



## IR-Reflective Opaque Water-Based Acrylic Coatings on White Pine Wood Substrates

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### ABSTRACT

**T**wo sets of opaque water-based acrylic coatings were prepared with IR-reflective pigments and conventional pigments. The objective of this work was to determine the efficiency of IR-reflective pigments in limiting the heat buildup of opaque coating formulations. Experiments performed on PVC substrates revealed that IR-reflective pigments significantly decreased the temperature increase above room temperature. A similar behavior was observed for coating formulations applied onto white pine substrates. The temperature increase difference between the two sets of pigments was found to be lower with white pine, which is a better insulator than PVC. Prog. Color Colorants Coat. 7(2014), 61-72. © Institute for Color Science and Technology.

### 1. Introduction

IR-reflective pigments were first introduced to counteract a phenomenon called «urban heat island» [1]. This phenomenon can be roughly explained by the absorption of solar energy by concrete and paved surfaces. As surface temperatures rise, the overall ambient temperature also rises, causing an overage in energy demand for cooling (and higher costs), which promotes smog formation, intensifying pollution and health problems [2].

IR-reflective or cool color pigments are characterized by high solar reflectance and thermal infrared (IR) emittance values [2]. A high solar reflectance allows building surfaces to minimize absorption of solar energy, whereas a high thermal or infrared emittance allows the

return of most of the solar energy to the environment [3]. Cool color pigments can help reduce the heat buildup in materials by reflecting some of the solar radiation. In fact, the solar spectrum that reaches the ground is constituted of 5% of ultraviolet light (300-400 nm), 42% of visible light (400-700 nm) and 53% of near-infrared light (NIR) (700-2500 nm). As the majority of this solar spectrum consists of near-infrared light, a cool pigment has to reflect much of this part of the solar radiation. Conventional pigments tend to absorb NIR radiation while maintaining appropriate absorption in the visible spectrum to impart color [4]. In conventional pigments, light colors have a somewhat high visible-NIR reflectance while the dark colors have low visible-NIR

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reflectance. For example, a clean, smooth, and solar-opaque white surface strongly reflects both visible and NIR radiation, achieving a total solar reflectance of about 85%. This is known as the coolest type of surface [5]

Total solar reflectance (TSR) is a measure of the amount of incident solar energy reflected from a surface. Total solar reflectance is expressed as a percentage. Mathematically, the TSR is expressed as the integral of the reflectance percentage times the solar irradiance divided by the integral of the solar irradiance when integrated over the 280 to 2500 nm range. Typical white coatings usually have a TSR of 75% or greater. This means that a white coating will absorb 25% or less of the incident radiation. By comparison, black coatings containing carbon black pigments will show a TSR as low as 3.5%, therefore absorbing 96.5% of the incident solar energy [4]. A pigment that has a high TSR can be considered an IR-reflective pigment.

A variety of cool white materials are available on the market for building and other surfaces; these include surface coatings (elastomeric, acrylic, etc.), cool single ply membranes, reflective tiles, metal roofs, light-color marble, as well as concrete and conventional asphalt [2]. However, there is a need for non-white materials to meet esthetical preferences. Over the years, many scientists have worked on replacing conventional pigments (NIR absorbing) with cool color pigments (NIR reflective) offering similar colors but higher solar reflectance [2]. Several classes of non-conventional inorganic pigments have thus been developed to achieve high reflectance in the near infrared radiation and high thermal emissivity with dark colors; they include complex inorganic color pigments (CICPs) and mixed metal oxide (MMO) [6]. These types of pigments are used in energy-efficient colored paint formulations. CICPs and MMO are more durable and stable at high temperature than conventional inorganic pigments such as ultramarine blue ( $\text{Na}_2\text{O}5\text{Al}_2\text{O}_3\text{SiO}_2$ ), cadmium sulfide (CdS) and cadmium selenide (CdSe), which react with oxygen. Even carbon black fades to some extent [7]. The intensive research carried out in recent years has led to the development of new-generation materials providing advanced thermal characteristics, dynamic optical properties and increased thermal capacitance [8].

Factors other than weathering effects and chemical composition can influence the infrared reflectivity of pigments; these include milling and dispersion, particle size, opacity, contamination and the mix of infrared reflective pigments. Infrared reflective pigments are used

in a wide range of fields such as the coating industry; vinyl windows and sidings, fire-resistant paints, concrete, cement or pavers. They are also used in the automotive industry and for military applications [9].

Wood is known to be more of an insulating material than other building materials such as steel. For this reason, one might assume that the accumulation of heat in wood building structures would be relatively low. However, heat accumulation in wood exposed to high temperatures may cause other problems. Resin exudation occurring with coniferous species widely used in outdoor uses usually leads to critical failure of the finishing system, followed by wood moisture and fungus problems. Splitting is another problem encountered with various wood products (e.g., cross-laminated timbers, siding) on south-exposed surfaces, where extreme temperature variations result in fast wood drying and shrinkage.

The main objective of this project was to reduce heat buildup on wood product surfaces by incorporating cool (IR-reflective) pigments in exterior wood coating formulations used in industry. This should allow manufacturers to improve product quality and extend warranties. It would also reduce the incidence of problems associated with high wood surface temperatures.

## 2. Experimental

### 2.1. Materials

The coating used in this project was a water-based exterior acrylic formulation intended for exterior wood products. The solids content by weight before pigment addition was 30%.

Table 1 identifies the pigments that were added to the basic coating formulation. Two pigments; one conventional (Clariant) and another IR-reflective (Dynamix), were used for each color; green, black and yellow. The formulations were prepared with 5, 7.5 and 10% of pigment by weight of the acrylic resin only. Pigment volume concentration is reported in Table 2. The test formulations were applied to two different substrates: black polyvinyl chloride (PVC) from Poly Alto group (Quebec, Canada) and white pine (*Pinus strobus*, L.) (Québec, Canada). PVC was selected as a reference substrate and white pine as a substrate prone to resin exudation problems. The PVC test specimens were 100 mm x 100 mm x 1.56 mm (L x W x T).

**Table 1:** Pigments used in test formulations.

ID	Commercial name	Supplier	Chemical composition
Sh-Y	Dynamix Yellow 30C236	Shepherd	Chrome antimony titanium Buff rutile
Sh-B	Dynamix Black 30C940	Shepherd	Chromium Green-Black Hematite
Sh-G	Dynamix Green 30C612	Shepherd	Cobalt titanate green spinel
Cl-Y	Colanyl oxyde yellow R132	Clariant	Iron oxide
Cl-B	Colanyl black N131	Clariant	Carbon black
Cl-G	Colanyl green GG131	Clariant	Cu phthalocyanine

**Table 2:** Pigment volume concentration for the formulations prepared with 5, 7.5 and 10wt%.

ID	5%	7.5 %	10%
Sh-Y	2,1	3,2	4,7
Sh-B	1,9	2,8	4,2
Sh-G	1,9	2,9	4,2
Cl-Y	4,8	7,0	9,3
Cl-B	7,3	10,6	15,1
Cl-G	7,0	10,1	14,4

The wood specimens were planed and then conditioned to equilibrium at 20% RH and 20°C. Their final dimensions were 100 mm x 100 mm x 10 mm.

For an assessment of the effect of the coating resin on heat buildup, a PVDF-acrylic resin prepared from a Kynar emulsion (Kynar Aquatec) was also selected. The PVDF/acrylic ratio was 70%. The solids content was 33%wt.

**2.2. Methods**

**2.2.1. Specimen preparation**

The coating application method varied according to the test performed. For the heat buildup tests, the coatings were applied onto the substrates with a paint brush and dried at ambient temperature for 24 hours. Each coat was 100- to 125-micron thick. For color measurements, one coat of 150 microns was applied onto LENETA charts also dried at room temperature for 24 hours. For the total solar reflectance experiments, coating films were prepared in Teflon molds. Dry film thickness was 0.15 mm.

**2.2.2. Color and Opacity Measurements**

The color of the different specimens was determined by means of a portable sphere spectrophotometer from X-rite model SP62 (USA). The CIE L\*a\*b\* color scale was used for color measurements. It is the most complete color space

specified by the *Commission Internationale de l'Éclairage* (International Commission on Illumination). It describes all the colors visible to the human eye. Three basic coordinates (L\*, a\* and b\*) were determined for each specimen. The color axes (a\* and b\*) are based on the fact that a color cannot be both red and green, or both blue and yellow, because these are opposite colors. On each axis, the values run from positive to negative. On the a-a' axis, positive values indicate amounts of red while negative values indicate amounts of green. On the b-b' axis, yellow is positive and blue is negative. For both axes, zero is neutral gray. The central vertical axis represents lightness (signified as L\*) whose values run from 0 (black) to 100 (white).

From the  $L^*$ ,  $a^*$  and  $b^*$  values, delta values ( $\Delta L^*$ ,  $\Delta a^*$  and  $\Delta b^*$ ) were calculated for each coordinate. The total color change,  $\Delta E$ , was measured according to the following equation:

$$\Delta E = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2} \quad (1)$$

Opacity was measured using the contrast ratio method. 100 microns thick films were applied on LENETA charts and measurements were performed on the light (white) and dark (black) backing. The opacity was measured the X-rite spectrophotometer equipment function.

### 2.2.3. Total Solar Reflectance

Total solar reflectance experiments were performed. Spectra of the different coatings were taken using a UV-Vis spectrophotometer Varian Cary 500 with an integrating sphere of 150 mm at an incidence angle of  $8^\circ$ , over a spectral region of 280 nm to 2500 nm. The spectral measurements were recorded in a manner similar

to that described in ASTM E903-96 Standard Test Method for Solar Absorbance, Reflectance, and Transmittance of Materials Using Integrating Spheres. This same standard method was used to calculate the total solar reflectance of the various coatings. The ASTM G173-03 Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on  $37^\circ$  Tilted Surface were also used in the calculation of TSR.

### 2.2.4. Heat Buildup Measurements

ASTM D-4803 Standard Test Method for Predicting Heat Buildup in PVC Building Products was used to measure the heat buildup on the PVC test specimens. This standard allows for the prediction of heat buildup in exterior objects under laboratory conditions. A PVC test specimen is placed above a thermocouple in an insulated box. The specimen is then exposed to a 250-watt infrared lamp located at a specific distance until thermal equilibrium is reached. In this project, a Digi-Sense thermocouple scanning thermometer with 12 channels was used with Scanlink 2.0 software. Figure 1 summarizes the setup.

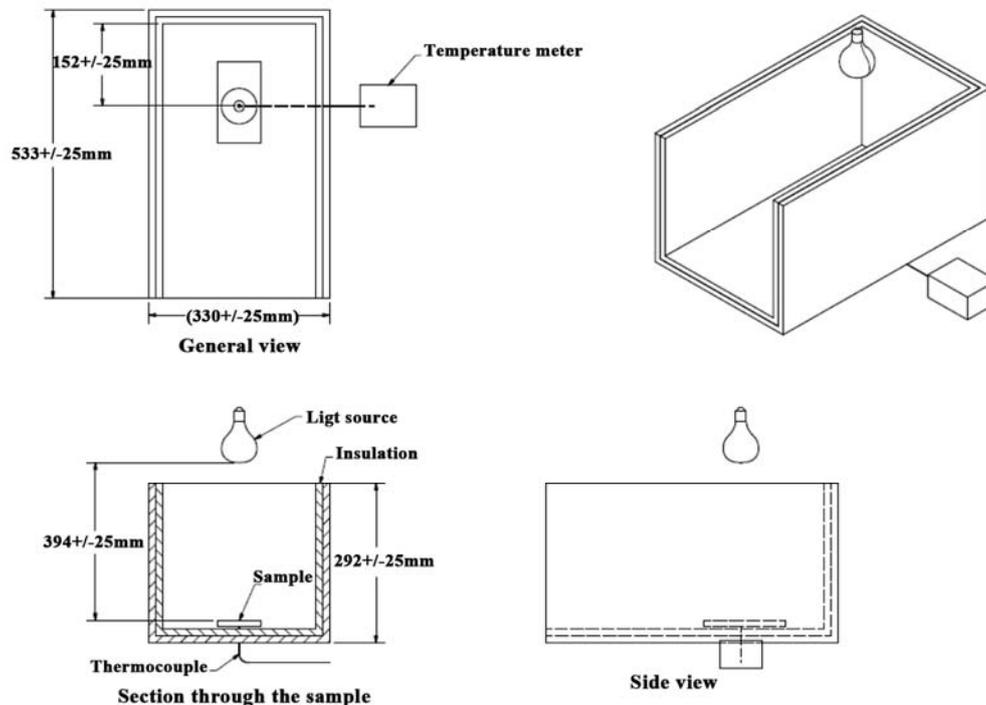


Figure 1: Setup prepared to measure heat buildup.

The value of heat buildup for each specimen was obtained using the equation provided in ASTM Standard D-4803. First, the temperature rise above ambient temperature is calculated with the following equation:

$$\Delta T_{lu} = T_m - T_a \tag{2}$$

Where  $\Delta T_{lu}$  is the temperature rise above ambient temperature in the laboratory under the heat lamp,  $T_m$  the maximum temperature of the specimen as read from the digital temperature meter, and  $T_a$  the ambient air temperature in the laboratory.

Then, from these values, heat buildup can be calculated using Equation 2:

$$\Delta T = \frac{\Delta T_{lu}}{\Delta T_{lb}} \times \Delta T_b \tag{3}$$

Where  $\Delta T$  is the predicted heat buildup in the specimen due to heating by the sun,  $\Delta T_{lu}$  is the temperature rise of the specimen above the ambient laboratory temperature,  $\Delta T_{lb}$  is the temperature rise of a black control specimen above the ambient laboratory temperature, and  $\Delta T_b$  is the heat buildup in a black control specimen under controlled conditions due to absorption of solar energy (the value used here was 41°C as a vertical application was targeted).

### 3. Results and discussion

#### 3.1. Characterization of the Coating Formulations

The spectra used to calculate the TSR are shown in Figure 2. Percentages of reflectance (%R) were measured at different wavelengths.

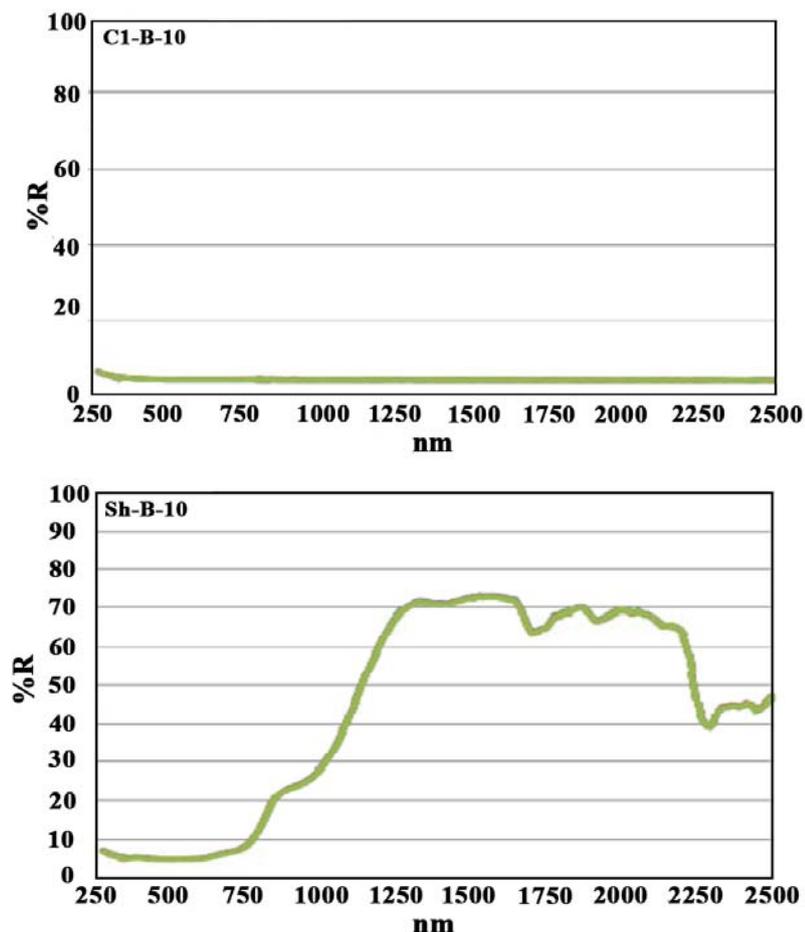


Figure 2: Spectral reflectance of the formulations with a 10% pigment concentration.

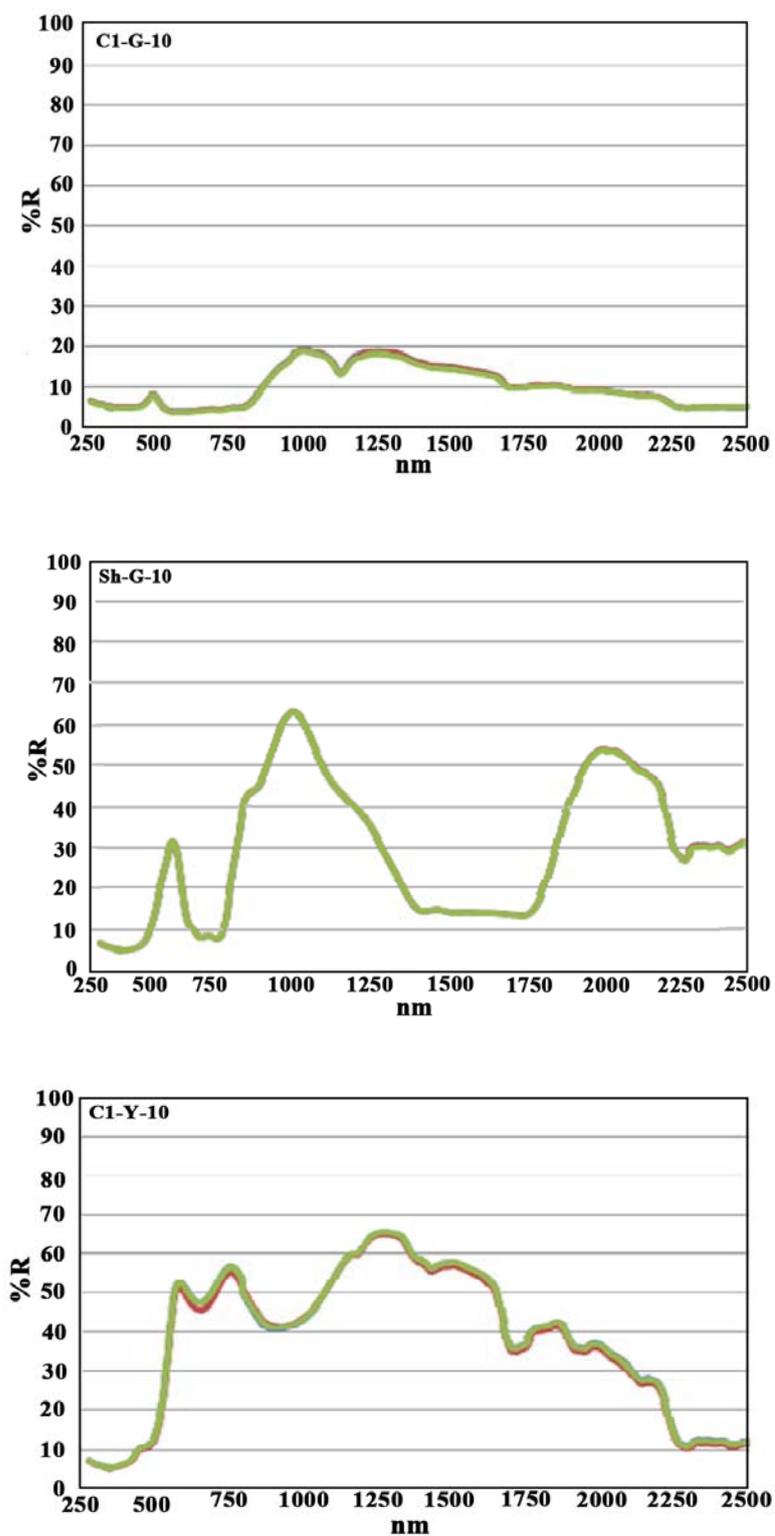


Figure 2: Continued.

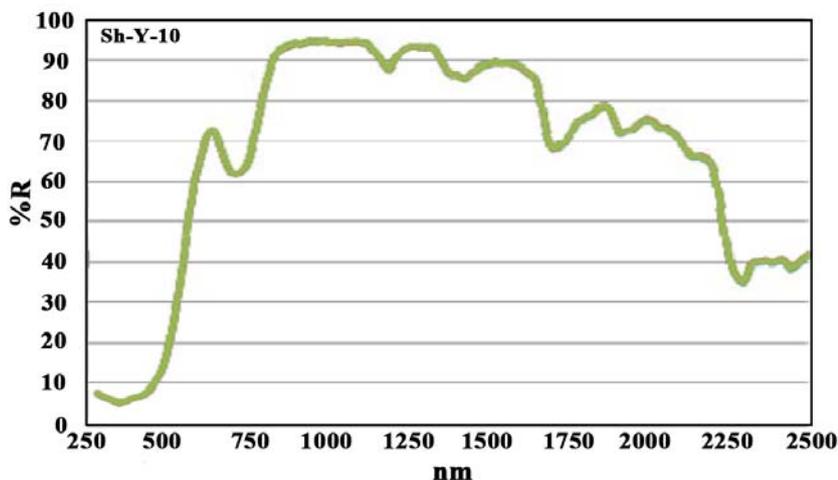


Figure 2: Continued.

Spectrum comparisons between IR-reflective and conventional coatings for a given color indicate that the percentage of reflectance was clearly greater for the IR-reflective coatings. For example, the formulations containing carbon black (CI-B-10) were found to reflect almost no light in the spectral region analyzed. This means that the infrared light was absorbed by the coating film or transmitted to the wood. The results for the green and the yellow pigments were not as clear as those found for the black pigments but one can see that both IR-reflective pigments led to higher %R values throughout the analyzed spectral range.

For better comparisons between the different spectra, total solar reflectance (TSR) values were calculated. These values are shown in Figure 3.

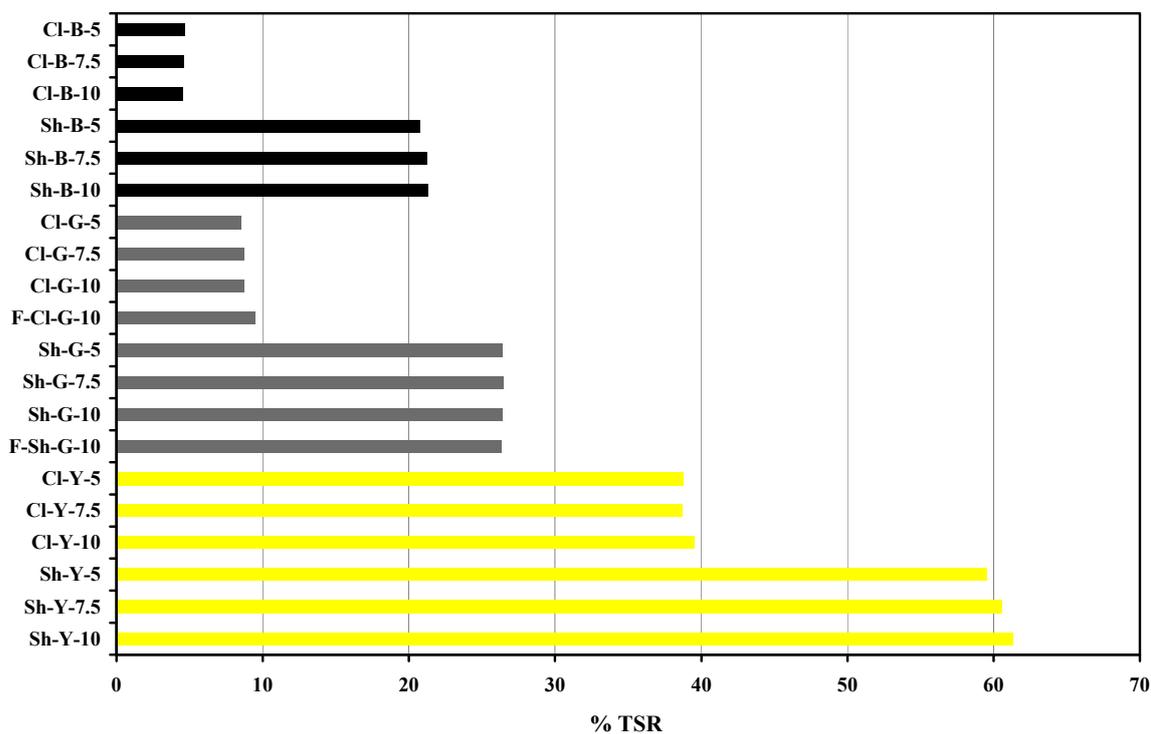
The black pigments led to highly different TSR values (4.6 for the conventional pigment and around 21.0 for the IR-reflective pigment). According to these results, heat buildup experiments should show higher temperature increases for the formulation containing carbon black. Important differences were also observed between conventional and IR-reflective green and yellow pigments. The most pronounced difference was observed for the yellow pigment. The high refractive index of the yellow IR-reflective pigment (2.75 according to the supplier) may partly explain this result.

Pigment concentration was not found to affect substantially the TSR results. The films prepared for the TSR experiments were thick and, even for the formulations with lower pigment concentration, the opacity was almost 100%, which can explain why no difference was observed between the formulations of different concentrations.

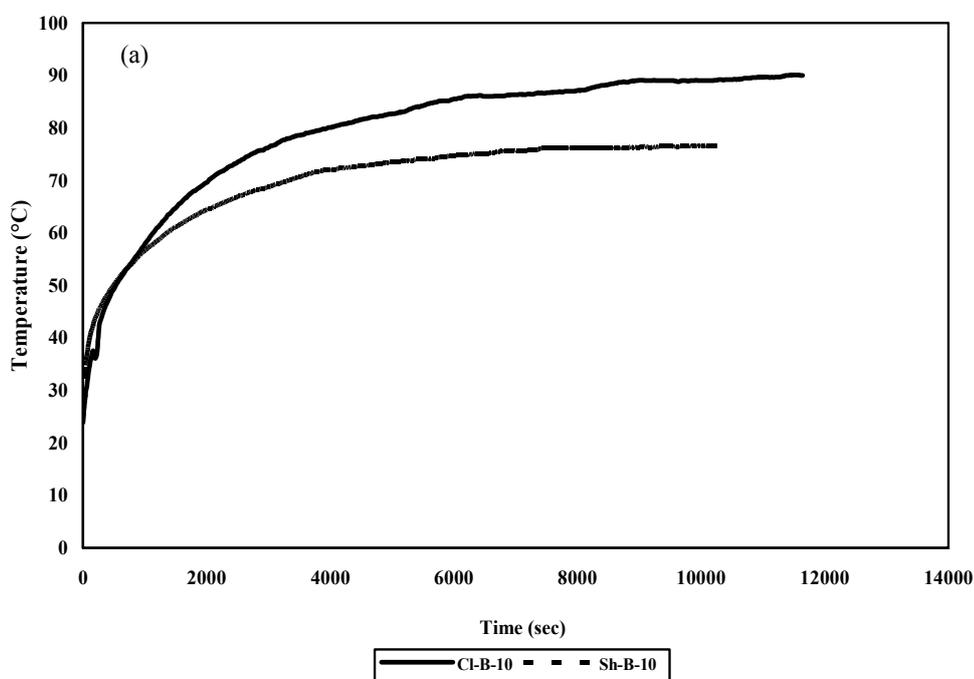
The green pigment was also dispersed into another resin at 10% by weight, a PVDF-acrylic resin, as a way of assessing whether the resin had much influence on total solar reflectance. Only small differences in TSR were observed for the samples prepared from the PVDF-acrylic resin (F-CI-G-10 and F-Sh-G-10) compared to the samples prepared from the acrylic. The use of a resin having a significantly lower or higher refractive index could lead to different TSR values.

### 3.2. Heat Buildup Measurements

Figure 4 illustrates temperature variations against time for the three colors at a pigment concentration of 10% on PVC substrates. All three systems prepared with IR-reflective pigments reached thermal equilibrium before their non-IR-reflective counterparts, and at lower temperatures. This means that heat absorption was lower for the formulations prepared with IR-reflective pigments.



**Figure 3:** Total solar reflectance values of the formulations prepared with the different pigments at different concentrations.



**Figure 4:** Temperature variations as a function of time for the systems based on black (a); green (b) and yellow (c) pigments on PVC substrates.

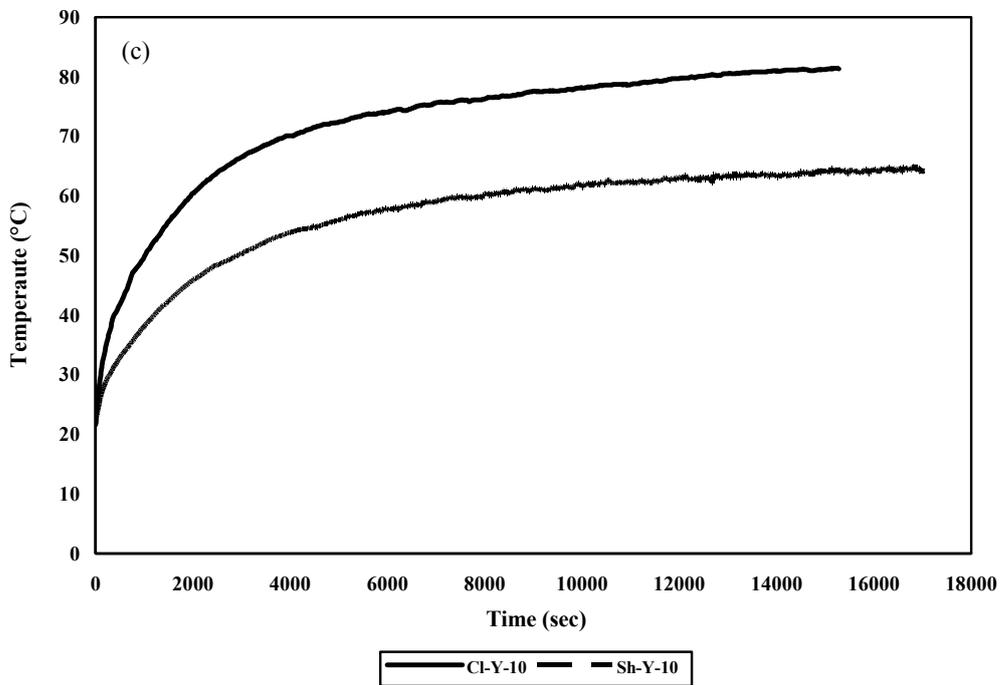
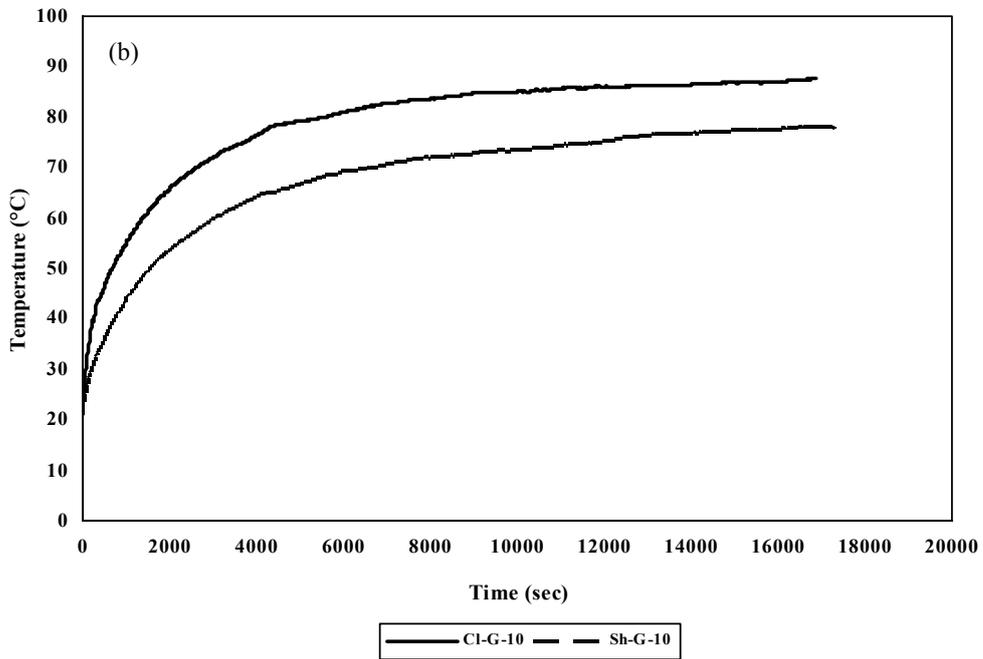


Figure 4: Continued.

Table 2 summarizes the chromatic color values of the formulations at 10%wt of pigments and Table 3 temperature rise above the ambient level. As can be observed, temperature rises varied substantially with the pigments used. The Shepherd pigments led to lower temperature rises than those from Clariant. As previously stated, the colors of the two pigments were not exactly the same. For the yellow and the black specimens, lightness was very similar for the two sets of pigments; yet an important difference in temperature rises above ambient temperature was observed.

Table 4 reports the heat buildup values measured with the different formulations on PVC substrates. Similar conclusions can be drawn from these values. IR-reflective yellow and black pigments were found to absorb significantly less IR energy than their conventional counterparts.

Color difference, especially lightness, was

important for the two green pigments, the IR-reflective pigment from Shepherd being paler. Heat absorption was therefore expected to be significantly lower for the green formulations based on the IR-reflective pigment as was the case with the other colors, but it was not. Refractive indexes may be one of the reasons for this observation with the green pigments. Those of the conventional pigments were not available but the refractive indexes of the IR-reflective pigment were found. They were: 2.75 for the yellow pigment (ID: Sh-Y); 2.70 for the black pigment (Sh B); and 2.0 for the green pigment (Sh-G). A higher refractive index should normally lead to a coating with a higher reflectance and lower heat absorption. Since the green pigment from Shepherd had a lower refractive index than the other two pigments, it can be expected to promote lower reflectance and higher heat absorption.

**Table 2:** Chromatic color values ( $L^*$ ,  $a^*$ ,  $b^*$ ) found for the formulations with the different formulations at 10%wt.

ID	$L^*$	$a^*$	$b^*$
Sh-Y	70,47	20,34	57,56
Sh-B	26,87	1,25	0,55
Sh-G	51,01	-35,71	20,84
Cl-Y	65,32	17,12	49,38
Cl-B	24,56	0,26	0,52
Cl-G	26,35	-8,00	-2,76

**Table 3:** Temperature rise above ambient temperature ( $\Delta T_{lu}$ ) for PVC specimens (5 specimens).

Systems	$\Delta T_{lu}$	S.D
Sh-B-10	55.2	2.0
Cl-B-10	69.1	2.3
Sh-G-10	57.1	1.5
Cl-G-10	65.6	1.5
Sh-Y-10	44.9	2.3
Cl-Y-10	58.2	1.2
Black PVC	69.1	2.3

Heat buildup was not measured on the white pine specimens as it is impossible to have a black standard as for the PVC substrate but temperature rises above ambient temperature were measured. Table 5 summarizes the values obtained. Again, the Shepherd pigments led to lower temperature rises, especially the yellow and black pigments. Differences in temperature rise were found to be lower with white pine than with PVC. These results are not surprising as wood is more of an insulating material than PVC. One can also observe that the gap in temperature rises between conventional and IR-reflective pigments was lower with the wood than with the PVC. However, the gap in

temperature rises between the formulations prepared with the IR-reflective and the conventional pigments were not negligible. These results indicate that the use of an IR-reflecting pigment was able to limit heat absorption in a coated wood product, which should lead to slower degradation and reduced resin exudation. Wood splitting could also be limited by the use of these pigments in opaque coatings, especially on south exposed surfaces, where the products are directly exposed to the sun. Mitigating the performance problems related to heat absorption should help the wood industry to compete with other building material suppliers.

**Table 4:** Heat buildup ( $\Delta T$ ) for PVC specimens.

Systems	$\Delta T$	S.D
Sh-B-10	32.7	2.3
CI-B-10	41.0	2.7
Sh-G-10	33.9	2.1
CI-G-10	38.9	2.2
Sh-Y-10	26.6	2.2
CI-Y-10	34.5	1.9
Black PVC	41.0	2.7

**Table 5:** Temperature rise above ambient temperature ( $\Delta t_{lu}$ ) for white pine specimens.

Systems	$\Delta t_{lu}$	S.D
Sh-B-10	48,8	1,6
CI-B-10	60,5	0,7
Sh-G-10	49,3	1,7
CI-G-10	52,4	1,8
Sh-Y-10	39,2	2,7
CI-Y-10	46,3	1,4

#### 4. Conclusions

The main objective of this work was to determine if the use of IR-reflective pigments could really decrease heat absorption at the surface of wood products. Reflectance spectra were recorded in an attempt to clarify pigment behavior when exposed to IR radiation

(light), and determine total solar reflectance values. The clear differences found between specimens treated with conventional and IR-reflective pigments indicated that the IR-reflective pigment indeed reflected more IR radiation and reduced heat buildup. The difference between the two green pigments was found to be

smaller than with the other colors. This could be explained by the refractive index of the green IR-reflective pigment which was lower than for the two other colors.

Temperature rises over ambient temperature were also measured, and these experiments showed that even if wood can be considered a better insulator than other building materials, it does absorb heat. The IR-reflective pigments proved less effective with the wood

substrates than with the PVC controls. However, the formulations prepared with black or yellow IR-reflective pigments clearly showed potential with reducing heat absorption, and may contribute to mitigating practical problems related to extreme solar radiation exposure such as premature wood coating degradation, wood splitting and resin exudation in resinous wood species.

## 5. References

1. H. H. Kim, Urban Heat Island, *Int. J. Salt Lake Res.*,13(1992), 2319-2336.
2. A. Synnefa, K. Apostolakis, M. Santamouris, On the development, optical properties and thermal performance of cool colored coatings for the urban environment, *Sol. Energy*, 81(2007), 488-497.
3. A. Libbra, A. Muscio, C. Siligardi, P. Tartarini, Assessment and improvement of the performance of antisolar surfaces and coatings, *Prog. Org. Coat.*, 72(2011), 73-80.
4. D. M. Hyde, S. M. Brannon, Investigation of infrared reflective pigmentation technologies for coatings and composites applications, In: Convention and Trade Show American Composites Manufacturers Association, St. Louis, MO, USA, (2006).
5. R. Levinson, H. Akbari, P. Berdahl, I. Joedicke, W. Miller, J. Reilly, Y. Suzuki, M. Vondran, Methods of creating solar-reflective nonwhite surfaces and their application to residential roofing materials, *Sol. Energy Mater. Sol. Cells*, 91(2007), 304-314.
6. K. L. Uemoto, V. M. John, N. Sato, Estimating thermal performance of cool colored paints, *Energy Build.*, 42(2010), 17-22.
7. P. Berdhal, H. Akbari, R. Levinson, W. A. Miller, Weathering of roofing materials-an overview, *Constr. Build. Mater.*, 22(2008), 423-433.
8. A. K. Bendiganavale, V. C. Malshe, Infrared reflective inorganic pigments, *Recent patents on Chemical Engineering*, 1(2008), 67-79.
9. H. Akbari, The cool colors project, <http://coolcolors.lbl.gov/>, Accessed online Feb. 2013.