Color Performance of Dye-based and Pigment-based Color Toners

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Abstract

A comparative analysis of color performance, i.e., color gamut, image density, and lightfastness for a set of dye-based CM toner®, a set of commercial pigment-based color toner and a set of commercial inkjet ink was carried out. CM toner® was prepared by first forming small particles of a functionalized polyester resin and subsequently dyeing the particles with a dye to form a chemical bond between them.

Three types of color performance were studied in detail; the color gamut of the toner sets, the optical density, and the lightfastness of the printed images. The dye toner set gave a larger gamut than the pigment toner set. The gamut number was used as an index to estimate an area of 2d gamut. The gamut number of dye toner was 1.5 times larger than that of the pigment toner set and 2.4 times than that of the inkjet ink. For visualizing 3d gamut, Neugebauer model was adopted. From the comparison of 3d gamuts, the dye toners provided a gamut solid with larger volume than the pigment toners. The wide and larger gamut is primarily due to the high saturation and the lightness values, which in turn, result from that the dyes are dispersed in the molecular level due to intrinsic affinity to the base resin, whereas the pigments are dispersed in micro-scale due to poor affinity to the binder resin. The optical density per unit thickness was doubled by incorporating additional 1.5 wt.% of dye. To enhance the lightfastness of dye toner, a UV stabilizer was incorporated. The UV stabilizer improved the lightfastness to 80% level as compared to that of the pigmented toner, a value which was significantly superior to that of the inkjet ink.

Introduction

The novel chemical milling method of forming small particles with a narrow size distribution from a functionalized polyester resin was introduced by Kim et al.[1] Due to the ionic moiety of resin backbone to facilitate dyeing, a large amount of dye easily makes chemical bonding with toner resin. The dye-based CM toner® was produced by chemical milling and dyeing process.

Pigment is another colorant widely utilized for toner production. The dye and the pigment are distinguished by their solubility, transparency, presence of binder, and etc.[2] Dyes are generally water-soluble while pigments are always insoluble in the medium. The colorants that dissolve in resin and thus gave transparent mixtures are called dyes, in contrast to pigments, which do not dissolve but scattered light and gave turbid appearance. Dyes have an affinity for the substrate and will become a part of the colored material without the need for an intermediate binder, whereas pigments have no affinity to the substrate and require a binder so that the pigment is fixed to the substrate.

The criteria for evaluating of color performance of toner are color gamut, optical density or image density, light-fastness, and etc. The color gamut is defined as the limits of the array of colors that can be captured by an image-capturing device, represented by a color-encoding data medium or physically realized by an output device of medium.[3] Therefore, a large color gamut of toner means the capability to produce a wide window of mixed colors. In addition to color gamut, of particular importance in imaging applications involving hardcopy media is the optical density. The OD value of colored media is measured using a three-channel densitometer. Appropriate OD value is one of the fundamental characteristics of a high quality printed image. Especially, a recent trend is the toner particle size becomes smaller for higher resolution. To obtain appropriate OD value despite thin toner layer resulting from such small sized toner is an emerging issue for toner and image industry. For lightfastness, the sunlight is an important cause of damage to printing inks, paints, sealants and other organic materials. Short wavelength ultraviolet and visible UV light is recognized as being responsible for most of this damage.[4] Generally, pigment toner has good lightfastness and weatherability, while dyed materials including inkjet ink and dye-based toner are known to have poor lightfastness and weatherability. However, the recent development of UV stabilizers has improved the lightfastness of dye-based materials.

In this paper the comparison of color gamut, optical density, and lightfastness for inkjet inks, commercial pigment toners, and dyed CM toner® is described.

Experimental

Gamut Analysis

The concept of gamut number introduced by Kapple[5] provides a tool to estimate the area of 2d gamut. The Kapple's method is theoretically based upon the Green's theorem, which converts a surface integral to a line integral, and vice versa. The gamut number estimates the area of a*b* projection by following equations.

$$G \sim \frac{1}{2}\sum_c \left\{ \frac{a^*_{i+1} - a^*_i}{2}\left(b^*_{i+1} - b^*_i\right) - \frac{b^*_{i+1} - b^*_i}{2}\left(a^*_{i+1} - a^*_i\right) \right\} \quad (1)$$

where C is the perimeter of the Gamut plot, and a^*_i, b^*_i and a^*_{i+1}, b^*_{i+1} are the coordinates of two neighboring primaries and secondary colors. And multiplying the terms of Eq. 1 allows it to be simplified to[6]:

$$G \sim \frac{1}{2}\sum_c \left\{ \left(a^*_i - b^*_{i+1}\right) - \left(a^*_{i+1} - b^*_i\right) \right\} \quad (2)$$

Two dimensional color gamut was obtained by measuring colorimetric coordinates of color patch images (cyan, magenta, yellow, blue, red, and green) using a spectrophotometer (CM 2002, Minolta, Japan). Three dimensional printer color gamut was visualized using Neugebauer[7] model. XYZ colorimetric values were converted to sRGB values.[8] The detailed procedure for visualizing the 3d gamut was introduced by Saito et al.[9]

Optical Density

For the relation of optical density per unit thickness with dye concentration, several yellow colored solid images were printed on the OHP film with different dye contents of 1.5, 2.0, and 3.0wt.%, respectively. Optical density values were measured by a densitometer (TR1224, GretagMacbeth, USA).

Light-fastness

A commercial benzotriazole UV absorber was selected for this study. For a simulation of sunlight condition, a xenon arc tester chamber with windows glass filter (Q-Sun/1000 Xenon test chamber, Q-Panel lab products, USA) was used at irradiance settings of 0.72W/m^2/nm at 420nm, at temperature condition of 45°C, and for 144hrs. The specimen was prepared as magenta colored patch (solid image) from printers.

Results & Discussion

Gamut Analysis

Figure 1 shows the 2d gamuts of pigment-based toner (dotted line), inkjet ink (broken line), and CM toner® (solid line). Gamut numbers for gamuts in Figure 1 were summarized in Table 1.

As shown in Figure 1 and Table 1, the CM toners® occupied a larger gamut than the commercial toners and the inks, so it can be stated that CM toner® has superior color realization performance.

Table 1. Gamut numbers for given toners and ink

	CM toner®	Pigment-based toner	Inkjet Ink
Gamut #	11,419	7,323	4,783

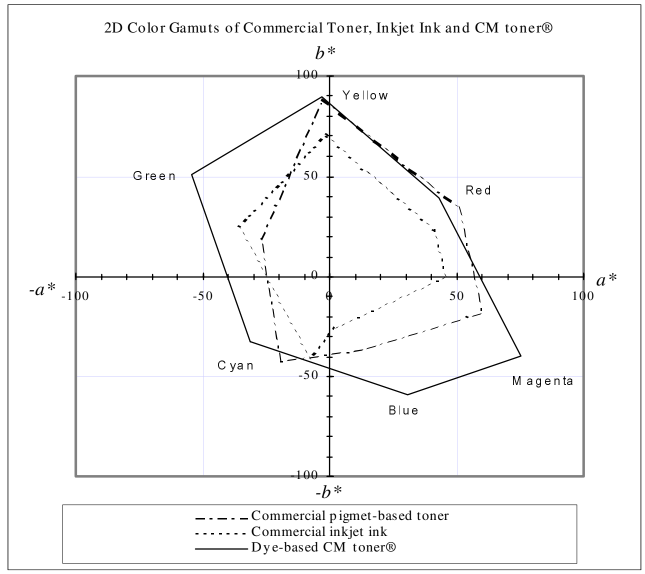

Figure 1. 2D gamuts of commercial pigment-based toner, inkjet ink, and CM toner®.(D_{65}, 10° observer)

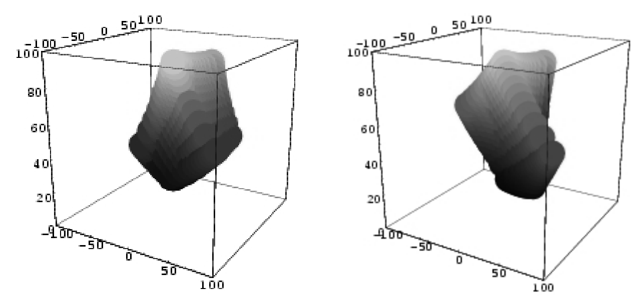

Figure 2. 3D gamuts of commercial pigment-based toner (left) and CM toner®(right).

Of course, a gamut matching between input device and output device and other factors play important roles in obtaining diverse colors. However, it is clear that the larger color gamut the toner provides, the more chance to produce various colors the toner has.

The similar behavior was observed in 3d gamut analysis (Figure 2). CM toners® (right) has a larger volume than the commercial pigment-based toners (left).

It may be explained by that generally dyes generally are dispersed in the base resin at molecular level, while pigments are dispersed at micron scale. The molecular level dispersion of dye reduces the light scattering effect. As a result, an image from a dye toner is more transparent and saturated than that from a pigment toner.

Optical Density Analysis

The optical density of printed output has received more attention in recent times. The increasing need for high-resolution image and more use of small size toner or small inkjet droplet require that the colorant concentration per toner particle or in inkjet ink be higher.

More specifically the smaller size toner produces thinner toner pile height on the paper. Hence, to obtain an acceptable optical density with thinner toner layer, the colorant concentration of the toner should increase.

Table 2 shows the relationship of toner particle size, the transferred toner mass per unit area (M/A), the required pigment content, the toner pile height, and the optical density per unit pile thickness.

Table 2. The relation of toner particle size, M/A value, pigment concentration, toner pile height, and optical density per unit toner layer thickness[10]

Particle size(μm)	M/A (mg/cm^2)	Pigment conc.(%)	Pile height (μm)	OD (/μm)
5.5	0.4	9.5	4	0.35
6.7	0.5	7.5	5	0.28
8	0.6	5.7	6	0.23
10.2	0.8	3.0	8	0.175

According to Table 2, the reduction of particle size requires enhanced amount of colorant to produce acceptable color density. For example, the 5.5 μm sized color toner should contain 9.5% of pigment concentration, which leads a potential problem in production as well as in economics. This forms a basis for the advantage of dye-based toner.

The dye-based CM toner® accomplished a unit OD value of 0.35 with only 3% of dye as a colorant (Figure 3). Furthermore, the unit OD value was changed flexibly from 0.175 to 0.35 with a small change of dye concentration (1.5% to 3%).

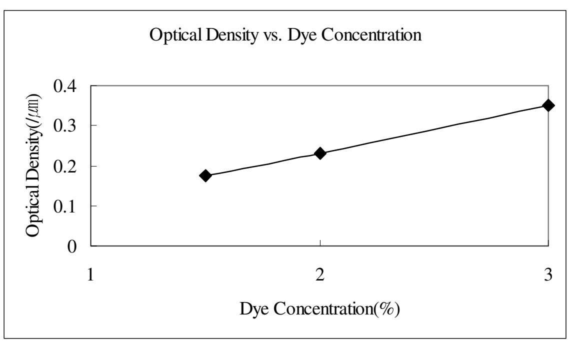

Figure 3. The relation of optical density with dye concentration of CM toner®.

From the standpoint of the versatility in changing the OD value, the CM toner® is superior to a typical pigment-based toner for high OD and thus for high-resolution.

Light Fastness

The OD retention curves below depict strong dependency of lightfastness on the type of colorants. The pigment toner nearly kept its original density with time, while the inkjet deteriorated rapidly in the presence of UV and visible light. The CM toner® demonstrated less decrease in OD than the inkjet ink.

Addition of a UV stabilizer in the CM toner® enhanced the resistance to UV and visible light. The lightfastness of CM toner® was originally only 70% of the lightfastness of the pigment toner. However, with an incorporation of 2% of the UV stabilizer the lightfastness was improved to 80% of the level of the pigment toner. At present, the overall light stability of pigment-based toner is better than that of dye-based toner, however, it is expected that the light stability of the dyed toner is to improve thanks to further development of UV stabilizers.

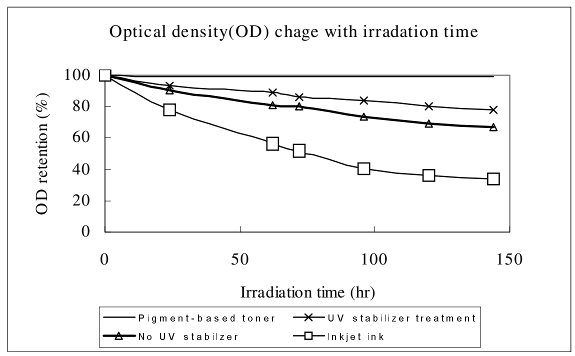

Figure 4. Optical density value change with the expose to xenon arc for pigment-based toner, Inkjet ink, and CM toner®.

Conclusion

We carried out a comparative study of dye-based CM toners®, commercial inkjet inks, and commercial pigment toners for their color gamut, optical density, and lightfastness. Dye-based toner showed a larger gamut than the other marking materials. Change in the dye concentration in toner particles easily controlled the optical density of image layer. The optical density increased from 0.18/μm to 0.35/μm by increasing the dye concentration from 1.5 to 3.0 wt.%. Finally, lightfastness was improved by about 10% by adding a UV stabilizer.

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Biography

Mr. Jongkwan Kim is a research scientist in R&D Team of DPI Solutions, Inc., a materials technology development company in Korea. He received BS in chemical engineering and MS in polymer science from Seoul National University. His research interests include color science, polymeric nano-composites, and imaging materials such as EP toners and electrophoretic display materials.