Study of Infrared Thermal Images Of Chameleon-Type Building Coatings

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As reported in this article, infrared thermal images of chameleon-type building coatings were studied. The results show that when reversibly thermochromic pigments were added to normal white building coatings, so-called chameleon-type building coatings could absorb energy from a sunlamp below a switching temperature of 20°C. The surface temperatures could reach almost the same value as that of a normal colorful building coating. The absorption stopped automatically above the switching temperature of 20°C, and the surface temperatures could be lower than that of normal colorful building coatings by about 4°C. The results from exposure to solar radiation show that when the temperature was below the switching temperature, the chameleon-type building coating could absorb almost the same amount of solar energy as an ordinary colorful coating. When the temperature was above the switching temperature, these coating could reflect more solar energy than the ordinary colorful coating, which was similar to the results from infrared thermal images. All the results show that there is some possibility that the chameleon-type building coatings could be used to create a thermally comfortable building environment.

INTRODUCTION

Since there are different seasons in nature, the solar energy absorbed by buildings varies greatly between winter and summer.[1] Therefore, a building's thermal environment is not always comfortable for living and working. To create a thermally comfortable building environment, many measures have been taken such as the wide use of porous insulating materials. Although they can save energy, problems of fossil fuel consumption and environmental protection cannot be resolved by using these materials. Reasonable use and disposal of solar energy, including various solar walls and other solar devices, may be the solution, but these materials and devices may be complex and expenisve for buildings. To meet these needs, the authors have developed the so-called chameleon-type building coatings[2,3] which would cost less and be more convenient in application. The colors of the coatings change from red, blue, etc., below a switching temperature of 20°C to white above 20°C. During the process, solar energy can be absorbed below 20°C, and the absorbance can be stopped above 20°C. In the present article, the effect of solar energy absorbance by coatings under the switching temperature and the effect of solar energy reflectance by coatings above the switching temperature were researched using infrared thermal imaging and exposure to solar radiation, respectively.

EXPERIMENT

Preparation of Samples

The chameleon-type building coatings were prepared by adding microencapsulated thermochromic pigments, such as R30, G30, B30, R20, G20, and B20, as

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Table 1—Thermochromic Pigments at Normal Temperatures

No.	Composition	Color-Changing Temperature, °C	Changing of Color
R30	Lactone 1: Dihydroxydiphenyl:Solvent 1=1:5:30	30	Red ⇔ Colorless
G30	Lactone 2: Dihydroxydiphenyl:Solvent 1=1:5:30	30	Green ⇔ Colorless
B30	Lactone 3: Dihydroxydiphenyl:Solvent 1=1:5:30	30	Blue ⇔ Colorless
R20	Lactone 1: Dihydroxydiphenyl:Solvent 2=1:5:30	20	Red ⇔ Colorless
G20	Lactone 2: Dihydroxydiphenyl:Solvent 2=1:5:30	20	Green ⇔ Colorless
B20	Lactone 3: Dihydroxydiphenyl:Solvent 2=1:5:30	20	Blue ⇔ Colorless

shown in *Table* 1,[2,3] to ASTEC 100, a white outer wall coating made by American Insulating Coatings Corp.

The amount of the thermochromic pigments was 20% (by weight) based on the weight of the white coating. Then, the chameleon-type building coatings were brushed onto asbestos cement plates that measured about 10 × 8 cm. The coating was brushed twice; each time the brushed weight of the coating was controlled to about 0.05 g/cm^2. For convenient comparison, in some samples half of the sample was brushed with ASTEC 100 coating and the other half was brushed with the chameleon-type building coatings. The samples were stored in an indoor environment for 24 hr and then tested by a thermal infrared image meter.

The chameleon-type building coatings were also brushed onto ampoule bottles, which were exposed to sunlight. The samples were stored in an indoor environment for 24 hr and then exposed to solar radiation.

Experimental Methods

A TH 1101 thermal infrared image meter made in Japan was applied in this study. The infrared detector mainly consisted of an HgCdTe semiconductor with a wavelength range about 8 to 13 µm. The detector cooling was performed with liquid nitrogen (77.3K), and the detecting accuracy of the temperature was 0.1°C. The test set-up is illustrated in *Figure* 1.

Before carrying out the infrared thermal image testing of chameleon-type building coatings, the thermal emittance of each sample was obtained. According to some reference material,[4] a series of ampoule bottles were coated with corresponding chameleon-type building coatings and other coatings. The coated bottles were filled with different temperatures of water and a thermometer was inserted into each bottle. When the temperature of the water in the bottle reached the same temperature as that shown simultaneously in the infrared thermal image meter by adjusting the thermal emittance button (the accuracy of temperature was 0.1°C), the thermal emittance displayed in the infrared thermal image meter was considered to be the thermal emittance of the sample at the same temperature.

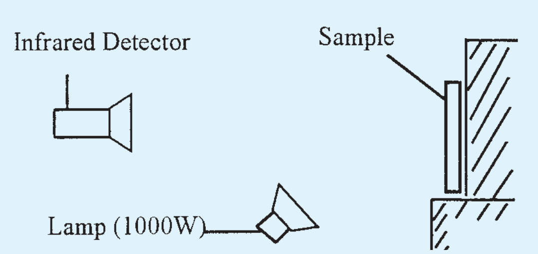


Figure 1—Set-up of infrared thermal image testing.

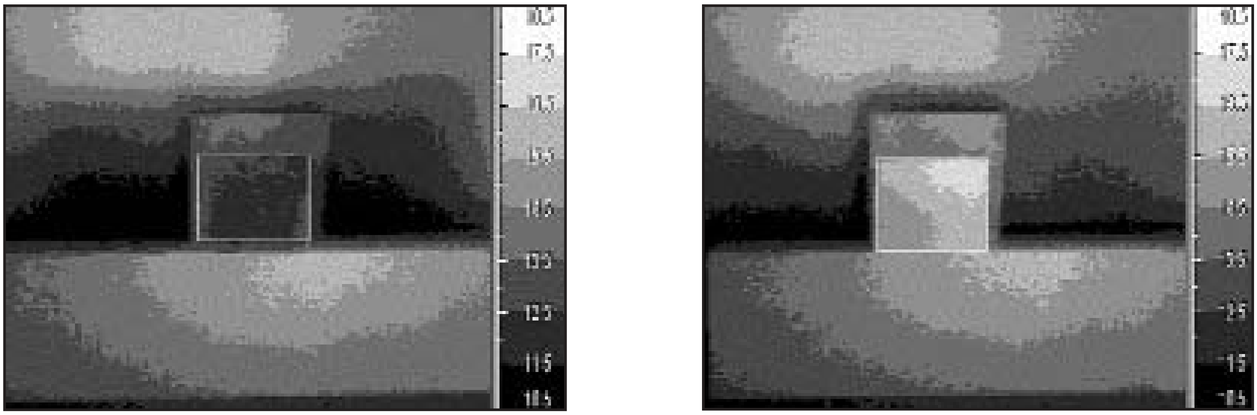
During infrared thermal image testing, the initial surface temperature of a sample was recorded when the thermal emittance of the meter was set up to 1, and the temperature graduation was set at 1.0°C. The heated surface temperature of the same sample was recorded when the thermal emittance of the meter was adjusted to the same value as the corresponding ampoule bottle. The maximum surface temperature of the sample was measured to represent the sample temperature when the temperature graduation of the meter was set up to 0.1°C.

Before being exposed to solar radiation, all the ampoule bottles were filled with water and stored indoors for at least 24 hr, and then all the ampoule bottles were taken out into sunlight. After every 10 min, the temperature of each bottle was measured by inserting a thermometer (the accuracy was 0.5°C) into the water in the bottle.

RESULTS AND DISCUSSION

Infrared Thermal Images of Chameleon-Type Building Coatings Mixed with Series 20 Thermochromic Pigments

Before the experiment, the plate samples with the coatings mixed with series 20 thermochromic pigments were placed in the experimental environment in which the temperature was about 10°C for at least 24 hr. *Figures* 2a and b, respectively, show the surface temperature states of the sample exposed to a sunlamp (1000W) for one minute and eight minutes, in which the left half was coated with ASTEC 100 coating and the right half was coated with ASTEC 100 coating mixed with 20% R20 thermochromic pigment. In *Figure* 2a, the sample was placed in the center, and the temperature scale was located in the right side of the figure. From *Figure* 2a, it can be seen that at the beginning of exposure, the sample surface temperature is almost uniform. From *Figure* 2b, it can be seen that after exposure for eight minutes, the surface temperature of the left half of the sample, coated with ASTEC coating without R20 thermochromic pigment, increased to about 15.5°C, but the surface temperature of the right half of the sample, coated with ASTEC coating mixed with R20 ther-



(a) (b)

Figure 2—Infrared thermal images of chameleon-type building coating mixed with R20 thermochromic pigment at different exposure times, (a) 1 min, (b) 8 min.

mochromic pigment, increased to about 18.5°C. During testing, it was found that after exposure for eight minutes, the increase in the surface temperature slowed down and reached a constant value. The difference between the temperatures of the two coatings was about 3°C when the thermal emittance of the meter was set at 1. If adjusting the thermal emittances to the corresponding values of the two coatings (0.94 and 0.93, respectively), the difference between the temperatures would reach about 3.5°C. Since the difference of the thermal emittances of the two coatings was very small, it can be concluded that adding thermochromic pigment R20 to an ordinary white coating could result in the absorbance of more energy from the sunlamp than the ordinary coating at low temperatures.

When other thermochromic pigments, such as B20 and G20, were added to ASTEC coating, the surface temperatures were similar to that of R20, and the temperature difference reached about 3.0°C and 3.3°C, respectively.

Comparison of Infrared Thermal Images of Chameleon-Type Building Coatings Mixed with Series 20 Thermochromic Pigments with Those of Ordinary Surfaces above 20°C

To study the reflecting effect of the chameleon-type building coating and its comparison with ordinary surfaces, a series of separate samples were made for the infrared thermal image testing. *Figure* 3 shows the results in which the samples from left to right are, respectively, black paint, ASTEC coating mixed with the fuchsine basic (a normal red pigment), ASTEC coating mixed with R20 and G20, ASTEC coating mixed with TiO_2, R20 and G20, ASTEC coating (as lower layer) combined with R20 and G20 (as upper layer), ASTEC coating mixed with TiO_2 (as lower layer) combined with R20 and G20 (as upper layer), inner wall white coating, aluminium foil, and ASTEC coating mixed with TiO_2.

Before testing, all the samples were stored in the testing environment for at least 24 hr. The room temperature was about 21°C and the colors of all the chameleon-type samples had changed to white. From *Figure* 3, it can be seen that when the temperature is above 20°C, the chameleon-type building coating mixed with R20 and G20 thermochromic pigments absorbs less energy from the sunlamp than the ASTEC coating mixed with the fushsine basic, and absorbs much less energy than the black paint. By adjusting the emittances, the temperature difference between the chameleon-type building coating mixed with R20 and G20 and the ASTEC coating mixed with fuchsine basic is about 3.3°C, and the temperature difference between the chameleon-type building coating mixed with R20 and G20 and the black paint is about 12.9°C. These results mean that when the environmental temperature is above the switching temperature of 20°C, as with summer conditions, ordinary colorful coatings, especially black coating, still absorb much energy from the sunlamp, causing the buildings' thermal environment to be uncomfortable. On the other hand, the chameleon-type building coating can stop absorbing much energy from the sunlamp, which will be helpful in creating a thermally comfortable building en-

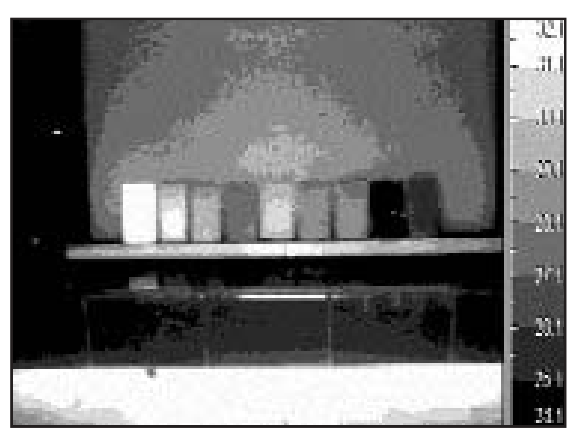


Figure 3—Comparison of infrared thermal images of chameleon-type building coatings mixed with R20 and G20 with ordinary surfaces at above 20°C after exposure for 8 min.

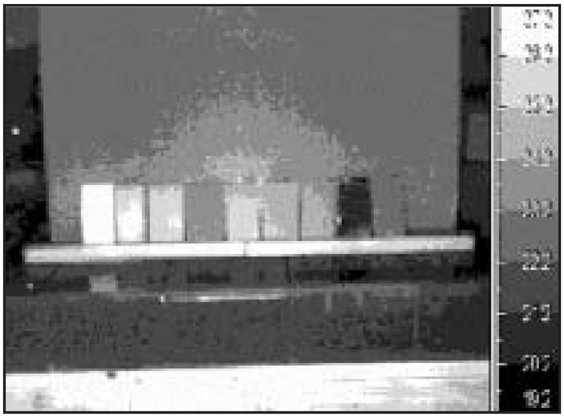


Figure 4—Comparison of infrared thermal images of chameleon-type building coatings mixed with R30 and G30 with ordinary surfaces at below 30°C after exposure for 6 min.

vironment. Of course, if the solar absorptance of the chameleon-type building coating could be changed in a larger range, and if its thermal emittance could be changed reversibly from a low value at lower temperature to a high value at higher temperature, the effect of chameleon-type building coating on the extent of thermal comfort of buildings could be improved greatly. This point can be seen from the large temperature difference between black paint and aluminium foil at about 17°C in *Figure* 3, and can be verified by the large temperature difference of 30°C under the building roof between a black coated roof and a white coated roof in summer.[5, 6]

Comparison of Infrared Thermal Images of Chameleon-Type Building Coatings Mixed with Series 30 Thermochromic Pigments with Those of Ordinary Surfaces below 30°C

To study the energy-absorbing effect of the chameleon-type building coating and its comparison with ordinary surfaces, as in the previous section, a series of separate samples were made for the infrared thermal image testing, in which R20 and G20 were replaced with R30 and G30, and the testing conditions and samples arrangement were the same. *Figure* 4 shows the results.

Since the environmental temperature was also 21°C, the color of the chameleon-type building coating remained gray. After exposure to the sunlamp for six minutes, its color changed to white; at this time the surface temperatures of all the samples were measured by adjusting the emittances. *Figure* 4 shows that when the environmental temperature is below 30°C, the chameleon-type building coating mixed with R30 and G30 thermochromic pigments absorbs almost the same energy as the ASTEC coating mixed with fuchsine basic, but absorbs much less energy than the black paint. By adjusting the emittances, the temperature difference between the chameleon-type building coating mixed with R30 and G30 and the ASTEC coating mixed with fuchsine basic is only about 0.5°C, and the temperature difference between the chameleon-type building coating mixed with R30 and G30 and the black paint is about 9.6°C. These results mean that before the color of thermochromic pigment is changed to white, as with winter conditions, the chameleon-type building coating can absorb energy from the sunlamp, which will be helpful in creating a thermally comfortable building environment. Of course, if at lower temperatures (below the switching temperature), the chameleon-type building coating's solar absorptance could be increased and its thermal emittance decreased, the energy-absorbing effect of the chameleon-type building coating could be improved greatly, which can be seen from the temperature difference between the chameleon-type building coating and black paint remaining at about 9.6°C in *Figure* 4.

Exposure of the Chameleon-Type Building Coating to the Sun

To study the practical effects of the chameleon-type building coating when exposed to the sun, a series of ampoule samples were made, which included the chameleon-type building coating mixed with R30 and G30 thermochromic pigments, black paint, ASTEC coating mixed with fuchsine basic, and ASTEC coating mixed with TiO_2. *Figures* 5a and b, respectively, show the results in which the samples were exposed to the sun at

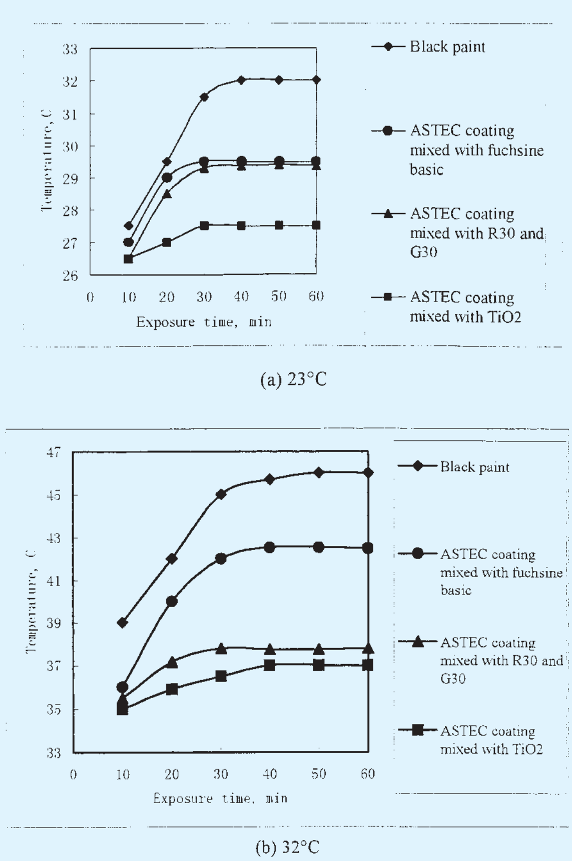


Figure 5—Exposing of the chameleon-type building coating mixed with R30 and G30 to the sun at different temperatures, (a) 23°C, (b) 32°C.

23 and 32°C. From *Figure* 5a, it can be seen that since the environment temperature was 23°C, the color of the chameleon-type building coating had not been changed, its temperature was almost the same as that of the ordinary colorful coating when exposed to the sun. The result was similar to that of the infrared thermal image testing. *Figure* 5b shows that since the environment temperature was 32°C, the color of the chameleon-type building coating changed to white, the temperature of the same sample was lower than that of the ordinary colorful coating by about 4°C after exposure to the sun for about one hour. The result was also similar to that of the infrared thermal image testing. From the aforementioned results it can be concluded that the chameleon-type building coating can meet the needs of creating a thermally comfortable building environment. It is believed that after some more improvement, the energy-absorbing and energy-reflecting effects of the chameleon-type building coating could be further increased. Considering that the aging properties of the thermochromic pigments used were not ideal,[2] improvements on these properties are being carried out in our laboratory, and the relative results will be published in the future.

CONCLUSION

From the infrared thermal image testing, it was found that when thermochromic pigments are added to an ordinary white building coating, the so-called chameleon-type building coating can absorb almost the same amount of energy as an ordinary colorful building coating at low temperatures (below the switching temperature), but at high temperatures (above the switching temperature), it can stop the absorbance of energy. Its surface temperature will be lower than that of an ordinary colorful building coating by 3-4°C. When exposed to the sun below the switching temperature, the temperature of the chameleon-type building coating is near that of an ordinary colorful building coating, and when exposed to the sun above the switching temperature, the temperature of the chameleon-type building coating is lower by about 4°C, which is similar to that of the infrared thermal imaging results. All these results show that, after some improvement, the chameleon-type building coating can meet the needs of creating a thermally comfortable building environment.

References

(1) Yamada, M.H., *Insulation of Buildings*, Igami Press, Tokyo, 1984.
(2) Ma, Y., Zhu, B., and Wu K., “Preparation of Reversible Thermochromic Building Coatings and Their Properties,” JOURNAL OF COATINGS TECHNOLOGY, *72*, No. 911, 67 (2000).
(3) Ma, Y., Zhu, B., and Wu K., “Preparation and Solar Reflectance Spectra of Chameleon-Type Building Coatings,” *Solar Energy*, 70 (5), 417-422 (2001).
(4) Mi, Z., Chu, Z., and Xia, J., “Mechanism and Application of Drying by Infrared Radiation,” *Mechanical Industry Press of China*, Beijing (in Chinese) (1996).
(5) Shen, Y., “Effects of Different Colors on Temperature Decrease of Roofs and Thermal Insulating Water-Proofing Coating,” *Coatings Industry*, (2), 25-28 (in Chinese) (1987).
(6) Kang, C., Meng, Q., and Qiao, Y., “Research on Reflectance of Solar Radiation by Use of Solar-Reflecting Coating,” *Coatings Industry*, (4), 12-13 (in Chinese) (1996).