Electrostatic Adhesion Force Measurement of the Partly Charged Toner

Takayuki Tanaka; Printing Device & System R&D Center, Canon Inc.; Tokyo, Japan

Abstract

The electrostatic adhesion of a charged toner particle is important for the electrophotographic process. Some models for electrostatic adhesion have been suggested. One of the models, the charge patch model, hypothecates that electrostatic adhesion force is caused by charge patches in close proximity to a substrate. It has been reported that the model fits measured data, but the experimental evidence was insufficient. We examined the relation between the charged region on a toner particle and its electrostatic adhesion by experiment. The partly charged toner particles were prepared by means of a corona discharge device, and their adhesion forces were measured using an apparatus based on vibratory detachment method. As a result, it has been verified that the slight charge in the proximity region causes most of electrostatic adhesion as mentioned by the charge patch model, and the rest of charge produces a bit of electrostatic adhesion. Additionally, it is suggested that the magnitude of electrostatic adhesion force depends on the fine charge distribution in the proximity region.

Introduction

Charged toner particles are transferred from a member surface to another one in electrophotographic processes such as development and transfer processes. In these processes, charged toner particles are in the tug of war between a coulomb force and an adhesion force. Therefore, the control of adhesion force is as important as the control of toner charge.

Adhesion force of a charged toner particle consists of electrostatic adhesion force and non-electrostatic adhesion force. The electrostatic adhesion increases as toner charge increases, so it is especially important in electrophotographic processes using strong charged toner. Furthermore, the electrostatic adhesion is closely linked with the charge distribution on the surface of a toner particle, so understanding electrostatic adhesion leads to the clarification of the charge distribution.

The most basic model for electrostatic adhesion of a charged toner particle against a substrate is the electrostatic image force model. The model assumes that a spherical toner particle is charged continuously and uniformly over its surface, the electrostatic adhesion force is calculated as Coulomb attraction between a point charge and its image, and the point charge exists at the center of the toner and has the same amount of charge as the toner particle has. However, it is reported that the magnitude calculated by using this model is much smaller than measured.

Several models have been proposed in order to estimate the measured magnitude of electrostatic adhesion force [1-3]. One of the models, the charge patch model [1], hypothecates that only small frictions of the surface of a toner particle are charged. They are called as "charge patch." According to this model, electrostatic adhesion force is caused by charge patches in close proximity to a substrate, and its magnitude is calculated as attractive force between the parallel flat plate electrodes.

It has been reported that the model fits measured data [4], but experimental evidence is insufficient. Especially, it is uncertain that only charge patches in the proximity region are contribute to electrostatic adhesion force.

All experiments done in the past used toner particles charged all over the surface, by contrast, we measured the adhesion force of partly charged toner particles. We examined the relation between charged region of toner particles and their electrostatic adhesion by experiment.

Experimental Method

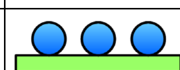
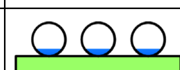
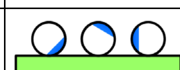
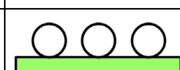
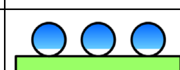
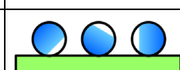
Partly Charged Toner

We measured the electrostatic adhesion force of a toner particle against a photoreceptor sheet. The toner particle is a spherical insulative particle coated with nano-scale hydrophobic silica fines. Its mean diameter is 6.5 um.

The photoreceptor sheet was peeled off from a photosensitive drum, and was glued on the top end of the ultrasonic transducer of a vibratory detachment apparatus. Its thickness and relative permittivity are about 23 um and about 3, respectively. Toner particles and the photoreceptor sheet used in this study are available on the market (Hewlett-Packard Co.: CE260A printer cartridge)

6 types of partly charged toner particles were prepared. Each sample is different in size of charged region and orientation against a substrate. Table 1 shows details of these samples.

Table 1: List of illustrations and charging conditions for each sample

No.	Illustration	Charged region	Orientation
1		All	
2		Spot	Charged region face substrate
3		Spot	Random
4		None	
5		All but spot	Uncharged region face substrate
6		All but spot	Random

Firstly, we describe the sample preparation procedures of sample 1-3 with Figure 1.

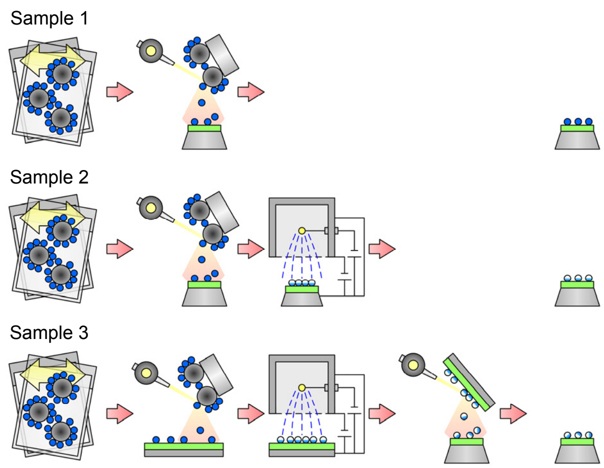


Figure 1. Procedure of preparing sample 1– 3

For sample 1, toner particles were mixed with the standard carrier beads named N-01, provided by the Imaging Society of Japan, charged entire surface triboelectrically. And then, toner particles were sprinkled on the photoreceptor sheet glued on the top end of the ultrasonic transducer by using an air blower. For sample 2, as is the case with sample 1, toner particles were charged entire surface and sprinkled on the photoreceptor sheet. In addition, bipolar ions were poured on the top of the toner particles by means of a bipolar neutralizer, after that, toner particles are charged only in close proximity to the photoreceptor sheet. For sample 3, like sample 1, toner particles were charged with carrier beads, sprinkled on another photoreceptor sheet glued on conductive plate, and were poured bipolar ions. Here again, toner particles were sprinkled on the photoreceptor sheet glued on the ultrasonic transducer. By sprinkled after charging partly, it is randomized that the proximity region of the toner particles are charged or not. Sample 2 and 3 have the same surface charge distribution, and differ only in orientation of charged surface against the substrate.

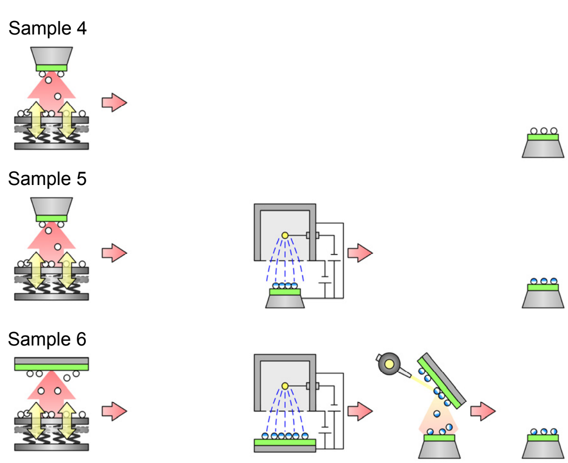


Figure 2. Procedure of preparing sample 4 – 6.

Next, we describe the sample preparation procedures of sample 4-6 with Figure 2.

For sample 4, uncharged toner particles were sprinkled on the photoreceptor sheet glued on the top end of the ultrasonic transducer by using a vibrator. We prepared sample 4 for the purpose of measuring the non-electrostatic adhesion force. For sample 5, uncharged toner particles on the photoreceptor sheet were poured unipolar corona ions on the top of the toner particles, after that, we got toner particles charged except for the proximity region. For sample 6, uncharged toner particles were sprinkled on another photoreceptor sheet glued on conductive plate, then poured unipolar corona ions on the top of the toner particles. Here again, toner particles were sprinkled on the photoreceptor sheet glued on the ultrasonic transducer. The relation between sample 5 and 6 is the same as the relation between sample 2 and 3, that is, sample 5 and 6 have the same surface charge distribution, and differ only in orientation of charged surface against the substrate.

As for all 6 samples, toner particles are separately deposited so that we treat adhesion force as interaction between a sphere particle and a planar substrate. The mean toner charges of these samples were measured with E-SPART analyzer (Hosokawa micron Ltd.).

Vibratory Detachment Method

We assembled an apparatus based on vibratory detachment method [5] in order to measure the adhesion force between a toner particle and a photoreceptor sheet. The apparatus consist of the following parts shown in Figure 3: an ultrasonic transducer, an oscillator generating a sinusoidal signal, a high frequency power amplifier for applying power to the ultrasonic transducer, and a camera training on the top end of the ultrasonic transducer. They are operated under computer control.

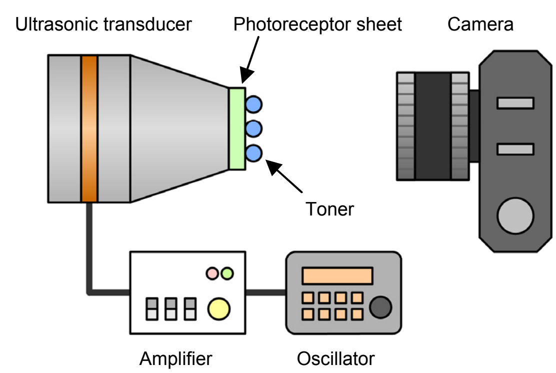


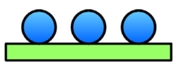
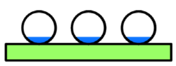
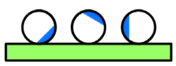
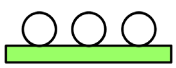
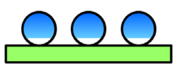
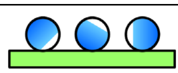
Figure 3. Schematic diagram of the adhesion force measurement of vibratory detachment method

Toner particles were deposited sparsely on the photoreceptor sheet glued on the top end of the transducer as mentioned above. The transducer was driven at a given power, and toner particles are detached from the photoreceptor sheet by inertia force. We observed the toner particles on the photoreceptor sheet before and after vibration by using the camera, and the subtractive image showed toner particles detached. The mass of toner particle was calculated from projected area diameter and its density. We get adhesion force by multiplying the mass of the toner particle and the vibratory acceleration that the toner particle was detached from the photoreceptor sheet. This step was repeated, increasing the power supplying to the ultrasonic transducer, until almost all toner particles were detached, and the adhesion force distribution was obtained.

Result

Table 2 shows mean adhesion forces and mean toner charges measured. The mean electrostatic adhesion forces are also written in parenthesis. The electrostatic adhesion forces were obtained by subtracting non-electrostatic adhesion force determined with sample 4 from total adhesion force.

Table 2: List of adhesion forces and charges for each sample. (The electrostatic adhesion forces are written in parenthesis.)

No.	Illustration	Adhesion Force (nN)	Charge (fC)
1		65 (57)	4.2
2		65 (57)	0.6
3		13 (5)	0.4
4		8 (0)	0
5		16 (8)	2.2
6		41 (33)	3.3

We decomposed adhesion force into electrostatic adhesion force and non-electrostatic adhesion force, moreover, decomposed electrostatic adhesion force into by the charge in the proximity region of the toner surface against the photoreceptor sheet and by the rest of charge. We used experimental results of sample 1, 2 and 4 because all of these samples were charged triboelectrically. The breakdown list of the adhesion force is shown in Figure 4.

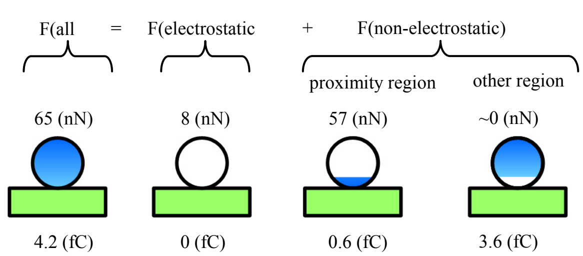


Figure 4. Decomposition of the adhesion force measured

Discussion

Relation with charge distribution and electrostatic adhesion force

Sample 2 and 3, sample 5 and 6, respectively have the same surface charge distribution, and differ only in orientation of charged region against a substrate. If we assume that adhesion force depends not on surface charge distribution including its orientation against a substrate, but on amount of charge, each pair should have the same electrostatic adhesion force, respectively. On the contrary, there are differences in those results as shown in Table 2.

Sample 2, with charge located at the spot in close proximity to the photoreceptor sheet, have a strong adhesion force. Sample 3, with the same charge distribution of sample 2 but toward random direction, has weaker electrostatic adhesion force than sample 2. On the other hand, sample 5, with charge in the region except for the spot in close proximity to the photoreceptor sheet, have weaker electrostatic adhesion force than sample 6 which had the same charge distribution of sample 5 but toward random direction.

As a result, it is clear that the slight charge in the proximity region causes most of electrostatic adhesion force, and the rest of charge produces a bit of adhesion. These results are the evidence of the physical image of the charge patch model.

Electrostatic adhesion force caused by charge outside proximity region

Now, we assume the electrostatic adhesion force as the sum of two components as shown in Figure 4. The one component is caused from the charge in the proximity region, and another component is caused from the charge outside the proximity region.

Firstly, we discuss the electrostatic adhesion force caused by charge outside the proximity region. The charge outside the proximity region is far from a substrate, therefore, is regarded as continuous and uniform distribution, and the electrostatic adhesion force is calculated by using the electrostatic image force method as

$$F_E = \alpha \frac{\varepsilon - \varepsilon_0}{\varepsilon + \varepsilon_0} \frac{1}{4\pi\varepsilon_0} \left(\frac{Q}{D} \right)^2$$

where α is a polarization correction factor, ε_0 is the permittivity of free space, ε is the permittivity of the photoreceptor sheet, Q is the charge of the toner particle, D is the toner diameter.

Comparing the calculated value 2.2 (nN) and the experimental value 0 (nN), these two values are approximately corresponding. Accordingly, it is validate that the electrostatic adhesion force caused from the charge outside the proximity region is calculated from the electrostatic image force method.

Electrostatic adhesion force caused by charge in proximity region

Next, we discuss the electrostatic adhesion force caused by charge in proximity region. It is presumed that charge patch model is applicable for the electrostatic adhesion force caused by charge in proximity region. Using the charge patch model, the magnitude of electrostatic adhesion force can be expressed as

$$F_E = \frac{Q^2 f}{2\varepsilon A_t}$$

where Q is the charge of the toner particle, f is the ratio of charged area of the proximity region to the total area of the toner particle, ε is the permittivity of the photoreceptor sheet, A_t is total charged area of the toner.

f and A_t, are arbitrary parameters in this equation, and the calculated value is varied by these parameters. The area ratio f is estimated about 0.14, because of the charge loss between before and after neutralization from the results of sample 1 and 2. This value is approximately equal to 0.2, the value that the charge patch model is assumed.

The total charged area A_t expresses the degree of microscopic charge localization of a toner particle. Decreasing A_t, charge is localizing, and charge density of charge patches and electrostatic adhesion force are increasing. We investigate the effect of A_t quantitatively using the result of sample 2. The electrostatic adhesion force was calculated by changing A_t based on the area of the proximity region A_s. Here, $f = 1$ is assumed, because charge of sample 2 is all in the proximity region. The results are shown in Table 3.

Table 3: The electrostatic adhesion force calculated by the charge patch model varing the parameter A_t

A_t / A_s	(nN)
1	0.36
0.1	3.6
0.01	36
Measured	57

Assuming A_t is equal to A_s, that is, charge distribution in the proximity region is uniform, and the magnitude of the measured electrostatic adhesion force cannot be explained. If the charge is concentrate in the area that one-hundredth of the proximity region, the calculated value is approximately equal to the experimental value. Accordingly, the charge distribution of the toner particle is assumed to be discrete in the proximity region microscopically. To verify this microscopic charge distribution, it is necessary to measure charge distribution on a toner surface with high resolution by using such as a scanning probe microscopy.

Conclusion

Measurements of electrostatic force of partly charged toner particles were carried out with vibratory detachment method. We verified by experiment, that slight charge in the proximity region causes most of electrostatic adhesion force, as proposed by the charge patch model. By contrast, the rest of charge outside the proximity region produces a bit of adhesion, and its magnitude is calculated from the electrostatic image force model. Additionally, it is suggested that the magnitude of electrostatic adhesion force depends on the fine charge distribution in the proximity region.

References

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Author Biography

Takayuki Tanaka received his B.S. and M.S. degrees from Osaka University, Japan in 1999 and in 2001, respectively. Since he joined Canon Inc. in 2001, he has engaged in the development of electrophotographic processes.