Doctor Process of Toner Layer in Non-Magnetic Single-Component Development System in Electrophotography

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Abstract
In a non-magnetic single-component development system in electrophotography, formation of a thin and uniform toner layer on the development roller is important for obtaining high image quality. We conducted experimental and numerical investigations to clarify the dynamics of toner particles in this process. Two approaches were adopted for the investigation. One is experimental and the other is numerical simulation using the distinct element method. We manufactured a mock-up apparatus consisting of a supply roller, a development roller, and a doctor blade for forming a thin toner layer on the development roller. The thickness, surface roughness, and charge density of the formed toner layer were measured after the doctoring process. It was clarified that the thickness of the toner layer was increased, but the charge density was decreased, by increasing the applied voltage and rotational speed. These findings were confirmed by direct observation of the toner motion in the doctoring area with a high-speed microscope camera. Numerical calculations performed using an improved distinct element method revealed that the elastic energy applied to the toner particles, which is an index of toner degradation, was increased by increasing the stiffness and pressing force of the doctor blade, but decreased when the curvature of the blade tip was large. The present experimental and numerical results can be used to improve non-magnetic single-component development system in electrophotography.

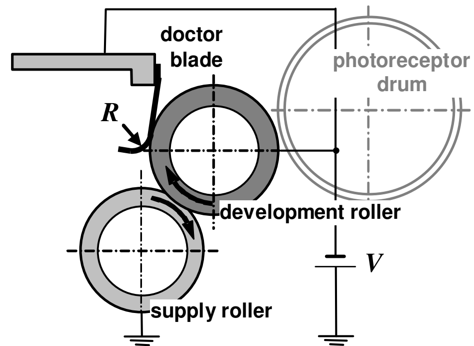


Figure 1. Non-magnetic single-component development system in electrophotography.

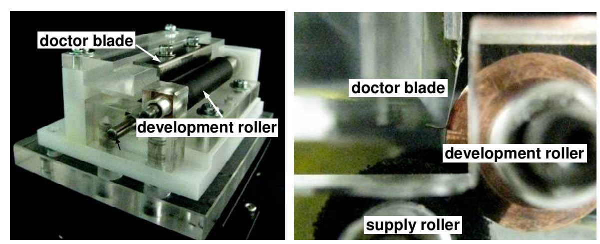


Figure 2. Photograph of experimental setup.

Introduction
Non-magnetic single-component development system is adopted in low-speed and low-cost laser printers because this system is relatively simple compared with the dual-component system, and because it can be used in color printers [1]. The system consists of a supply roller, a development roller, and a doctor blade, as shown in Fig. 1. Toner particles are supplied from the supply roller to the development roller, and then the doctor blade forms a thin toner layer on the development roller. The toner charge and the electrical field move the particles toward the latent image on the photoreceptor drum, thereby achieving development. This system requires the toner layer to be uniform in both volume and charge to obtain high image quality. This paper describes an investigation of the characteristics of the doctoring process, using experimental and numerical approaches.

Experimental
Figure 2 shows photographs of the experimental setup used to investigate and to observe the dynamic characteristics of the doctoring process. A mock-up apparatus rather than a commercial printer was used in the experiment. The apparatus consisted of a supply roller, a development roller, a doctor blade, and a driving system. The supply roller and the development roller, which were made of stainless steel, were coated with a conductive sponge layer and a rubber layer, respectively. The diameters of the supply roller and the development roller were 11 mm and 12 mm, respectively, and the distance between the center of the supply roller and that of the development roller was set at 11.1 mm. The supply roller and the development roller were contiguous and rotated in the same direction, with a speed ratio of 3:4. A DC voltage was applied to the development roller and the doctor blade. Friction resulting from scraping and the voltage applied to the development roller and the blade charge the toner particles. The rotating development roller conveys the particles to the doctor blade made of stainless steel. This blade presses against the development roller, and levels the accumulated toner particles to form a thin and uniform layer. The dynamic behavior of the toner particles in the doctoring area was observed from the lateral side using a high-speed microscope camera (Photoron, Fastcam-SA5).

Yellow-pigmented pulverized non-magnetic toner was used for the experiment. The average particle size was 6.5 μm and it had negative charging properties.

Experimental Results

The amount of toner particles on the development roller and the charge density after the doctoring process were investigated. These parameters were determined from toner particles vacuumed up in a charge-to-mass ratio test system (Trek, 210HS-2A) of area 3.1 cm^2. The experiments were repeated three times under the same experimental conditions and the data were averaged.

Figure 3 shows that, with a high roller speed, thick layers were formed and low charges were generated on the particles. Similar results were seen with a high supply voltage, as shown in Fig. 4. These results show that increasing the supply voltage and the rotational speed increases the thickness of the toner layer but decreases the charge density. Because the average diameter of the toner particles was 6.5 μm, the thickness of the formed toner layer corresponded to a double to fourfold layer. It was confirmed that in all cases the surface roughness, measured using a scanned laser displacement meter (Keyence, LT-8010), was less than 5 μm that is smaller than the diameter of the toner particles, as shown in Fig. 3 (b) and Fig. 4 (b).

Numerical Results

3D numerical simulations based on the distinct element method were performed. This method repeatedly calculates the motion equation of individual particles for each time step. Mechanical contact forces, coulombic forces, electrostatic image forces, gravity, air drag, and Van del Waals forces were included in the calculation. Contact forces were calculated using the Voigt model and Hertzian contact theory [2].

Figure 5 shows the calculation model for the process of toner layer formation. Toner particles are initially positioned at the lower part of the development roller. The doctor blade is simplified to a flat plate connected to a spring. An initial spring force F_0 is applied to the roller. Toner particles push the doctor blade against the spring to form a layer. This position of the doctor blade, x, is;

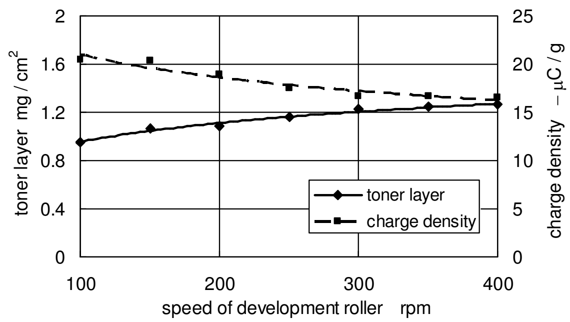
$$\Sigma F_C + F_0 = Kx \quad , \tag{1}$$

where ΣF_C is the total contact force of the toner particles applied to the doctor blade and K is the spring constant of the blade. The thickness of the toner layer is estimated from the distance between the doctor blade and the roller surface. The tip of the blade has a curved edge R corresponding to the bended radius of the actual doctor blade. Figure 6 shows the calculated and observed behaviors of toner particles in the doctoring process. The calculated toner dynamics agreed qualitatively with the observed results.

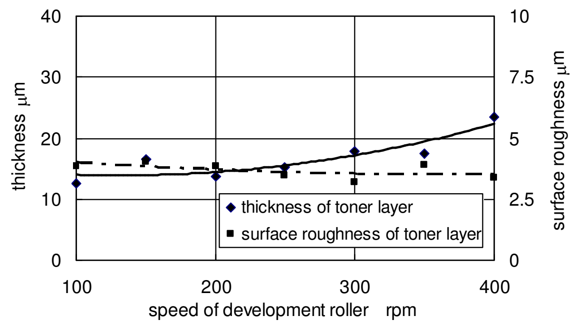
To quantify toner degradation, the total elastic energy U_a of the particles was calculated by

$$U_a = \sum_{i=1}^{N} \frac{1}{2} k \left(d_{ni}{}^2 + d_{ti}{}^2 \right), \tag{2}$$

where d_n and d_t are the strains of toner particle i in the vertical and horizontal directions, respectively, and k is the elastic coefficient of the toner particles. The total elastic energy U_a represents the index of toner degradation resulting from compression of toner particles in the doctoring process [3].

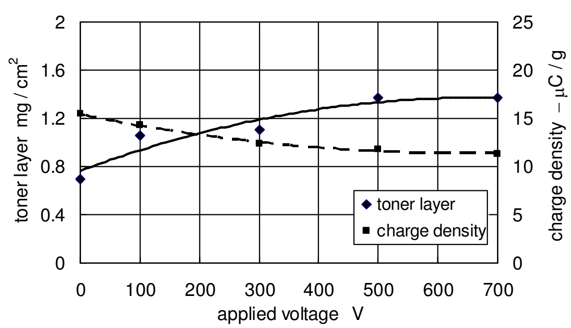


(a) amount of toner particles in formed layer and charge density after doctoring process

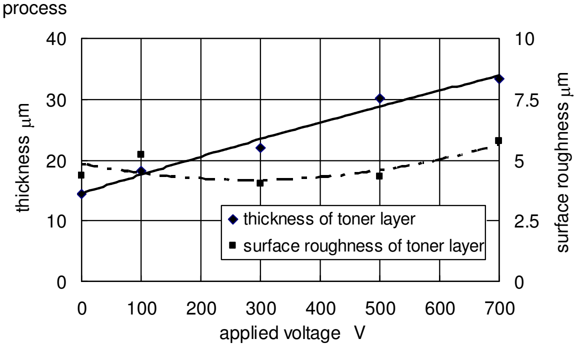


(b) thickness of toner layer and surface roughness after doctoring process

Figure 3. Effects of rotational speed of development roller on the toner amount, charge density, thickness, and surface roughness of formed toner layer (supply voltage: 300 V).



(a) amount of toner particles in formed layer and charge density after doctoring process



(b) thickness of toner layer and surface roughness after doctoring process

Figure 4. Effects of supply voltage on the toner amount, charge density, thickness, and surface roughness of the formed toner layer (rotational speed of development roller: 292 rpm).

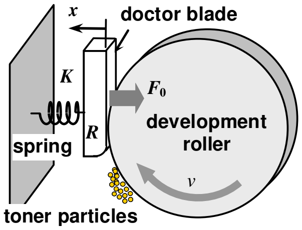


Figure 5. Calculation model.

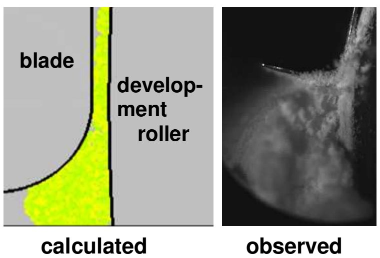


Figure 6. Calculated and observed behavior of toner particles in doctoring process.

The results of the calculations showed that a thin layer was formed when the spring constant was high (Fig. 7). A thin layer was also formed when the radius of the blade tip was small (Fig. 8). The elastic energy increased slightly with both of these conditions. This means that although a low spring constant and a large radius of the blade tip are preferable in order to suppress the degradation of toner particles, a thick toner layer is formed under these conditions. These results indicate that, in designing the system, there is a trade-off between formation of a thin toner layer and achieving low toner degradation.

Conclusion

Experimental and numerical investigations were carried out to clarify the characteristics of toner layer formation in non-magnetic single-component development system in electrophotography. Following features have been clarified:

(1) Experiments clarified the effects of supply voltage and roller speed on amount of layered toner particles, layer thickness, surface roughness of the formed toner layer, and toner charge.

(2) Calculated toner motions clarified the trade-off between layer thickness and toner degradation with respect to the spring constant and the tip radius of the doctor blade.

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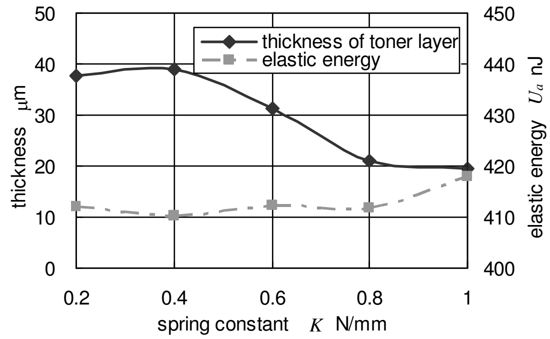

Figure 7. Effects of spring constant of blade on thickness of toner layer and total elastic energy applied to toner particles.

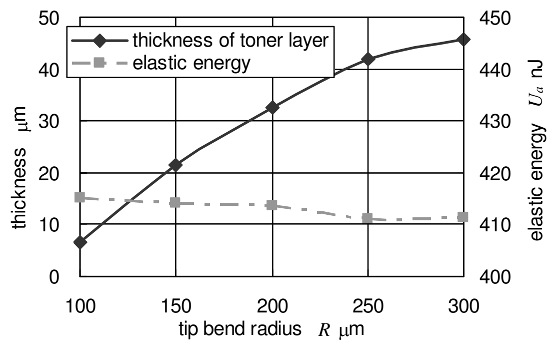

Figure 8. Effects of tip radius of blade on thickness of toner layer and total elastic energy applied to toner particles.

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Author Biography

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