



The methods for creating energy efficient cool gray building coatings—Part II: Preparation from pigments of complementary colors and titanium dioxide rutile

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ABSTRACT

The method to create cool gray coatings colored with mixtures of black and white pigments was described in a companion paper. In the current article, the method to prepare colorful cool gray coatings by mixing pairs of pigments of complementary colors and titanium dioxide rutile is introduced. The qualified cool light blue–gray and orange–gray coatings are created by mixing complementary cobalt aluminate blue and chromophthal yellow paste with the white coatings in appropriate proportions. The cool light to moderate yellow–gray and violet–gray coatings are formulated by blending complementary nickel titanate yellow and dioxazine purple paste and the white coatings in suitable proportions. The eligible cool light green–gray and red–gray coatings are colored with mixtures of complementary cobalt titanate green and irgazin red paste and the white coatings in appropriate proportions.

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1. Introduction

Cool bluish and greenish gray coatings play an important role in visual camouflage and the reduction of the infrared signature of warships in the ocean environments; therefore, they have been studied to a certain extent [1]. Cool gray coatings are also of particular significance for building energy efficiency because the gray color is one of the most preferred colors for the exterior of buildings [2]. However, little attention has been paid to the cool gray coating preparation methods.

According to the basic color theory, any two colors that lie opposite one another on the color wheel are referred to as complementary colors [3–11]. The complement of red is green, the complement of blue is orange, and the complement of yellow is purple [3,9]. Mixing white and black can produce a neutral gray [3,4]. Blending any two complements together may form a neutral [3–8]. Adding white to a neutral eventually yields a colorful gray [3–7].

The color effect of an industrial coating is achieved by adding the desired pigments [12]. Therefore, a gray coating can be created by mixing white and black pigments or by blending two pigments of complementary colors with white pigment. Because the colored pigments selectively absorb specific wavelengths in the visible

(VIS, 400–700 nm) region and strong ultraviolet (UV, 250–400 nm) absorptance is required to shield the coatings and substrates [13,14], the most effective way to improve the solar reflectance of a gray coating is to maximize the NIR reflectance. In addition, the backscattering and absorption coefficients of a mixture can be approximated from the volume-weighted averages of the backscattering and absorption coefficients of its constituents [15]. Therefore, moderate to strong NIR-transmitting pigments should be selected to create cool gray coatings.

In the companion paper [2], we described the method to create cool gray coatings by mixing titanium dioxide rutile white and black pigments with weak NIR absorptance. In the current article, we present the method for preparing colorful cool gray coatings by blending pigments of complementary colors with moderate to strong NIR transmittance plus titanium dioxide rutile white. The optical properties of the developed cool gray coatings are measured and analyzed.

2. Experimental section

2.1. Selection of materials

Knowledge of component pigments is of particular importance for the preparation of cool gray coatings. The cool gray coatings

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used on the roof and exterior walls of a building should have good weather resistance to maintain high solar reflectance. Therefore, the pigments selected should have moderate to strong NIR transmittance and reflectance; they should also be durable and lightfast if they are organic pigments. Of the commercially available NIR-transmitting pigments, the representative pigment pairs of complementary colors selected are as follows: cobalt aluminate blue (C.I. Pigment blue 28) and cromophtal yellow (C.I. Pigment yellow 110); nickel titanate yellow (C.I. Pigment yellow 53) and dioxazine purple (C.I. Pigment violet 23); and cobalt titanate green (C.I. Pigment green 50) and irgazin red (C.I. Pigment red 254). The three organic pigments of cromophtal yellow, dioxazine purple and irgazin red have good light fastness (class 7–8, 1/25 SD); however, they are less chemically stable than the corresponding inorganic pigments.

2.2. Preparation of the samples

The preparation process for the pigment pastes of the complementary colors was identical to that of the single pigment paste described in the companion paper [2]. In addition, a self-manufactured cool white coating (designated as S_w) was mixed with the pigment pastes of the complementary colors, whose weight content was 20 wt%. The composition and optical properties of the white coating were described in detail elsewhere [16–18]. The coatings were airlessly sprayed onto fiber cement boards, polywoods and fiber cement boards with white basecoats, whose solar and NIR reflectances were listed in Table 1 of the companion paper [2]. The dry film thickness of all the gray coatings were approximately 50 μm .

2.3. Measurements of the optical properties

To study the optical properties of the cool gray coatings, they were sprayed on to polywoods, fiber cement boards with and without cool white basecoats. The dry film thickness of the cool white basecoats was approximately 150 μm and their solar reflectance was 0.87. The spectral reflectance and the lightness of the created cool gray coatings were measured using a UV/VIS/NIR spectrophotometer (Perkin Elmer Lambda 750) equipped with an integrating sphere (150 mm diameter, Labsphere RSA-PE-19) and a color reader (CR-10, Konica Minolta Sensing, Inc.), respectively, following the procedures described in the companion paper [2].

3. Results

3.1. Preparation from blue and orange pigments

Cobalt aluminate blue and cromophtal yellow are complementary colors and were thus selected as representative pigments to create the cool blue–gray and the cool orange–gray coatings. Of the commercially available orange pigments, cadmium orange is an ideal option because it has weak scattering and strong absorption in the 400–600 nm band but strong scattering and virtually no absorption at longer wavelengths [19]. However, cadmium based pigments may cause cancers and are not environmentally friendly. Cromophtal yellow has been found to be an orange pigment with weak NIR absorptance and strong NIR transmittance despite the fact that it is an organic pigment. Therefore, it was selected as the representative orange pigment in this work.

To explain the optical properties of the resultant cool gray coatings, the blue and orange coatings, pigmented separately with cobalt aluminate blue and cromophtal yellow, were also prepared and the resulting samples were designated as S_b and S_o , respectively. Their solar reflectance values are 0.229 and 0.523, respectively.

3.1.1. The cool blue–gray coatings

To prepare the blue–gray coatings, the weight ratio of cobalt aluminate blue to cromophtal yellow in the pigment paste was 97:3. After the pigment paste of the complements was prepared, it was added to the cool white coatings. The weight contents of the pigment paste were 2, 4, 6, 8 and 10 wt% and the resulting specimens were designated as S_{b-g-1} , S_{b-g-2} , S_{b-g-3} , S_{b-g-4} and S_{b-g-5} , respectively. The corresponding pigment volume concentrations (PVCs) of the cobalt aluminate blue and cromophtal yellow of S_{b-g-1} , S_{b-g-2} , S_{b-g-3} , S_{b-g-4} and S_{b-g-5} were 0.1%, 0.2%, 0.3%, 0.4% and 0.5%, respectively.

The measured spectral reflectance curves of the above samples over fiber cement boards, polywoods and white basecoats, together with that of the white, orange and blue coatings and the substrates, are compared in Fig. 1a(I)–c(I), respectively. The corresponding lightness dependence of the solar and NIR reflectances of the gray coatings are compared in Fig. 1a(II)–c(II). The corresponding color images of the gray coatings are shown in Fig. 1a(III)–c(III). Several observations can be derived from Fig. 1. First, Fig. 1a(I)–c(I) are similar; however, the reflectance curves of the blue–gray coatings in Fig. 1b(I) are slightly higher than those of the corresponding blue–gray coatings with identical PVC of pigments in Fig. 1a(I) but slightly higher than those of the corresponding blue–gray coatings with identical PVC of pigments in Fig. 1c(I). Similar phenomena will also be observed below for the other gray coatings. Second, as shown in Fig. 1a(I)–c(I), the spectral reflectance curves of the blue–gray coatings lie between the spectral reflectance curve of the white coating and that of the colored coating pigmented with one of the pair of the complements with lower solar reflectance. The spectral reflectance curve of the other colored coating with higher solar reflectance intersects with the spectral reflectance curves of the blue–gray coatings. In this case, the colored coatings with the lower and higher solar reflectance are the coatings simply pigmented with cobalt aluminate blue and cromophtal yellow, respectively. This observation will also be repeated below for the other gray coatings. Third, in the VIS and NIR regions, the spectral reflectance curves of the blue–gray coatings shift downward as the PVCs of the complements increase. This is a common phenomenon for all of the cool gray coatings. Fourth, there are overshoots in the VIS region between approximately 460 and 600 nm. The peaks of the overshoots are between the peaks of the overshoots of the blue coating curve and the orange coating curve. This is a consequence of the mixture of the complements. Fifth, corresponding to the wide and deep reflectance dip of the blue coating in the NIR region, there are slightly narrower reflectance dips in the similar NIR region in the spectral reflectance curves of the blue–gray coatings. The shapes of these dips are slightly different from that of the spectral reflectance curve of the blue coating; they are similar to the result of the combined action of the blue pigment and titanium rutile. This indicates that the blue pigment and titanium rutile optical properties dominate the optical properties of the resultant blue–gray coatings in the NIR region. In addition, in the higher NIR region between approximately 1600 and 2500 nm, the dip shapes of the blue–gray coatings are similar to those of the white coating.

As shown in Fig. 1a(II)–c(II), the lightness, NIR and solar reflectance of the blue–gray coatings decrease as the PVCs of the complements increase. At identical PVC of the complements, the solar reflectance values of the blue–gray coatings over polywoods are slightly higher than those over fiber cement boards but slightly lower than those over white basecoats. This is because the solar reflectance of a coating pigmented with NIR-transmitting colorants increases with the solar reflectance of the background [14]. The solar reflectance values of the fiber cement board, the polywood and the white coating (used as basecoat in this work) are 0.47 and 0.48 and 0.87, respectively [2]. The lightness of the

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