Study on Properties of Ultra-Light Thermal Insulation Foamed Cement-Based Composites

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Abstract. In this paper, ordinary portland cement, aerogel powder, graphite modified polystyrene (EPS) particles, foaming agent and additives were used to successfully prepare ultra-light insulation foamed cement-based composite with dry density of 120 kg/m³. The effects of graphite modified EPS particles on its density, mechanical properties and thermal conductivity were studied. The research results show that: When adding graphite modified EPS particles with volume content of 30%, the foam concrete has the best performance, with compressive strength of 0.25 MPa and thermal conductivity of 0.0326 W/(m·K); It shows that the compressive strength can be maximized and the thermal conductivity can be minimized when the filling amount of graphite modified EPS particles and the pore structure of foamed cement-based materials reach the best composite ratio.

1. Introduction
Foamed cement-based materials are concrete products containing a large number of fine closed pores and having considerable strength, which are made by introducing gas into slurry made of cement, admixture, admixture and water through physical or chemical methods, and then are stirred, formed and maintained[1]. Foamed cement-based material, namely foamed concrete, as an inorganic thermal insulation material containing a large number of closed pores, has the advantages of light weight, heat preservation, sound insulation, fire resistance, low cost, and waste utilization[2-4]. However, foam concrete has many problems, such as low strength, easy cracking, high water absorption and large drying shrinkage[5,6]. Ultra-light foamed cement-based materials usually have dry density ≤300 kg/m³. In practical application and research[7-9], the dry density of ultra-light foam concrete prepared by it is between 150~300 kg/m³, and its thermal conductivity is between 0.06 ~ 0.12 W/(m·K), which generally has the problems of high water absorption and low strength.

Polystyrene particles(EPS) have the characteristics of ultra-low density, good thermal insulation and good energy absorption. Because of their ultra-low density and good thermal performance, EPS particles are often considered as an ideal lightweight aggregate and added into concrete[10-12]. EPS cement is widely used in structural or non-structural parts of buildings[13, 14], for example, EPS concrete is used as structural lightweight concrete in a new structural system called light steel lightweight concrete[15]. EPS concrete has lower thermal conductivity and better thermal insulation performance than traditional concrete, and is a very potential building energy-saving material[16]. EPS particles are dispersed in foamed cement paste, and the hardened body formed after the foamed cement paste is solidified and hardened wraps EPS particles to form organic-inorganic composite thermal insulation material, which is EPS foamed cement-based material.

In this paper, ultra-light thermal insulation foamed cement-based materials with dry density of
about 120 kg/m$^3$ were successfully prepared by adding appropriate amount of graphite modified EPS particles, and the effects of the content of graphite modified EPS particles on its density, strength and thermal conductivity were studied.

2. Raw Materials and Test Methods

2.1. Raw Materials
Cement comes from Esheng Cement Group Co., Ltd. P·O 52.5; Aerogel powder comes from Suzhou Thermal Image Nanotechnology Co., Ltd., with a density of 80 kg/m$^3$; Basalt chopped fiber comes from Sichuan Aerospace Tuoxin Basalt Industrial Co., Ltd., with elastic modulus of 75GPa, elongation at break of 3.1%, fiber length of 1~4mm and diameter of 10 μm; Graphite modified EPS particle is Langfang Fengtao Thermal Insulation Material Co., Ltd., and its performance indexes are shown in Table 1. The appearance and particle size analysis are shown in Figure 1 and Figure 2. The maximum particle size is 5.84mm and the average particle size is 3.39mm; The foaming agent is HTQ-1 composite foaming agent produced by Henan Huatai New Materials Technology Corp., Ltd., with foaming multiple of 30 times and foam density of 32 kg/m$^3$. The coagulant is a self-developed ionic coagulant. Organic silicon hydrophobic agent is GP SHP50 from Dow company; The water reducer is a self-made polycarboxylic acid high-performance water reducer with a water reduction rate of 35% and a solid content of 50%; The water is tap water.

Table 1. Performance Index of Flame Retardant Polystyrene Particles

| Name | Fire rating | Density/(g/cm$^3$) | Water absorption rate (%) | Coefficient of thermal conductivity W/(m·K) |
|------|-------------|--------------------|---------------------------|------------------------------------------|
| Graphite modified flame retardant polystyrene (EPS) particles | B1 | 18 | 3 | $\leq 0.032$ |

2.2. Design of Mix Proportion
The foamed cement-based composite material with a designed wet bulk density of 120 kg/m$^3$ is calculated as follows:

$$\frac{m_c}{\rho_c} + \frac{m_{co}}{\rho_{co}} + \frac{m_a}{\rho_a} + \frac{m_f}{\rho_f} = 1$$  \hspace{1cm} (1)

$$m_c + m_{co} + m_w + m_a + m_f = 120$$  \hspace{1cm} (2)
In which: $\rho_c, \rho_{co}, \rho_w, \rho_a$ and $\rho_f$ are cement density, coagulant density, water density, aerogel powder density and foam density respectively; $m_c, m_{co}, m_w, m_a$ and $m_f$ are cement mass, coagulant mass, water mass, aerogel powder mass and foam mass respectively.

Table 2. Mix Proportion of Ultra-Light Thermal Insulation Foamed Cement-Based Composite Material (kg/m$^3$)

| Number | Cement | Aerogel powder | Setting accelerator | Water reducing agent | EPS particles | Water repellent | Bubble | Water |
|--------|--------|----------------|---------------------|---------------------|--------------|----------------|--------|-------|
| FC     | 80     | 1.2            | 6.5                 | 2.0                 | 0            | 0.5            | 30     | 30    |
| EFC-1  | 80     | 1.2            | 6.5                 | 2.0                 | 5.4          | 0.5            | 30     | 30    |
| EFC-2  | 80     | 1.2            | 6.5                 | 2.0                 | 8.3          | 0.5            | 30     | 30    |
| EFC-3  | 80     | 1.2            | 6.5                 | 2.0                 | 10.8         | 0.5            | 30     | 30    |

The preparation method of foam is to mix foaming agent and water according to the ratio of 1:19, and pour them into a foaming machine until the foam is fine, stable and uniform in size. Generally, the foaming time is 3 min, and the foam density is 32 kg/m$^3$.

Molding process: Firstly, dry mix cement and other raw materials in a mixer until uniform, then add water to stir for 2-3 min, then add aerogel powder to stir for 3 min, slowly pour the foam prepared before into the mixture, continue to stir for about 5 min until it is evenly distributed, then add graphite modified EPS particles to stir for 30min, finally pour the slurry into a prepared mold, and scrape the surface to complete the preparation of ultra-light insulation foamed cement-based composite.

2.3. Test Method
Samples with dimensions of 100 mm × 100 mm × 100 mm are removed, cured in standard curing box for 27 d, then transferred to drying box, dried continuously at 60±5°C for 1 d, and then tested for compressive strength, which is in accordance with standard JG/T 266-2011 Foam Concrete. The thermal conductivity is measured by thermal shield method, and the size of the test specimen is 300 × 300 × 30 mm, and the equipment used is IMDRY3001-VII double-plate thermal conductivity tester manufactured by Imbell (Tianjin).

3. Experimental Results and Analysis

3.1. Density
The test results of wet density and dry density of ultra-light insulation foamed cement-based composites are shown in Figure 3. With the increase of the content of graphite modified EPS particles, the wet density of the slurry increased first and then decreased. The minimum wet density was 137 kg/m$^3$ with 0% content and the maximum wet density was 153 kg/m$^3$ with 45% content. With the increase of the content of graphite modified EPS particles, the effect of the content of graphite modified EPS particles on dry density showed an overall increasing trend, but the increase was small. Compared with air introduced by foaming agent, the dry and wet density of graphite modified EPS particles will increase.
3.2 Compressive Strength

It can be seen from fig. 4 that the compressive strength of ultra-light thermal insulation foamed cement-based composites can be obviously improved by adding graphite modified EPS particles. When the content of graphite modified EPS particles is 30%, the compressive strength can reach 0.25 MPa, which is 66% higher than that of 0%. However, with the content of graphite modified EPS particles exceeding 30%, its compressive strength tends to decline, and the compressive strength is only 0.17 MPa when the content of graphite modified EPS particles exceeds 60%, which is equivalent to the compressive strength without graphite modified EPS particles. It shows that the compressive strength can be maximized when the filling amount of graphite modified EPS particles and the pore structure of foamed cement-based materials reach the best composite ratio.

3.3 Thermal Conductivity

Fig. 5 shows the test results of thermal conductivity of ultra-light insulation foamed cement-based composites. It can be seen from the figure that adding graphite modified EPS particles can obviously reduce the thermal conductivity of the ultra-light thermal insulation foamed cement-based composite. When the content of graphite modified EPS particles is 30%, the thermal conductivity of the ultra-light thermal insulation foamed cement-based composite can reach 0.0326 W/(m·K) at the lowest, which is about 20% lower than that of 0%. However, with the increase of the content of graphite modified EPS particles, the thermal conductivity increased. When the content of graphite modified particles was 60%,
the thermal conductivity was 0.0377 W/(m·K), which was only about 8% lower than that without graphite modified EPS particles. It shows that the thermal conductivity can be minimized when the filling amount of graphite modified EPS particles and the pore structure of foamed cement-based materials reach the best composite ratio.

Figure 5. Effect of graphite modified EPS particle content on thermal conductivity

4. Conclusion
(1) Compared with the air introduced by foaming agent, the dry and wet density of graphite modified EPS particles will increase when they are mixed into foamed cement-based materials, and the minimum wet density is 137 kg/m³ when the content of graphite modified EPS particles is 0%.

(2) With the increase of the content of graphite modified EPS particles, the compressive strength of foamed cement-based materials increases at first and then decreases. When the content of graphite modified EPS particles is 30%, the compressive strength can reach 0.25 MPa.

(3) Adding graphite modified EPS particles can obviously reduce the thermal conductivity of ultra-light thermal insulation foamed cement-based composites. When the content of graphite modified EPS particles is 30%, the thermal conductivity of ultra-light thermal insulation foamed cement-based composites can reach 0.0326 W/(m·K).

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