Considerations in Formulating and Using COOL ROOFING COATINGS

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White, cool roofing coatings are associated with reduced heat build-up of roofing surfaces and are directly correlated to the lowering of utility bills associated with the cooling costs for the buildings which utilize them. White coloration, however, is not the only criterion to use in judging whether a cool roofing coating will be effective. An efficient cool roof is a system combining the coating formulation and the underlying substrate, exposed to the elements. Using measurement of solar reflectivity and resulting heat build-up (temperature rise), the effect of TiO_2 grade, extender content, substrate type, and dirt condition of the paint film surface is discussed in terms of its ability to retard temperature build-up.

INTRODUCTION

White, highly reflective coatings are materials that present environmental benefits in at least two ways. First, when these coatings are applied to buildings (mainly over the roof), there are direct energy savings since less air conditioning is required to cool the building's interior due to a major reflection of solar radiation.[1] Second, these coatings decrease the outside temperature in urban areas by moving the sun's energy away from the building, thereby mitigating the so-called "urban heat island effect." These coatings will also have a negative impact on the total radiative forcing, which is an index of the importance of the factor as a potential climate change mechanism,[2] by increasing the albedo value (or reflection coefficient) in urban areas. This means large offsets of greenhouse gases (GHG) in the atmosphere.[3] Solar reflectivity value goes from 0–1 (with 0 being the minimum value for a perfect black body, and 1.0 being the maximum for a perfect white body that reflects all the sun's radiation). The higher the total solar reflectivity of a material, the more energy is reflected back to the sky. Some materials present high emissivity as well, which is the ability of the coating to radiate back to the sky the heat absorbed by the coating.

Typically, construction materials present low reflectivity and emissivity values, which make them absorb a considerable amount of heat from the sun. The easiest way to improve the reflectivity and thermal emissivity features of a specific material is by using a coating with high reflectivity and emissivity properties over its surface, which will enhance the cooling performance of the material.[1]

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With the different raw materials for high reflective and emissive coatings, the white pigment—titanium dioxide (TiO_2)—is among the highest for solar reflectivity and emissivity. TiO_2 provides the ability to reflect the sun's energy along the whole wavelength spectrum (400–2500 nm), completely reflecting visible and near infrared wavelengths.[4] This property makes TiO_2 one of the most effective raw materials for imparting high solar reflectance to a coating.

It is known that nearly one third of the heat entering the inside of a house comes from the roof. To decrease temperature inside buildings and prevent excessive usage of air conditioning systems, the employment of cool roof coatings with high TiO_2 content that reflect solar radiation is highly recommended.[1] One of the lowest cost and easiest options for covering a roof with high reflective material is by using a high reflective coating, which allows the application of a homogenous layer of high reflective materials, such as TiO_2, to the entire roof surface. Several high reflective coatings have been developed; however, complete reports detailing temperature diminishment in different substrates are scarce. In this article, we discuss the role of high reflective coatings containing TiO_2 as pigment on the temperature reduction of different roofing materials. Moreover, formulation of typical waterproof coatings to improve their reflectivity value will also be discussed, showing a close relationship between TiO_2 amount and quality with their cool roofing properties, such as L*, solar reflectivity, and resulting heat build-up.

FORMULATION OF HIGH REFLECTIVE ROOFING COATINGS

Recent studies on the formulation of waterproof coatings have shown that the amount of TiO_2 has a significant impact on the cool roofing performance of waterproof coatings, such as reflectivity and heat build-up values. For instance, as seen in *Figure* 1, the reflectivity value of a typical roof coating formulation shows a direct relationship with TiO_2 content, reaching a limiting value around 0.85 with 20 wt% TiO_2.

After performing heat build-up tests over coated aluminum panels (modified version of ASTM D4803), a direct and linear relationship between reflectivity and temperature reduction (resulting from the difference in heat build-up values between white coated panel and a non-coated panel) of waterproof coatings was found (*Figure* 2).

As shown in *Figure* 2, by increasing the reflectivity value of a roof coating, it is possible to improve the temperature reduction of coated aluminum panels. This demonstrates that solar reflectivity is an important feature for having good performance on a cool roofing product.

Coating formulators know that the best raw materials are critical for providing the best coating performance. In the case of high reflective coatings, the quality of TiO_2 used in the formulation has a direct impact on the final reflectivity value of a coating. In this work, four different

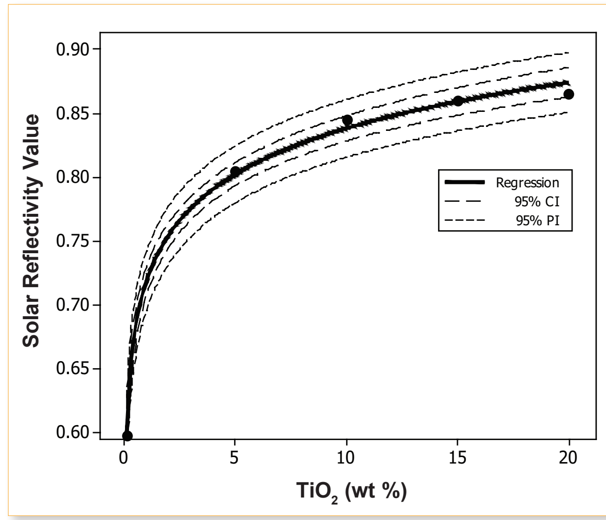

Figure 1—Solar reflectivity value of white roof coatings increasing the amount of TiO_2 in the formulation.

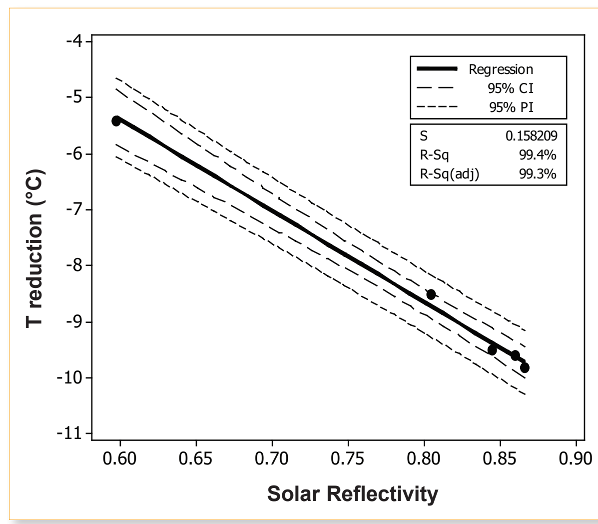

Figure 2—Temperature reduction on aluminum panels coated with high reflective coatings achieved by increasing their reflectivity value.

commercially available grades of TiO_2 were tested to compare their reflectivity performance in a typical roof formulation (ARM-91-1, a RHOPLEX™ binder system developed by Rohm and Haas[5]).These commercial TiO_2s, representing typical TiO_2s used for roof coating applications, varied in particle size, surface treatment (total amounts and composition), as well as in the manufacturing process used to apply the surface treatments.

Figure 3 demonstrates that, in the same formulation (optimized at 5.81 wt% TiO_2), the final reflectivity value is directly affected by the type of TiO_2 used in the coating formulation. If the TiO_2 content were to be increased to 20% (a commercially undesirable approach), it should be expected that the differences between the grades of TiO_2 would be diminished as they asymptotically approached their maximum reflectance values, as illustrated in *Figure* 1.

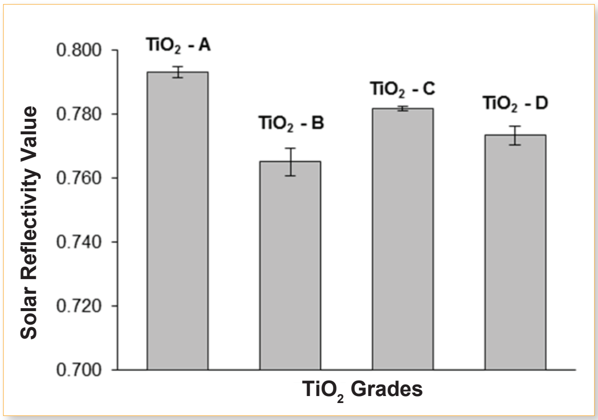

Figure 3—Reflectivity values of a typical roof coating formulation (ARM-91-1) containing 5.81 wt% TiO_2.

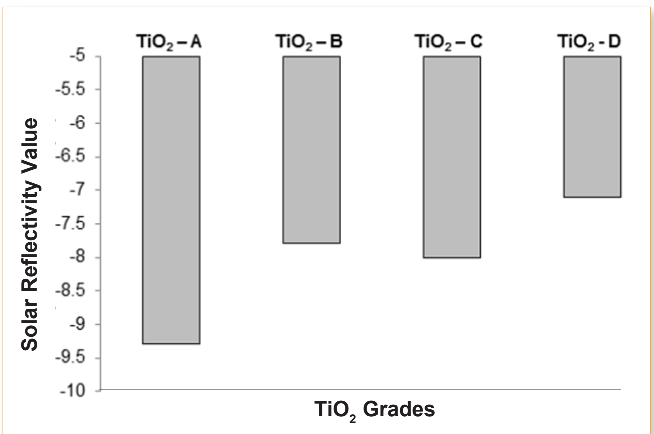

Figure 4—Temperature reduction on the surface of coated aluminum panels, using a typical roof coating formulation (ARM-91-1) containing 5.81 wt% TiO_2.

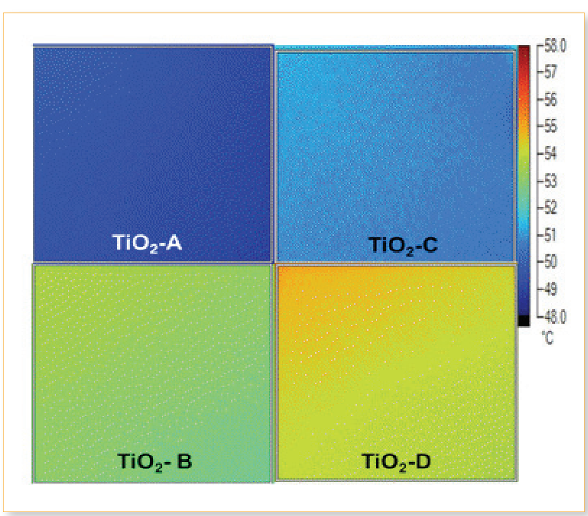

Figure 5—Thermographic images of roof coatings (ARM-91-1) with different TiO_2 grades. Cooler temperatures are represented by darker shades of blue, while warmer images trend towards yellow and red.

The same coatings shown in *Figure* 3 were subjected to heat build-up tests and their temperature reduction value was determined. As can be observed in *Figure* 4, those coatings demonstrating the higher reflectivity also present the best cooling performance. This observation is in agreement with the results previously shown in *Figure* 2. In the same way, it can be deduced that temperature reduction on the surface of coated aluminum panels can be related to the type of TiO_2 used in the formulation. It can be observed that the coating formulated with TiO_2-A, which presents the best reflectivity value, is the one having the best temperature reduction. On the other hand, coatings using TiO_2-B and TiO_2-D evidenced lower reductions, due to a lower reflectivity value.

Thermographic images in *Figure* 5 corroborate the data obtained in heat build-up tests of coatings containing different TiO_2 grades. This figure demostrates that the formulation containing TiO_2-A presented the best cooling performance.

COOL ROOFING PROPERTIES OF A HIGH REFLECTIVE COATING OVER DIFFERENT SUBSTRATES

It is known that construction materials have low solar reflectivity values, i.e., concrete (0.3–0.4), red tiles (0.4), and wood (0.4–0.6). As a result, these materials may likely be the main cause of heat build-up in urban areas, due to solar energy absorption. It has been proposed that increasing the reflectivity value of urban areas (by increasing solar reflectivity value of roofs and roads) can result in several environmental benefits. As mentioned previously, it has been proposed that one of the easiest ways to increase the solar reflectivity value of construction materials is by applying a thin layer of high reflective coating over them. However, the emissivity and heat capacity of the materials themselves should also be taken into account to ensure a good cooling performance when these materials are coated with a high reflective coating. Several heat build-up tests on different coatings materials were performed to determine the temperature reduction after coating a given material with a high reflective coating (reflectivity 0.845 and emissivity 0.91).

Table 1 shows the values for the temperature rise of different construction materials using three coatings with different reflectivity values. The reflectivity value of the coatings can be related to their color. Thus, the reflectivity value for the black coating (10% carbon black) is 0.050, 0.334 for the red coating, and 0.845 (measured over aluminum plate) for the white coating. Temperature rise for raw materials is also reported in *Table* 1.

As can be observed in *Table* 1, the reflectivity value of construction materials improves when a white high reflective coating is used. In most of the cases, there is also a positive impact on temperature reduction. *Table* 1 shows that there is only one substrate where the temperature reduction, after being white coated, is very low. The red clay tiles decreased just 1.1°C. With all the other substrates,

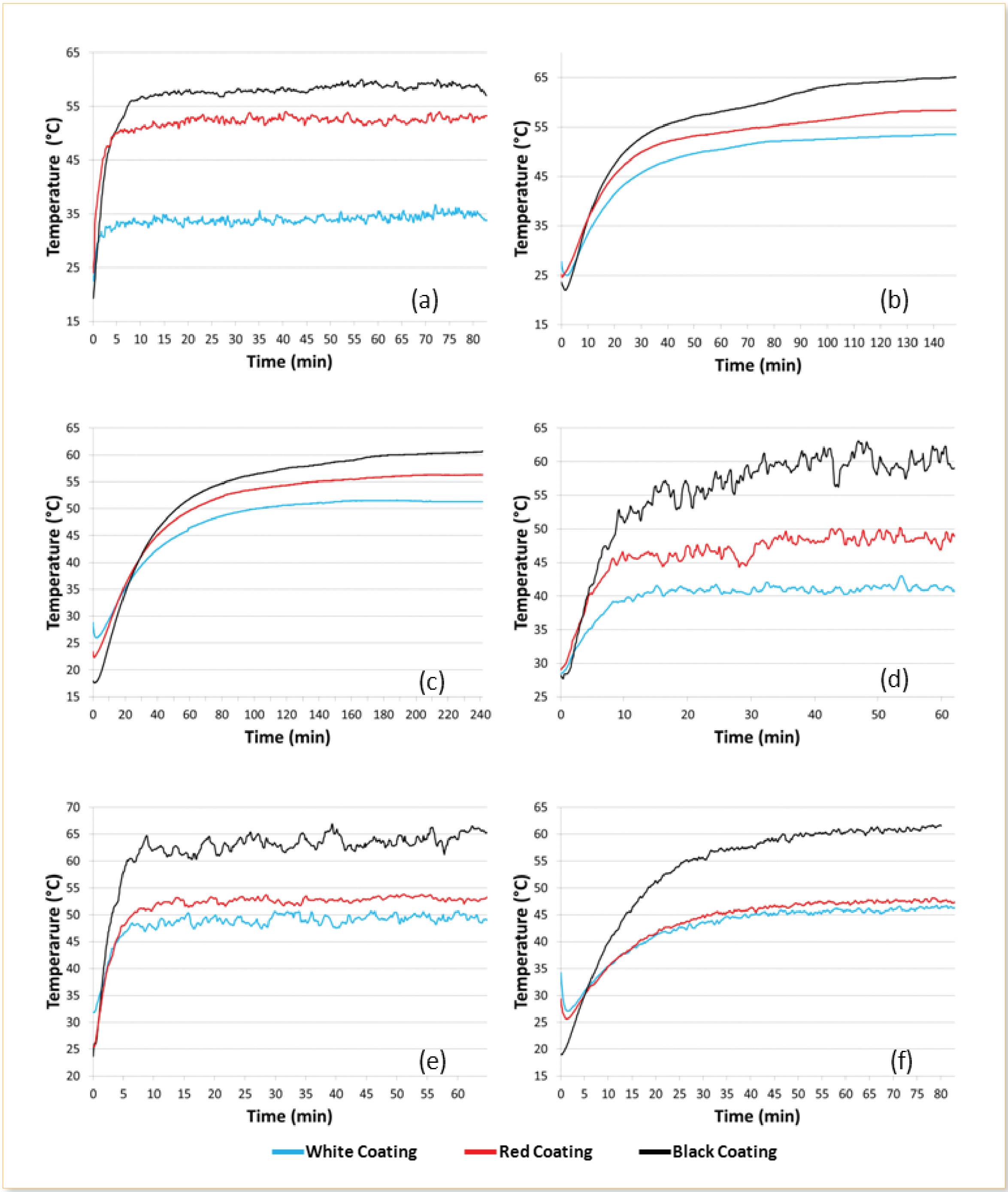

Figure 6—Temperature increase test for different roofing materials coated with coatings with different reflectivity values. (a) Galvanized steel roof, (b) red brick, (c) cinder brick, (d) PVC panels, (e) polycarbonate red roof, and (f) red clay tile.

the temperature reduction is over 5°C and, in some substrates, such as the galvanized steel roof and aluminum panels, this benefit is over 10°C. Thermal behavior and temperature rise of construction material coated with different coatings are shown in *Figure* 6, corroborating the data presented in *Table* 1.

After evaluation, materials showing the best temperature reduction were dusted with carbon black in an attempt to simulate natural exposure, and then the L* value, reflectivity, and heat build-up were measured. The resulting values are represented in *Table* 2.

As observed in *Table* 2 and previously shown in *Figure* 2, there is a direct relationship between reflectivity and maximal temperature of materials. After the simple carbon black dusting process, it was shown that any loss of reflectivity on the coatings' surface directly impacts their surface temperature. This is due to the fact that dirt can readily absorb IR radiation, and thus, transmit it to the substrate. A method to prevent coatings from picking up dirt needs to be developed in order to maintain reflectivity and cooling performance in roof coatings, which are normally exposed to harsh environmental conditions.

Table 1—Reflectivity Value and Maximal Temperature (°C) of Different Construction Materials Coated with Different Coatings (20 mil)[a]

Material	Reflectivity Raw Material	Reflectivity after White Coating	Reflectivity after Red Coating	Reflectivity after Black Coating	T_{max} Raw Material	T_{max} White Coating	T_{max} Red Coating	T_{max} Black Coating
Galvanized steel roof	0.272	0.706	0.291	0.048	51.40	34.23	52.50	58.33
Red brick	0.387	0.731	0.285	0.048	58.40	53.50	-----	65.10
Cinder brick	0.367	0.720	0.285	0.052	56.30	51.30	54.39	60.30
PVC panels	0.670	0.760	0.320	0.050	----	41.50	48.70	60.39
Polycarbonate red roof	0.271	0.749	0.278	0.046	52.01	48.70	53.60	65.39
Red clay tile	0.410	0.731	0.315	0.043	47.35	46.48	51.45	61.53
Aluminum panels	0.605	0.845	0.334	0.050	64.20	53.51	-----	81.80

(a) Test performed under a modified version of ASTM D4803.

Table 2—Reflectivity and Maximal Temperature of Different Materials Coated with a White High Reflectance Coating after Dusting Process with Carbon Black[a]

Material	Reflectivity before Dusting	Reflectivity after Dusting	T_{max} before Dusting	T_{max} after Dusting	ΔT
Aluminum panel	0.845	0.469	53.60	69.50	15.90
Stainless steel panel	0.668	0.350	53.23	72.00	18.77
PVC plate	0.724	0.400	41.50	54.80	13.30

(a) Test performed under a modified version of ASTM D4803.

CONCLUSIONS

This article shows that there is a close relationship between TiO_2 content in a roofing formulation and its solar reflectivity value. Increasing a roof coatings' reflectivity value results in a positive effect on temperature reduction, thus improving environmental benefits due to a reduced need for air conditioning systems, as well as a reduction in the heat island effect in urban areas. Furthermore, it was demonstrated that the quality of TiO_2 used in high reflective coatings formulations directly affects the reflectivity and temperature reduction values.

In addition, temperature reduction in a roof system depends not just on the coating, but also on the substrate used. A better cooling performance was observed with metallic substrates, such as galvanized steel roofs and aluminum panels. Good temperature reduction was also noted with PVC, bricks (red and cinder), and polycarbonate roofs. However, poor performance was observed with red clay tiles.

Finally, it was shown that after a dusting process, white coatings applied over real substrates change their cooling properties, offering a dramatic increase in temperature as reflectivity drops. CT

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