# Particle Adhesion Force Measurements by Toner Jumping Method

***Yutaka Fukuchi and Manabu Takeuchi***
***Department of Electrical and Electronic Engineering, Ibaraki University***
***4-12-1 Nakanarusawa Hitachi, 316-8511, Japan***

## Abstract

Toner adhesion forces to an aluminum substrate were measured by toner jumping method to study its adhesion mechanism. When measuring the toner adhesion forces by the toner jumping method, toner particles were sprinkled 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 that have a certain adhesion force were estimated from the voltage and current. Conductive toners as well as conductive polymer particles were used in this study. The toner adhesion forces were distributed from $10^{-11}$ to $10^{-7}$ N.

## Introduction

Adhesion force of toners to carrier beads, photoreceptors and papers plays 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 others, 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 in this study. First, experimental procedures for measurements of toner adhesion forces by toner jumping method are described. Then experimental results are given. Finally the toner adhesion forces determined by the toner jumping method will be discussed.

## Experimental

### Toner Jumping Method

The experimental set up for the toner jumping method for toner adhesion force measurements 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 was -1500 V, power supply unit (Takasago, HV 1.5-03) for high voltage amplifier, electrometer for current measurement, integrator for integrating current, and an X-Y chart recorder. A pair of parallel planer electrodes which had an air gap of 500 μm were prepared.

Sample toner particles were sprinkled over onto the lower aluminum electrode without tribocharging, and its adhesion force, most of which consist of van der Waals force and surface tension of adsorbed water, to the aluminum electrode was measured. The upper electrode surface had an insulating 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. The resistivity and relative dielectric constant of the coating resin were $6.3\times10^{13}\ \Omega\cdot\mathrm{cm}$ and 4.5, respectively.

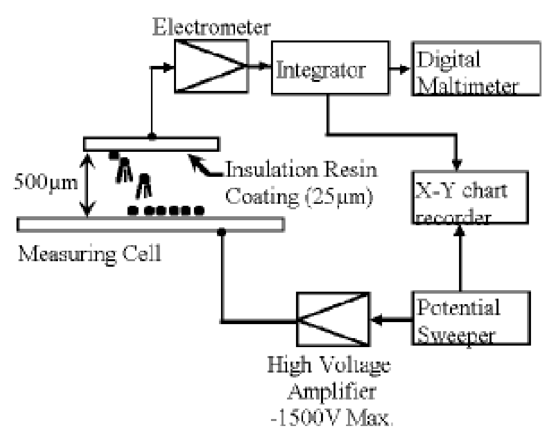


*Figure 1. Toner adhesion force measuring system by toner jumping method.*

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 about fifteen times for one measurement, increasing the preset voltage ($V_{max}$), and the adhesion force distributions were obtained. The voltage increasing rate was kept to be 5 or 10 V/s in this measurement.

### 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

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

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

$$Q = 1.65 \times 4\pi\varepsilon_0 r^2 E \tag{2}$$

where $r$ is the radius of the particle and $\varepsilon_0$ is dielectric constant of the free space. Then, the adhesion force of a toner particle is given by

$$\begin{aligned} F_a &= F_e - F_g \\ &= 1.65 \times 4\pi\varepsilon_0 r^2 E^2 - \frac{4\pi r^3 \rho g}{3} \end{aligned} \tag{3}$$

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

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

where

$I$ = total current

$C$ = capacitance of measuring cell

$\mathrm{d}V/\mathrm{d}t$ = rate of voltage increment

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

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

This equation can be written as follows,

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

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

### Sample Toners

The toner jumping method can be applied to conducting powders, because it is based upon electrostatic induction in particles. Several kinds of conductive toners and polymer powders were used as samples, and their adhesion forces to an aluminum electrode were measured. Fundamental properties of the toners and polymer particles used in this study are given in Tables 1 and 2.

The toner was sprinkled over onto the aluminum electrode for the adhesion force measurement. The particles coverage of the electrode was about 0.1mg/cm$^2$. All the measurements were made immediately after the toner was sprinkled over.

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

| Toner | Resistivity[Ω·cm ] | d[μm] | [g/cm$^3$] |
|---|---|---|---|
| A | $3\times10^1$ | 7.6 | 1.8 |
| B | $1\times10^5$ | 11 | 1.8 |

d: mean particle size
ρ: specific gravity

**Table 2. Fundamental properties of conductive polymer particles used in this study.**

| Sample | d[μm] | ρ[g/cm$^3$] |
|---|---|---|
| C | 7.4 | 1 |
| D | 32 | 1 |
| E | 50 | 1 |

d: mean particle size
ρ: specific gravity

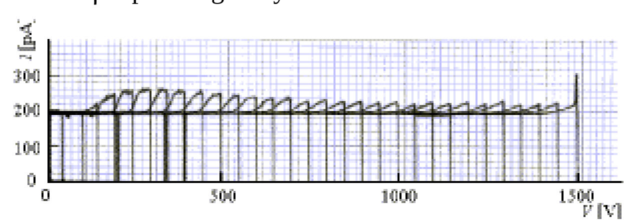


*Figure 2. Dependence of current due to particle jumping on voltage (current form).*

## Results and Discussion

### Adhesion Forces of Toners

Figure 2 shows voltage dependence of electric currents flowing between the electrodes due to particle jumping, where the voltage was increased at a constant rate. The voltage at which the toner jumping began was shifted in higher direction with an increase in repetition of measurements. This result indicates that the toner particles which jump up and adhere on the upper electrode never fall from the electrode.

The number of toner particles jumped up and adhered on the upper electrode can be estimated by integrating the current in Fig. 2. As a result, the number of toner particles which detached from the lower electrode at a certain voltage can be evaluated. Some typical results are given in Fig. 3, which shows the numbers of toner particles jumped up and adhered on the upper electrode as a function of voltage.

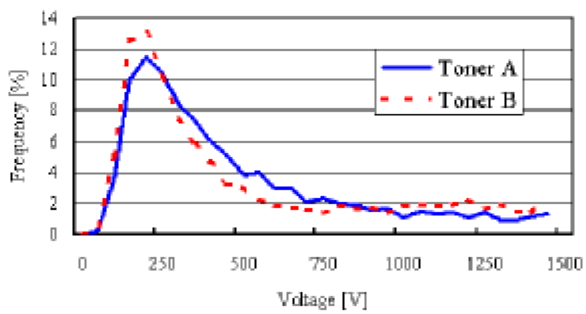


*Figure 3. Dependence of frequency of toner particles jumped up and adhered on the upper electrode on voltage.*

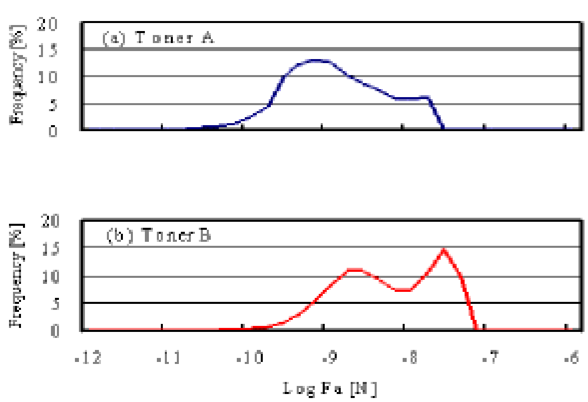


*Figure 4. Adhesion force distributions of toners A and B, where toners were sprinkled over the aluminum substrate.*

Figure 4 shows the adhesion force distributions for toners A and B. The adhesion force distribution shifted in larger direction for toner B than toner A. This result can be attributable to the larger particle size of toner B than toner A. The adhesion force may consist mostly of van der Waals force and some surface tension of adsorbed water in these cases. As a whole, the adhesion forces are distributed over the order of $10^{-11}$ to $10^{-7}$ N, which is smaller by about an order of magnitude than those of charged toner particles.

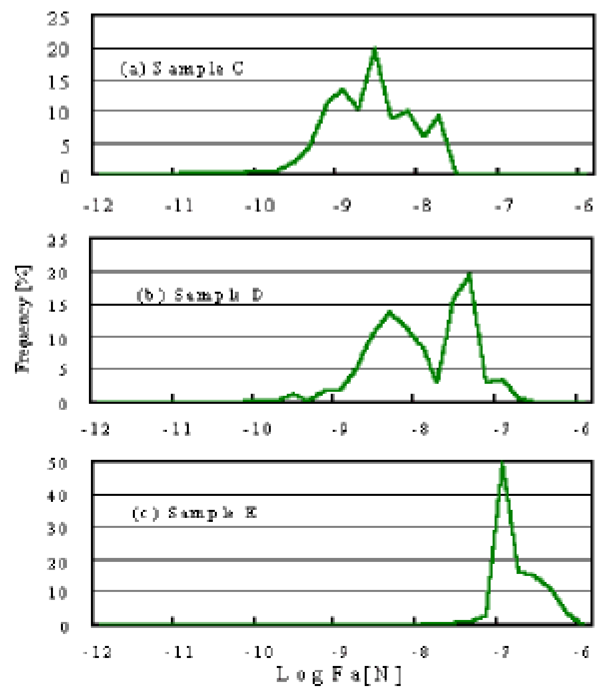


*Figure 5. Adhesion force distributions of three kinds of conductive polymer particles, where polymers were sprinkled over the aluminum electrode.*

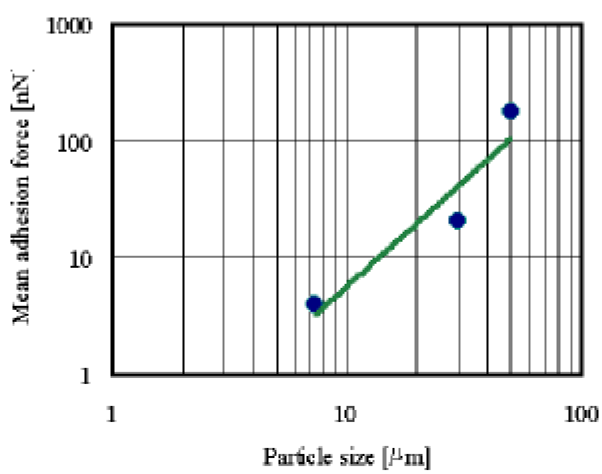


*Figure 6. Particle-size-dependence of mean adhesion forces of conductive polymer particles.*

**Adhesion Forces of Conductive Polymer Particles**

Similar results for the conductive polymer particles are given in Fig. 5. The sample C showed a similar adhesion force distribution as toner A, the particle sizes of both samples are nearly same with each other. The mean adhesion forces increased with an increase in mean particle size as shown in Fig. 6. These results confirm that van der Waals force correlates to particle size.

## Conclusions

Adhesion forces of toners and conductive polymer particles were measured by toner jumping method, and following results were obtained.

1. The adhesion forces are distributed over the order of $10^{-11}$ to $10^{-7}$ N and $10^{-11}$ to $10^{-6}$ N for the toner and conductive polymer particles, respectively.
2. The adhesion force of larger particles is larger than that of smaller one for both toner and conductive polymer particles.
3. Adhesion force distribution is narrower for larger than smaller particles.

## References


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## Biography

Manabu Takeuchi received his B. Sc., M. Sc. and D. Sc. degrees in Applied Physics from the Tokyo Institute of Technology, Tokyo, Japan, in 1966, 1968 and 1971, respectively. Since 1972, he has worked in the department of electrical and electronic engineering at Ibaraki University. His research interest includes static electrification of electrophotographic developers, electrical properties of polymer powders and photoelectronic properties of semiconductor layers. He is a member of the IS&T, the Imaging Society of Japan, the Institute of Electrostatics of Japan and the Japan Society of Applied Physics.