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Preparation and Study of High Reflectance Color Solar Heat-reflective Insulation Coatings

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Abstract. Based on the existing preparation process of common thermal insulation coatings, a kind of high reflectance color solar heat-reflective insulation coatings was developed by improving the thermal insulation coatings. The effects of hollow glass beads, titanium dioxide and other factors on the properties of the coatings were discussed, and the thermal insulation properties of the coatings were characterized by solar reflectance ratio. The results show that the water-based color solar heat-reflective insulation coatings with high solar reflectance, high weathering resistance and high stain resistance can be prepared by using pure acrylic emulsion and silicone acrylic emulsion as the film-forming base material, using the rutile type titanium dioxide, calcined kaolin, precipitated barium sulphate and hollow glass beads as the insulated function pigments and fillers, and using the auxiliaries for coatings.

1. Introduction

Since the 21st century, with the rapid development of industrialization, massive emission of CO₂ and other exhaust gases, destruction of the ozone layer [1,2], and even the rapid warming of the North and South Poles, the global greenhouse effect has become increasingly significant, affecting more and more people's lives and industrialization process. The greenhouse effect and intensification of solar irradiation have led to the increasingly significant urban heat island effect. The heat island effect has become a serious problem for both developed and developing countries. Intense solar radiation will lead to the excessively high surface temperature of objects, and will cause the surface layer of objects and other materials directly receiving a large amount of solar radiation to be heated and aged, so the objects cannot maintain their original performance [3]. Reflective heat insulation coating is a new energy-saving material developed in recent years, which can significantly reduce the temperature of external wall, roof and room of buildings by effectively reflecting, blocking and radiating the energy of sunlight and reduce the energy consumption of refrigeration equipment such as air conditioner under high temperature conditions, thus not only improving the working environment but also saving a lot of energy [4].

In order to achieve the purpose of cutting off the reflected solar radiation, improving the use safety of materials and reducing energy consumption, developed countries abroad [5,6] have started to develop various types of heat insulation coatings since the 1970s, which are widely used in various fields such as petrochemical industry, construction and military affairs, etc. Since its introduction into China in the 1990s [7], it has attracted the attention of domestic researchers. However, the heat reflective and thermal insulation properties of the current heat reflective coatings will be greatly reduced when they are color-adjusted. Therefore, on the basis of previous work, a kind of color heat-reflective insulation coating with high solar reflectivity, high weather resistance, high stain resistance



is prepared in this study by adding hollow beads and functional pigments; the surface smoothness of coating film is improved through the use of large particle size titanium dioxide, so that the developed coating has both excellent thermal insulation performance and excellent decorative performance.

2. Experiment

2.1. A Subsection

The materials used in the experiment are divided into four parts: base materials, beads, additives, pigments and fillers.

Base material: pure acrylic emulsion AC-261 (Dow Chemistry), silicone acrylic emulsion 996 (BATF), elastic emulsion 2468 (Dow Chemistry).

Beads: glass beads, Ma On Shan Mining Institute of Sinosteel (H32, H40), 3M (S15, VS5500), Haino Technology (HN25, HN36); 3M ceramic beads WT-210; nano ceramic insulation powder (UNIC Technologies).

Pigments and fillers: ALTIRIS 550, 800 (Huntsman titanium dioxide), rutile type titanium dioxide, calcined kaolin, superfine coarse whiting (800 meshes), precipitated barium sulfate, etc. (all of them are industrial products), American Ferro pigments (iron chrome black SPP3025, nickel titanate yellow 10401S, cobalt green Spp2006, cobalt blue Spp2008, brown V760, green 6009, iron oxide red 8008), ordinary color paste (carbon black, iron yellow, iron red, phthalocyanine blue, phthalocyanine green, bright red, organic orange).

Auxiliaries: wetting agents, dispersants, defoamers, thickeners and so on (all of them are industrial products).

2.2. Instrument and Equipment

High-speed dispersant, electronic scale, ultraviolet-visible infrared spectrophotometer PerkinElmer Lambda 950, thermal insulation thermometer, AE1 radiometer, NS800 spectrophotometer, scanning electron microscope, X-ray diffractometer.

2.3. Preparation Process

(1) Add dispersant, wetting agent, defoamer, preservative and appropriate amount of water into the dispersing tank according to the formula, and start the mixer to mix evenly for 5 minutes;

(2) Then add titanium dioxide, kaolin and coarse whiting into the mixture obtained from the step 1, adjust the rotating speed of mixer to 1000 to 2000 revolutions per minute, mix at high speed for 30 minutes to 1 hour, and obtain the mixture with fineness less than 60 μ m.

(3) Adjust the rotating speed of mixer to 300 to 600 revolutions per minute, add latex, film builder and defoamer to mix for 5 minutes, and then add functional filler to mix for 10 minutes.

(4) Add thickener, and disperse at low speed for 5 minutes.

2.4. Performance Test

Prepare samples according to the requirements, and measure the 2h insulation temperature difference, brightness value and solar reflectance of the coating by using the thermal insulation thermometer, color meter and spectrophotometer.

2.5. Test Process

(1) According to the basic formula, various functional fillers are used to measure the reflectivity and temperature difference between the two sides of the coating under different dosage conditions; observe the thermal insulation effect of the coating, and screen functional fillers.

(2) According to the performance requirements of the coatings, the varieties and dosage of the emulsion are selected through experiments.

(3) Conduct the test and comparison under the same condition, process the test data and determine the formula according to the test results.

(4) Determine the final formula.

3. Result and Discussion

3.1. Influence of Hollow Glass Beads on the Thermal Insulation Property of Coatings

3.1.1. Effect of Glass Beads on the Thermal Insulation Property of Coatings. It can be seen from the Table 1 that the order of thermal insulation temperature difference is HN25 > HN36 > VS5500 > H40 under the same dosage addition (wt6%). This is caused by many reasons: the first one is the influence of the density of hollow glass beads (0.25-0.40g/cm³); theoretically speaking, the lower the density of hollow glass beads, the better the thermal insulation effect, and the lower the reflectivity of light and the barrier property to heat energy. The second one is the smaller the particle size and volume of different types of hollow glass beads, the lower the ability of hollow glass beads to block heat transfer by forming continuous cavity structure in the coatings. The third one is the damage rate of beads, and the smaller the damage rate, the better the insulation effect. The fourth one is the interface performance of beads, and the better the compatibility of beads with the high molecular emulsion, the less the agglomeration of beads, the better the dispersion, and the better the heat insulation performance is.

Table 1. Technical parameters of different types of hollow glass beads

Product category	Product model	Compressive strength MPa	Density g/cm ³	Average particle size μm	Insulation performance (2h temperature insulation difference, °C)
Hollow glass beads	VS5500	37.9	0.38	40	35
	H40	27.5	0.40	40	54
	HN25	5.15	0.25	60	24
	HN36	13.79	0.32	40	25

3.1.2. Effect of Different Contents of Glass Beads on the Properties of Coatings. When the amount of glass beads is low, the beads are sparsely arranged in the coating, and it is difficult to form an effective continuous cavity in the coating to block the heat transfer, so the reflective heat insulation effect of the coating is limited. With the increase of the content of hollow beads, the arrangement of beads in the film is gradually compact, and the thermal insulation effect of the film is significantly enhanced. When reaching the saturation state, the reflectivity of sunlight reaches the maximum, and the thermal insulation effect is the most obvious at this time.

Hollow glass beads have a small bulk density and large volume and are easy to cause post-thickening of coatings. When the amount of glass beads exceeds a certain range, the texture and levelling property of coatings will be poor, and the storage stability of coatings will also be reduced. It can be seen from Fig.1 that the dosage of glass beads is appropriate at 4-10%.

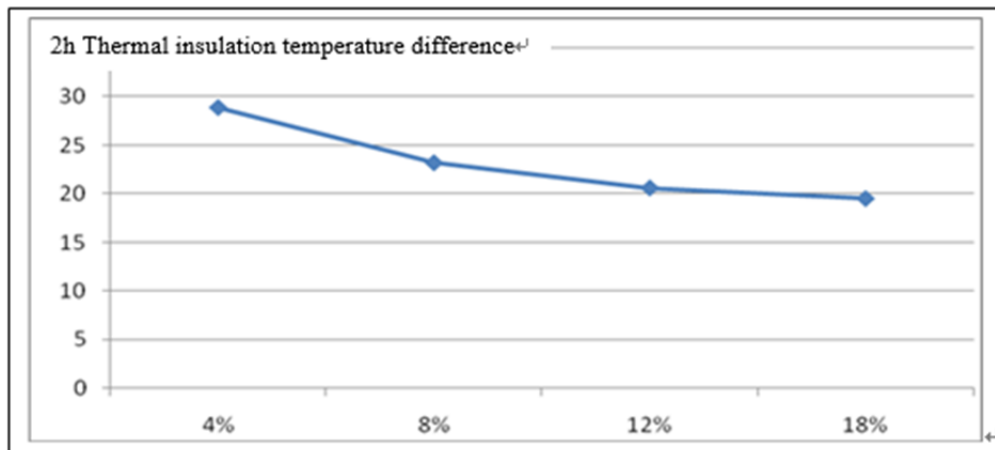


Figure 1. Effect of different dosage glass beads on the thermal insulation properties of the coating (Rutile titanium dioxide 8%)

3.1.3 Effect of Hollow Glass Beads on Reflection Ratio. Using rutile titanium dioxide as the coloring pigment, different amounts of hollow glass beads are added to test the reflectivity data of the coating. It can be seen from the Table 2 and Fig.2 that the addition of hollow glass beads can significantly improve the near infrared reflectance ratio and total solar reflectance ratio of coatings. The main reason is that hollow glass beads are thin-walled hollow spheres with low thermal conductivity, and they are closely arranged in multiple layers in the coatings to form a vacuum layer, which has a strong reflection and barrier effect on the solar radiation heat.

Table 2. Effect of hollow glass beads on coating reflectance

No.	Dosage of hollow glass beads %	L*	a*	b*	TSR %	RNIR %
1	0	95.47	0.08	2.21	83.98	82.12
2	4	96.79	0.12	3.55	88.17	89.12
3	8	96.84	-0.04	3.75	92.75	94.39

Note: (1) TSR is the total solar reflectance ratio, i.e. the ratio of the 250-2000nm reflected solar radiation energy to the 250-2000nm incident solar radiation energy; (2) RNIR is the ratio of near infrared reflectance ratio, i.e. the ratio of 780-2000nm solar radiation energy.

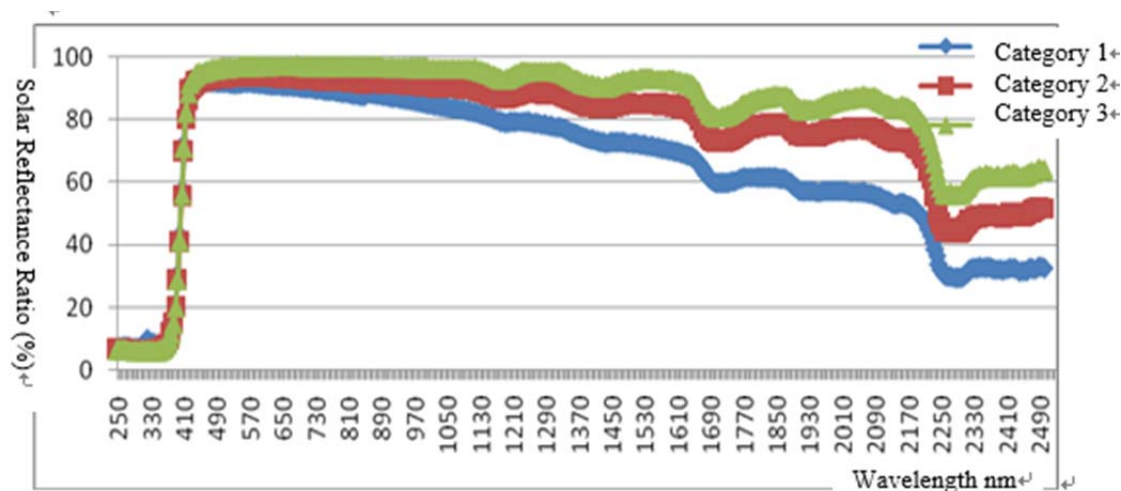


Figure 2. Diagram for the solar reflectance ratio of white insulation coating of hollow glass beads

3.1.4 Effect of Glass Beads on Surface Morphology of Coatings. It can be seen from Fig.3 that the coating film surface in the formula without beads is smooth, continuous and compact; in the formula with beads, the glass beads with different sizes are interlaced in the coating, and the small particles effectively fill the voids among the large particles, so that the hollow glass beads are compactly accumulated in the coating, thus improving the reflective heat insulation effect of the coating; the spherical glass beads float on the surface, and as the content of glass beads increases, the surface roughness of the coating film also increases.

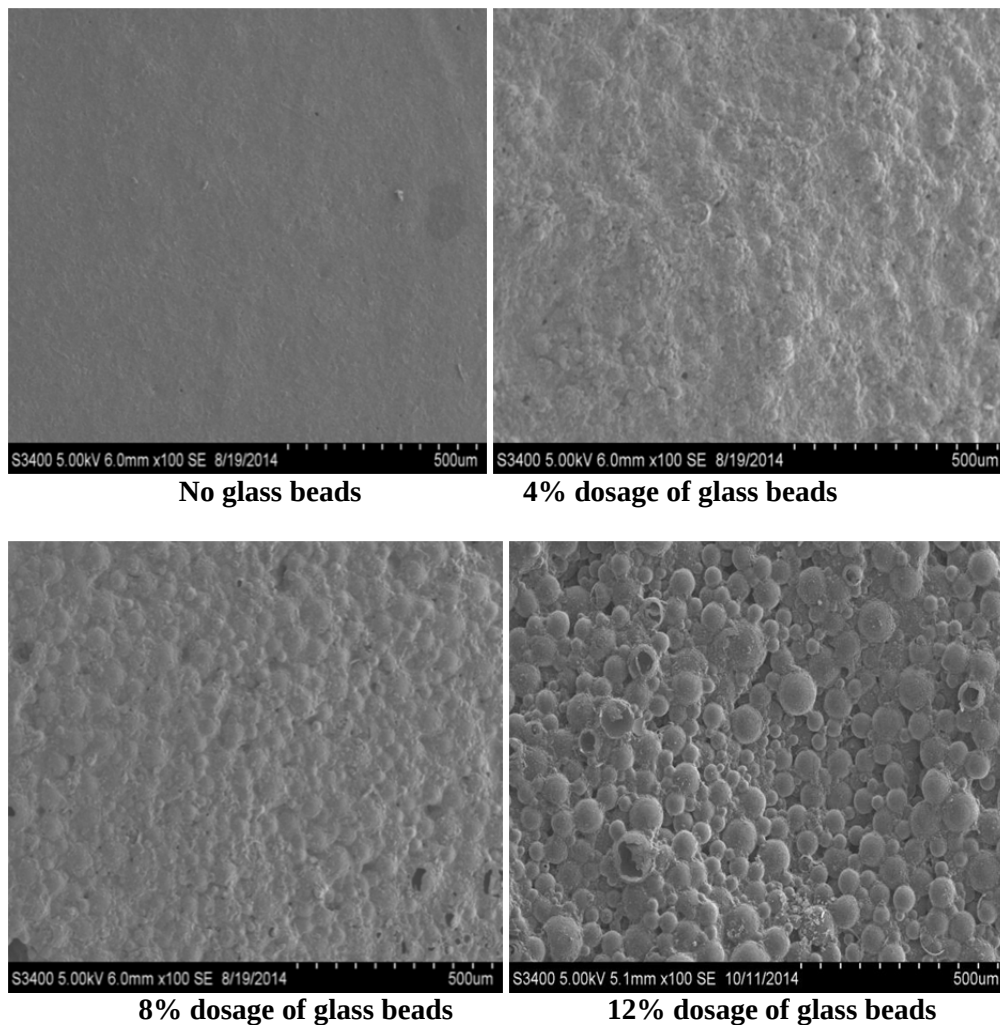


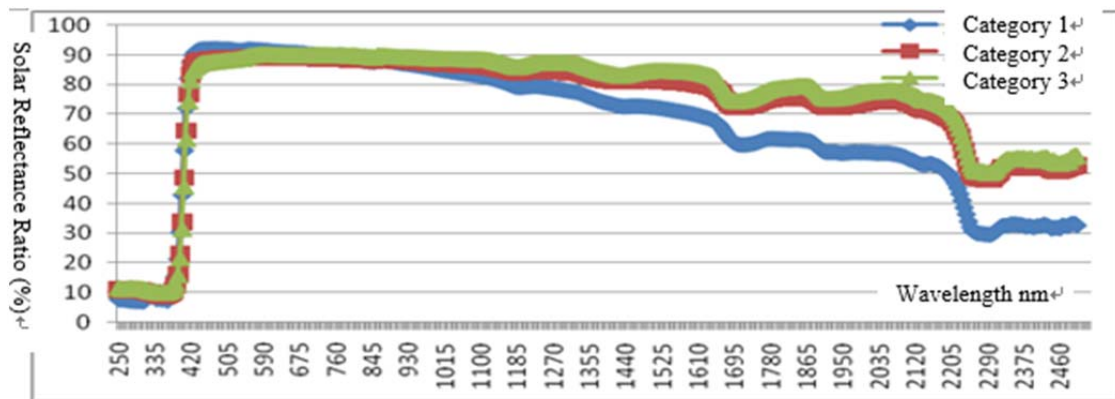
Figure 3. Surface morphology of thermal insulation coating film (100x)

3.2 Effect of Titanium Dioxide on Thermal Insulation Performance of Coatings

Rutile titanium dioxide is a white pigment with the best thermal reflection effect, and it is also an important factor affecting the thermal insulation performance of the base paint of white reflective heat insulation coatings. It can be seen from Table 3 and Fig.4 that the total solar reflectance ratio of white coatings made of different titanium dioxide powders has little difference, and 2# and 3# coating samples have a high reflectance ratio in the long-wave near infrared region (1100nm-2500nm).

Table 3. Effect of titanium dioxide variety on the solar reflectance ratio

No.	L*	a*	b*	TSR	RNIR
1	95.47	0.08	2.21	0.8398	0.8212
2	94.04	0.32	2.93	0.8430	0.8517
3	93.99	0.35	3.03	0.8532	0.8709

**Figure 4.** Diagram for the Solar Reflectance Ratio of White Coatings made of Different Titanium White Powders

4. Conclusion

(1) The particle size of hollow glass beads has a great influence on the reflectivity of coatings. In the coating whose formula contains beads, glass beads of different sizes are interlaced in the coatings, and small particles effectively fill the voids among large particles, so that hollow glass beads are compactly accumulated in the coatings, thus improving the reflective heat insulation effect of coatings. Spherical glass beads float on the surface, and as the content of glass beads increases, the surface roughness of the coating film also increases.

The larger the average particle size of hollow glass beads is, the greater their light reflective ability and thermal barrier property, which leads to the enhancement of reflective insulation performance of coatings. When 3M glass beads are selected, the thermal insulation performance of the coating is the best.

(2) The surface smoothness of the coatings can be improved by using titanium dioxide with large particle size, so that the coatings developed have both excellent thermal insulation performance and decorative properties.

(3) Fillers have little effect on the solar reflectance ratio of coatings. After adding different common fillers, the change rule of solar reflectance ratio with wavelength is basically the same, and there is little difference in the solar reflection ratio of white coatings.

(4) Infrared reflective pigments have good physical and chemical properties. The reflective heat insulation coatings using the infrared reflective pigments have high solar reflectivity and good heat insulation performance. In addition, it has excellent weather resistance, temperature resistance, chemical stability, and better environmental protection performance.

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