Dynamics of Toner and Carrier Particles in Two-Component Development System Used in Electrophotography

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Abstract

We have studied the dynamics of toner and carrier particles in a two-component development system used for electrophotography in order to improve the image defect due to the bead-carry-out (BCO) phenomenon. We have manufactured a mock-up apparatus consisting of a pseudo-photoreceptor drum, development sleeve, and stationary magnetic roller. We have measured the number density of carrier particles adhered to the photoreceptor surface after the development process and have observed the behavior of the toner and carrier particles using a high-speed color microscope camera. It has been confirmed that the number density of the adhered carrier particles increases when the DC development voltage is high, toner concentration is low, and speed ratio of the development sleeve to photoreceptor drum is low. It has been observed that depletion of toner particles from the tips of carrier chains occurs in the post-nip region of the development area. It is assumed that when the initial toner concentration is lower than the threshold value, 6 wt%, insulative toner particles do not affect the electrical conduction of the conductive carrier chains, and therefore, the electrical charge at the top of the chains, which is induced by the applied voltage, increases. This increase in the electrical charge causes an increase in the Coulomb force applied to the top of the chains, and the BCO phenomenon occurs. On the other hand, when the speed of the development sleeve is low, the number of toner particles developed on the latent image is not sufficient to neutralize the surface potential of the latent image. The effective voltage between the sleeve and photoreceptor drum is not sufficiently reduced in this case, and thus, the BCO phenomenon occurs.

Introduction

The dynamics of toner and carrier particles in an electromagnetic field are of great importance in two-component magnetic brush development systems that are used in color and/or high-speed electrophotography machines. Magnetic carrier particles with electrostatically attached toner particles are introduced in the vicinity of a rotatory sleeve that encloses a stationary magnetic roller. The diameter of a carrier particle is of the order of several tens of micrometers, and that of a toner particle is approximately 5−10 μm. The magnetized carrier beads form chain clusters, a so-called brush, on the sleeve in the presence of the magnetic field, as shown in Fig. 1. The tips of the chains come in contact with the photoreceptor surface in the development area, and the toner particles on the chains move toward the electrostatic latent images created by a laser beam on the photoreceptor to form real images.[1]-[5]

It is well known that, during the operation of such development systems, some carrier particles adhere to the photoreceptor surface and cause serious image defects called "bead-carry-out (BCO)."[5] Although one of the authors of this report has investigated the fundamental mechanism of this phenomenon, further practical investigation is necessary to improve the performance of actual machines under actual operating conditions. In this study, an experimental investigation has been carried out on the BCO phenomenon to clarify the effects of parameters such as development voltage, the ratio of toner to carrier particles in the brush, and the rotating speed of the development sleeve. In addition to the parametric experiment, we have observed the behavior of the toner and carrier particles in the development area with a high-speed color microscope camera and have examined the three-dimensional shapes of toner piles formed on the latent image after the development process with a scanned laser displacement meter. Some interesting findings that are highly related to the occurrence of the BCO phenomenon have been obtained in these experiments.

Experimental

Figure 2 shows a schematic of the experimental setup used to investigate and to observe the dynamic characteristics of the BCO phenomenon in the development area. A mock-up machine instead of a commercial printer was used in the experiment. The machine consisted of a short photoreceptor drum, a development sleeve, a magnetic roller, and driving systems. The drum, which was made of aluminum, was not coated with a photoconductor; however, it was coated with an insulative polypropylene tape (thickness: 90 μm, relative permittivity: 2.0), because high-intensity light had to exposed to observe the motion of the toner particles in the development area with a high-speed microscope camera. The diameters of the drum and development sleeve were 30 mm and 18 mm, respectively, and the gap between the drum and sleeve was set to be 400 μm. The rated rotational speeds of the drum and development sleeve were 150 mm/s and 240 mm/s (speed ratio: 1.6), respect-

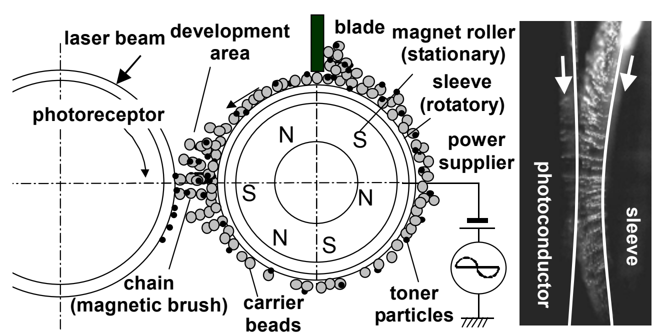


Figure 1. *Schematic drawing of two-component magnetic brush development system in electrophotography (left) and image of magnetic brush in development area (right).*

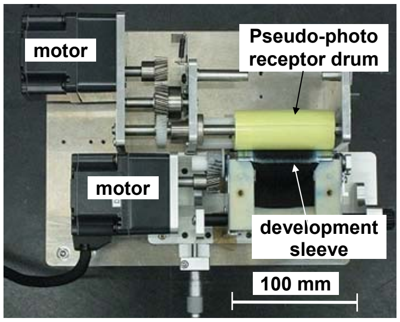


Figure 2. *Mock-up apparatus of two-component magnetic brush development system.*

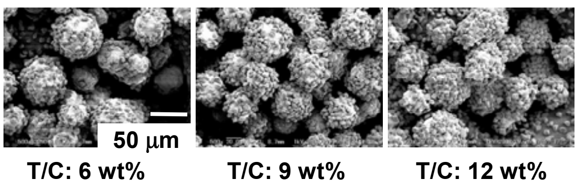


Figure 3. *SEM images of mixtures of toner (6 μm) and carrier (40 μm) particles.*

tively, but these could be altered during the parametric experiment. We conducted the experiments under two conditions: a drum speed of 150 mm/s and sleeve speed of 240 mm/s (speed ratio: 1.6), and a drum speed of 150 mm/s and sleeve speed of 480 mm/s (speed ratio: 3.2). A magnetic flux density at the surface of the sleeve was 120 mT normal to the gap at the center of the development area. DC development voltage was applied between the drum and sleeve, and an AC voltage (1.5 kVp-p, 6 kHz sine wave) was superposed on the DC voltage. The dynamic behavior of the toner and carrier particles in the development area was observed at the right end of the development gap using the high-speed color microscope camera (Photron, Fastcam-SA5) at a frame speed of 50,000 fps and shutter speed of 1/50,000 ms.

Spherical-shaped soft magnetic carrier particles and pulverized nonmagnetic toner particles provided by the Samsung Yokohama Research Institute were used in the experiment. The magnetic carrier particles comprised soft ferrite with an average diameter of 40 μm. The toner particles were cyan or yellow pigmented with an average diameter of 6 μm. Figure 3 shows SEM images of mixtures of the carrier and toner particles.

Number Density of Adhered Carrier Particles

Before conducting the experiment, the surface of the drum was wiped with a wet tissue paper to neutralize the surface potential, and then, carrier particles that adhered to the drum after the development process were collected by using a permanent magnet. The number of collected carrier particles was counted by performing image data processing. Figures 4 (a) and (b) show plots of the number density of the adhered carrier particles against the applied DC voltage. The experiment was conducted five times under identical conditions, and the averaged values were plotted. The parameters to be studied were the concentration of the toner particles and speed ratio of the development sleeve to photoreceptor drum. The results indicate the following.

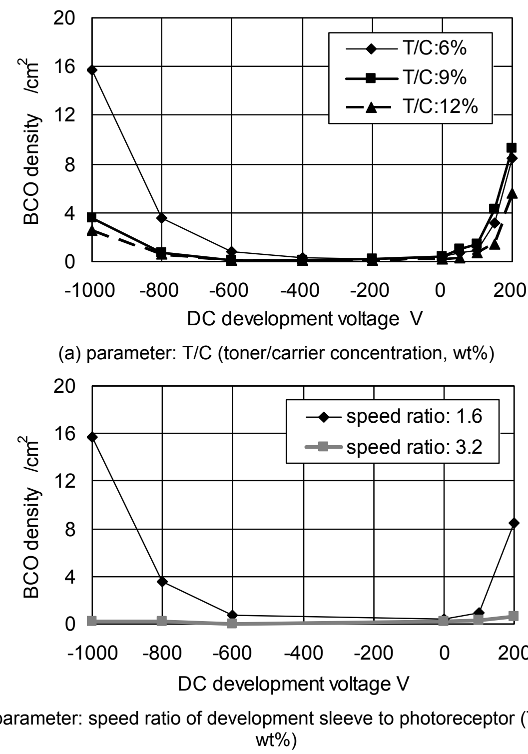


Figure 4. *Relationship between number density of adhered carrier particles on photoreceptor and DC development voltage.*

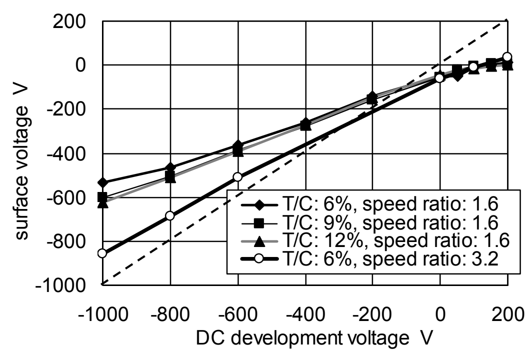


Figure 5. *Surface voltage of photoreceptor after development with respect to DC development voltage.*

(1) The BCO phenomenon was apt to take place at the condition of the positive voltage application than that of the negative voltage application. Toner particles were developed on the drum when the negative voltage was applied. The reason for the occurrence of this phenomenon is simple: because the photoreceptor was covered with negatively charged toner particles when the toner particles were adhered to the photoreceptor, the effective voltage at the development gap was reduced by the surface voltage.[6] The reduction in the surface voltage due to the application of the DC voltage was confirmed experimentally, as shown in Fig. 5. The surface voltage of the photoreceptor drum was measured using a surface potential meter (Trek, Model 344) after the development process.

It can be clearly observed that the surface voltage was induced when the DC voltage was applied. The induction in the surface voltage was almost independent of the toner concentration, but it decreased slightly when the toner concentration was low. In any case, the induced voltage was lower than the applied DC development voltage, especially when the speed ratio and toner concentration were low, probably because a reduction in the concentration of toner particles in the brush in the image area caused an increase in the counter charge of the brush.

(2) The second observation was that the number density of the adhered carrier particles was high when the toner concentration was low. The mechanism of how the toner concentration affects the BCO phenomenon has already been clarified.[5] Because insulative toner particles disturbed the electrical conduction of the brush, the electrical charge at the top of the chains, which was induced by the applied voltage, decreased above the critical concentration of toner particles in the brush. This decrease in the electrical charge caused a reduction in the Coulomb force applied to the top of the chains, and the BCO phenomenon was improved when a sufficient concentration of toner particles was added to the carrier brush.

(3) The number density of the adhered carrier particles was also high when the speed ratio of the development sleeve to photoreceptor drum was low. There could be two possible reasons why the BCO phenomenon occurred when the speed ratio was low. One was the shortage of toner particles in the brush, as was the case when the initial toner concentration was low. When the rotational speed of the development sleeve was low, a concentration of toner particles was diluted in the brush at the post-nip region and a relatively large Coulomb force was applied to the top of the chains. The other possible reason could be that the surface voltage of the latent image was not sufficiently neutralized at the low speed ratio due to a shortage of developed toner particles on the photoreceptor drum. This hypothesis was supported by the experimental result, as shown in Fig. 5; the surface voltage approached the applied DC voltage when the speed ratio was high, but it deviated from the applied DC voltage when the speed ratio was low.

Direct Observation

In order to observe the behavior of the toner and carrier particles in the development area under actual operation conditions, an electrostatic latent image was formed using line electrodes that were made of aluminum foils (thickness: 10 µm, width: 500 µm) and insulated with a polyimide tape (thickness: 75 µm, relative permittivity: 3.2). These electrodes were embedded parallel to the rotating axis of the aluminum drum coated with the acetate tape (thickness: 90 µm, relative permittivity: 2.5), as shown in Fig. 6. By applying the DC voltage (Matsusada Precision, HEOPT-5B20) to the electrodes, the electrodes generated the electrostatic latent image that was similar to the latent image created on the real OPC drum. The voltage applied to the electrodes was 1,800 V, and the voltage applied to the development sleeve was 200 V. (DC development voltage: 1,600 V)

Figure 7 shows snap-shot images of the pre- and post-nip regions observed using the high-speed camera. The overall behavior of the brush was the same as that in the absence of toner particles.[5] At the beginning of chain formation, chains were formed almost parallel to the magnetic flux line and leaned against the sleeve, but they gradually assumed an upright position as they approached the development gap. Then, the chains came in contact with the photoreceptor drum and were depressed by the drum. The chains slipped and brushed against the drum under this condition. At the end of the nip, the chains again became free and aligned along the flux line. The motion of the toner particles was observed by recording movies, and they showed that development, i.e., the adhesion of the toner particles to the latent image oh the photoreceptor, occurred not only in the contact area between the carrier brush and photoreceptor but also in the pre- and post-nip regions where the carrier brush did not come in contact with the photoreceptor. The toner particles separated from the carrier brush and formed a toner cloud in the pre- and post-nip regions, and airborne toner particles adhered to the latent image.

Depletion of toner particles from the tip of some long chains (circles in Fig. 7) was found to occur in the post-nip region of the development area. This phenomenon was not observed in the pre-nip region. The reason for the depletion of the toner particles in the post-nip region of the development area was the low toner concentration. Thus, the BCO phenomenon occurred when a sufficient concentration of toner particles was not supplied to the development area. The mechanism of this phenomenon was similar to that observed when the speed ratio of the development sleeve to photoreceptor drum was low. The development caused a shortage of toner particles in the brush in the post-nip region, and the BCO phenomenon occurred at the boundary between the image and non-image areas, as shown in Fig. 8.

Amount of Developed Toner Particles

The three-dimensional shape of the toner particles developed on the pseudo-latent image was observed using the scanned laser displacement meter.[7] Figures 9 (a) and (b) show the averaged height and width of the toner piles, respectively, that were derived from the 3D profiles of the observed toner piles. The toner particles were developed above the threshold voltage, 200 V, and the

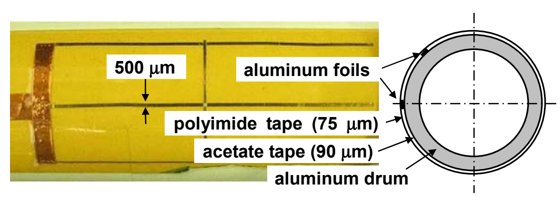


Figure 6. Pseudo-photoreceptor drum. Aluminum foils are insulated and embedded on aluminum drum.

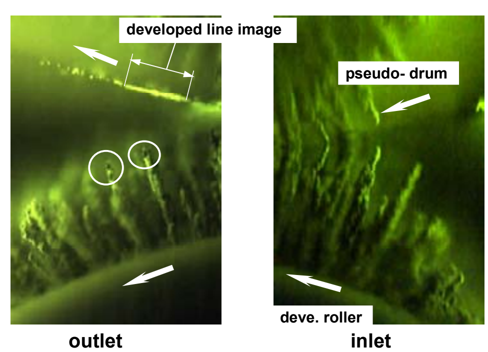


Figure 7. Observed behavior of toner and carrier particles in pre- (inlet) and post-nip (outlet) region of development area. (T/C: 6 wt%, speed ratio: 1.6)

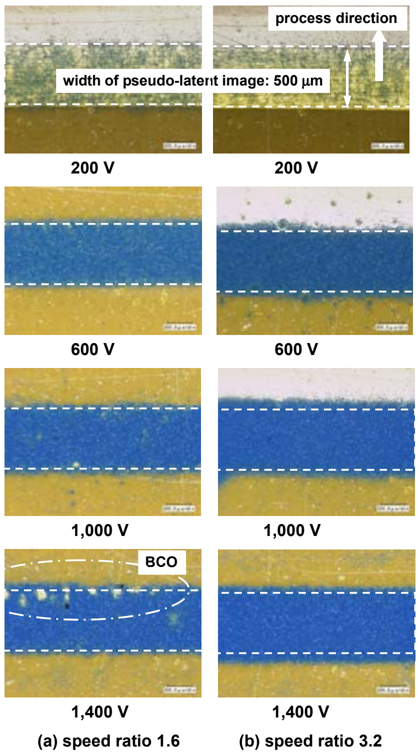
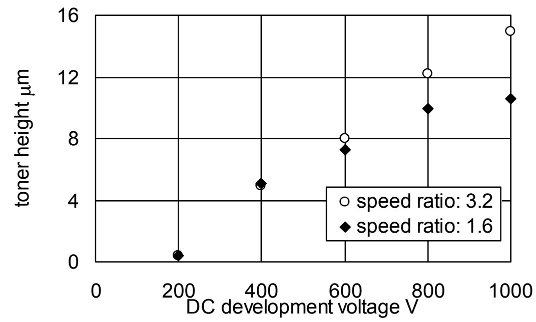
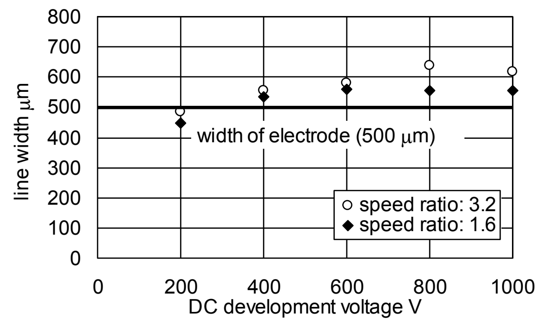


Figure 8. *Developed line images on pseudo-latent image. (T/C: 6 wt%) The designated values of voltage are the effective DC voltages applied between the latent image and the development sleeve.*



(a) height of developed toner piles



(b) width of developed toner piles

Figure 9. *Figure 9. Averaged width and height of developed toner piles derived from 3D profiles of toner piles. (T/C: 6 wt%).*

number of developed toner particles increased with the DC development voltage. The width increased slightly with an increase in the development voltage. The saturated width of the toner pile was larger than that of the latent image.

The volume of the developed toner particles at a high speed ratio was larger than that at a low speed ratio. This result supports the hypothesis that a relatively high voltage was applied to the carrier particles at the top of the chain, and the BCO phenomenon was bound to occur at the low speed ratio, because the surface voltage of the latent image was not sufficiently neutralized at the low speed ratio due to the shortage of the developed toner particles.

Concluding Remarks

Experimental investigation has been carried out for improving the image defects caused due to the occurrence of the BCO phenomenon under actual operational conditions. The following features have been clarified.

(1) The BCO phenomenon is bound to occur when a high DC development voltage, low toner concentration, and low speed ratio of the development sleeve to photoreceptor drum are employed.

(2) The number of carrier particles adhered to the photoreceptor drum in the non-image area is higher than that in the image area, because the effective voltage at the development gap is reduced by the adhesion of negatively charged toner particles on the latent image.

(3) Depletion of toner particles in the brush occurs in the post-nip region of the development area when a sufficient concentration of toner particles is not supplied to the development area. This condition is realized when the initial toner concentration and rotational speed of the development sleeve are low.

(4) The toner particles are not sufficiently developed on the latent image when the speed ratio is low. This causes insufficient neutralization of the surface voltage of the latent image, and the BCO phenomenon occurs.

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