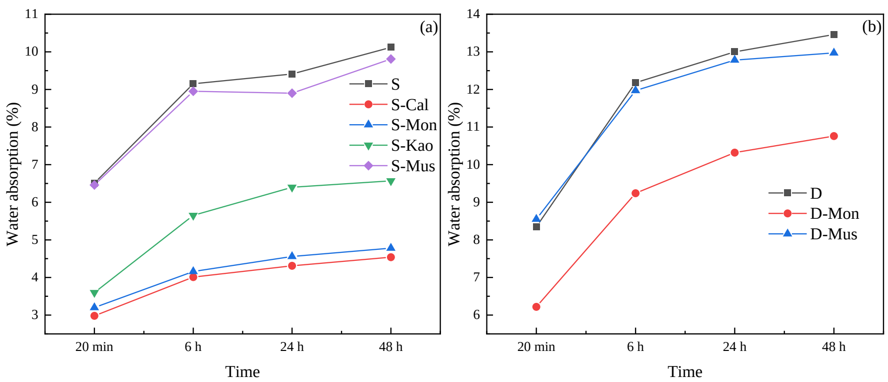

Figure 5. Water absorption of foamed concrete with different mineral powders

Table 4. Fluidity of foamed concrete with different mineral powders.

Fluidity (mm)	Blank	Cal	Mon	Kao	Mus
SDS	204	230	215	203	181
DTAB	204	226	220	182	186

Table 5. Dry density and porosity of foamed concrete with different mineral powders.

Mix	S	S-Cal	S-Mus	S-Mon	S-Kao
Dry density (Kg/m^3)	1031	1006	984	1122	944
Porosity (%)	39.362	41.926	35.8	33.234	44.675

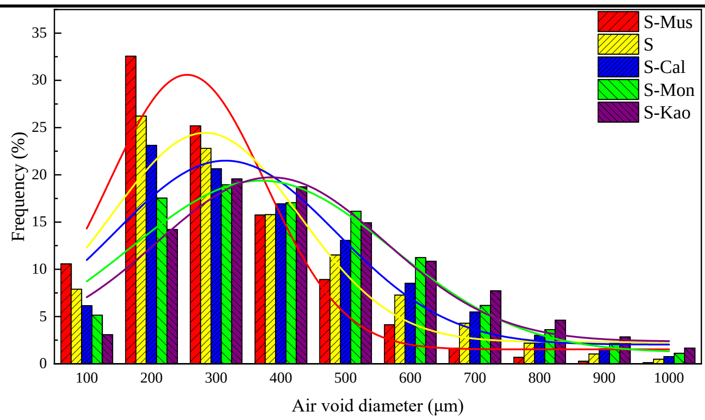

Figure 6. Water absorption of foamed concrete with different mineral powders

- The addition of mineral powders in foamed concrete will change the pore diameter of foamed concrete, and the pore diameter of different minerals is different. Compared with the blank group, the aperture distribution of S-Mus was narrower. The aperture distribution of S-Cal, S-Mon and S-Kao becomes wider. The mechanism behind it needs further study.

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