Efficient energy-saving and multifunctional insulation coating

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Abstract. In order to improve the insulation property of walls, hollow ceramic microspheres are applied to produce insulation coating. The thermal conductivity meter and electromechanical universal testing machine controlled by the microcomputer are employed to do research on the impacts that different proportions of ingredients have on the thermal conductivity, tensile and bonding strength and waterproof performance. According to the experimental results, with the increase of hollow ceramic microspheres and the decrease of resin, the thermal conductivity reduces to a certain degree. However, the tensile strength and waterproof performance become worse. As a result, under the premise of ensuring the tensile strength and waterproof performance conform to the national standards, it is rational to increase the proportion of hollow ceramic microspheres as much as possible to achieve a better thermal insulation performance.

1. Introduction

In the global growing energy consumption, building energy consumption accounts for a large proportion of total energy consumption in both developed and developing countries. The total building energy consumption includes production energy, construction energy, daily energy and demolition energy, among which the daily energy consumption is the largest. [1] In China, the building energy consumes more than 1/4 of the national energy consumption. Total building energy consumption is greater than that in any other department. Moreover, since China is a developing country with low per capita possession of resources and low energy efficiency, the development of energy-saving buildings is particularly significant for our international economic construction.

Apart from rational architectural design, placing the thermal insulation materials such as benzene board in the building envelope is now the main energy-saving ways of daily use. As a developing method of energy-saving, insulation coating has excellent effect and flexible application, so it might win a broad development prospects. [2-4]

Saving energy and improving economic efficiency is one of the basic goals of scientific research and technological development. On May 4, 2017, the Ministry of Housing and Urban-Rural Development organized the preparation and issuance of the "Thirteenth Five-Year Plan for Construction Industry Development" and issued the major tasks of deepening the reform of the institutional mechanism in the construction industry, promoting the modernization of the construction industry, and encouraging the development of energy-saving buildings and green buildings.

Barrier insulation coatings are thermally insulating coatings that have a significant resistance to heat transfer. If they are applied to the interior wall, the summer insulation and winter insulation could be achieved, therefore it would keep the interior cool in summer while improve indoor temperature in winter. In addition, if barrier insulation coatings are coated on the outer surface of the heating pipe,
they can play a role in reducing heat loss, preserving heat and saving energy. As a result, the development of thermal insulation coating has great practical significance. [5, 6]

2. Experiment

The base material of the thermal insulation coating is acrylic resin, and the filler is hollow ceramic beads while the film aid is propylene glycol. As the beads can not withstand the great shearing force, we take a uniform slowly stirring during the preparation. This experiment starts from immersing the rock wool into hot water and stirring for more than three minutes, after that it was placed in a 20 °C incubator for more than 12 hours. The next step is taking the acrylic resin emulsion and adding various additives to it, then mixing them with fully stirred rock wool and stirring again. Besides, beads are gradually added along with stirring, and the finished white paste paint could be produced after a period of more than half an hour. When used, the paint can be mixed with water according to the needs of application. The thermal insulation coating needs to be rushed multiple times when the designed coating is thick. The thickness of each layer is 2mm ~ 3mm, and the final coating thickness can reach 10mm ~ 15mm.

3. Results and discussion

3.1. Different mix and its related physical properties

It is measured that the bulk density of insulation coating with hollow ceramic micro beads can be controlled at about 200-400 kg/m3, and the different mix of product density, thermal conductivity and tensile bond strength are showed in Table 1 below (Water not included in the table, as water in the product could evaporate after brushing and it has no effect to the product performance; This table also does not record fungicides, preservatives, because the incorporation is small):

| No. | Hollow ceramic beads (wt.%) | Acrylic resin (wt.%) | Rock wool (wt.%) | Propylene glycol (wt.%) | Defoamer (wt.%) | Silane coupling agent (wt.%) | Bulk density (kg/m³) | Thermal Conductivity (W/m•K) | Stretch strength (kPa) |
|-----|-----------------------------|---------------------|------------------|------------------------|----------------|-----------------------------|---------------------|---------------------------|-----------------|
| 1   | 35.4                        | 58.9                | 2.7              | 2                      | 0.5            | 0.5                         | 342                 | 0.673                     | 119.9           |
| 2   | 38.1                        | 56.3                | 2.6              | 2                      | 0.5            | 0.5                         | 314                 | 0.322                     | 110.5           |
| 3   | 40.6                        | 54.0                | 2.4              | 2                      | 0.5            | 0.5                         | 292                 | 0.239                     | 102.4           |
| 4   | 42.9                        | 51.8                | 2.3              | 2                      | 0.5            | 0.5                         | 275                 | 0.169                     | 95.5            |
| 5   | 45.0                        | 49.8                | 2.2              | 2                      | 0.5            | 0.5                         | 262                 | 0.122                     | 89.2            |
| 6   | 46.9                        | 48.0                | 2.1              | 2                      | 0.5            | 0.5                         | 251                 | 0.073                     | 84.6            |

3.2 Tensile bond strength analysis

Coatings made from the above six combinations were used to connect two concrete blocks of 40 mm × 40 mm in cross-section, and then Load-bearing tensile testing was performed by electro-mechanical universal testing machine (WDW-40) after it was fully air-dried. Pulling the end until the paint bond is broken, and each sample with a different ratio did three times. When calculating the intensity, the weight of the concrete block should be considered, which is 8N. The average of three intensities was taken as the final tested intensity for each compounding ratio and the final tested intensity is reported in Table 1. It illustrates that the strength decreases with the increase of the proportion of microbeads, but the reduction is not too great. The strength of each mix meets the requirements of the project. In addition, after broken, the coating still adheres to the interface with the concrete and the bonding performance is excellent, which is enough to meet the needs of indoor and outdoor decoration. The most important performance of the product is thermal insulation, so the best mix design is analysed with thermal conductivity. Figure 1 is the sixth group of mix, that is, the optimal mix of the test results.
Fig. 1 The result of extension strength test for No. 6 sample

3.3 Thermal conductivity analysis

Fig. 2 The influence of proportion of micro bead on thermal conductivity

Figure 2 shows that the influence of microbeads content on thermal conductivity. It can be seen from Table 1 and Figure 2 that the thermal conductivity decreases with the increase of the content of the microbeads. Combined with the analysis results in 3.2, the smallest thermal conductivity group of mixes is the final product mix. The tensile bond strength of this formulated paint is 84.6 kPa with good strength.

3.4 Waterproof performance analysis

Three specimens prepared was described in section 3.2, and the paint used is produced according to the final product mix. During the experiment, those specimens are immersed in water and placed at room temperature for ten hours. After fully dried, electro-mechanical universal testing machine (WDW-40) would carry out load tensile test. Figure 3 shows one of the results. After averaging the test results, it presents that the ultimate strength is 70.6 kPa and the softening coefficient is 0.835. Through experiments we could find that the immersion in water could reduce bond strength of the product, but the softening coefficient is still more than 0.8, which is enough to meet the needs of the project.
3.5 Energy-saving effect analysis

This product has excellent waterproof performance and ultraviolet ray (UV) resistance, so it could withstand 160 °C high temperature (the drying temperature was set to 160 °C to prove the nature). Moreover, this product can be used for the rushing of internal and external walls of constructions and the painting of heating pipe (normally the highest temperature of heat pipe is about 150°C). The energy-savings effect of this product can be proved through the following two examples:

3.5.1 For the paint of internal and external walls of constructions:

Assuming that the coating is applied to a concrete wall of 240mm thickness and the thickness of the coating is 10mm. The thermal conductivity of concrete should be 2.94 W/ (m K) according to GB 5001-2010 "Code for Design of Concrete Structures". Indoor temperature $T_1 = 25$ °C, and outdoor temperature $T_2 = 0$ °C.

The thermal resistance of a building wall can be expressed as:

$$R_{tot} = \sum_{i=1}^{n} R_i$$

The thermal resistance of a building wall painted with traditional coating (neglecting coating thermal resistance):

$$R_1 = \frac{0.24}{2.94} = 8.16 \times 10^{-2} \text{ (m}^2 \cdot \text{K})/\text{W}$$

The thermal resistance of a building wall painted with 10mm thick this coating:

$$R_2 = R_1 + \frac{0.01}{0.073} = 0.219 \text{ (m}^2 \cdot \text{K})/\text{W}$$

The thermal resistance of the building wall is increased by 168.4%.

In addition, the heat flux density of a building wall can be expressed as:

$$q = \frac{\Delta T}{R_{tot}} = \frac{T_1 - T_2}{R_{tot}}$$

The heat flux density of a building wall painted with traditional coating:

$$q_1 = \frac{T_1 - T_2}{R_1} = 306.4 \text{ W/m}^2$$

The heat flux density of a building wall painted with 10mm thick this coating:

$$q_2 = \frac{T_1 - T_2}{R_2} = 144.4 \text{ W/m}^2$$
The heat flux density of the building wall is decreased by 62.7%, that is, the theoretical energy saving is 62.7%.

3.5.2 For the paint of heating pipe:
Supposing that the coating is applied to the commonly used 5 mm thick heating pipe, and the coating thickness is 10 mm. The thermal conductivity of Q235 steel is taken as 52.34 W/(m²·K).
The thermal resistance of steel pipe painted traditional coating (ignore paint resistance):

\[ R_1 = \frac{0.005}{52.34} = 9.553 \times 10^{-5} (m^2 \cdot K)/W \]

The thermal resistance of steel pipe painted with 10mm thick this coating:

\[ R_2 = R_1 + \frac{0.01}{0.073} = 1.370 (m^2 \cdot K)/W \]

The thermal resistance of the pipe becomes 1435 times that of the original, which significantly improves the working efficiency of urban heating system and greatly reduces its heat loss.

According to the current status of building insulation, only 4% of existing buildings adopt energy efficiency measures [7], and China's building energy consumption is expected to reach 1.089 billion tons of standard coal by 2020. Based on the energy-saving calculation, if the remaining 96% of the buildings adopt this product as the wall insulation coating, it can save 657.5 million tons of standard coal and reduce the CO2 emission by 2.124 \times 10^{12} kg per year. Furthermore, if the coating thickness is adjusted and it is applied to the heat pipe, energy-saving effect will be more significant. As a result, this product might slow global warming and promote China's energy-saving emission reduction process.

This product has almost the same remarkable thermal insulation and energy-saving effect as the multi-purpose thermal insulation wall currently used. However, this product is more flexible and could be applied into more diversified fields. If these two are combined, the energy-saving effect will be improved greatly.

4. Other excellent performance and progressive significance of this product
The selection and development of film-forming base is essential for the production of high-performance thermal insulation coating. This attempt to use XG-6001 acrylic resin emulsion as a film-forming base and select ethylene glycol butyl ether as a coalescent has achieved good results, as the performance test results show that its mechanical strength can meet the requirements of construction and heating pipes. Since the UV resistance of a coating depends mainly on the film-forming binder and this coating has excellent UV resistance, it is considered that the UV resistance of the coating is excellent.

The dispersion of the bead filler directly affects the performance of the coating. This product selects the silane coupling agent for the dispersion and stabilization of the coating. When testing the thermal conductivity, according to the test results of different samples, it can be known that the microbeads are evenly dispersed in the film-forming base; the coating effect of the paint which has been placed for different time shows that the product has good stability. Adding appropriate amount of water and secondly stirring the product before using could make the packing have a good dispersion. This method has strong guiding significance for the real construction.

The theoretical research on many kinds of materials, such as hollow microbeads and nanosemiconductors, is relatively mature, but there are few systematic studies on the application of these materials as heat-insulating materials added into thermal insulation coatings. This research and the final products can be used as a good reference for future development of relevant products and research. In addition, this product is free of volatile solvents and is therefore safer for humans and the environment.
5. Conclusion
In this experiment, hollow ceramic beads and acrylic emulsion are used as thermal insulation filler and main film-forming substances respectively, while silane coupling agent and propylene glycol are added as additives. As a result, the excellent insulation coating product is produced. This product is applied to ordinary concrete exterior wall with 10 mm thickness, then the heat flux density is 62.7% lower than that of original wall, which means 62.7% of theoretical energy saving. If it is combined with other building energy-saving measures, the total requirement of 65% energy-saving of residential building can be achieved. If the thickness of this product is adjusted, it would meet the higher energy-saving requirements. This product is applied to heat pipe with 10 mm thickness, and the pipe heat resistance becomes 435 times as large as the original one, which will significantly improve the work of urban heating system and greatly reduce its heat loss. Therefore, the energy-saving effect of this product is remarkable. And this product can be widely used in industrial and civil buildings as well as other conditions requiring energy-saving insulation, because it has excellent waterproof performance, stable volume and no shrinkage cracking phenomenon.

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