The research progress and prospect of building thermal insulation mortar

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Abstract: Energy conservation in building is a critical research direction for the society now and into the future. In order to better grasp the development trend, the paper reviews the current status of an important energy-saving material-thermal insulation mortar, introducing the properties, inorganic-organic composites, engineering construction application, and research progress of thermal insulation mortar.

1. Introduction

After decades of destruction from humans, the earth isn't happy these days. The overconsumption of energy worsens climate change and increases pollution. The average energy consumption in a household in many developed countries is over ten thousand kilowatt-hours per year [1,2]. Specifically, more than forty percent of this energy are used on heating and cooling. Our architectures play a key role in protecting the environment. When using the correct materials, we can adequately improve the energy efficiency of the building, as well as ensuring the construction's function and advancing indoor environment quality [3,4].

In many cases, heat loss is caused by a process called thermal bridging. For example, gaps between bricks in an exterior wall can create a funnel of heat flow that is unobstructed [5]. With the development of technology, thermal insulation mortar is a great solution to this problem. It not only holds building materials together but also is smeared over the walls. It can effectively reduce heat loss, and it's widely used in high-rise buildings and skyscrapers. This paper shall discuss the ingredients and variations of thermal insulation mortar along with its capacities and problems.

2. Thermal insulation mortar

Thermal insulation mortar is made of a variety of aggregates and additives, mixing with cement. It is mainly used for thermal insulation of building exterior walls, with the advantages of convenient construction and good durability. Thermal insulation mortar is divided into organic thermal insulation mortar and inorganic thermal insulation mortar according to its chemical composition. Among them, inorganic thermal insulation mortar, as a new type of thermal insulation material, has been widely used in the engineering field with its unique superior performance [6].

2.1 Inorganic Thermal Insulation Mortar

2.1.1 Traditional Inorganic Thermal Insulation Mortar

There are two main types of traditional inorganic thermal insulation mortar-expanded perlite thermal insulation mortar and expanded vermiculite thermal insulation mortar. Expanded perlite insulation mortar is made of cement or gypsum as cementing material, expanded perlite as aggregate, and a small amount of additives. It is one of the early insulation material used in construction. Compare to other thermal insulation material, the pros of expanded perlite thermal insulation mortar are lower costs and faster construction speed [7]. However, because of its porous property, water can carry cementing material into the hollow structure in the middle of expanded perlite during stirring

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process, thus increasing its thermal conductivity. Expanded vermiculite thermal insulation mortar has similar function and performance to expanded perlite thermal insulation mortar, but it contains expanded vermiculite as aggregate. Expanded vermiculite has loose structure, rough surface, and interwoven layers. During stirring process, the mechanical force and water can peel the layer structure, causing a decrease in its performance [8].

2.1.2 Inorganic Composite Thermal-Insulation Mortar

Inorganic thermal insulation mortar is a new type of insulation material. It contains a mixture that more than one inorganic aggregates in order to address the shortcoming of the traditional inorganic thermal insulation mortar. For example, it shows that the combined use of expanded perlite and vitrified microsphere can effectively reduce pores between expanded perlite particles, decreasing thermal conductivity. Furthermore, the combined aggregates can improve the strength and durability of the thermal insulation mortar [9].

2.1.3 Expanded Vitrified Microsphere Inorganic Thermal Insulation Mortar

Expanded vitrified microsphere inorganic thermal insulation mortar was invented in recent years and uses as lightweight aggregates. Its irregular sphere structure and sealed particles improve the strength of the mortar and solve the damage problem that the traditional inorganic thermal insulation mortar has during stirring process. In addition, its special microporous structure has good air permeability, accelerating the hardening and drying process in construction. Overall, expanded vitrified microsphere thermal insulation mortar has lower thermal conductivity and overcomes the disadvantages of traditional inorganic thermal insulation mortar, such as poor durability, large water absorption, easy pulverization, and large volume shrinkage during slurry mixing [10].

2.1.4 Cellular Foam Inorganic Thermal Insulation Mortar

Cellular Foam inorganic thermal insulation mortar combines an appropriate amount of tiny air bubbles with mortar, which effectively reduces the thermal conductivity of the thermal insulation mortar, improving its thermal insulation performance, saving materials and reducing costs. There are two main foaming technologies for the existing inorganic thermal insulation mortar: one is to add a small amount of air-entraining agent to the thermal insulation mortar; the other is to add foam into the insulation mortar slurry [11]. After the air-entraining agent is added, a large number of tiny bubbles in the mortar stably exist inside the slurry during the mixing process, which significantly increases the concentration rate of the thermal insulation mortar, reduces the bulk density of the thermal insulation mortar, and improves the thermal insulation performance. When preparing the thermal insulation mortar, adding an appropriate amount of foam composed of numerous independent, closed, small bubbles, and the foam can be maintained and evenly distributed in the thermal insulation material slurry. This method can effectively reduce the thermal conductivity of the thermal insulation mortar and improve its thermal insulation performance [12].

2.1.5 Existed Problems and Developing Trend

The ingredients of inorganic thermal insulation mortar can be adjusted according to different climate characteristics, which is convenient and flexible. It can be smeared over the exterior wall and effectively reduce thermal bridging, improve energy-saving and comfort of buildings. Although inorganic thermal insulation mortar has many advantages, there are still shortcomings and problems in its application and development [13-16].

(1) The aggregate of inorganic thermal insulation mortar has a wide range of qualities, especially for expanded vitrified microsphere inorganic thermal insulation mortar and expanded perlite insulation mortar because their particle sizes can be different. It can cause differences in physical properties such as density, gradation, water absorption, and etc., which can affect its thermal conductivity.

(2) The existing mortar preparation methods and equipment cannot yet meet the special requirements of inorganic thermal insulation mortar. The aggregate of inorganic thermal insulation

mortar needs to be brittle. On construction site, due to the incorrect mixing process, excessive mixing time, or excessive mixing force, it is easy to cause damage to the thermal insulation aggregate, resulting in a decrease in the thermal performance of the inorganic thermal insulation mortar.

(3) The existing construction method of inorganic thermal insulation mortar is mainly manual plastering, and multiple times of plastering are required. The time interval for each plaster has to be over twenty-four hours, and the total time for the mortar to solidify has to be no less than seven days. The construction period is long and inefficient.

(4) The compulsory specification of thermal insulation mortar in the construction process is not in place. There is a phenomenon of cutting corners in the external wall insulation project, and the thickness of the inorganic insulation mortar does not meet the design requirements. In addition, improper construction techniques of some projects have caused large-area hollowing and cracking of external wall.

(5) The performance test methods and requirements of thermal insulation mortar are not standardized. Some important testing methods (such as thermal conductivity) are expensive and lack intuitive and quantitative testing techniques. there is a lack of in-depth research on the quantitative relationship between dry density and thermal conductivity.

2.2 Organic Thermal Insulation Mortar

Expandable polystyrene (EPS) mortar is an organic thermal insulation material developed based on the principle of composite materials. Compared with the inorganic material, the EPS mortar has numbers of advantages such as better water absorption, lower price, higher durability, etc. EPS mortar is receiving more and more attentions. In recent years, thousands of tons of expandable polystyrene have been used in commodity packaging, and some packaging has been thrown away directly after use, causing serious environmental problems. EPS concrete can turn waste into treasure, effectively solving the problem of "white pollution". At the same time, the material can also consume a large amount of fly ash and slag during the preparation process, which plays an important role in eliminating environmental pollution. In addition, EPS mortar can significantly reduce the weight of the building. It is a building material with high economic, social and environmental benefits. It has a broad field in the future for building energy conservation. However, for now, the EPS mortar still has certain technical problems, such as fast aging, poor weather and fire resistance, etc [17].

2.3 Inorganic-organic Thermal Insulation Mortar

Inorganic-organic thermal insulation mortar combines advantage of both inorganic mortar and organic mortar and overcomes their drawbacks. It has been drawing attention in recent years. The department of architecture of developed a mixture of vitrified microsphere and EPS insulation materials, and applied it to external wall insulation in real projects. The sandwich wall insulation mortar developed by Zhang [18] is an insulation material that is a mixture of ordinary expanded perlite and EPS with hydrophobic treatment. A “paste-like” foam is also added in the mixing process while not affecting the overall strength. The results show that, when introducing 30% foam, the thermal conductivity reaches 0.061 W /(m·K), which improves the insulation performance of the insulation mortar. These studies only focused on improving the insulation effect, but not the inflammability of the chemicals. They are no longer belong to the national key promotion of environmental protection insulation product catalog.

3. Prospect

3.1 New Types of Thermal Insulation Mortar

Aerogel is a kind of light nanometer solid material, the solid phase and the void structure are all in nanometer scale. Aerogel has very low density, as low as 0.16 mg per cubic centimeter. The thermal conductivity of aerogel is also extremely low. Under normal temperature and pressure, the thermal conductivity of aerogel is generally less than 0.02 W/(m·K), but it can be as low as 0.004 W/(m·K) under vacuum. Therefore, aerogel can be used as an excellent thermal insulation material. It can almost block all three types of heat transfer: conduction, convection, and radiation. The proportion of air in the aerogel is at least 99.8% of the total volume, and the pore size is between 1 and 100 nm, which can effectively prevent the flow of air. The solid structure of the aerogel is the way of heat conduction, but due to the high porosity, the heat conduction path is very long, thus preventing the heat transfer. The porous structure acts like countless "walls", blocking the heat radiation. In addition to excellent thermal insulation properties, aerogel also has great performance in acoustics, catalysis, optics, and electricity. At present, there are four main forms of application of aerogel as a thermal insulation material in buildings: aerogel glass, aerogel thermal insulation coating, aerogel fiber composite material and aerogel mixed into concrete or mortar [19,20].

Mixing aerogel into concrete and mortar can effectively lower its thermal conductivity. In an experiment, Kim et al. [21] added aerogel into cement slurry and found that when the mass of aerogel accounts for 2% of the cement slurry mass, the thermal conductivity of the cement slurry can be greatly reduced. However, as the percentage of SiO_2 aerogel increases, it would negatively impact the density and other physical properties of concrete and mortar [22].

3.2 Developing Trend

The current world energy crisis is getting worse and worse. Building energy efficiency, as the highlight of energy conservation, will be the focus of worldwide attention. In China's "12th Five-Year Plan", energy-saving was stated as a clear target. Research on building energy-saving technology and materials has also been greatly developed, especially external wall thermal insulation technology, which has been widely used due to its unique advantages. The use of inorganic thermal insulation mortar not only saves a lot of energy (electricity, water, etc.), but also comprehensively reuses mineral wastes. It is safe, environmentally friendly, durable, and resistant to hollowing and cracking. The prospect of this type of mortar is very bright [23,24].

In the future, in order to improve thermal performance, construction efficiency, and prevent cutting corners during construction, cellular foam inorganic thermal insulation mortar would be a great option. Thermal conductivity can be decreased by mixing tiny air bubbles into the mortar. These tiny air bubbles can boost workability of the mortar. It can easily meet required measurements and better construction efficiency. To go one step further, spray construction technology of foam thermal insulation mortar can also be developed. In the multi-layer construction of mortar, it's the best to achieve continuous spraying technique (generally, the multi-layer construction of inorganic thermal insulation mortar requires an interval of more than 24 hours) [25]. Accelerating agent can be introduced into the foam thermal insulation mortar to accelerate the setting and hardening of the mortar and shorten the curing and drying time of the insulation layer (generally, the drying time for inorganic thermal insulation mortar should not be less than 7 d). This continuous spraying construction technology changes the traditional plastering process, further improves the construction efficiency of the thermal insulation mortar, shortens the construction period, greatly reduces the slipping and ash falling during the construction process, and lower the amount of wastes. This continuous spraying construction technology of cellular foam insulation mortar has fast construction and excellent insulation effect, which has become a new trend in the development of inorganic insulation mortar [26,27].

4. Conclusion

At present, inorganic thermal insulation mortar is mainly used for external wall thermal insulation system. The common materials used for external wall insulation also include: expanded polystyrene foam (EPS), extruded polystyrene foam (XPS), polyurethane foam (PU), rubber powder polystyrene particle insulation slurry, etc. Most of these materials are made of organic compounds. Because of their great thermal insulation performance and cheap price, these materials are widely used currently. However, they have shortcomings, such as poor fire resistance and bad weather resistance.

Thermal insulation mortar has high thermal conductivity compare to other thermal insulation materials, so its use in areas with hot summer and cold winter is limited. In fact, it is more suitable for the application of external insulation or internal insulation of external walls in hot summer and warm winter areas, places near the equator. Especially for exterior walls that require pasting of facing bricks or decorative stone or curtain wall decoration, using thermal insulation mortar for internal thermal insulation is a good choice. The future development of thermal insulation mortar is mainly from the following aspects:

(1) At present, there is little research on the interface bonding performance between lightweight aggregates and cement-based materials, and the lack of revealing the interface performance of thermal insulation mortar from a microscopic point of view limits the further improvement of thermal insulation performance and physical properties of building thermal insulation mortar.

(2) There are few types of lightweight aggregates, and it is urgent to develop new types of lightweight aggregates with low thermal conductivity to further improve the insulation performance of mortars. In the future, it is necessary to further strengthen the research on the application of nano-materials in thermal insulation mortar, and improve the microstructure of thermal insulation mortar from nanometer scale, thereby improving its physical properties and thermal insulation performance.

(3) There are few researches on the durability of building insulation mortar, lack of a unified evaluation method for durability of insulation mortar, lack of quantitative testing technology, and no relevant national standards. Therefore, in the future, it is necessary to strengthen the research on the durability evaluation method of insulation mortar and establish standard requirements.

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