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An alternative nighttime radiative cooling paint using glass microspheres in water-based acrylic paint

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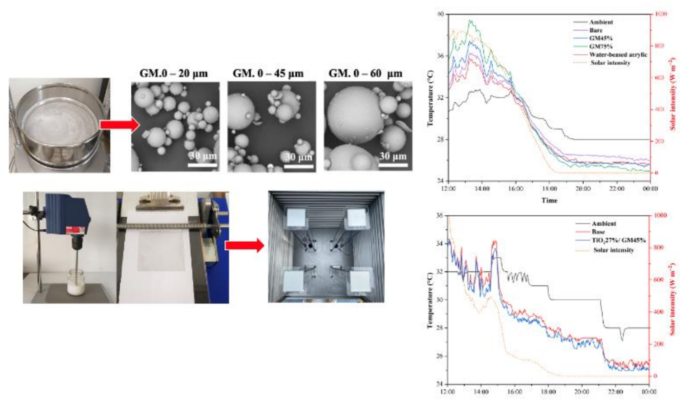
Abstract



An alternative method for producing radiative cooling paint using sustainable and cost-effective green materials, which can significantly reduce indoor temperatures. Prior research on radiative cooling systems revealed that multilayer metal oxide systems require expensive raw materials and high-end facilities, limiting large-scale production. Therefore, this study aimed to identify optimal conditions for producing radiative cooling paint using commercial spherical glass microspheres and titanium dioxide nanoparticles. The study investigated the effect of glass microsphere size, quantity, and coating thickness on emissivity and light reflectance. Results showed that glass microsphere size did not significantly affect emissivity. However, increasing coating thickness and glass microsphere quantity initially increased emissivity but stabilized at saturation points. The addition of glass microspheres decreased light reflectance, increasing temperatures during the daytime. The radiative cooling efficiency of the paint was tested, and the results showed that the glass microsphere content significantly affected the reduction in daytime temperatures. A mixture content of 45 and 75 wt% reduced the temperature by 2.96 and 3.09 °C, respectively, lower than the ambient temperature during the nighttime. The double layer of titanium dioxide/glass microspheres paint was more effective at cooling than the single layer of 45% glass microspheres, despite similar emissivity values.

Keywords: Glass microsphere; Radiative cooling; Water-base acrylic paint

1. Introduction

In regions with high solar radiation intensity, such as regions near the equator, the high energy consumption of buildings and residences is a significant issue. The building's dependence on air conditioning systems, which can account for 50 to 60 percent [1] of a building's total energy consumption, is the primary cause of this issue. To address this problem, researchers have explored ways to reduce energy consumption by employing building envelope materials with superior solar reflectance. It has been demonstrated that these materials are extremely effective at reducing the amount of heat radiation entering a building, thereby decreasing the energy consumption of electrical appliances and air conditioners. [2 – 4] Energy-saving exterior paint coatings have also been developed for the purpose of beautifying buildings while simultaneously conserving energy. These coatings are available in a range of hues and applications, including exterior architectural coatings, industrial paint coatings, and protective varnishes. These coatings are designed to protect the surfaces of materials from ultraviolet and infrared light. UV light has high energy and can easily cause materials to deteriorate, whereas infrared light produces heat, causes exterior coatings to deteriorate, and increases the energy consumption of air conditioners. However, due to the properties of the roof shell and current color schemes, they cannot prevent residual heat or absorption in the surface of the roof cladding inside the structure. Reflection or release from the exterior of the building is a significant cause of the urban heat island phenomenon, which results in higher temperatures and uneven wind directions, dust, and pollution over a large area, thereby creating a large heat reservoir. [5] The radiative cooling system is an effective method to decrease indoor temperatures, especially in hot and sunny climates. By converting near-infrared radiation to wavelengths between 8 and 13 µm, which are not absorbed by the atmosphere, the system is able to effectively cool the surface of a building or other structure. While multi-layer metal structures, [6] including silicon dioxide (SiO_2)-based layered structures, have demonstrated significant radiative cooling, and uniform-sized silicon dioxide microspheres [7] can exhibit a lower surface temperature than the surrounding area due to phonon-polariton resonance [8], the processing requirements and related material costs may not be suitable for building applications.

In this study, we examine the low-cost material glass microsphere with acrylic water-based paint on a metal sheet substrate by attempting to control the size range, concentration, and thickness of the glass microsphere paint, which exhibits significant emissivity properties for metal roof paint. The nighttime radiating temperature of our glass microsphere paint is comparable to that of commercial white paint. Using an outdoor temperature measurement, we compare a paint coating sample to an indoor temperature.

2. Materials and Methods

Particle sizing using sieve analysis. The size range of glass microsphere powder was studied using dynamic light scattering (DLS) to measure the size of particles. The particles were first separated by a sieve method and then compared to the unsighted particle size separation method. In addition, the shape and characteristics of the particles were examined using scanning electron microscopy (SEM).

Fig. 1 Sieve Analysis EML 200

Adding particles to the paint. A metal coating paint was prepared by mixing in glass microspheres of different sizes (0 – 20 μm, 20 – 45 μm, and 0 – 60 μm). The paint was coated on metal sheets with a thickness of 80 μm. The emissivity of the coated metal sheets was then measured using an emissometer TMC 1371 – 98 standard test method for determination of emittance of materials near room temperature), a device that measures the ability of a surface to emit thermal radiation. By comparing the emissivity of the coated metal sheets with different sizes of glass microspheres, we aimed to investigate the effect of the glass microsphere size on the performance of the paint. In the next step of the study, glass microsphere powder was added to a cooling paint mixture to examine its impact on emissivity. The weight content of glass microsphere powder was varied at 15, 30, 45, 60 and 75 wt**%**. The effect of coating thickness on the emissivity of thermal radiation was also studied. The thickness of the coating was varied at 60, 80, and 100 μm respectively.

Fig. 2 Mixing paint process by overhead stirrer.

The cooling performance measurement was conducted to evaluate the effectiveness of the glass microsphere paint in reducing surface temperature. The temperature measurement was taken outdoors and compared to the efficiency of the paint in reducing temperature using a weather station test kit. The test also included monitoring sun intensity, sun irradiation intensity, and ambient temperature. The comparison was made between the glass microsphere paint and a control sample without the addition of glass microspheres.

Fig. 3 Outdoor testing temperature measurement at “S8 building” KMUTT, Bangkok, Thailand.

3. Results and Discussion

In this study, the sieve shaker was used to separate the particles according to size of 0 – 20, 20 – 44, 45 – 62 and 63 – 74 μm were used to measure the sizes of the sorted particles. As depicted in Fig 4(a), the volume of the filter layer was measured at a rate of 200 g / 15 min. The results indicated that after sorting, the volume weight was 3.14 g / time, or 1.57% / time. Due to the time and resources required to classify the particle size, mixing the sorted particles into paint in bulk or on an industrial scale is challenging.

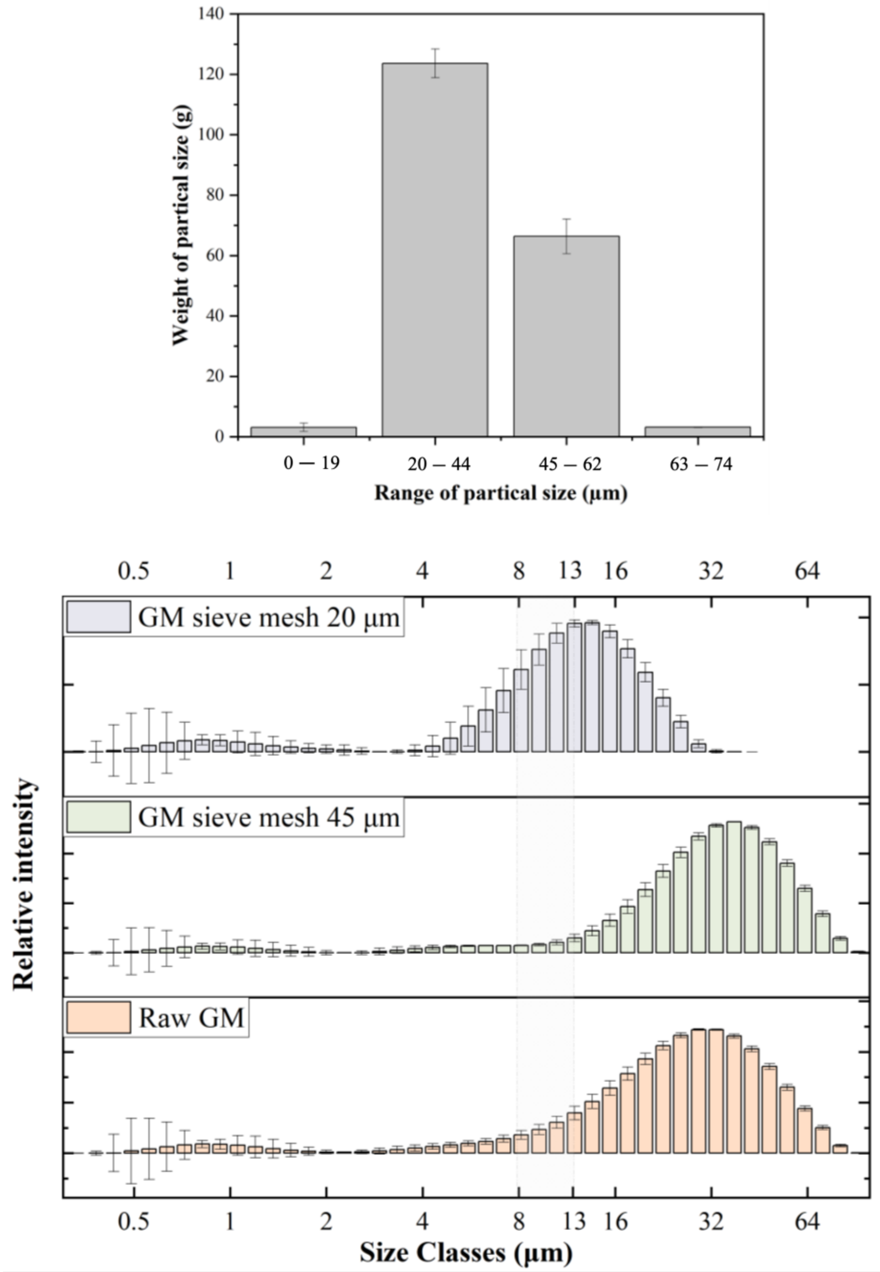


Fig. 4 The particle sizer and size analysis (a)The particle weight with difference size sieve mesh (b)The particle size with sieve mesh 20, 45 μm and raw glass microsphere (not sieve).

The size distribution of particles that pass through various sieve shakers is in Fig. 4(b) Results show that at the 20 μm sieve range, particles fall within the range of 8.1 – 19.9 μm with a most frequent size of 11.9 μm. For the 45 μm sieve range, particles fall within the range of 15.4 – 55.2 μm with a most frequent size of 29.2 μm. There are three size ranges that can be determined by the test (0 – 20 μm, 0 – 45 μm, and 0 – 60 μm). Each particle size range of glass microspheres was added into an industrial paint and coated on the metal sheet by bar coater and tried to control the thickness of 80 μm.

Table 1 The emissivity of metal sheets coated with a cooling paint that contains 30 wt% Glass Microspheres (GM) of various particle sizes

Sample	**Paint thickness (μm)**	**Emissivity (Ɛ)**
Metal sheet	N/A	0.10 (± 0.00)
Metal sheet + Paint	305.0 (± 11.0)	0.79 (± 0.06)
Metal sheet + (Paint +GM 0 – 20 μm)	83.3 (± 3.2)	0.90 (± 0.01)
Metal sheet + (Paint +GM 0 – 45 μm)	90.8 (± 4.0)	0.89 (± 0.00)
Metal sheet + (Paint +GM 0 – 60 μm)	83.8 (± 3.0)	0.89 (± 0.00)

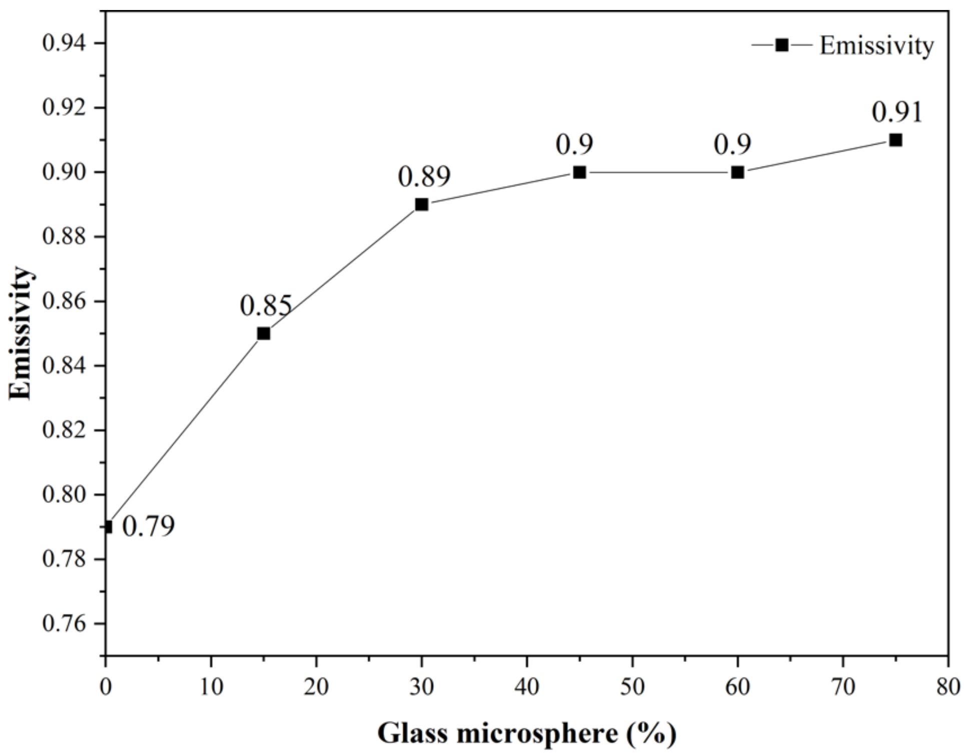


Fig. 5 The relationship between the amount of glass microsphere and the emissivity of the paint.

Table 1. shows the measurement results of emissivity for various paint coatings. The thickness of all coatings was found to be within the range of 83.3 – 90.8 μm, after the paint was coated and allowed to dry. The emissivity of the three size ranges were then compared, and it was found that there was a minimal difference value, about 0.01. Based on these results, it was suggested to use the glass microspheres within the size range of 0 – 60 μm, which have not undergone particle size screening, would be suitable for further experimentation.

The correlation between the amount of glass microsphere particles in the size range of 0 – 60 μm. The glass microspheres were added into the acrylic water-based paint at 15, 30, 45, 60 and 75 wt%. The paint was then coated on the metal sheet with the bar coater and the thickness was controlled at 80 μm. Fig. 5 shows the relationship between the amount of glass microsphere and the emissivity of the paint. It was observed that in the range of 45 – 75 wt% of glass microspheres, the emissivity was slightly increased. The highest value was 0.91 when a 75 wt% glass microsphere was added (which was only 0.01 higher than that of the 45 wt% glass microsphere). Therefore, this indicates that there is no effect on the emissivity when the amount of glass microspheres increases within this range.

A cross-section of the spherical glass microsphere of Fig. 6 inside the paint was observed. It was found that increasing the amount of spherical glass microsphere resulted in an increase in the dispersion of the glass microsphere. However, when the content of the spherical glass microsphere was at 75 wt%, agglomeration of the glass microsphere was observed. Additionally, the more air void was side the paint with higher amounts of spherical microsphere powder. These voids may affect the physical properties of the paint and its lifetime. Therefore, it was concluded that the optimal amount of spherical glass microsphere should be 45 wt%.

The emissivity as a function of thickness at the various amount of glass microspheres was shown in Fig. 7 It was found that the emissivity increased significantly when the thickness increased from 60 to 80 μm and then became constant when the thickness was more than 80 μm. When adding glass microspheres increased from 45 and 75 wt%, it was found that the emissivity was increased compared with 15 wt%. In addition, it was found that when the amount of glass microspheres increased, the effect of thickness on the emissivity will decrease due to many particles that could make the particles distributed in the paint close to the saturation point.

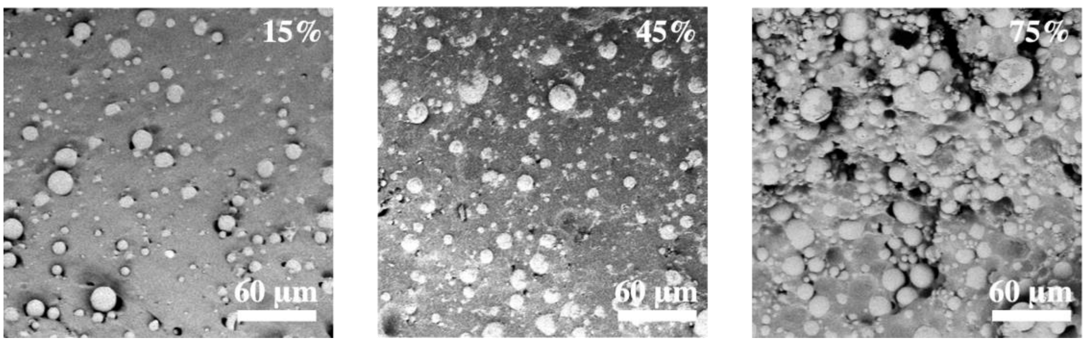


Fig. 6 The cross-section of a mixed 15, 45 and 75 wt% coating layer containing glass microsphere.

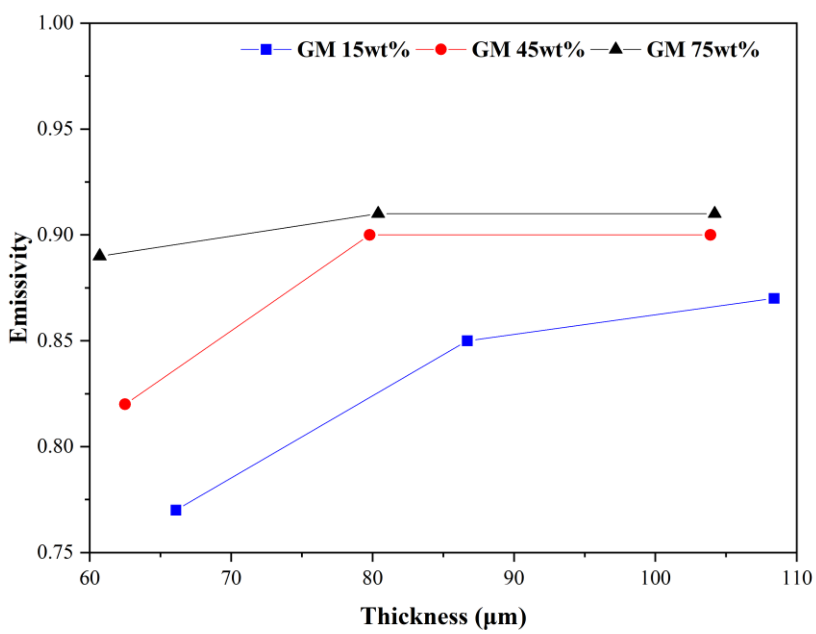


Fig. 7 The emissivity as a function of thickness of the various amount of glass microspheres.

Fig. 8(a) the results of a study comparing the cooling performance of coated metal sheets in Bangkok, Thailand during the clear sky conditions. Three samples of coated metal sheets were examined, with a different weight percentage of glass microspheres added to the paint. A type-K temperature probe was placed under each sample, and the samples were monitored for a 12 h period. The samples with 45 and 75 wt% of glass microspheres added to the paint had a good cooling performance during nighttime, with the temperatures decreasing below the ambient temperatures by 2.9 and 3.2 °C, respectively. However, during daytime peak solar intensity, the addition of glass microsphere particles decreased the light reflectance. As a result, the temperature increases during the daytime, leading to a higher daytime temperature than the sample without glass microspheres. This was attributed to the lower reflectivity of the glass microspheres 45 wt% with 0.65 and 75 wt% with 0.55 reflectivity. It is highly recommended to optimize the reflectivity of paint [9] by adding the 27 wt% titanium dioxides (TiO_2) topcoat layer on 45 wt% glass microsphere paint coat on the metal sheet as shown in Fig. 8(b) the reflectivity of a double layer sample of titanium dioxide (TiO_2) on glass microsphere at 45wt% was found to increase up to 0.79, and the daytime temperature was lowered by an average of 2.2 °C compared to the ambient temperature.

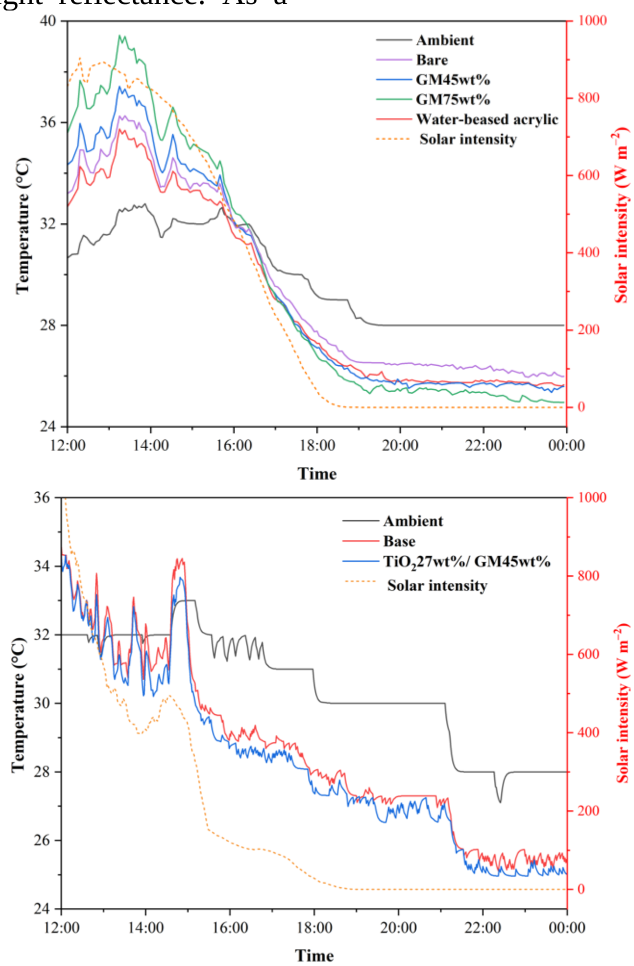


Fig. 8 The cooling performance of glass microsphere paint. (a) the comparison temperature of 45 and 75 wt% glass microsphere paints with a thickness of 100 µm, the bare metal sheet, commercial white paint, and ambient temperature. (b) temperature measurement of double-layer titanium dioxide paint on 45 wt% glass microsphere paint.

4. Conclusion

The glass microspheres were introduced to the metal roof paint and then sorted by size using a sieve shaker in this investigation. The best size range for glass microspheres in industrial paint, as determined through volume weight measurement and size distribution studies, was 0 to 60 μm. When glass microspheres were added at quantities between 45 and 75 wt%, the emissivity was slightly improved. However, at 75 wt% the paint aggregation and air voids increased, indicating that 45 wt% was the optimal concentration. The cooling performance of coated metal sheets was also studied in Bangkok, Thailand, under clear sky conditions, and it was observed that the paint containing 45 wt% of glass microspheres had the highest emissivity and the lowest temperature difference compared to the other paint coatings. Overall, the study reveals that the addition of glass microspheres ranging in diameter from 0 to 60 μm to industrial paint at a concentration of 45 wt% was the best improve the cooling performance of nighttime radiative cooling.

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