ANALYSIS OF NEW INORGANIC EXTERIOR INSULATION MATERIALS AND THERMAL ENERGY STORAGE

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Abstract: In order to reduce the energy efficiency of the construction industry and improve the building safety, in this research, a new type of inorganic insulation material - vitreous bead insulation mortar is studied and its properties are analyzed. Quantitative method is used to analyze the influence of glass bead mixing amount, cellulose ether mixing amount and redispersible emulsion powder mixing amount on the consistency, water retention rate, dry density, softening coefficient and compressive strength of glass bead insulation mortar. The effect of different raw materials allocation on the thermal conductivity of vitrified microbeads thermal insulation mortar is explored. The results show that the performance of insulation mortar decreases significantly with the increase of glass bubbles. With the increase of cellulose ether content, the consistency and compressive strength of insulation mortar first increased and then decreased, the water retention rate increased significantly, but the dry density decreased significantly. With the increase of the content of redispersible emulsion powder, the consistency and compressive strength of insulation mortar first increased and then decreased, but the dry density decreased gradually. Glass bubbles and fly ash parameters are the main factors that affect the thermal conductivity of thermal insulation mortar, and their thermal conductivity decreases with the increase of the proportion of air-entraining agent. As a result, the performance of vitreous microbeads thermal insulation mortar will change to a certain extent with the different proportion of raw materials, which provides data support for the preparation and application of inorganic external wall thermal insulation materials.

Key words: *Inorganic external wall insulation material, Vitreous microbeads insulation mortar, Vitreous microbeads mixing amount, Thermal energy storage energy, Water retention rate*

1. Introduction

With the continuous rise of China's economy and population, China's building energy consumption has accounted for about 24% of the total social energy consumption, and the trend is gradually increasing. The heating energy consumption per unit area of buildings in China is 3 times or even higher than that of developed countries with similar climate, while the difference between China's main industrial products and developed countries is only 10 to 30 percent [1]. With the continuous improvement of people's living standards, the requirements for thermal comfort of buildings are also increasingly high, and the use of heating and air conditioning is becoming more and more common. The use of air conditioning in summer every year causes the peak of urban electricity load, which leads to power rationing in many provinces and cities [2].

The heat consumption of residential building is 75% through the heat transfer consumption of the envelope, so the envelope becomes the key part of energy saving. External wall internal insulation is a common way. It has low requirements on material performance and supporting technology, and is easy to maintain which can play the role of heat preservation and insulation [3]. At present, organic exterior insulation has developed quite mature, our country has also launched the corresponding industry standards and design atlas. Its thermal conductivity and dry density are small than inorganic materials, but high temperature resistance is generally not more than 800°C, and burning will also emit volatile toxic gas. But the inorganic exterior insulation material construction is simple, which produces no harmful volatile gas, and is green and environmental with high temperature resistance. Its combustion performance is grade A, after combustion it will not emit volatile toxic gas. At present, some enterprises and research institutes have been developing and using it in some projects [4]. However, at present, there are few relevant research data and no description of the performance of inorganic external insulation materials, which limits the practical application of inorganic external insulation materials.

In conclusion, in order to reduce the energy consumption of the construction industry, meet the national requirements for thermal comfort of buildings, and at the same time, in order to make inorganic external wall insulation materials into actual buildings as soon as possible, through self-made inorganic external wall insulation material - vitreous microbeads insulation mortar, quantitative analysis is used to explore the effects of different raw material allocation on the thickness, dry density, compressive strength, softening coefficient and thermal energy storage capacity of vitreous microbeads insulation mortar, so as to find the most appropriate amount, which provides experimental data for the use of inorganic external wall insulation materials in the building industry.

2. Methods

2.1. Experimental materials and instruments

The instruments and materials used in this experiment are shown in Tab. 1.

Table 1 Instruments and materials

Instruments and materials	Manufacturer
Fly ash	Shanxi, Hejin Longjiang Fly Ash Development and Utilization co. LTD
Vitrified micro bubbles	Shanxi, Linfen Minqin Thermal Insulation Material co. LTD
Redispersible latex powder	Hebei, Renqiu city Haoyu Chemical co. LTD
Concrete	Hebei, Hebei Warner New Building Materials co. LTD
Cellulose ether	Guangzhou Runhong Chemical co., LTD
Polypropylene fiber	Shaanxi Tongshenghua Engineering Technology co., LTD

Mortar mixer	Shandong Anqiu Longxiang Machinery co. LTD
Electronic scales	Shenyang Longteng Electronics co., LTD
Heat conductivity coefficient	Hunan Xiangtan Xiangyi Instrument co. LTD

2.2. Preparation of vitrified microbeads insulation mortar

According to the demand, a certain amount of cement, fly ash, polypropylene fiber and re-dispersible latex powder are added to the mixer and appropriate water is added. It should be stirred for about 2 minutes, after which the glass bubbles are added. Then. it continues to be stirred for about 3 minutes. The mixing materials are respectively loaded into the triple mode parts. During the loading process, the cement sand vibrating table should be used to make the mixing materials fully and evenly fill the whole test mold. Due to the low strength of vitrified microbeads insulation mortar, it is required that specimens with mold can only be released after curing for three days. Specimens with mold are placed in curing room (temperature 21±3°C, humidity 92%) for curing for three days.

2.3. Water retention rate measurement

The electronic balance is used to weigh the quality of the mold and the quality of the filter paper, and the mortar mixture is loaded into the mold at one time, so that the surface of the mortar is about 10mm below the mold opening. The mold is rammed from the center to the edge for 30 times with a ramming rod, and then gently shook or knocked about 6 times to make the mortar surface smooth. The electronic balance is used to weigh the quality of the test mold and mortar, and then the water retention rate of mortar is calculated according to the distribution and water addition of insulation mortar. The specific equation is as follows:

$$W=\left[1-\frac{\mathrm{m}_4-\mathrm{m}_2}{\alpha\times\left(\mathrm{m}_3-\mathrm{m}_1\right)}\right]\times 100 \tag{1}$$

2.4. Dry density measurement

After the specimen is fully solidified and hardened, the specimen is taken out and placed in an electric air-blast drying box at 110°C for drying. The dry density value of vitreous microbeads insulation mortar is measured and calculated. The specific equation is as follows:

$$\rho=\frac{\mathrm{m}}{V}\left(\mathrm{kg/m^3}\right) \tag{2}$$

2.5. Determination of compressive strength

The tri-mode specimen is taken out, and measured according to the provisions in the cement strength inspection method (IOS method), then the test result is recorded and calculated, and the equation is as follows:

$$R = \frac{P}{F} \tag{3}$$

2.6. Determination of softening coefficient

The microcomputer controlled electronic universal testing machine is used to conduct loading failure on the specimen, the failure load is recorded, and the softening coefficient of vitreous microbeads insulation mortar is calculated. The specific equation is as follows:

$$K = \frac{\mathrm{f}}{F_1} \tag{4}$$

2.7 Measurement of thermal conductivity

The 100mm cube specimen was taken out and measured in accordance with the specific requirements and procedures of the thermal conductivity tester in the manual of "determination of steady state thermal resistance and related characteristics of adiabatic materials". Tab. 2 shows the letter meaning of the above equation. The equation is as follows:

$$\lambda = \frac{W\mathrm{d}}{A\left(\mathrm{t}_1 - \mathrm{t}_2\right)} \tag{5}$$

Table 2 Letter meaning of the equation

Letter	Meaning
m_1	Weight of dry mold (kg)
m_2	Total weight of filter paper (kg)
m_3	Quality of sample and mortar (kg)
a	Mortar water content (%)
m	Weight of sample after drying (kg)
V	Sample volume (m^3)
P	Failure load (N)
F	Compression area (mm^2)
f	Unconfined pressure resistance (Mpa) of materials at water saturation
F_1	Unconfined compressive strength (Mpa) of materials in dry state
W	Power of calorimeter plate (W)
A	Calculated area of sample (m^2)
t_1	Heating plate temperature (°C)
t_2	Cold plate temperature (°C)

d	Sample thickness (m)

2.8. Setting of influencing factors

When preparing, different mixing amounts of glass bubbles, cellulose ether and redispersible latex powder were taken to calculate the water retention rate, compressive strength, softening coefficient and dry density of glass bubbles insulation mortar under different factors. Each experiment was repeated twice. The thermal conductivity of vitrified beads thermal insulation mortar was calculated by adding different proportions of air-entraining agent, volcanic stone powder, vitrified beads and fly ash parameters.

2.9. Statistical analysis

SPSS 19.0 software was used for statistical analysis. The measurement obtained is expressed as $\bar{\chi}$ + SD, and T test was used to compare groups. The obtained enumeration data were expressed as a percentage (%) and compared between groups by χ^2 test.

3. Results

3.1 Effect of mixing amount of vitrified microbeads on performance of vitrified microbeads insulation mortar

Vitrified microbeads are the aggregate of vitrified microbeads insulation mortar. Under the condition that the proportion of other ingredients remains unchanged, glass bubbles of different qualities are added to measure the dry density, water retention rate, compressive strength and softening coefficient of glass bubbles insulation mortar. The influence of mixing amount of vitrified microbeads on the performance of vitrified microbeads insulation mortar was explored, and each experiment was repeated twice. Cement parameters were 45wt%, re-dispersible latex powder 4%, polypropylene fiber 0.3wt%, air-entraining agent 0.45wt%, cellulose ether 0.4wt%, and the proportion of fixed water was 1.3. Fig. 1 shows the influence of different mixing amounts of glass bubbles on the performance of insulating mortar, where A is the influence of mixing amounts of glass bubbles on the consistency of insulating mortar; B is the influence of mixing amount of glass bubbles on dry density of insulation mortar; C is the influence of mixing amount of glass bubbles on compressive strength of insulation mortar; D is the influence of mixing amount of glass bubbles on softening coefficient of thermal insulation mortar. It can be concluded from the figure that both experiments showed that the consistency, dry density, compressive strength and softening coefficient of thermal insulation mortar decreased with the continuous increase of mixing amount of glass bubbles. Due to the fact that vitreous microbeads are inorganic materials with certain water absorption, during the production process, the water absorption of vitreous microbeads is further increased due to mixing and extrusion, thus reducing the consistency of thermal insulation mortar. The dry density and compressive strength of insulation mortar decrease with the increase of the mixing amount of vitreous microspheres because vitreous microspheres are hollow and have low strength.

In conclusion, the mixing amount of vitrified microbeads will cause the change of performance of vitrified microbeads insulation mortar. According to China's regulations on the consistency, dry density, compressive strength and softening coefficient of inorganic exterior insulation materials, it is most suitable when the mixing amount of glass bubbles is between 36~52wt%.

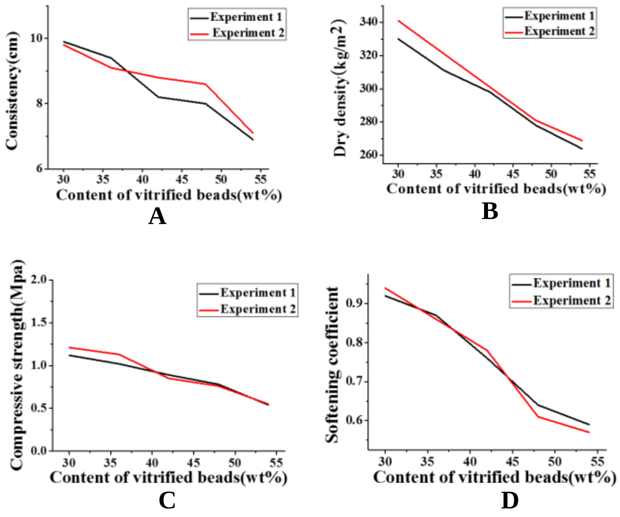

Figure 1 Influence of different mixing amount of vitrified microbeads on the performance of insulating mortar

Note: A is the influence of the mixing amount of glass bubbles on the consistency of insulation mortar; B is the influence of mixing amount of glass bubbles on dry density of insulation mortar; C is the influence of mixing amount of glass bubbles on compressive strength of insulation mortar; D is the influence of mixing amount of glass bubbles on softening coefficient of thermal insulation mortar

3.2 Effect of cellulose ether content on performance of vitreous bead insulation mortar

The cement content was set as 45wt%, re-dispersible latex powder 4%, polypropylene fiber 0.3wt%, air-entraining agent 0.45wt%, proportion of fixed water material as 1.3, glass bubbles 42wt%. The effect of cellulose ether on insulating sand was determined by changing the content of cellulose ether. Each experiment was repeated twice. Fig. 2 shows the influence of different cellulose ether content on the performance of insulation mortar, where A is the influence of cellulose ether content on the consistency of insulation sand; B is the effect of cellulose ether content on the water retention rate of insulation sand; C is the effect of cellulose ether content on the compressive strength of insulating sand; D is the effect of cellulose ether content on the dry density of insulation sand. According to the figure, the water retention rate of insulation sand increased with the increase of cellulose ether content. The dry density decreased with the increase of cellulose ether content. The consistency and compressive strength first increased and then decreased with the increase of cellulose ether content. When adding a small amount of cellulose ether, it can introduce some uniform bubbles in the mortar, and these bubbles can improve the properties of the mortar. When more cellulose ether is added, the viscosity of cellulose ether itself impedes the fluidity of mortar and makes mortar consistency decrease. The oxygen atoms and hydroxyl groups in cellulose ether molecules can be combined with water molecules, so that the free water becomes the combination water, increasing the water retention rate of thermal insulation mortar.

In conclusion, the content of cellulose ether can change the performance of vitreous microbeads insulation mortar. According to China's regulations on the consistency, dry density, compressive strength and water retention rate of inorganic external insulation materials for external walls, it is most appropriate when the content of cellulose ether is between 0.2~0.6wt%.

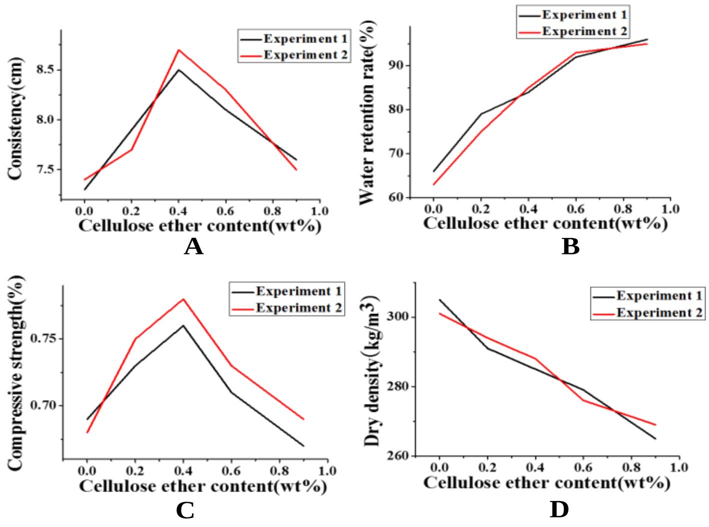

Figure 2 Effect of different cellulose ether content on the performance of insulation mortar

Note: A is the effect of cellulose ether content on the consistency of insulation sand; B is the effect of cellulose ether content on the water retention rate of insulation sand; C is the effect of cellulose ether content on the compressive strength of insulating sand; D is the effect of cellulose ether content on the dry density of insulation sand

3.3 Influence of the content of redispersible emulsion powder on the performance of vitreous microbeads insulation mortar

The cement parameters were set as 45wt%, glass bubbles 42wt%, polypropylene fiber 0.3wt%, air-entraining agent 0.45wt%, cellulose ether 0.4wt%, and the proportion of fixed water was set as 1.3. The effect of redispersible emulsion powder on insulating sand was determined by changing the content of redispersible emulsion powder. Each experiment was repeated twice. Fig. 3 shows the influence of different content of redispersible emulsion powder on the performance of insulation mortar, where A is the influence of content of redispersible emulsion powder on the consistency of insulation mortar; B is the influence of the content of redispersible emulsion powder on the dry density of insulation mortar; C is the influence of the content of redispersible emulsion powder on the compressive strength of insulation mortar. It can be concluded from the figure that the dry density of insulation mortar decreases with the increase of redispersible emulsion powder. The consistency and compressive strength first increased and then decreased with the increase of redispersible emulsion powder content. The addition of redispersible emulsion powder increases the viscosity of the mortar, and its interaction with cellulose ether can produce many stable and closed bubbles in the mortar, thus reducing the dry density of the mortar. Besides, it is combined with water to form emulsion to increase the aggregate lubrication, thus making mortar consistency increase.

To sum up, mixing amount of redispersible emulsion powder will cause the change of performance of vitreous microbeads insulation mortar. According to China's regulations on the consistency, dry density and compressive strength of inorganic exterior insulation materials, it is most suitable when the content of redispersible emulsion powder is between 2~4wt%.

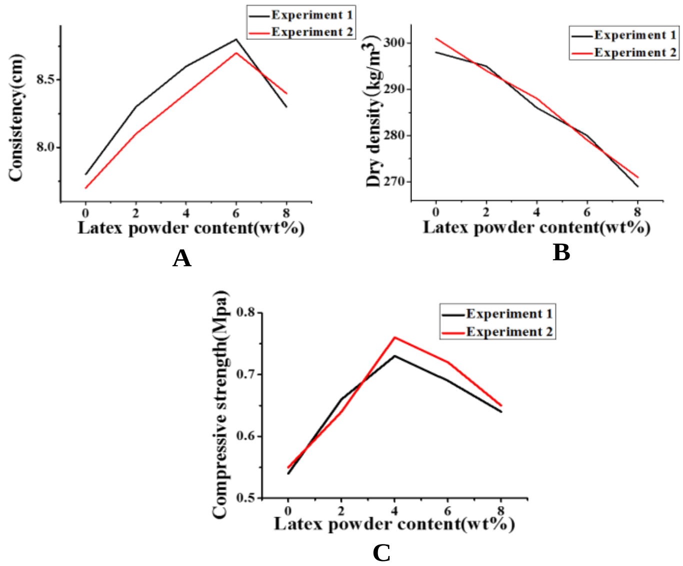

Figure 3 Influence of different content of redispersible emulsion powder on the performance of insulating mortar

Note: A is the influence of the content of redispersible emulsion powder on the consistency of insulation mortar; B is the influence of the content of redispersible emulsion powder on the dry density of insulation mortar; C is the influence of the content of redispersible emulsion powder on the compressive strength of insulation mortar

3.4 Effect of different raw material ratio on heat energy storage of vitrified microbeads thermal insulation sand

The influence of different raw material ratio on thermal conductivity of vitrified microbeads thermal insulation sand was investigated, and the possible thermal energy storage application of vitrified microbeads thermal insulation sand was analyzed. Fig. 4 shows the influence of different raw materials ratio on the thermal conductivity of vitrified microbeads thermal insulation sand, where A is glass bubbles: influence of fly ash on thermal conductivity of thermal insulation sand; B is the influence of volcanic pumice on thermal conductivity of thermal insulation sand; C is the influence of air entrainer on thermal conductivity of insulating sand. According to the figure, the thermal conductivity of thermal insulation sand decreases gradually with the increase of the proportion of glass bubbles and fly ash. At the same time, thermal conductivity of thermal insulation sand decreases with the increase of air entrainer. The effect of volcanic pumice on thermal conductivity of thermal insulation sand is not great.

In conclusion, different raw material rationing has a certain impact on the thermal conductivity of vitrified microbeads thermal insulation sand, and the selection of appropriate proportion can greatly improve the performance of thermal insulation sand, which provides a guiding idea for thermal energy storage and application of thermal insulation sand.

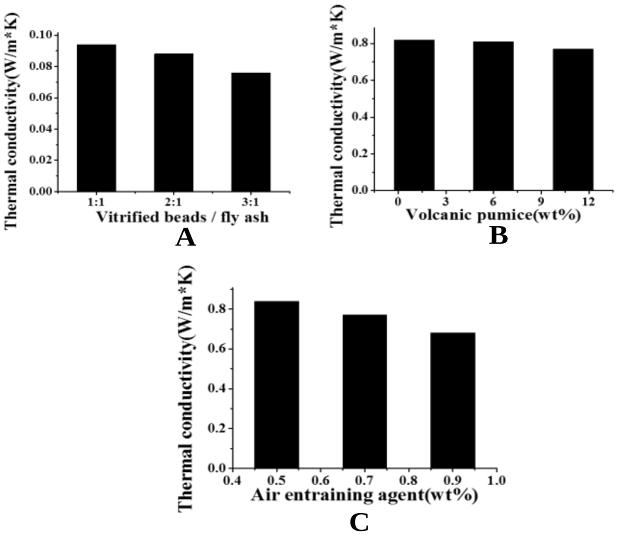

Figure 4 Effect of different material ratio on thermal conductivity of vitrified microbeads thermal insulation sand

Note: A is glass bubbles: effect of fly ash on thermal conductivity of thermal insulation sand; B is the influence of volcanic pumice on thermal conductivity of thermal insulation sand; C is the influence of air entrainer on thermal conductivity of insulating sand

4. Discussion

With the continuous development of our society, there is a growing demand for energy. The energy consumption of the construction industry accounts for 20% to 25% of the total energy consumption of our society, and the heating energy consumption is one of the main reasons for the energy consumption of buildings. Exterior wall insulation is one of the main energy-saving measures in the construction industry. Inorganic external insulation material has become a research hotspot in various countries, compared with organic materials, it has non-toxic, high temperature resistance, not easy to crack and other advantages [12]. As a kind of inorganic external wall thermal insulation material, glass bubbles thermal insulation sand has obvious advantages such as high strength, light weight, thermal insulation, corrosion resistance and radiation protection. Some studies have shown that the proportion of different raw materials in the vitreous microbeads insulation sand will directly affect its main properties, which is consistent with the viewpoint obtained in this paper. But its precise rationing is unclear, limiting its practical use. In this research, the main factors influencing the performance of vitreous microbeads insulation sand were investigated by setting the mixing amount of different raw materials to provide data support for the application of inorganic external insulation materials.

5 Conclusion

With the increase of the mixing amount of glass bubbles, the performance parameters of insulation mortar decrease. The water retention rate of insulation sand increased with the increase of cellulose ether content, dry density decreased with the increase of cellulose ether content, consistency and compressive strength increased first and then decreased with the increase of cellulose ether content. The dry density of insulation sand decreases with the increase of redispersible emulsion powder. Its consistency and compressive strength first increased and then decreased with the increase of redispersible emulsion powder content. At the same time, the thermal conductivity of vitrified microbeads thermal insulation sand decreases with the increase of the relative ration of raw materials.

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