สีเขียวสะท้อนอินฟราเรดใกล้สำหรับหลังคาเซรามิกส์เพื่อการประหยัดพลังงาน

Near-Infrared Reflective Green Pigment on Ceramic Tile Roofs for Energy Saving

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บทคัดย่อ

งานวิจัยนี้เป็นการสังเคราะห์สีเขียวที่ให้ค่าสะท้อนรังสีอาทิตย์ช่วงอินฟราเรดใกล้สูง โดยส่วนผสมหลักใช้ Cr_2O_3 ผสมกับ TiO_2, Al_2O_3 และ V_2O_5 ซึ่งได้เปลี่ยนอัตราส่วนผสมเป็น 39 ตัวอย่าง จากการศึกษาพบว่าตัวอย่างที่ 9 (S9) ซึ่งมีส่วนผสมของ Cr_2O_3, TiO_2, Al_2O_3 และ V_2O_5 ในอัตราส่วน 80, 4, 14 และ 2 โดยน้ำหนัก ตามลำดับ ให้ค่าสะท้อน 82.2% ซึ่งในการทดลองได้เปรียบเทียบกับสีเขียว cool pigment ในท้องตลาดเพื่อเปรียบเทียบประสิทธิภาพด้านพลังงาน โดยการนำสีทั้ง 2 ตัวอย่างมาเตรียมแผ่นกระเบื้องหลังคาเซรามิกส์แล้วนำไปมุงยังห้องทดลองเพื่อวัดอุณหภูมิ ผลการศึกษาพบว่าอุณหภูมิห้องทดลองที่มุงด้วยการใช้สีตัวอย่าง S9 มีอุณหภูมิต่ำกว่าห้องทดลองที่มุงด้วยสีขายในท้องตลาด 2 องศาเซลเซียส

Abstract

Complex inorganic green pigments having a high near infrared (NIR) solar reflectance were synthesized. Cr_2O_3 was used as the host component with mixtures of TiO_2, Al_2O_3 and V_2O_5 as the guest components. TiO_2, Al_2O_3 and V_2O_5 were mixed into 39 different compositions. It was found that a sample, denoted by S9, with the composition of Cr_2O_3, TiO_2, Al_2O_3 and V_2O_5 are 80, 4, 14 and 2 wt%, respectively, gives a maximum near infrared solar reflectance of 82.8% compared with 69.6% of a commercially available cool pigment powder. The comparison study on the effectiveness of the synthesized pigment and a commercial pigment on ceramic glaze and sprayed on ceramic tile roofs show that the new powder has given a better result by keeping the tested room about 2 ^{o}C cooler. It can be concluded that the new formulated green pigment is a highly thermal effective as a NIR reflective roof coating.

1. Introduction

Urban areas around the world are experiencing rapid population growth resulting in rapidly increasing energy consumption, particularly by the air conditioners which are widely used in big buildings. Air-conditioning energy saving can be achieved by reducing the temperature of the building envelope, which in turn reduces the heat penetrating into the building. Exterior surface temperatures may be reduced by protecting the building envelope from the heat of solar radiation. Several techniques have been proposed for protection from solar radiation. Among them the use of cool materials has gained much interest during the past few years. Cool materials referred to pigments that have high near infrared (NIR) solar reflectance or low NIR solar absorptance [1] which have been widely used for coatings on roofs and walls [1-3].

There are currently a number of cool materials commercially available for tile roof coating [4-6]. Inorganic pigments are widely used as cool materials for residential roofs. TiO_2 rutile, a white pigment with a high NIR solar reflectance of about 87.0% [4], is the best pigment used for roofing materials. However, the owners of homes with pitched roofs visible from ground level often prefer non-white roofing products for aesthetic reasons [1,3,7]. In the present study, new green pigments based on a Cr_2O_3-TiO_2-Al_2O_3-V_2O_5 composition have been synthesized. Then the green pigments were compounded with ceramic glaze and applied as reflective ceramic tile roofs and its effectiveness on cooling has been investigated.

2. Experimental

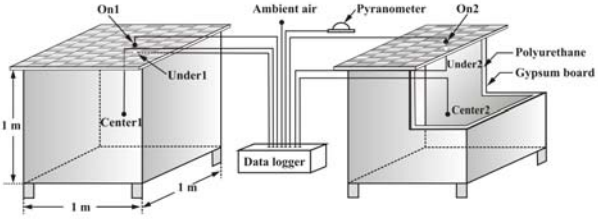
2.1. Study of the pigment powder in the ceramic glaze

Green pigments having a high near infrared (NIR) solar reflectance were synthesized with the composition of Cr_2O_3, TiO_2, Al_2O_3 and V_2O_5 are 80, 4, 14 and 2 wt%, respectively, gives a maximum near infrared solar reflectance of 82.8%. In the preparation of reflective coating, the pigment powder was prepared with a weight of 180 g mixed with 3,000 g of a commercial ceramic glaze (Dayang Glaze). The mixtures were ground in water in a ball mill for 2 hr at a speed of 100 rev/min to obtain very homogeneous slurries with the specific gravity of about 1.40. It was found that at this specific gravity value, the slurry is composed of 44.4 wt% solid and 55.6 wt% water. For comparison with a commercial green pigment powder, the pigment No.10241, (denoted by F) purchased from Ferro Cerdex (Thailand) was also prepared with 3,000 g of commercial ceramic glaze in the same procedure described above. All prepared samples were sprayed on the ceramic tile roofs of dimensions 8″ × 8″ per piece by a spray gun of diameter 0.1 mm with a spraying time of 30 sec. The coated ceramic tile roofs were heated at a heating rate of 4 ^{o}C/min until it reached a maximum temperature of 1100 ^{o}C. Then the tile roofs were cool down to room temperature in the air. The thickness of coated ceramic tile roofs was measured and it was found to be about 200 um. The spectral reflectance of the coated ceramic tile roofs was determined by a UV-Vis-NIR spectrophotometer. The coated ceramic tile roofs are now referred to S9-coated and F-coated tile roofs, respectively.

2.2 Thermal performance test of the coated ceramic tile roofs

In order to compare the thermal performance of S9-coated and F-coated tile roofs, two identical house models were built for the experimental study. The iron frame was 1m × 1m × 1m in dimension. The walls and floor of the house models were made of the gypsum board with a thickness of 7 mm. The outer wall surface was coated with white paint. The inner wall and floor were insulated with 2 inches of polyurethane ensuring heat seclusion of the walls. One house model was covered with 50 pieces of S9-coated ceramic tile roof carefully laid on roof frame; square steel tube of dimensions 18×18 mm, while another one were roofed similarly with F-coated ceramic tile roof as shown in Fig. 1(a), and 1(b), respectively. This way of construction ensured heat penetrating into room only via the roofs top.

For each house model, the temperature measurements were taken at three positions i.e. on the surface, under the surface of tile roofs and at the center of the house model as marked by "on", "under" and "center", respectively. Furthermore, the ambient air temperature was monitored during the thermal performance test of the house models. The temperatures were measured by K-type thermocouples and recorded by a data logger (Graphtec, GL200-UM-851). In addition, the solar irradiance was also measured using a pyranometer (Kipp & Zonen, CM4). The house models were installed on flat roof floor of an eight-stories building for the experiment test. In the present study, the temperature measurements were taken during the summer period from the 24th to 28th of February 2009.



(a) (b)

Fig. 1 Two test houses: (a) S9-coated roof and (b) F-coated roof

3. Results and discussion

3.1. Reflectance results of coated ceramic tile roofs

After the ceramic glazes were mixed with S9 and F pigment powders, and sprayed on the ceramic tile roofs and now they are referred to S9-coated and F-coated tile roofs. The spectral reflectance for S9-coated and F-coated tile roof samples were measured and the NIR solar reflectance values in the wavelength range of 780-2100 nm were determined. Reflectance spectra of

S9-coated and F-coated tile roofs are shown in Fig. 2 and corresponding NIR solar reflectance values of S9-coated is 76.3% and F-coated tile roof is 65.7%. It was found that the NIR solar reflectance values for S9-coated tile roofs have solar reflectance values much higher than those of F-coated tile roofs.

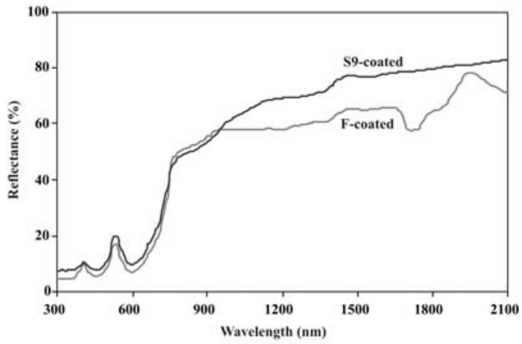


Fig. 2 The reflectance spectra of S9-coated and F-coated tile roofs

3.2 Results of thermal performance test

The thermal performance of the S9-coated and F-coated were measured on two identical houses as previously described. The temperature measurements were taken during the summer period from the 24th – 28th of February, 2009.

The result of thermal measurements from the two house models showed that on average the new synthesized S9-coated performed better than the commercial F-coated. Table 1 shows the maximum temperatures obtained from the three measurements i.e. on the surface, under the surface of the tile roofs and at the center of house models, respectively. From the tables, ΔT show that the temperatures obtained from S9-coated tile roof were lower than that of the F-coated tile roof by about 2 ^{o}C across the three measured positions.

As for an example, the average temperatures at the center of the two house models were recorded over the hours of the day in Fig. 3. The thermal efficiency of the S9-coated tile roof is clearly observed during the hottest hours from 10:30am to 16:30pm. It is observed that there is a shift in temperature spectrum recorded from the house models when compared with the spectrum of solar radiation over the hours of the day. These shifting of peaks can be accommodated by the accumulating and releasing heat of the roofs.

Table 1 Showing the temperatures obtained from S9-coated and F-coated tile roofs

February	Ambient air (^{o}C)	Solar irradiance (W/m^2)	On the roof (^{o}C)			Under the roof (^{o}C)			Center of the room (^{o}C)		
			S9-coated	F-coated	Δ T	S9-coated	F-coated	Δ T	S9-coated	F-coated	Δ T
24	33.9	866.4	51.7	53.9	2.2	50.9	53.2	2.3	43.3	45.1	1.8
25	33.1	877.2	49.9	51.4	1.5	49.1	51.1	2.0	41.2	43.1	1.9
26	33.6	849.9	51.1	52.6	1.5	49.7	51.4	1.7	42.4	44.4	2.0
27	32.8	938.3	50.2	51.5	1.3	48.6	50.8	2.2	41.5	43.4	1.9
28	32.9	950.1	50.3	52	1.7	48.5	50.7	2.2	40.9	42.5	1.6
Average	33.3	896.4	50.7	52.6	1.6	49.0	51.5	2.5	41.8	43.7	1.8

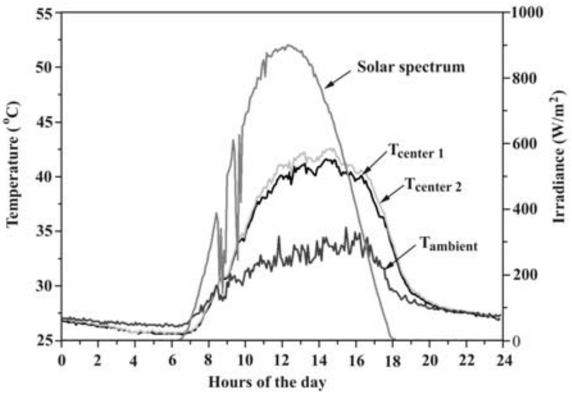


Fig. 3 Average hourly room temperature plot of two green ceramic tile roofs during 24th to 28th February, 2009

4. Conclusions

Green pigments having a high NIR solar reflectance for roofing materials have been developed. Pigment powders were prepared from Cr_2O_3 and mixtures of TiO_2, Al_2O_3 and V_2O_5. Cr_2O_3 was fixed at 80 wt% and mixed with 20 wt% of 39 different compositions of TiO_2, Al_2O_3 and V_2O_5. All prepared samples were calcined at 1150^{o}C. The reflectance spectra show that the sample S9 with a composition of Cr_2O_3, TiO_2, Al_2O_3 and V_2O_5 80, 4, 14 and 2 wt%, respectively has given a maximum NIR solar reflectance value of 82.8% higher than 69.6% of a commercial cool pigment powder, F. S9 and F pigment powders were prepared on ceramic tile roof for performance test on the NIR solar reflectance. Each coated tiles were roofed on two identical model houses for temperature measurement. It was found that the air temperature inside the room of S9-coated ceramic tile roof was about 2 °C lower than that of F-coated ceramic tile roof. It can be concluded that the coating materials containing ceramic glaze of S9 pigment powder is a suitable NIR reflective coating for ceramic tile roof.

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