Pale Defect of Halftone Following Solid Image in Two-Component Magnetic Brush Development System in Electrophotography

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Abstract
We studied the mechanism of and countermeasures against a pale image defect observed in the halftone area following a solid image in a two-component magnetic brush electrophotographic development system. We manufactured a model apparatus consisting of a pseudo-photoreceptor drum, development sleeve, and stationary magnetic roller. The image was created on an insulated film electrode pasted onto the drum. A parameter experiment confirmed that the image defect was enhanced when the voltage difference applied to the solid area and halftone area was large, ac voltage superposed on the dc development voltage was low, the development gap was large, and the speed ratio (sleeve speed to drum speed) was low. However, the defect was almost entirely independent of the frequency and waveform of the superposed ac voltage. The dynamic behavior of toner particles in the development area was directly observed using a high-speed microscope camera, and the mechanism of this print defect was investigated. The results of this experimental work can be utilized to improve the two-component magnetic brush development electrophotographic system.

Introduction
A two-component magnetic brush development system is widely used in color and/or high-speed electrophotographic machines [1-3]. In this type of system, magnetic carrier particles with electrostatically attached toner particles are introduced to a development area by a rotatory sleeve that encloses a stationary magnetic roller. The diameter of a carrier particle is on 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 a magnetic field. The tips of the chains come into 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.

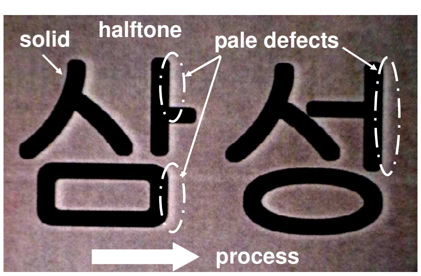

Fig. 1 Example of pale image defect observed in halftone area immediately after printing of solid image.

Although this system is highly reliable and can realize relatively high-quality printing compared with other methods such as nonmagnetic single-component systems [2,3], some types of image defects sometimes occur with the use of this system. Bead-carry-out is one image defect that is inherent in the two-component magnetic brush development system [4,5]. Pale halftone following a solid image is another inherent defect. As shown in Fig. 1, the halftone image becomes pale for 1–2 mm immediately after the printing of the solid image.

In this study, an experimental investigation was carried out on the pale image defect in the halftone to clarify the effects of parameters such as the development voltage, development gap, and rotation speed of the development sleeve. In addition to the experiment investigating these parameters, the dynamic behavior of the toner and carrier particles in the development area was observed with a high-speed microscope camera to clarify the mechanism of defect formation.

Experimental
Figure 2 shows a photograph and schematic of the experimental setup used to investigate and observe the pale image defect in the development area. A model machine was used in the experiment instead of a commercial printer. This machine consisted of a short photoreceptor drum, a development sleeve, a magnetic roller, and the driving systems [5].

The drum and development sleeve were 30 and 18 mm in diameter, respectively, and the rotational speed of the drum was 150 mm/s. The magnetic flux density at the surface of the sleeve was 120 mT normal to the gap at the center of the development area. The drum, which was made of aluminum, was not coated with a photoreceptor; however, it was coated with a nonconductive tape (thickness: 90 μm; relative permittivity: 2.0) because high-intensity light had to be used in order to observe the motion of the carrier and toner particles in the development area with a high-speed microscope camera.

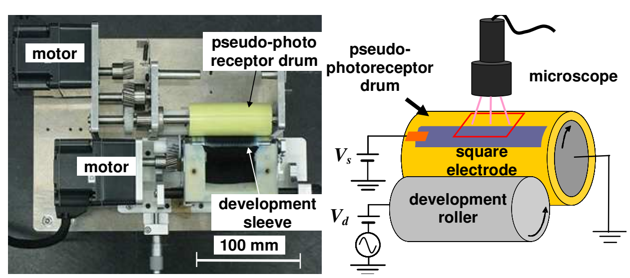

Fig. 2 Apparatus used to model a two-component magnetic brush development system.

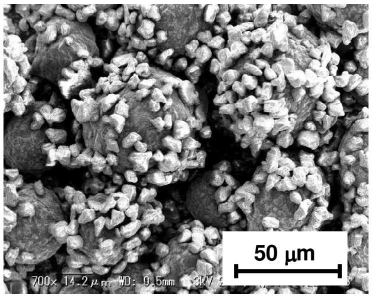

Fig. 3 SEM image of mixture of toner (6 μm) and carrier (40 μm) particles (toner/carrier concentration, 6 wt%).

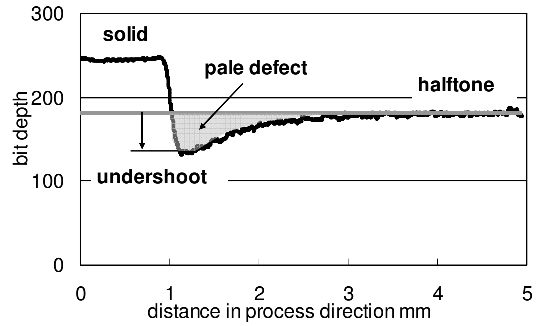

Fig. 5 Circumferential distribution of blue bits at the boundary between the trailing edge of the solid image and the halftone image.

An electrostatic solid latent image was formed by using a square electrode that was made of aluminum foil (thickness: 10 μm) and insulated with polyimide tape (thickness: 75 μm; relative permittivity: 3.2). Upon application of a dc voltage V_s to the electrode, the electrode generated an electrostatic latent image that was similar to a latent image created on an actual photoreceptor drum [5]. A dc voltage, V_d, was applied between the drum and development sleeve to create the analog halftone, and an ac voltage was superposed onto the dc voltage. The development voltage of the solid image is V_s–V_d, and that of the halftone is $-V_d$. Instead of a digital halftone, an analog halftone image was created by applying dc voltage to the development sleeve.

Before conducting the experiments, the surface of the drum was wiped with a piece of alcohol-impregnated tissue paper to neutralize the surface potential. The dynamic behavior of the toner and carrier particles in the development area was observed at the right end of the development gap by means of a high-speed microscope camera (Photron, Fastcam SA5).

Spherical soft magnetic carrier particles and pulverized nonmagnetic toner particles were used in the experiment. The magnetic carrier particles were composed of soft ferrite with an average diameter of 40 μm. The toner particles were cyan pigmented with an average diameter of 6 μm. Figure 3 shows a scanning electron microscopy (SEM) image of mixture of the carrier and toner particles.

After the drum was rotated one cycle to conduct the development, a still photograph was taken near the end edge of the solid image by the digital microscope camera (Fig. 4). The blue bits in the still image along the processing direction were then counted and averaged in the axial direction. The blue bits were used because cyan-pigmented toner particles were used for the experiment.

Figure 5 shows an example of the circumferential distribution of blue bits. This figure confirms that a large undershoot corresponding to the pale image defect exists in the halftone area immediately after the solid image. The bit depth of the undershoot, defined as the bit difference between the saturated bit in the halftone area and the minimum bit in the pale image defect, is used as an index of the pale image defect. Optical conditions such as the position of the camera and light and the intensity of the light were fixed throughout all experiments to ensure that all measurements could be fairly compared. The experiments were repeated five times under the same experimental conditions and the mean value was determined.

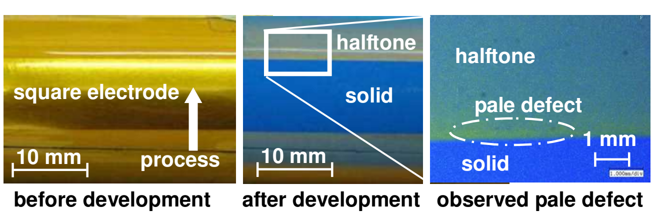

Fig. 4 Surface of the pseudo-photoreceptor drum before development (left) and after development (middle), and end edge of solid image after development (right).

The standard experimental conditions were as follows unless otherwise specified.

development voltage (solid): 700 V
development voltage (halftone): 400 V
superposed ac voltage: 1.5 kVp-p, 6 kHz sine wave
gap between the drum and sleeve: 400 μm
sleeve speed to drum speed: 1.5
toner/carrier concentration: 6 wt%
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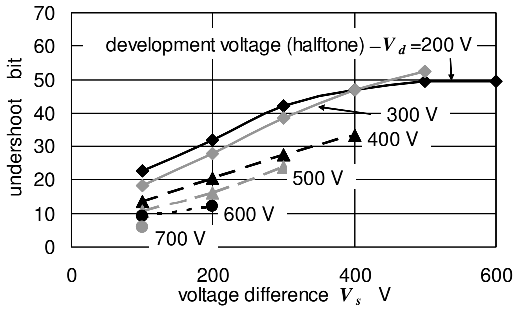
Results and Discussion

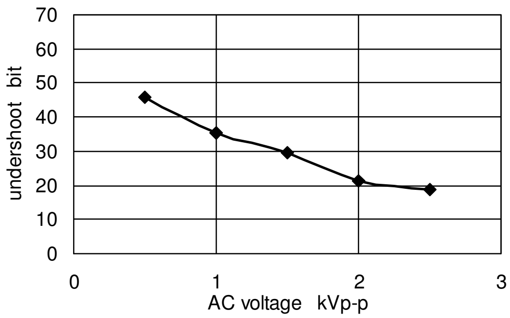
Figure 6 shows the experimental results, which indicate how the system parameters affected the pale image defect. The voltage difference between the solid and halftone areas, development voltage of the halftone area, amplitude of ac voltage, development gap, and speed ratio (sleeve speed to drum speed) were selected as the parameters to be studied. We also conducted the experiments to investigate the effects of ac voltage frequency and waveform. The results revealed the following aspects of defect formation.

Effect of applied voltage

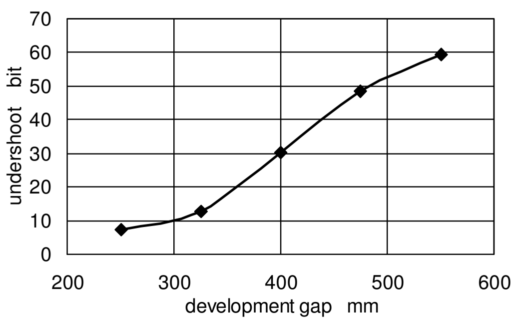
As shown in Fig. 6 (a), the pale image defect was enhanced with a high voltage difference between the solid and halftone areas. It is assumed that toner particles move circumferentially from the halftone area to the edge of the solid image by the circumferential electrostatic field when the voltage difference was high, and that this caused the pale image defect in the halftone image adjacent to the solid image. As described in the next section, this assumption was supported by direct observation of the toner motion in this area.



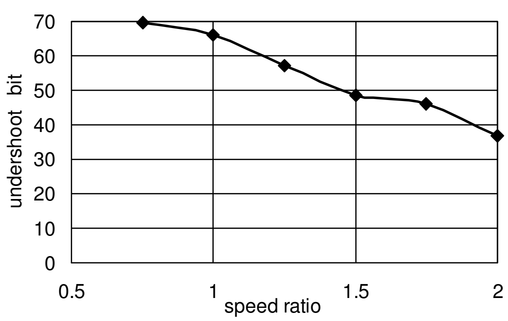
(a) Effect of development voltage



(b) Effect of amplitude of ac voltage



(c) Effect of development gap



(d) Effect of speed ratio (sleeve speed to drum speed)

Fig. 6 Effects of parameters on pale image defect of halftone.

Application of high ac voltage reduced the pale image defect as shown in Fig. 6 (b). Because ac voltage caused reciprocating motion of toner particles at the development gap and agitated the developed toner particles in the halftone area, the pale image defect was reduced by applying high ac voltage. This assumption was also supported by direct observation of the toner motion in the post-nip region. Another reason is that a relatively large amount of toner particles was supplied from the wide area of the brush with high ac voltage application. On the other hand, the pale image defect was almost completely unaffected by the frequency and waveform (sine or rectangular) of the ac voltage in the range of 1 to 18 kHz.

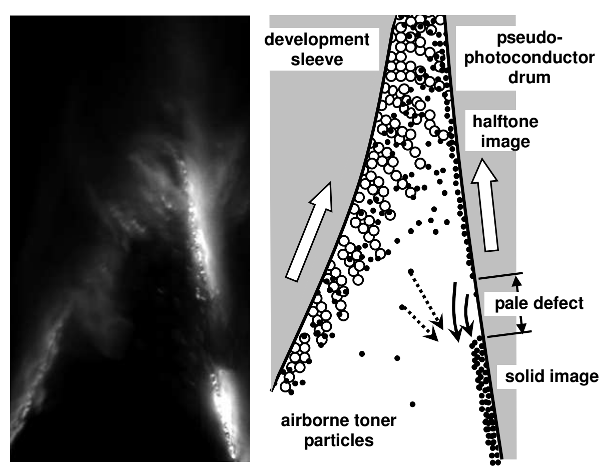
Effect of development gap and sleeve speed to drum speed

Figure 6 (c) shows the effect of development gap. The pale image defect was enhanced with a large gap. Because toner particles were not sufficiently supplied from the brush on the solid area under the large gap condition (i.e., low electric field), and therefore the latent image on the solid area was not well neutralized by the adhesion of negatively charged toner particles, toner particles were apt to transfer from the adjacent halftone area and thus the pale image defect was enhanced when the development gap was large.

The pale image defect was reduced at a high speed ratio (sleeve speed to drum speed) as shown in Fig. 6 (d). Because toner particles were sufficiently supplied to the solid area when the speed ratio was high [5], additional toner particles were not apt to transfer from the adjacent halftone area as in the case of high development voltage. In addition to this effect, the sufficient supply of toner particles to the halftone area might also reduce the pale image defect.

Direct Observation

Figure 7 (a) shows a snapshot of the pre-nip region observed using the high-speed microscope camera. Because the dynamic motion of particles cannot be captured with still images, a schematic diagram has been added to Fig. 7 (b). The overall behavior was the same as previously observed. At the beginning of brush formation, chains of magnetic carrier particles were formed almost parallel to the magnetic flux lines and leaned against the sleeve, but they assumed an upright position as they approached the development gap. The brush then came into contact with the drum and was depressed by the drum. The chains slipped and brushed against the drum under these conditions. At the end of the nip, the chains again became free and aligned along the magnetic flux lines.



(a) snapshot **(b) schematic**

Fig. 7 Snapshot (a) and schematic (b) of development in the pre-nip region.

The development, that is, the adhesion of toner particles to a latent image on the drum, occurred not only in the contact area between the carrier brush and drum, but also in the pre- and post-nip regions where the carrier brush did not come into contact with the drum. In the pre-nip region, carrier chains vibrated in the lateral direction when the leaning chains stood upright due to the abrupt change of the magnetic flux line, and at the same time, toner particles were forced to separate from the tip and inside of the chain. Some of the separated airborne toner particles adhered to the latent image. In the post-nip region, toner particles separated from the chain and formed a toner cloud in the gap. The toner cloud vibrated at the frequency of and synchronized with the ac voltage, and some of the airborne toner particles adhered to the latent image.

Movement of toner particles from the halftone area to the edge of the solid image was observed on the pseudo-photoreceptor drum in the pre-nip region as schematically shown in Fig. 7 (b) (indicated by solid-line arrows). The depletion of toner particles at the halftone area adjacent to the solid image was not well filled at the nip region and post-nip region. This phenomenon was clearly the cause of the pale image defect in the halftone image adjacent to the solid image. The electrostatic field between the halftone area and solid area was the driving force of the toner motion. Because the field was high when the voltage difference between the solid and halftone areas was high, the pale image defect was enhanced under this condition as discussed in the preceding section.

In addition to this phenomenon, it was observed that airborne toner particles were apt to adhere to the edge of the solid area, where the electrostatic field was concentrated, rather than to the adjacent halftone area in the vicinity of the boundary between the halftone area and solid area (indicated by broken-line arrows in Fig. 7 (b)). This also caused the depletion of toner particles in the halftone area following a solid image.

Concluding Remarks

We have investigated formation of a pale image defect observed in the halftone area following a solid image in a two-component magnetic brush electrophotographic development system.

Mechanism: The pale image defect was caused by the movement of toner particles from the halftone area to the edge of the solid image on the photoreceptor drum in the pre-nip region. The circumferential electrostatic field between the halftone area and solid area on the photoreceptor drum was the driving force of the toner motion. The local concentration of airborne toner particles at the edge of the solid image was another cause of the pale image defect.
Countermeasures: Preferred methods for reducing the pale image defect include the application of high ac voltage and the adoption of a high sleeve speed to drum speed ratio.

Acknowledgement

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