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Characterization of Angle Dependent Color Travel of Printed Multi-Color Effect Pigment on Different Color Substrates

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Abstract:

Color-travel pigments, which exhibit much more extensive color change as well provide angle-dependent optical effect can be used in many industrial products. In present paper the multi-color effect pigment printed on three different foils with different background color (black, silver and transparent) was investigated. The pigment was based on synthetically produced transparent silicon dioxide platelets coated with titanium dioxide. CIEL*a*b* values and reflection of prints were measured by multi-angle spectrophotometer at constant illumination at an angle of 45° and different viewing angles (-15°, 15°, 25°, 45°, 75° and 110°) were used. The measurements of printed multi-color pigment showed that CIEL*a*b* color coordinates varied to great extents, depending on detection angles as well on color of the printing substrate. The study revealed that pigmnet printed on black background obtained significant change in color. The study has also shown that when viewing angle increases, the reflection curves decreases.

Keywords:

Multi-Color Effect Pigment, Multi-Angle Spectrophotometric Measurements, Color Travel, CIELAB, Reflection

1. Introduction

Over the last decades, special effect pigments have found a broad range of apllications in decorative and functional purposes like paints, printing inks, and plastics. They have unique possibilities to achieve optical impressions such as eye-catching effects, angle-dependent interference colors, pearl luster and multiple reflections (Pfaff and Becker, 2012).

Special effect pigments are used in many applications to create new color impressions, pronouncing the design of a product and at the same time making the product appear alive. The color impression of effect finishes can not only change under different viewing angles but can also look different depending on the lighting conditions (Kiegle-Boeckler and Weixel, 2010).

The range of application media for pigments includes paint, coatings, plastics, printing inks, construction materials, ceramic products, glass, cosmetic and electonics products (Pfaff, 2008).

Effect pigments are predominantly flaky particles consisting of a substrate coated with a thin intense refracting layer which can be oriented parallel to the object surface (Atamas et al., 2012). In contrast to conventional solid colors, effect pigments change their appearance with viewing and lighting conditions (Debeljak et al., 2013). They show not only a lightness change with viewing angle, but also a chroma and hue change (Kiegle-Boeckler and Weixel, 2010).

In a group of angle-dependent pigments (pigments with strong color travel) belong also silica flake based pigments. Silica flake based pigments were introduced to the market 12 years ago. They consist of synthetic SiO_2 platelets coated with high refractive index metal oxides such as TiO_2 and Fe_2O_3. The flakes have an absolutely uniform and controllable thickness of several hundred nanometres with a smooth surface. Pigments act as a both a true optical layer and a transparent substrate without a masstone color. The coated flakes show improved chromatic strenght and a new color travel behaviour (Pfaff and Becker, 2012), (Color measurement from many angles, 2005). The color of these pigments exhibits extreme angle dependence, and objects printed with them change appearance with the direction of lighting and the location of observation. The strong color travel is seen even under subdued lighting conditions (Pfaff, 2003). Some of silica flake pigments show color travel effects such as violet-green, red-gold, green-red or gold-blue (Maile et al., 2005).

Synthetic SiO_2 flakes offer three advantages over the use of natural mica: 1. The thicknes of the SiO_2 substrate can be contolled in the preparation so that a pigment with a true optical three-layer sytem is obtained. The interference color of these system is stronger than that with the conventional mica pigments for which the effect of mica is "wiped out" by a broad thickness distibution. 2. As synthetic substrates they do not have the small iron impurities that cause the slightly yellow mass tone of natural mica. 3. SiO_2 has a lower refractive index (1.46) than mica (about 1.58) and, therefore, leads to a stronger interference effect (Baxbaum and Pfaff, 2005).

The research of synthesis, optical properties and application of special effect pigments based on silica flakes has been already done by Pfaff (Pfaff, 2003). Furthermore, the investigations have been made also of the colorimetric properties of goniochromatic colors using the MacAdam limits under different light sources (Perales et al., 2011), appearance measurements of goniochomatic colors (Atamas et al., 2012), special effect pigments in cosmetic applications (Pfaff and Becker, 2012), effects on substrate structure and substrate color on color differences in textile coating containing effect pigments (Malm et al., 2014) etc. In present paper the angle dependent color travel of special effect pigment based on silica flakes printed on foils was investigated.

2. Materials and Methods

The measurements presented here were performed on three different substrates with different background color, which were printed with multi-color effect pigment by screen printing technique (Screen Printer TSH Print Swiss S550). As the printing substrates two polyvinyl cloride foils and one polypropylene foil were used. Pigment Colorstream® T10-01 Viola Fantasy (produced by MERCK) used is based on synthetically produced transparent silicon dioxide platelets coated with titanium dioxide.

In Table 1 the properties of plastics foils, in Table 2 the properties of multi-color effect pigment and in Figure 1 the SEM image of multi-color effect pigment at 1000x magnification are presented.

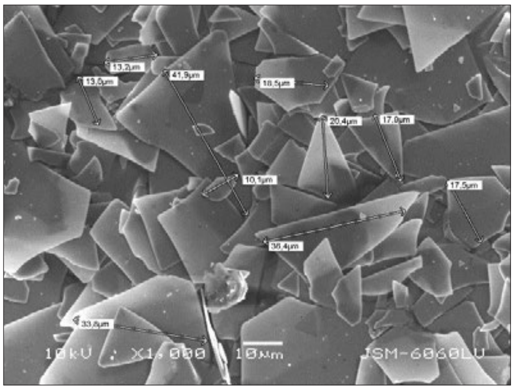

Figure 1. SEM image of multi-color effect pigment at 1000x magnification.

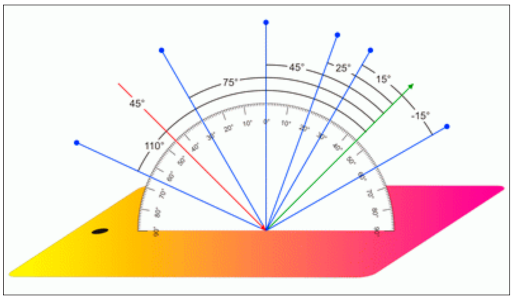

Figure 2. Six different angles with constant illumination at 45° (Goniovision, 2011).

3. Measurements

CIEL*a*b* values and reflection of prints were measured by X-Rite MA98 Portable Multi-Angle Spectrophotometer. In our study the constant illumination at an angle of 45° and different viewing angles (-15°, 15°, 25°, 45°, 75° and 110°) were used as shown in Figure 2. The reflection were measured at wavelengths from 400 nm to 700 nm with 10 nm intervals.

4. Results and Discussion

The effect pigments requires a totall different system of measurement and characterization (Measuring Special Effects, 2001). This effect cannot be captured with conventional multi-angle color instruments, because they measure the integral of the spectral reflection over the detected area and cannot distinguish between the basecoat color and the reflection of the effect pigments (Kiegle-Boeckler and Weixel, 2010).

4.1 Difference in CIEL*a*b* values

In the first stage of the investigation, the lightness (L*), green-blue values (a*) and blue-yellow values (b*) of printed multi-color effect pigment applied on three different plastic foils (Foil 1, Foil 2 and Foil 3) were analyzed. The measurements are presented in Figures 3-5.

As can be seen from Figures 3-5, the background color of foils and also viewing angles have influence on a lightness (L*) of printed multi-color effect pigment. As shown in Figure 3-5, there are samples with lightness values

Table 1. Properties of plastic foils.

	Foil 1	Foil 2	Foil 3
Chemical composition	PVC	PVC	PP
Color	black	silver	transperent
Surface roughness Ra	2.2 µm	2.0 µm	6.2 µm
Thickness	0.224 mm	0.206 mm	0.506 mm

Table 2. Properties of multi-color effect pigment.

	Multi-color effect pigment
Chemical composition	SiO_2 (81-90%), TiO_2 - Rutile (8-14%), SnO_2 (2-5%)
Form	dry, free-flowing power
Color	Lilac / Silver / Gren / Blue
Particle size	5-50 µm
Density	2,0-2,4 g/cm3

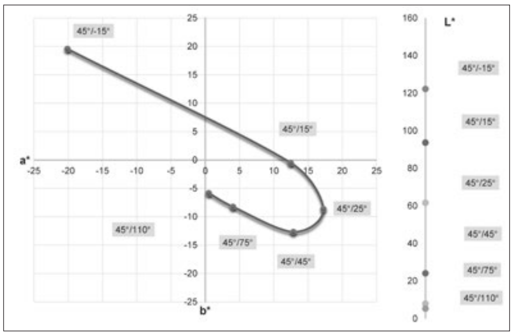

*Figure 3. The CIEL*a*b* color coordinates of printed multi-color effect pigment applied on Foil 1, measured at various viewing angles.*

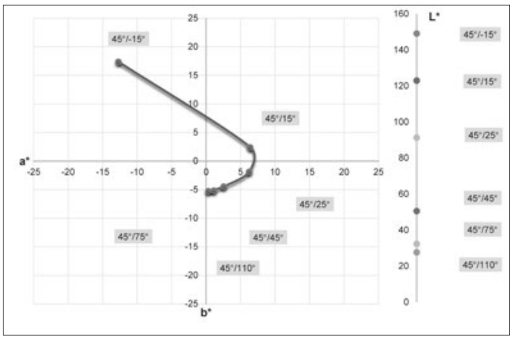

*Figure 4. The CIEL*a*b* color coordinates of printed multi-color effect pigment applied on Foil 2, measured at various viewing angles.*

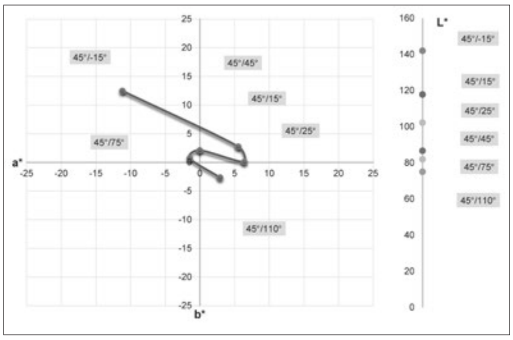

*Figure 5. The CIEL*a*b* color coordinates of printed multi-color effect pigment applied on Foil 3, measured at various viewing angles.*

greater than 100 (at all three printed foils at the measurement geometry 45°/-15°, at printed Foil 2 and Foil 3 at the measurement geometry 45°/15° and also at printed Foil 3 measurement geometry 45°/25°). The results have shown that the lightness decreased rapidly with inceased viewing angle from an angle of -15° to an angle of 110°. At viewing angle of -15° the prints at all three foils were the brightest, while at angle of 110° the darkest. On average the pigment printed on transparent Foil 3 was the brightest, while on black Foil 1 the darkest.

The viewing angles are grouped into three categories: "Face" (Near Specular: 15º or 25º), "Mid Specular" (or diffuse: 45º), and "Flop" (Far Specular: 75º or 110º) and correlate to the instrumental viewing angles. An angle of 25º [=L*(25º)] has become accepted to describe the visual effect on face. The angles of 110º [=L*(110º)], and 70º measure the darker appearance (Wißling, 2006).

The results of CIEa*b* color coordinates relating to the print on Foil 1 with black background showed significat change in color. At measurement geometry of 45°/-15° the color appearance of print was located in area of green-yelow quadrant , at 45°/15° in the positive red axis, at 45°/25°, 45°/45°, 45°/75° in red-blue quadrant and at 45°/110° ended in the negative blue axis. The color appearance travel from light green – pink - dark violet - dark blue -almost black (from the lowest to the highest viewing angle). In contrast to the prints on Foil 2 and Foil 3 the print on Foil 1 attained the most wide color area. The viewing angle and the illumination condition, considerably influence the perceived color as reported also by Kandi (Kandi, 2011). In the case of print on Foil 2 with silver background, the a* values increased from -12,72 (45°/-15°) to 1,12 (45°/110°), while b* values dropped from 17,41 (45°/-15°) to -5,15 (45°/110°). At print on Foil 3 with transparent background a slightly different distribution of values and a much smaller color range were noticed. In contrast to prints on Foil 1 and Foil 2, the color appearance at print on Foil 3 has obviously changed from mesurement geometies of 45°/25° to 45°/110°. The color appearance travel from light green - light pink - light gray - light violet. From measurement geometry of 45°/-15° to 45°/110°, the a* values changed for 14,07 units, while b* values for 15,17 units. Particularly "traveler" pigments, which exhibit much more extensive color changes than so-called "shifter" pigments, may exhibit highly complex interference lines (Cramer, 2006).

4.2 DIFFERENCE IN REFLECTION CURVES

Figures 6-8 show the reflection curves of printed multi-color effect pigment (applied on black PVC Foil 1, silver PVC Foil 2 and transparent PP Foil 3), measured at various viewing angles.

It was noticed, that reflection of printed pigment on all three foils (Figures 6-8) was diffenent at different measurement geometry, some values even exceeding 300%. The highest peaks at at all three printed foils were noticed at measurement geometry of 45°/-15° (Foil 1: 214%, Foil 2: 304% and Foil 3: 265%), while at measurement geometry 45°/110° the lowest. The reflection maximum/minimum shifts belong to different illumination angles which are typical for effect pigments (Pfaff, 2008). While conventional pigments produce color by absorbing selected wavelengths of light, effect pigments generally reflect all wavelengths of light. The special visual effect achieved through their use is due to the layering of the pigments throughout the coating (Measuring Effect Pigments, 2004).

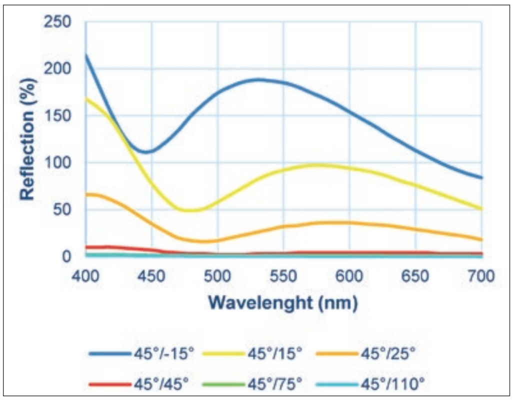

Figure 6. The reflection curves of printed multi-color effect pigment applied on black Foil 1, measured at various viewing angles.

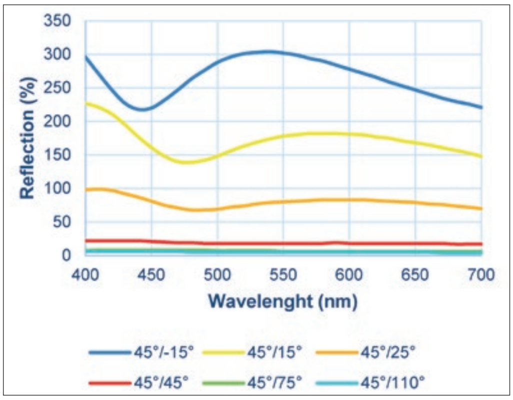

Figure 7. The reflection curves of printed multi-color effect pigment applied on Foil 2, measured at various viewing angles.

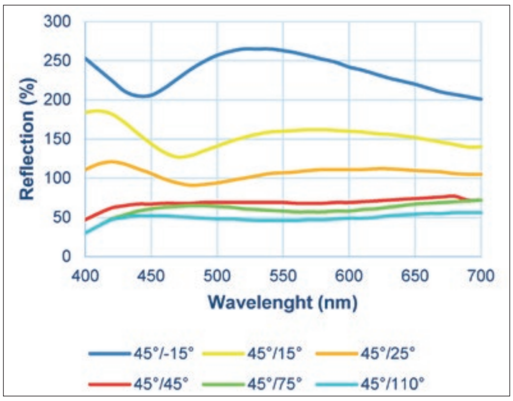

Figure 8. The reflection curves of printed multi-color effect pigment Foil 3, measured at various viewing angles.

5. Conclusions

This study demonstrates the influence of different measuring geometies on multi-color effect pigment printed on plastic foils with different background colors. It was established that the values of lightness decreased rapidly with inceased viewing angle from an angle of -15° to an angle of 110°. The background color of foils also influenced the lightness, the brightest values were obtained at printed transparent Foil 3. In the case of color travel of printed pigment on all three foils showed significant change in color. The color appearance travel from light green – pink - dark violet - dark blue - almost black (from the viewing angle of -15° to angle of 110°). At the Foil 1 with black background color the color change was the most obvious. The study has also shown that when viewing angle increases, the reflection curves decreases.

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