PREPARATION AND PROPERTIES OF SILICATE INORGANIC EXTERIOR WALL INSULATION BASED ON THERMAL ENERGY STORAGE

by

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The key to building energy conservation is how to make the exterior wall have good thermal insulation performance, reduce the heat loss of the building's peripheral structure, develop new exterior wall insulation materials, and effectively achieve energy saving. In this paper, a new type of composite silicate insulation material was prepared by using fly ash, sepiolite fiber, basalt fiber, and cement as raw materials. According to the analysis of the action of each component of the composite silicate thermal insulation material, the composite silicate thermal insulation material is prepared by selecting different raw material ratios, and the fly ash and sepiolite fibers are analyzed by a thermal conductivity measuring instrument and a hydraulic universal testing machine. The influence of water-cement ratio on the thermal conductivity, tensile strength, and compressive strength of composite silicate insulation materials. Through research, it is found that this composite silicate exterior wall insulation material utilizes some abandoned resources to help the building exterior wall to store thermal energy. The preparation process is simple, the insulation performance is good, the mechanical strength is high, and there is great promotion value and application prospect.

Key words*: thermal energy storage, silicate, external wall insulation, fly ash, sepiolite fiber, thermal conductivity, compressive strength*

Introduction

At present, the application of thermal insulation materials is mainly divided into two aspects: industrial energy conservation and building energy conservation. The existing external wall insulation materials in China are not ideal enough, and the technology is not mature enough. Therefore, research and development of new exterior wall insulation materials is an inevitable trend. Composite silicate insulation material is a new type of material developed in recent years. The silicate is the main material, and the material with closed pore structure compounded by the action of admixture has low thermal conductivity and resistance. The advantages of corrosion and small pollution have received wide attention and have developed rapidly in China in recent years [1]. It is suitable for both new buildings and existing building renovation projects. It is an external wall insulation material worthy of promotion. China has made certain achievements in research and application in this respect, but there are still many problems. The properties of composite silicate insulation materials need to be further optimized. As the external wall insulation material, its mechanical strength, crack resistance and water absorption rate are relatively high. We

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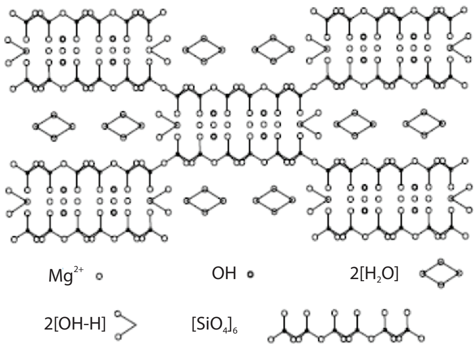

Figure 1. Crystal structure of sepiolite fiber

should strive to improve the comprehensive performance of the composite silicate exterior wall insulation material, and develop a new composite silicate exterior wall insulation material. And make it have better energy-saving effect, reduce building energy consumption, and thus get wider application.

This topic is based on the aforementioned special research, using fly ash, sepiolite fiber, cement as the main raw materials, and pre-activation of fly ash and sepiolite fibers, research and analysis of different raw materials. Based on the influence of preparation conditions on the properties of composites, a new composite silicate exterior wall insulation material was developed and its performance was optimized so that it could be better used for actual production, for the development of China's industry and society. Contribution the construction of the society [2].

Raw materials and properties of composite silicate exterior wall insulation materials

Raw material composition of composite silicate insulation material

Isolate fiber

Sepiolite is a layered chain structure of magnesium-rich silicate clay minerals, which are produced in Henan, Hebei and Hunan. The sepiolite fibers are mostly white and light gray and have a porous structure. The paper used the Yixian sepiolite in Hebei Province. The main components are shown in tab. 1. Its molecular structure is shown in fig. 1. Because sepiolite has strong adsorption capacity, low thermal conductivity, no pollution, corrosion resistance*, etc.*, it is widely used in light industry, metallurgy, water treatment and construction.

Table 1. Chemical composition of sepiolite

Ingredient SiO_2	MgO	Al_2O_3	CaO	Fe_3O2	MnO_2
Content [%] 54.29	24.7	0.24	1.94	0.87	0.11

Fly ash

The main components of fly ash in thermal power plants in China are SiO_2, $A1_20_3$, FeO, Fe_2O_3, CaO, TiO_2, MgO, K_2O, Na_2O, SO_3, and MnO. The specific chemical composition is related to the origin of coal, the way of combustion and the type of coal. The fly ash produced by Tianjin Xiqing Thermal Power Plant was used in this experiment, which was obtained after air separation, water washing and drying. Its components are shown in tab. 2:

Table 2. Chemical composition of fly ash

Composition SiO_2	MgO	Al_2O_3	CaO	Fe_3O_2	SO_3
Content [%] 50.2%	1.5%	32.5%	1.94%	2.1%	0.6%

Basalt fiber

The basalt fiber is obtained by melting and drawing at 750 °C using basalt ore as raw material. Its composition is mainly SiO_2 (45~60%), Al_2O_3 (12~19%), CaO (6~12%), Fe_2O_3, and FeO (5~15%), MgO (3~7%), and TiO_2 (0.9-2.0%). Because basalt fiber has the advantages of low production cost, low production pollution, low energy consumption, high temperature resistance, corrosion resistance, good chemical stability and high mechanical strength, it is used in acoustic thermal insulation materials, chemical stability materials, structural materials, reinforcing materials, and composites. There are a wide range of applications in materials and products [3].

Cement

Portland cement is prepared by mixing clay, limestone, iron powder*, etc.* in proportion, grinding, and calcining. It is a kind of powdery cementing material, which undergoes hydration reaction form a network structure composed of crystals and gels, filling the voids between the aggregates, and as a matrix of the composite material, materials such as fly ash and sepiolite fibers. Bonded together. Portland cement has a complex chemical composition, of which $CaSiO_3$ is the main component of Portland cement and a major source of cement strength [4]. The chemical composition is shown in tab. 3.

Table 3. Chemical composition of cement

Ingredient	SiO_2	Al_2O_3	Fe_3O_2	CaO	SO_3	MgO
Content [%]	23.5	5.52	3.58	65.2	1.03	0.75

Foaming agent

The foaming ratio refers to the foam volume being greater than the foaming volume. The method is the prepared foam is injected into the bottomless glass cover, the ends are flattened, the mass of the glass cover before and after the foam injection is weighed, and the foam is calculated. The foaming ratio of the agent:

$$M = \frac{V\rho}{G_2 - G_1} \tag{1}$$

where M is the expansion ratio of the blowing agent, V [cm^3] – the volume of the glass cover, ρ [gcm^{-3}] – the density of the aqueous foam solution, G_1 [g] – the mass of the glass cover, G_2 [g] – the glass cover in the foam the total mass.

Dispersant

Since the composite silicate insulation material is doped with sepiolite fibers and basalt fibers, in order to avoid the aggregation of the fibers, the sepiolite fibers and the basalt fibers should be dispersed in advance using a dispersant. There are many kinds of dispersing agents, among which DC dispersing agent, sodium dioctyl sulfosuccinate and sodium hexametaphosphate are commonly used. The dispersion effects of the aforementioned three dispersants on sepiolite fibers and basalt fibers were analyzed by experiments. The paper selected sodium hexametaphosphate as a dispersing agent for sepiolite fibers and basalt fibers [5].

Composite silicate insulation material performance test

Thermal conductivity

According to the Fourier heat conduction theorem, the heat flux density that is vertically guided through the isothermal surface is proportional to the temperature gradient there, and the direction is opposite to the temperature gradient:

$$q = -\lambda \text{grad} t \tag{2}$$

where q [Wm^{-2}] is the heat flow, λ [Wm^{-1}K^{-1}] – the thermal conductivity, grad$t$ [Km^{-1}] – the temperature gradient. The thermal probe is an infinitely long heat source body, ignoring the contact thermal resistance of the probe to the measured medium, and the heat conduction process of the probe to the surrounding medium can be regarded as infinitely large, 1-D heat conduction in the isotropic medium. Its heat conduction equation:

$$\begin{gathered}\frac{1}{\alpha_w}\frac{\partial \theta_w}{\partial \tau} = \frac{\partial^2 \theta_w}{\partial r^2} + \frac{1}{r}\frac{\partial \theta_w}{\partial r} + \frac{q}{\pi r_w^2 \lambda_w}, \ (0 \le r < r_w, \ \tau > 0) \\ \frac{1}{\alpha_m}\frac{\partial \theta_m}{\partial \tau} = \frac{\partial^2 \theta_m}{\partial r^2} + \frac{1}{r}\frac{\partial \theta_m}{\partial r}, \ (r \ge r_w, \ \tau > 0)\end{gathered} \tag{3}$$

The boundary conditions and initial conditions are:

$$\begin{gathered}\theta_w(r_w,\tau) = \theta(r_w,\tau), \quad \lambda_w\left(\frac{\partial \theta_w}{\partial r}\right)r_w = \lambda_m\left(\frac{\partial \theta_m}{\partial r}\right)r_w \\ \theta(0,\tau) = 0, \quad \theta_w(r,0) = \theta_m(r,0)\end{gathered} \tag{4}$$

where α_w, α_m [m^{2}s^{-1}] are the resistance wire and the thermal diffusivity of the measured substance, respectively, r [m] – the radial radius, r_w [m] – the radius of the resistance wire, τ [s] – the time, q [J] – the unit length resistance the heating power of the wire, θ [K] – the temperature rise, λ_m, λ_w [Wm^{-1}K^{-1}] – the resistance wire and the thermal conductivity of the tested substance, respectively. Divide the differential equations and boundary conditions to time τ, respectively, and organize them:

$$\theta(r,\tau) = \frac{q}{4\pi\lambda_m}\left[\ln\frac{4a_m\tau}{r_w^2} - \gamma + \frac{1-\frac{r}{r_w}}{\frac{\lambda_w}{\lambda_m}} - A_1\frac{r_w^2}{4a_m\tau} + A_2\left(\frac{r_w^2}{a_m\tau}\right)^2\right] \tag{5}$$

where γ is the Euler constant, A_1 and A_2 are the coefficient term.

Flexural strength

The flexural strength, also known as the flexural strength, refers to the ultimate breaking stress when the material per unit area is subjected to bending moments. The unit is megapascals. Test pieces with dimensions of 300 ×100 × 20 mm were prepared according to different ratios. The failure load of the test piece was measured by hydraulic universal testing machine, and the flexural strength of the test piece was calculated [6]. The specific experimental steps are:

– test piece Place in a dry box, dry to a constant mass, and cool to room temperature in a desiccator,
– measure the thickness and width of the test piece, measure it three times, and find the arithmetic mean value, the width is accurate to 0.5 mm, and the thickness is accurate to 0.1 mm, and
– adjust the spacing between the two seats of the hydraulic universal testing machine to 200 mm.

The test piece was placed symmetrically on the support roller shaft, and the descending speed of the pressure roller shaft was 10 mm per minute. Pressurize until the test piece breaks and record the damage load P_l. Then the flexural strength of the test piece is calculated:

$$R = \frac{3P_l L_l}{2bh^2} \tag{6}$$

where R [MPa] is the compressive strength of the test piece, P_l [N] – the breaking load of the test piece, L_l [mm] – the center distance of the lower bearing roll axis, b [mm] – the width of the test piece, and h [mm] – the thickness of the test piece.

Compressive strength

Compressive strength refers to the maximum compressive stress that a material is subjected to during compression. The unit is MPa, and the test pieces with the size of 100 ×100 × 20 mm are prepared according to different ratios. The compressive load of the test piece is measured by the hydraulic universal testing machine, and the compressive strength of the test piece is calculated. The specific experimental steps are:

- the test piece is placed in a dry box, dried to a constant mass, and cooled to room temperature in a desiccator,
- take out the test piece and place it on the testing machine, make the center of the test piece coincide with the center of the bearing plate of the hydraulic universal testing machine, start the pressure testing machine and adjust the ball seat so that the pressure receiving surface of the test piece is in uniform contact with the bearing plate,
- pressurize the test piece to a failure of the test piece at a speed of 10 mm per minute, and record the damage load P_2, and
- calculate the compressive strength of the test piece:

$$\sigma = \frac{P_2}{S} \tag{7}$$

where σ [MPa] is the compressive strength, P_2 [N] – the failure load, and S [mm] – the compressed area.

Preparation of composite silicate exterior wall insulation material

Preparation process of composite silicate external wall insulation material

The main steps are:

- weigh fly ash and cement according to the experimental ratio, and stir with water for 30 minutes to mix well,
- weigh the sepiolite fiber and basalt fiber according to the proportion, mix it evenly, add water and dispersant, soak for 0.5 hour, make the fiber evenly dispersed, pour into the mixed slurry of cement and fly ash, use The electric stirrer was stirred for 20 minutes,
- a foaming agent was added and stirred by a power agitator for 30 minutes,
- pour the evenly stirred slurry into a self-made mold, gently compact and flatten,
- the mold was placed in an electric blast drying oven and dried at a temperature of 90 °C for 24 hours, and
- take out the dried product, remove the mold, and test the performance of the product, and test and calculate the bulk density, thermal conductivity and mechanical strength.

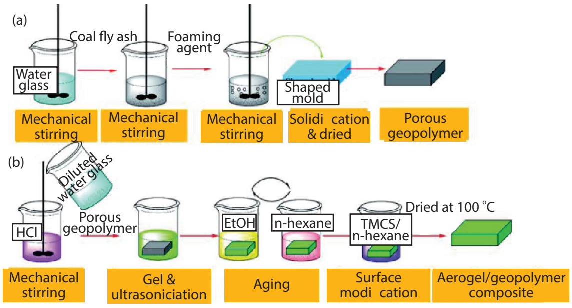

Figure 2. Preparation process of composite silicate insulation material

The preparation process of the composite silicate insulation material is shown in fig. 2 [7].

Effect of cement on properties of composite silicate exterior wall insulation materials

In this test, we set the water-cement ratio in the test sample to 0.6 in order to prepare the sample content of the composite silicate insulating cement. We prepare a composite silicate insulation cement content of the specimen prepared according to different processes composite silicate insulation material. Measured compressive strength and thermal conductivity of the test piece were drawn mixed cement and the amount of compressive strength, thermal conductivity graph, influence of cement content of composite silicate insulation properties. Effect of cement content on the compressive strength and thermal conductivity of composite insulation specimen silicates fig. 3.

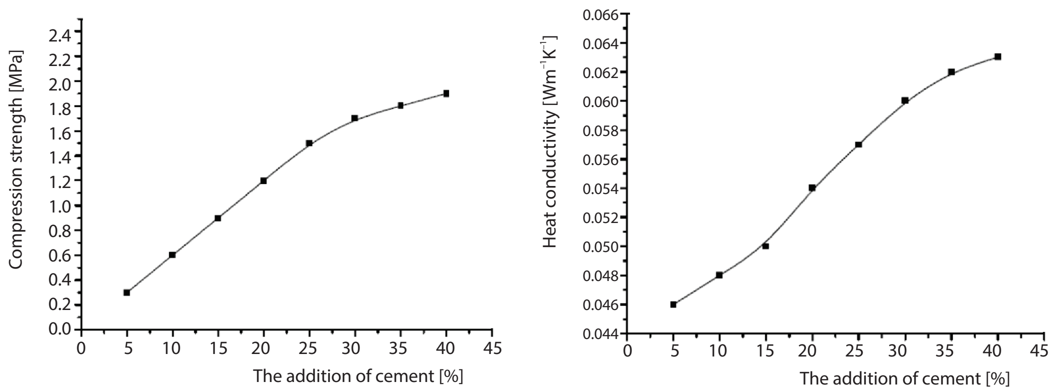

Figure 3. Effect of cement content on compressive strength and thermal conductivity

With the increase of the cement content, the strength of composite silicate insulation material increasing, but the insulation performance will be getting worse. Based on the principle of reducing material costs and waste utilization, should minimize the amount of cement, a suitable dosage is increased slightly better insulation performance of fly ash, designed composite silicate insulation material in the case of compressive strength to meet the requirements of, thermal conductivity, the better the properties of the material. So cement dosage should not be too large.

Effect of fly ash on properties of composite silicate exterior wall insulation materials

In the course of the experiment, we selected a certain number of experimental samples, classified the samples by equal weight, and then set-up a control test based on the water-cement ratio of this experiment. According to the preparation of different samples of composite silicate insulating pulverized coal. The composite silicate insulation material prepared by the ash method, the measured compressive strength and thermal conductivity of the test piece, and the compressive strength of the fly ash are used to draw the thermal conductivity map, and the insulation performance of the fly ash to the composite silicate is analyzed Impact. The effect of fly ash on the compressive strength of composite silicate insulation materials, the thermal conductivity is shown in fig. 4.

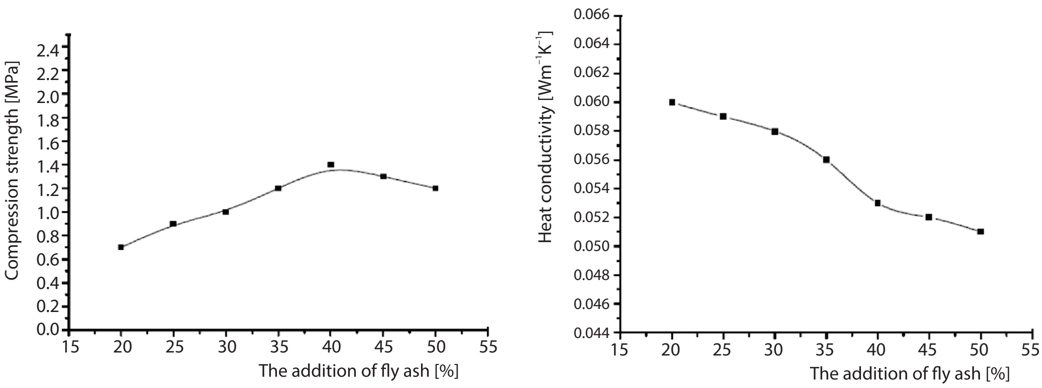

Figure 4. Effect of fly ash content on compressive strength and thermal conductivity

Ash thermal conductivity of about 0.21 W/mK, significantly lower than the thermal conductivity of cement 0.93 W/mK, the fly ash to effectively improve the insulation performance composite silicate insulation material. Binding fly ash on the compressive strength and thermal conductivity of both composite silicate insulation material considerations, it should be added fly ash is between 40-45% [8].

Effect of sepiolite fiber on properties of composite silicate exterior wall insulation materials

Weigh the same material parts 7, each raw material fly ash, cement, basalt fiber mass ratio of 40: 30: 5; was added 0.3% of the total material mass of a foaming agent, 7 parts of sepiolite weighed fiber, sepiolite mass fraction of the total mass of the fibers were 10%, 15%, 20%, 25%, 30%, 35% and 40%; water-cement ratio is set to 0.6, the composite silicate insulation material preparation of composite silicate insulation prepared specimens

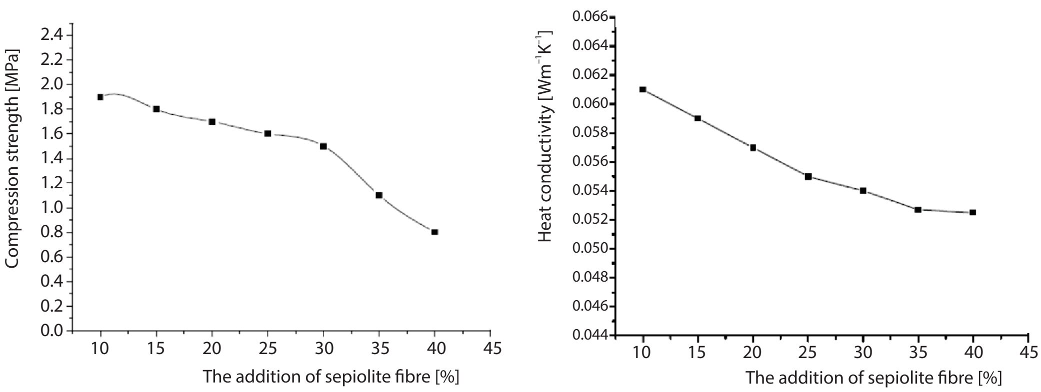

Figure 5. Effect of the amount of sepiolite fiber on compressive strength and thermal conductivity

sepiolite different fiber content, measured compressive strength and thermal conductivity of the specimen, the curve sepiolite fiber content and compressive strength. Based on the corresponding data that appeared in the experiment, we plotted the detailed records of each set of test data. After analysis, we found that the volume of sepiolite fiber insulation material affects the thermal conductivity and compressive strength of the composite material as shown in fig. 5.

Compressive strength and thermal conductivity of composite silicate insulation material have sepiolite with increasing fiber content is lowered, sepiolite fibers admixture improves insulation performance composite silicate insulation material, but their anti compressive strength to a certain extent. But sepiolite doped fiber will cause excessive compressive strength of the composite material cannot meet the application requirements, we should seek to ensure that the lowest coefficient of thermal conductivity under conditions of compressive strength to meet the requirements, so the composite silicate insulation material in the sea bubble stone dosage should be about 30% [9].

Effect of basalt fiber on properties of composite silicate exterior wall insulation materials

We analyzed the ratio of the various components of cement in the sepiolite fiber in the aforementioned materials. In order to obtain the best experimental effect, the content of the sample was classified in various ways, the specific values were recorded, and then the data was analyzed, and the experimental results were expressed in the form of a graph, the thermal conductivity of the substance was analyzed, and then the impact of the amount of basalt on the insulation performance of the composite silicate was analyzed. The compressive strength and thermal conductivity of volume basalt fiber composite silicate insulation materials are shown in fig. 6.

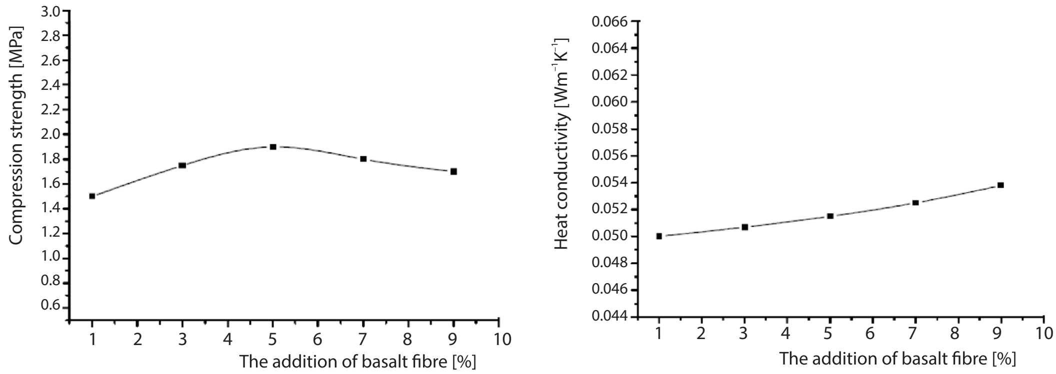

Figure 6. Effect of basalt fiber content on compressive strength and thermal conductivity

With the increase of basalt fiber content, the compressive strength of insulation materials is gradually increased within a certain range, but if the basalt mixed is too large, it will cause the junction basalt fiber during the preparation of composite silicate insulation material group, resulting in reduced properties of composite silicate insulation material. Further silicate insulation material, the thermal conductivity of the composite increases as the basalt fiber has increased by a certain extent, a small margin. Based on the aforementioned points into account, when the dosage is 5% basalt fiber, silicate insulation properties of the composite material is preferable.

Effect of foaming agent on properties of composite silicate exterior wall insulation materials

In the course of carrying out the subsequent experimental steps, we will classify the different materials in the sample, and then take five samples of the same quality for the control test, measure the compressive strength and thermal conductivity of the sample, and draw the compressive strength. The amount of foaming agent, the thermal conductivity chart, the effect of the foaming agent composite material on the silicate insulation, fig. 7.

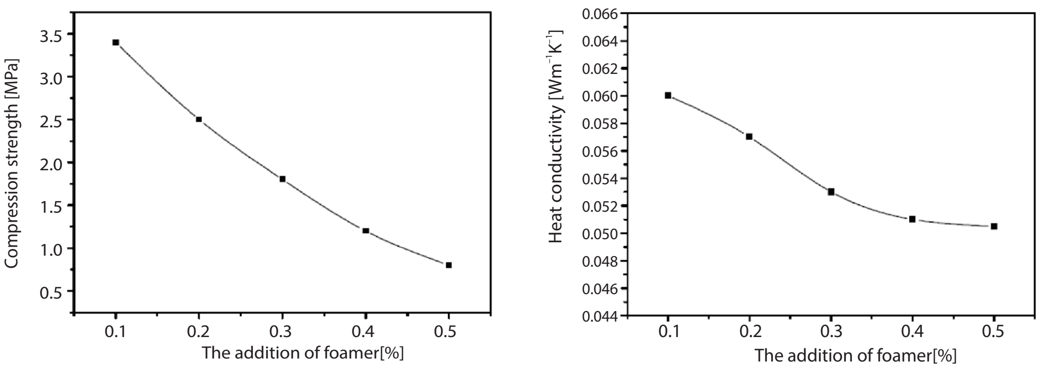

Figure 7. Effect of foaming agent dosage on compressive strength and thermal conductivity

It can be seen that composite silicate insulation material, the thermal conductivity increases as the blowing agent dosage is reduced due to the thermal conductivity of air is much less than the thermal conductivity of other solid material. Therefore, with the increasing amount of the blowing agent, the thermal conductivity of composite silicate insulation material decreases, which decreases as compressive strength. Also due to the increase of pores will lead to increased water absorption of the compound silicate insulation material, which limits the composite silicate insulation material, the blowing agent cannot be too large dosage. Therefore, considering the previous three factors, the dosage of the foaming agent is determined to be less than 0.4%.

Determination of thickness of composite silicate exterior wall insulation material

In the case of wall structure and insulation materials, the thickness of the insulation layer restricts the energy-saving effect. Therefore, considering the requirements of building energy-saving design, the thickness of the insulation layer is analyzed and discussed. The heat transfer coefficient of the building envelope can be calculated:

$$K = \frac{1}{R_0} = \frac{1}{a_n} + \sum_{i=1}^{n} \frac{\delta_i}{\lambda_i} + \frac{1}{a_w} \tag{8}$$

Conclusion

The composite silicate external wall thermal insulation material is made of composite materials such as fly ash, cement and sepiolite fiber, and the compressive strength and thermal conductivity of the test piece prepared by mixing different raw materials are measured, and the effects of various factors on the composite silicate insulation materials were analyzed. The paper discusses the composite mechanism between fly ash, cement, sepiolite fiber, basalt fiber and foaming agent through the micro-structure of composite silicate insulation material. The crack resistance is analyzed according to the structure and *reinforced* characteristics of basalt fiber. Using the modified porous ash and modified sepiolite fiber, adding it to the composite silicate insulation material, researched and analyzed the thermal insulation mechanism of the composite silicate insulation material. The composite silicate thermal insulation material prepared by the experiment has the characteristics of low thermal conductivity, light weight, simple process and low price, and can be widely applied to the external wall insulation of new buildings and the energy-saving transformation of existing buildings.

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