A Comparative Study on Toner Adhesion Force Measurements by Toner Jumping and Centrifugal Methods

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Abstract

Toner adhesion forces to an aluminum substrate were measured by toner jumping and centrifugal methods to study the adhesion mechanism of toner particles. When measuring the toner adhesion forces by the toner jumping method, a toner was spattered over on one of a pair of parallel aluminum electrodes. The dc voltage applied to the electrode was increased at a constant rate, and the occurrence of the toner jumping was observed by measuring the current flowing between the electrodes. The toner adhesion force was estimated from the voltage at the occurrence of the toner jumping. The numbers of toner particles which have a certain adhesion force were estimated from the voltage and current. Low resistivity toners were used in this study. The toner adhesion forces were distributed from 10^{-11} to 10^{-7} N. The influence of electrostatic and van der Waals forces to toner adhesion was discussed by comparing results of the toner jumping method and centrifugal method.

1. Introduction

Adhesion force of toners to carrier beads, photoreceptors and papers play an important role in electrophotographic performance. Adhesion force of toner particles consists of electrostatic force, van der Waals force, surface tension of adsorbed water, and so on. Since each force is correlated to other, it is not easy to evaluate the contribution of each force to the total toner adhesion force. All the forces are affected by many factors such as toner size, toner shape and toner charge, substrate morphology, environmental conditions, etc.

Several studies have been made on the adhesion of toners to various substrates, and their adhesion mechanism has been discussed. However, most of those studies discussed only average adhesion force of toners to several kinds of substrates.[1,2]

Adhesion force distributions of toner particles to an aluminum substrate were measured by toner jumping method and centrifugal method in this study. First, experimental procedures for measurements of toner adhesion forces by toner jumping method and centrifugal method are described. Then experimental results are given. Finally the toner adhesion forces determined by the toner jumping method are compared to those by the centrifugal method, and the toner adhesion mechanism will be discussed.

2. Experimental

2.1. Toner jumping method

The experimental set up for the toner jumping method is shown in Fig. 1. The system consisted of the following parts: potential sweeper for ramp voltage source, high voltage amplifier for applying voltage to an electrode, whose gain was -10 and maximum voltage -1500 V, power supply unit (Takasago, HV 1.5-03) for high voltage amplifier, electrometer for current measurement, and an X-Y chart recorder. A pair of parallel planer electrodes which had an air gap of 500 μm were prepared.

A sample toner was spattered over the lower aluminum electrode without charging, and its adhesion force to the aluminum electrode was measured. The upper electrode surface had an insulation resin coating of 25 μm in thickness for avoiding charge exchange between the toner particles and the upper electrode. In other words, the resin coating prevented the removing of toner particles deposited on the upper electrode to the lower electrode again. An appropriate resistivity and relative dielectric constant for the coating resin were $8.3 \times 10^{11}\Omega$·cm and 3.4, respectively.

The dc voltage applied to the electrode was increased at a constant rate from the initial voltage $V_{initial}$ to a preset voltage V_{max}, and the occurrence of the toner jumping was observed by measuring the current flowing between the electrodes. When the applied voltage reached the preset value (V_{max}), it was returned to the initial value ($V_{initial}$) automatically. Then, the toner moved from the lower electrode to the upper electrode was wiped off. This step was repeated several tens of times, increasing the preset voltage (V_{max}), and the adhesion force distributions were obtained. The voltage increasing rate was kept to be 10 V/s in this measurement.

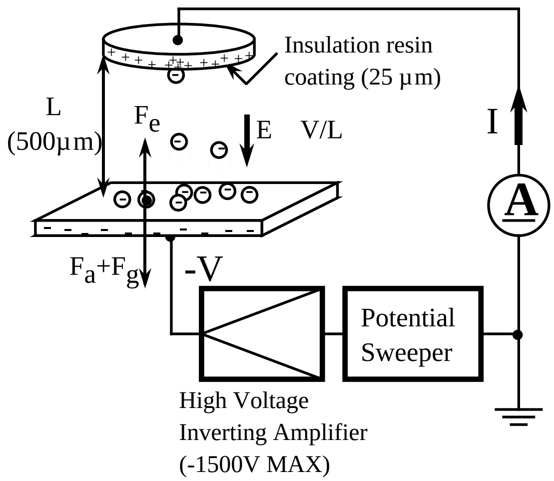

Figure 1: *Toner adhesion measuring system by toner jumping method.*

2.2. Basic theory

When one of the toner particles begins jumping from the lower electrode to the upper electrode, the following relationship is valid,

$$F_e = F_a + F_g, \tag{1}$$

where

$$\begin{aligned} F_e &= electrostatic\ force \\ &= QE \\ Q &= induced\ toner\ charge \\ E &= magnitude\ of\ electric\ field \\ F_a &= adhesion\ force \\ F_g &= gravitational\ force \end{aligned}$$

The induced toner charge Q can be calculated as follows,[3]

$$Q = 1.65 \times 4\pi\epsilon_0 r^2 E \tag{2}$$

where r is the radius of the particle and ϵ_0 is dielectric constant of the free space. Therefore the adhesion force of a toner particle is given by

$$\begin{aligned} F_a &= F_e - F_g \\ &= 1.65 \times 4\pi\epsilon_0 r^2 E^2 - \frac{4}{3}\pi r^3 \rho g \end{aligned} \tag{3}$$

where ρ is specific gravity of toner particle and g is acceleration of gravity. According to Hoshino and his co-workers, the current $I_{toner\ jump}$ due to toner jumping can be written as follows:

$$I = C\mathrm{d}V/\mathrm{d}t + I_{toner\ jump}, \tag{4}$$

where

$$\begin{aligned} I &= total\ current \\ C &= capacitance\ of\ measuringcell \\ \mathrm{d}V/\mathrm{d}t &= rate\ of\ voltage\ increment,\ 10V/s. \end{aligned}$$

Because $\mathrm{d}V/\mathrm{d}t$ is constant, $I_{toner\ jump}$ can be measured. Here, if we assume that n toner particles jump in a unit time, the following equation will be obtained,

$$I_{toner\ jump}(t) = Q(t) \cdot n(t) \tag{5}$$

This equation can be written as follows,

$$n(t) = \frac{I_{toner\ jump}(t)}{Q(t)} \tag{6}$$

Then, the number of toner particles jumped in a definite time can be calculated by integrating eq. (6).

2.3. Centrifugal method

Toner adhesion force measurements by the centrifugal method was carried out by using an ultracentrifuge (Hitachi Koki: SCP85H2). An aluminum substrate on which toner particles were spattered over and a collecting plate were placed, facing with each other, in a capsule and were mounted in a rotor of the centrifuge. The centrifuge was driven at a rotating frequency for a definite time, and then the surface of collecting plate was observed by an optical microscope and a CCD camera, so that the number and the size of the toner particles, transferred from the aluminum substrate, were measured by a computer. This step was repeated, increasing the rotating frequency, and the adhesion force distributions were obtained.

2.4. Sample toners

Fundamental properties of the toners were measured before the adhesion force measurements. The results are given in Table 1. The toner was spattered over on the electrode for the toner jumping method or on the aluminum substrate for the centrifugal method. Both the toner coverage of the electrode and the aluminum substrate were 0.2mg/cm^2. Both measurements were made immediately after the toner was spattered over.

3. Results and Discussion

3.1. Toner jumping method

First, adhesion force distributions of toners were measured by toner jumping method. The results are shown in

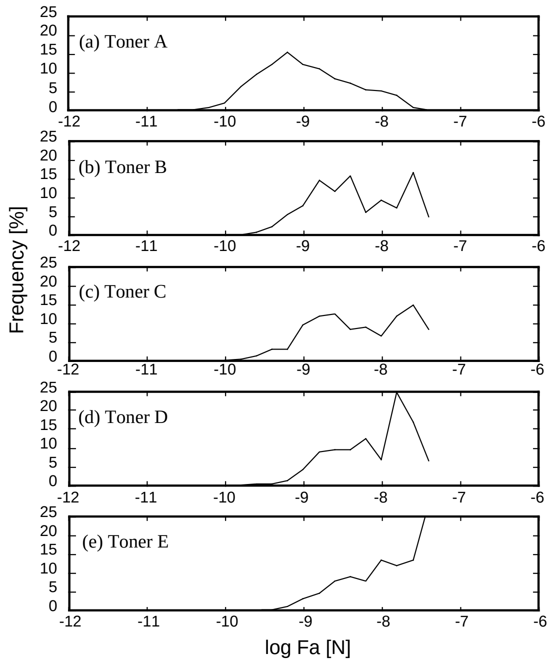

Figure 2: *Adhesion force distributions of five kinds of toners, measured by toner jumping method, where toners were spattered over the aluminum substrate.*

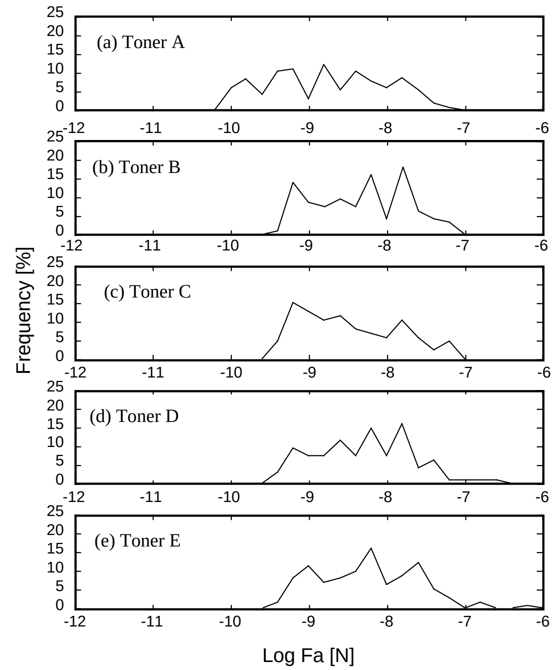

Figure 3: *Adhesion force distributions of five kinds of toners, measured by centrifugal method, where toners were spattered over the aluminum substrate. Only the data on toner particles of each average size are plotted in this figure.*

Table 1: Fundamental properties of toners used in this study.

(d: mean particle size)

Toners	Resistivity [Ω·cm]	d [μm]
A	1×10^1	7.6
B	1×10^5	11
C	9×10^5	11
D	1×10^7	11
E	3×10^8	11

Fig. 2. Adhesion forces were distributed over the order of 10^{-11} to 10^{-7} N. The mean adhesion force of toner A, B, C, D, and E were 2.3, 9.6, 11.1, 12.9, and 19.2 nN, respectively. Mean adhesion force of toner A was particularly smaller than those of the other four kinds of toners. This result is due to the difference in the toner size. The adhesion force of the smaller toner was smaller than that of the larger one. It should be noted that the obtainable maximum value of adhesion force was limited by the breakdown of air. A little toner remained on the lower electrode after the final measurement in this method.

3.2. Centrifugal method

Next, the adhesion force distributions measured by the centrifugal method are discussed. The adhesion force distributions of the toners which had the mean particle size were measured for each toner in this method. The results are shown in Fig. 3. The toner adhesion forces were distributed from 10^{-11} to 10^{-7} N for each toner.
Figure 4 shows the particle-size-dependence of mean adhesion forces for each toner on the aluminum substrate. The toner adhesion forces were proportional to 1st, 1.6th, 1.7th, 2.3rd and 1.8th power of particle size for toner A, B, C, D and E, respectively. This results show that the toner particles of larger size show the larger adhesion force.
The effect of toner resistivity on adhesion force of toners is discussed. Toner-resistivity-dependence of mean adhesion forces of the toner which was measured by toner jumping method and centrifugal method were shown in Fig. 5. The results of mean adhesion forces by the toner jumping method is in good agreemwnt with those by the centrifugal method qualitatively. The toners of higher resistivity tend to show the larger adhesion force.

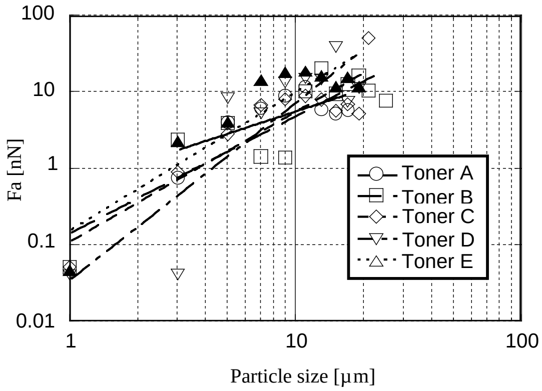

Figure 4: *Particle-size-dependence of mean adhesion forces for five kinds of toners on the aluminum substrate, where toner particles were spattered over the substrate.*

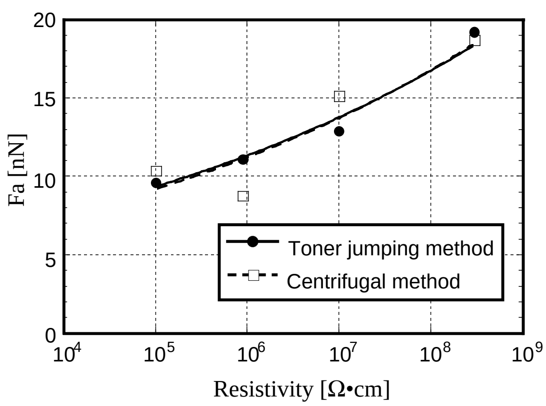

Figure 5: *Toner-resistivity-dependence of mean adhesion force of toner B, C, D and E on aluminum substrate, where toners were spattered over the substrate.*

3.3. Influence of humidity

Finally, the influence of humidity on toner adhesion forces was investigated. Figure 6 shows the adhesion force distributions of toner A and B for the two choices of relative humidity of 40 % and 80 %, measured by the toner jumping method. The number of toner particles, which had smaller adhesion force, decreased with an increase in relative humidity for both toners. On the contrary, the number of toner particles with larger adhesion forces increased at higher relative humidity. The mean adhesion force for toner A and B were increased from 2.3 to 5.2 and from 9.6 to 15.2 nN, respectively, when the relative humidity increased from 40 %to 80%. This results conclude that hummed air increases toner adhesion forces, and the adhesion force of smaller toner is more sensitive to humidity than the larger one.

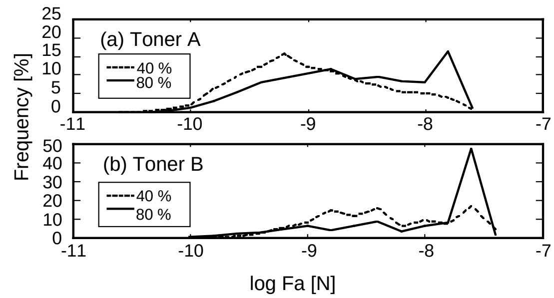

Figure 6: *Adhesion force distributions for toner A and B at relative humidity of 40 % and 80 %, measured by the toner jumping method. (a) Toner A, (b) Toner B.*

4. Conclusions

Toner adhesion forces were measured by the toner jumping method and centrifugal method, and following results were obtained.

1. The toner adhesion forces are distributed over the order of 10^{-11} to 10^{-7} N.
2. The adhesion force of larger toner particles is larger than that of the smaller one.
3. The results of the toner adhesion force measurements by the toner jumping method agree with those by the centrifugal method.
4. Humidity increases the toner adhesion forces.

Acknowledgment

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Biography

Yutaka Fukuchi received his B.Eng. in Electrical and Electronic Engineering from Ibaraki University in 1997. He is now working for his M.eng at the same university. Adhesion forces of toner particles is the core of his research interest.