The Effect of Surface Characteristics on the Optical Density of a Print Image by Using Carbon Black Dispersion Ink

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Abstract

We investigated effective factors on optical density of a print sample printed by using of carbon black dispersion ink for ink jet printers, and studied characteristics of carbon black to get higher optical density of print images. We observed carefully the surface of the printed areas and we found out the relationship between the properties of the surface area and optical density. We focused the surface roughness in nanometer order, and confirmed that the optical density gets higher as the S.A.D. (= Surface Area Difference measured by A.F.M.) of the printed area becomes larger. To make high S.A.D. surface (= high surface area) of the printed areas, new furnace carbon black was developed by using our original technology. It has small particle diameter, very large DBP absorption and sharp particle size distribution. The ink jet ink containing this carbon black could make really high optical density print images even on a plain paper for copier.

Introduction

Carbon black inks are now widely used as ink jet printing ink, because they have many advantages such as water fastness, light fastness and little blurs compared with the dye-based ink. However, as for the optical density or blackness, the carbon black inks are not fully satisfied.

Carbon black dispersions are commonly used also in the paint and printing ink applications. Many experiences of ink formulation have been accumulated for these applications in many years. Various kinds of carbon blacks have been developed for inks. For instance, in the paint applications, the carbon black dispersion can provide very high blackness with smooth surface of paint layers by use of the carbon black particles with very small particle diameter.

The carbon black ink jet ink includes much less polymers than paint and printing inks and has very low viscosity. In the ink jet printing application, therefore, it is not clear which factors are important to control the blackness or optical density. In this paper we have studied effective factors for controlling the optical densities of printed areas by using carbon black dispersed ink jet inks.

Experimental

Various kinds of furnace black made by Mitsubishi Chemical Corporation were used as carbon black. They were dispersed into aqueous medium with dispersant by using a sand grinder. The dispersion was diluted by adding water and hydrophilic organic solvent, and filtered to prepare the ink jet ink. Hydrophilic acrylic copolymers were used as dispersants. The amounts of carbon black in the prepared inks were from 4.0 to 5.0 wt%, those of dispersant were from 0.4 to 4.0 wt%. The viscosities of the prepared inks were from 2.5 to 3.5 cP, the surface tensions of them were from 50 to 55 dyne/cm, and the pH values of them were from 7.0 to 9.0. The ink was filled up in a ink jet cartridge and the ink in the cartridge was printed onto commercially available plain paper (Xerox-4024) by use of a ink jet printer, HP DeskWriter 600series or HP DeskJet 895Cxi. Printed areas were measured for the evaluation of optical density by use of a Macbeth reflection densitometer (Kollmorgen Instruments Corporation). For the scanning electron microscopy (SEM), S-4000 (Hitachi, Ltd.) was used. NanoScope III (Digital Instruments Company) is used for atomic force microscopy (AFM). Ra and fractal dimension (f) were measured by AFM in the same condition (measured region was 1 μm × 1 μm and number of pixels were 512 × 512).

Results and Discussion

We made dispersion inks containing various kinds of carbon black. These inks were printed onto the plain paper by use of an ink jet printer, then optical density of these print samples was measured. Figure 1 shows that inks containing carbon black having the properties of medium surface area (medium particle size) and high structure (high DBP absorption) resulted in high optical density print sample. These results suggest that, in order to obtain high optical density in the ink jet printing, carbon blacks should have different properties from the high blackness carbon blacks for the paint application.

Figure 2-A and Figure 2-B show the SEM micrographs of the surface of the print samples with different optical densities at the same magnification.

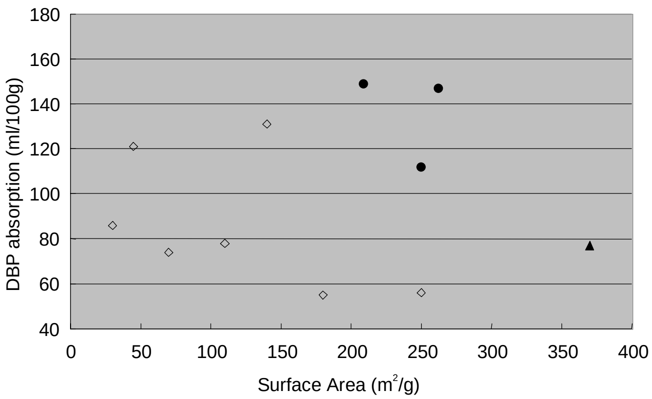

Figure 1. Carbon Black Properties

•: Carbon black with high optical density ranged from 1.40 to 1.55 when they were used for ink jet printing
▲: Carbon black with superior blackness for paint applications

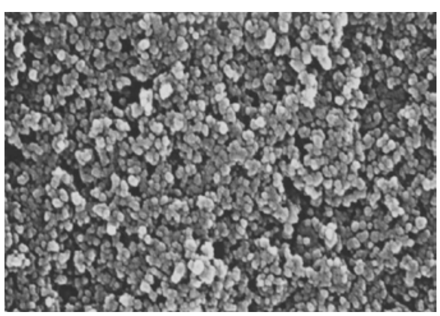

Figure 2-A. SEM micrograph of the surface of the print sample of which optical density is 1.41

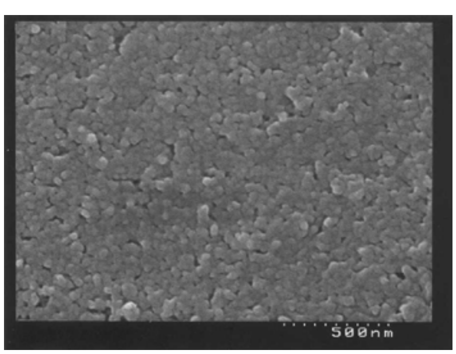

Figure 2-B. SEM micrograph of the surface of the print sample of which optical density is 1.19

The difference of the surface roughness seems to correlate to the optical density. The dense or flat surface of the print sample 2-B shows low optical density. It should be noted that surface flatness of colorant layer is very important factor to obtain higher blackness in the paint and printing ink applications. To find the factors influencing the optical density of printed area by use of ink jet ink, we need more information about the surface structure of the printed area on paper, especially, nanometer order (~10nm) surface structure and the effect of carbon blacks.

In order to investigate the effect of properties of carbon black on the surface structure, we correlated the optical densities with the surface structures of printed areas by use of inks made of various kinds of carbon black.

The structure of the carbon black layers on plain papers printed by use of these inks was diverse. The surface structures in nanometer order of the print samples were measured by atomic force microscopy (AFM) in order to quantify the difference of surface structure in these samples.

The average roughness (*Ra*) is the most common parameter to represent the roughness of the surface. Fractal dimension is the index that stands for the fractal degree of the surface. The average roughness (*Ra*) and the fractal dimension (*f*) are described as

$$Ra = (1/LxLy)\int^{Ly}\int^{Lx} |z(x, y)|\, dxdy$$

$$n = C \times a^f.$$

The terms of the equation are defined as follows:
LxLy : size of measured area.
x, *y* : position.
z(*x*, *y*) : height at (*x*, *y*).
n : the number of cell that the surface cross.
a : cell size.
C : constant.

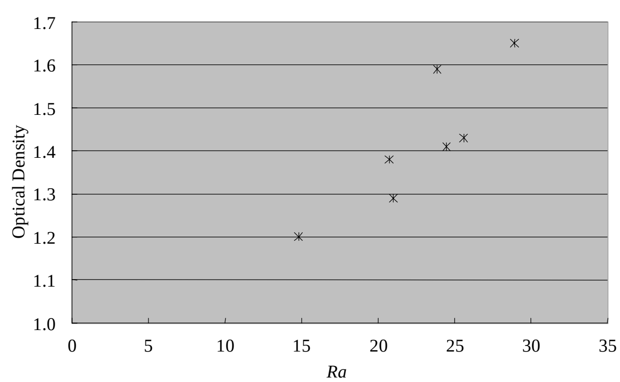

Figure 3. Ra vs. optical density of the print samples printed with carbon black inks

As shown in Figure 3, some interrelation between *Ra* and optical density was observed, although the degree of correlation is not so good. On the other hand, the fractal dimension (*f*) was not effective factor for changing the optical density of print samples, because the fractal dimension of carbon black layers on plain paper is about the same value from 2.1 to 2.3.

Parameters representing the roughness of the carbon black layer were investigated, and it was found that surface area difference (S.A.D.) was the important factor for ink jet prints.

The S.A.D. value was described as

S.A.D. (Surface Area Difference)

$$= \{(\sum Si - \sum Pi) / \sum Pi\} \times 100\ (\%)$$

$$= \{(\sum Si / \sum Pi) - 1\} \times 100\ (\%).$$

The terms of the equation are defined as follows:

Si : the area of every triangle formed by adjacent three points.

Pi : the area when Si is projected to a xy plane.

$\sum$Si : the sum of all Si.

$\sum$Pi : the sum of all Pi.

The S.A.D. value on the plain paper was 7.0, which means that the S.A.D. values shown in Figure 4 expressed the surface roughness of the carbon black layers of print areas on the plain papers. The results show a good correlation between the S.A.D. values and the optical density of the print samples.

From these results, it seems necessary to make high S.A.D. carbon black surface on paper to obtain print image with higher optical density. We tried to develop new furnace black by our original production method and made special furnace black (1). The furnace black (1) has the properties of the small particle, high structure and sharp particle size distribution.

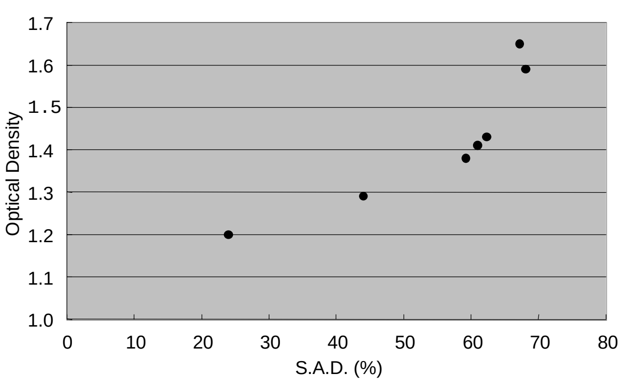

Figure 4. S.A.D. vs. optical density of the print samples printed with carbon black inks

Mitsubishi Special Furnace Black (1)

Particle size	14 nm
Surface area	294 m^2/g
DBP absorption	147 ml/100g
pH	7.3

We made ink jet ink using the furnace black (1) and evaluated the print sample prepared from the ink. The optical density of the print sample showed the highest value, 1.61. The SEM micrograph of this print sample is shown in Figure 5.

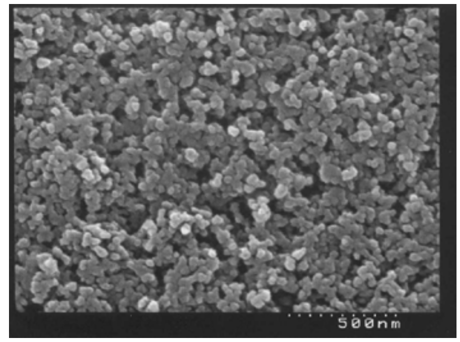

Figure 5. SEM micrograph of the surface of the print sample of which optical density is 1.61

Furthermore, we prepared ink A using the special furnace black (1) for the purpose of making much higher S.A.D. value of the print sample. In making the ink A, we optimized dispersants and dispersing process.

With the new carbon black and the optimized dispersing process, we were able to obtain the high optical density carbon black ink that provided the optical density 1.70 even when it was printed on the plain paper.

We made it sure that, in the ink jet print application, the structure of the carbon black layers on paper is a dominant factor on the optical density of the printed image with carbon black ink. It is confirmed that the important parameter deciding the optical density is the S.A.D. value of the carbon black layer on paper.

These results indicate that the mechanism to achieve high optical density in the ink jet printing application is different from that of the conventional paint and printing ink applications which includes a lot of polymer.

As shown in the results above, the nanometer order roughness of the carbon black on paper is necessary to achieve high optical density in the ink jet printing.

Summary

We investigated effective factors on optical density of a print sample printed by using of carbon black dispersion ink for ink jet printers and studied characteristics of carbon black to get higher optical density of print images. We found the correlation between the S.A.D. and the optical density of the print sample, and confirmed that the optical density is higher as the S.A.D. value of the printed area is larger. To prepare high S.A.D. surface of the printed areas, we have developed new furnace carbon black and dispersing process. Especially, a brand-new carbon black that has the property of small particle diameter, very large

DBP absorption and sharp particle size distribution was developed by using our original technology. The ink jet ink containing the brand-new carbon black could make really high optical density print images even on plain papers.

Acknowledgement

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Biography

Takashi Hirasa received his master degree in polymer chemistry from the Tokyo Institute of Technology in 1993. Since 1993 he has worked at Yokohama Research Center of Mitsubishi Chemical Corporation. He is working on the research and development of carbon black dispersion ink for ink jet printing. He is a member of the IS&T, the Society of Polymer Science, Japan and the Society of Rheology, Japan.