Estimation of Toner Adhesive Force by Toner Jumping in Increasing Electric Field

Yasushi Hoshino, Noboru Kutsuwada, Yoshio Watanabe and Harunobu Izawa
Nippon Institute of Technology, Saitama-ken, Japan

Abstract

Toner plays an important role in the electrophotographic printing process, such as developing, transfer and cleaning. Toner motion is controlled by the electric force, adhesive force, mechanical force and so on. Adhesive force is estimated by electric field forced toner jumping. Conductive toner is sprayed on one of the electrodes which are spaced parallel. Voltage of increasing constant rate is applied to electrode and toner jumping starts at certain voltage that electric force (charge induced to toner × electric field) overcomes adhesive force and gravitation force. From the toner jumping voltage, adhesive force is estimated. Toner diameter and substrate dependencies are obtained.

Introduction

Electrophotographic technology is applied to copy machine and printer, and is used very widely in our life. Electrophotographic printing process has six processes, which are charging, exposure, developing, transfer, fixing and cleaning. In these processes, the processes of developing, transfer and cleaning are mainly based on movement of toner. The movement is controlled by applied forces to toner as electric force, adhesive force, gravitational force, acceleration force and so on. Magnetic force is also worked in the case of magnetic toner.

Adhesive force has an important effect on printing characteristics, as much as the electric force. Adhesive force is depended on the substrates. In electrophotography, there are adhesive forces between toner and photoconductor, carrier, paper and toner. Several researches about the force were carried out, but more studies are expected to understand and improve these printing processes.

A method of estimating toner adhesive force to substrate is proposed. The method is applied to three sizes of conductive toners.

Measuring Mechanism

The schematics of experimental set up is shown in Fig. 1. Toner sample for measure is distributed on under electrode. Two electrodes are arranged parallel. Voltage applied to electrode increases linearly with time. The current flows through this circuit, is measured by electrometer and is recorded. The current I is shown as:

$$I = I_{capacitance} + I_{toner\ jumping}, \quad (1)$$

$$\text{Capacitance} = C(dV/dt) = C\beta, \quad (2)$$

where Icapacitance is current component by capacitance charging, Itoner jumping is current component by toner jumping, C is capacitance between electrodes, V (= ßt) is the voltage applied to electrode, t is time and ß is the increasing rate of applied voltage.

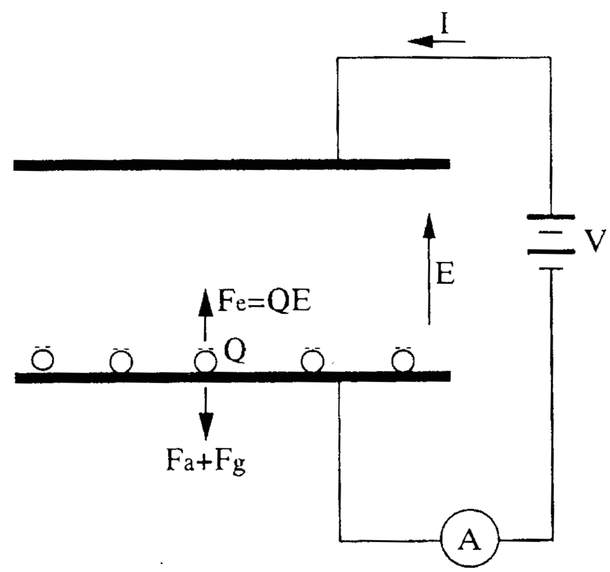

Figure 1. Schematics of experimental set up

It is shown from Eq. (1) and (2) that the current measured I consist of Itoner jumping + constant term. Toner jumping arises when electric force induced by applied voltage overcomes adhesive force and gravitational force. After start of toner jumping, toner moves up and down between electrodes and Itoner jumping rises from zero because toners carry electric charge.

Figure 2 shows the method of obtaining the voltage, at which toner starts to jump. The forces worked on the toner on electrode are electric force, adhesive force and gravitation force. Toner starts to jump, when electric force overcomes adhesive force and gravitation force. Electric force *Fe* is estimated as Eq. (3), when toner is conductive,

$$Fe = Qe = (\varepsilon ES)E, = \varepsilon SE^2, \quad (3)$$

where Q is charge amount of toner induced by electric field, E is electric field applied between electrodes, ε is dielectric constant of air and S is effective area of toner, which means electric flux reach toner.

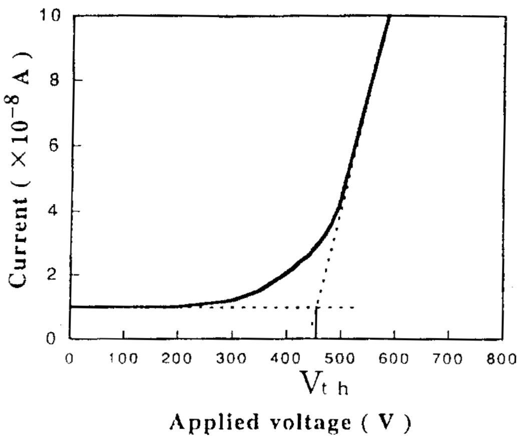

Figure 2. Threshold voltage of toner jumping

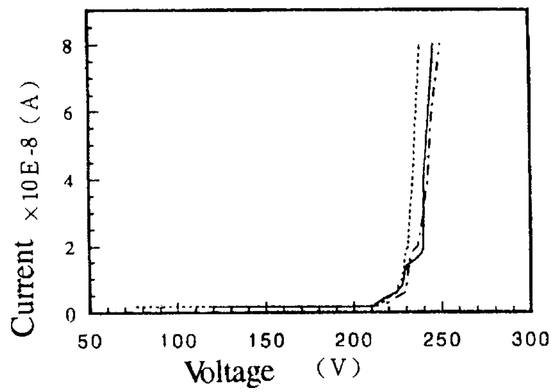

Figure 3. Repeatability of increasing current by toner jumping

Table 1. Toner Samples

	S-size	M-size	L-size
Conductivity (ohm cm)	1.9×10^7	1.5×10^6	5.8×10^5
Particle size (μm)	7.52	9.20	12.10

When toner has conductivity, toner is charged up with certain relaxation time, which is controlled by capacitance of toner and conductivity of substrate to toner. It is a good assumption that toner is charged up with applied voltage, when relaxation time is negligibly small compared with the time scale of the measurements.

Experiments

Toners used in this experiments are shown in Table 1. These toners are made from same raw materials and then classified. The electrodes used in the experiments are stainless steel, conductive silicone crystal, ITO (Indium Tin Oxide) spattered glattered glass and humidified paper for conductivity. The space of electrodes is arranged 0.5mm. Ramp voltage is generated by voltage source (Hewlett Packard: model HP 4140B) and is amplified by DC amplifier (maximum voltage 1000V). The increasing rate of voltage are 2.5V/sec., 5V/sec. and 10V/sec. The current is detected by electrometer and is recorded.

Results and Discussion

Figure 2 shows the typical result of current measurements. When the applied voltage starts to increase, constant current starts, and the additional current begins to increase more than the certain voltage. The increase means something moving with carrying electric charge.

We obtain the threshold voltage of toner jumping as Fig. (4), in order to eliminate the effect of dust and the toner far beyond the average.

Figure 3 shows the current waveforms of same conditions. The threshold voltages for toner jumping are estimated with small dispersion. So, it is considered that the method has good repeatability.

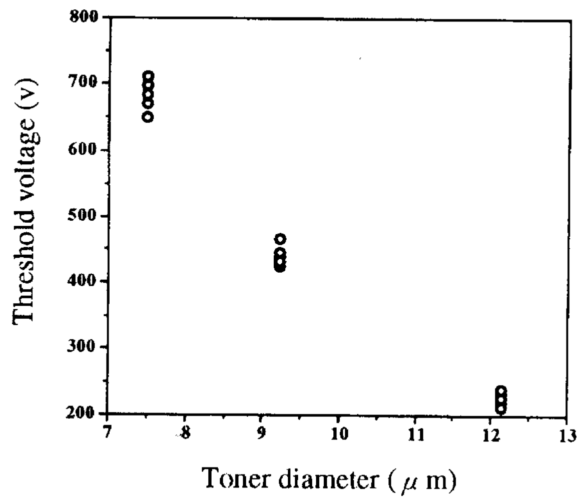

Figure 4. Toner diameter dependency

Figure 4 shows the threshold voltage dependency of toner diameter. From the result, the adhesive force does not increase according to toner size, and shows the tendency of slight decrease. The adhesive force measurements of other series toners shows little dependencies of toner size (7.7 μm – 14.6 μm).[4] It is considered that the adhesive force is mainly van der Waals force.[5] It is thought that the points and the nearest distance between toner and substrate is not so varied within these toner size. About the difference of toner size dependency, it is possibly considered that the effective area S in Eq. 3 is not varied proportional to square of toner diameter. The shape of toner used in this experiment is plate rather than block, so the ratio of S vs. πr^2 decreases as toner diameter r increases. So, it is considered that the adhesive force seems to decrease as diameter increases on the assumption that the ratio of S vs. πr^2 is not varied.

Figure 5 shows the rising rate dependencies of jumping voltage. These dependencies are very slight and the jumping voltage shows slight increase as applied voltage rising rate is increased. The reason of dependencies are considered electrical and mechanical relaxation. In the experiment, it is considered that electrical relaxation time is negligible compared with this time range of the experiment.

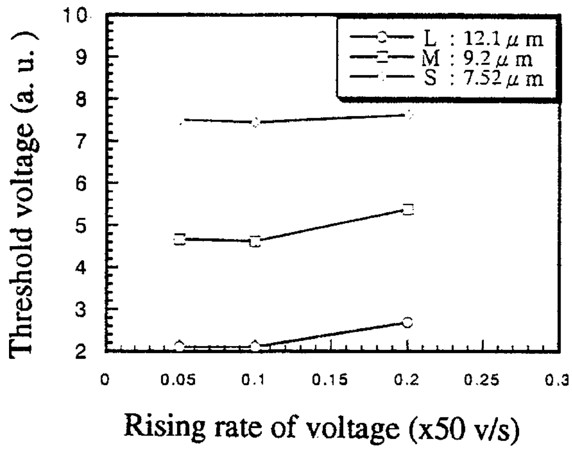

Figure 5. Voltage rising rate dependency

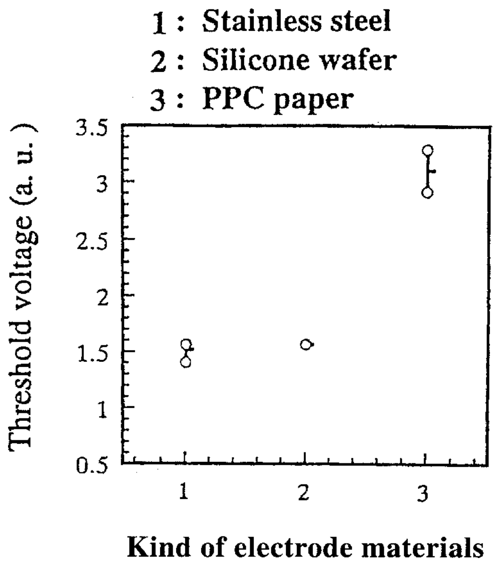

Figure 6. Substrate dependency

Figure 6 shows the substrate dependency of toner jumping voltage. The jumping voltage of paper substrate is higher than the voltage of other substrates that are harder. Paper is consisted from lots of fibers, so adhesive area and number of adhesion points becomes more than other substrates.

Summary

It is shown that jumping of toner in the increasing electric field is able to be detected by measuring the current between electrodes. The toner jumping starts at the certain electric field which contains the information of the toner adhesive force and the electric field depends on toner material, size, and substrates. It is expected that this method is applied to examine the mechanism of the adhesive forces on various substrates.

References

1. C. J. Mastrangelo, "The Effects of Charge, Size, and Shape on Toner Photoconductor Adhesion in Electrophotographic Systems", *Photographic Sci. and Eng*. **26**-4(1882) pp. 194-197.
2. M. H. Lee and J. Ayala, "Adhesion of Toner to Photoconductor", *J. Imaging Tech.* **11**-8(1985) pp. 279-284.
3. S. Banerjee and M. K. Mazumder, "Adhesion of Charged Powders on Metal Surface in Powder Coating Process", (private communication).
4. Y. Hoshino, S. Kiatkamjornwong, S. Noppakundilograt, and Y. Ando, "Adhesive Force Estimation from Toner Jumping by Electric Field: Difference in Adhesion Methods", *Extended Abstracts of the 55th Autumn Meeting of The Japan Society of Applied Physics* (1994).
5. H. Krupp and G. Sperling,"Theory of Adhesion of Small Particles", *J. Appl. Phys.* **37**-11 (1966) pp. 4176-4180.