

The Effects of Surface Treatment on Toner Adhesion Force

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Abstract

We have studied the effects of toner surface treatment by an additive on toner adhesion force. Toner samples, which have various concentrations of the additive, were prepared and the toner surface coverage by the additive were evaluated by means of the image analysis of electron micrographs. The adhesion force between toner and photoconductor was measured with the centrifugal method. It was found that the non-electrostatic adhesion force rapidly decreased with increasing the surface coverage, and saturated at a certain coverage. A relationship between the non-electrostatic adhesion force and the surface coverage can be explained as the change of van der Waals force. Electrostatic adhesion force increases in proportion to the square of toner charge to mass ratio, and the slope decreases exponentially with increasing the surface coverage. It is suggested that the change of the electrostatic adhesion force by the additive is related to the difference of a charge distribution on toner surface.

Introduction

Various forces acting on toner particles control the particle motion in the electrophotographic process. For example, in the transfer stage, the transfer properties are influenced by the balance of the Coulomb force and the adhesion force between toner and the photoconductor. Therefore, the control of toner adhesion force is important for the transfer of toner deposition with high fidelity in the transfer process. Toner adhesion force consists of non-electrostatic and electrostatic adhesion forces. In order to control the toner adhesion force, it is required to investigate the effects of various factors on non-electrostatic and electrostatic adhesion forces of toner. The surface treatment of toner by the additive such as silica, used for improvement of toner flowability, is one of the important factors influenced the toner adhesion force[1-4].

In this paper, the adhesion forces between a photoconductor and non-tribocharged toner or tribocharged toner, which have various toner surface coverages by the additive, are measured by the centrifugal method[5]. Then we will discuss the effects of the surface treatment by an additive on non-electrostatic and electrostatic adhesion forces of toner.

Experiment

Sample Preparation

Toner samples, which have various concentrations of the additive between 0.1 wt% and 3 wt%, were prepared in this study. Toner particles without the additive prepared by pulverization method were irregularly shaped and negatively charged. The additive was hydrophobic treated silica particle that the average diameter of a primary particle was around 14 nm, and had negative charge property. The volume-weighted average diameters of these toner samples were approximately 9 μm.

The organic photoconductor film consisting of polycarbonate and the charge transport material was formed on the aluminum substrate used for the adhesion force measurement as the substrate of toner deposition.

Measurement of Toner Surface Coverage by Additive

The areas shaded by each additive particle on toner surface were measured by the image analysis of electron micrographs, and the toner surface coverage by the additive was evaluated from the total area of the additive.

Measurement of Toner Adhesion Force

Adhesion force between toner and the photoconductor was measured by the centrifugal method using a Hitachi Koki CP100α Ultracentrifuge. Non-tribocharged or tribocharged toner particles were sprinkled on the photoconductor film. This film was placed in the centrifuge and spun at various rotational speeds. If the centrifugal force acting on a toner particle became larger than the adhesion force between the toner particle and the photoconductor, the toner particle was removed to the capture substrate from the photoconductor. The surfaces of the capture substrates were observed by an optical microscope, and the diameters of each toner particles on the capture substrates were evaluated by the image analysis. The adhesion forces between each toner particles and the photoconductor were calculated from the diameters of the toner particles and the rotational speed at which the toner particles were removed, and the average adhesion force and the adhesion force distribution of the toner were obtained.

Results and Discussion

Surface Coverage by Additive

Figure 1 shows the relationship between the average toner surface coverage and the concentration of additive. The surface coverage increases with increasing the concentration of additive. Additive particles on toner surface form aggregates with the average diameters of 50 to 60 nm.

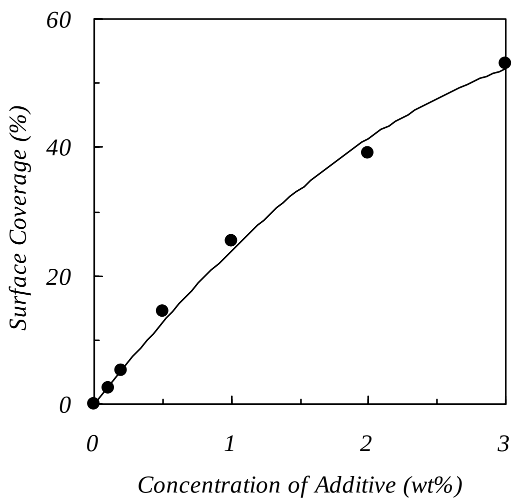

Figure 1. Relationship between the toner surface coverage by additive and the concentration of additive.

Non-electrostatic Adhesion Force

Adhesion forces between the non-tribocharged toner and the photoconductor are measured for each toner samples. Since the adhesion forces and the diameter of each toner particles are measured in this experiment, the average adhesion forces of each toner diameter can be obtained. Figure 2 shows the size dependence of the adhesion force. It is found that the adhesion force of non-tribocharged toner increases in proportion to toner diameter and the slope decreases with increasing the surface coverage.

To explain this result, van der Waals force is considered as non-electrostatic adhesion force. Van der Waals force between a spherical particle and a plane, say Fv, is expressed as follows [6]:

$$Fv = HD / 12Z^2 \quad (1)$$

where H is the Hamaker constant, D is the diameter of particle, and Z is the distance between a particle and a plane. Van der Waals force is proportional to a particle diameter, and the result of Figure 2 corresponds to the size dependence of van der Waals force. For $H = 7\times10^{-20}$ J, D = 9 μm and Z = 0.4 nm, van der Waals force calculated from equation (1) is 330 nN. The average adhesion force of 9 μm toner particles without the additive is 101 nN, which is of the same order of, but smaller than the calculated value of van der Waals force. This reason is considered that the radius of curvature of irregularly shaped real toner surface is smaller than the spherically converted radius of toner particle.

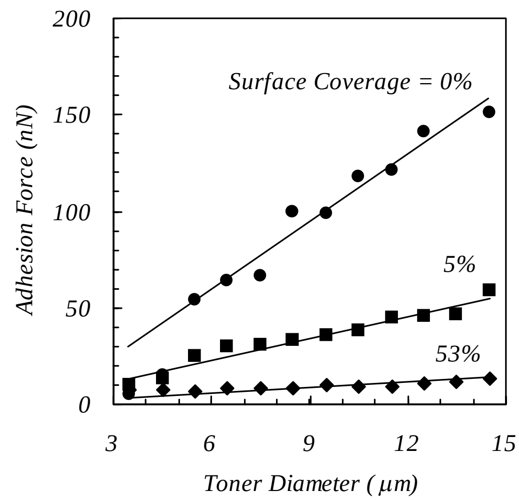

Figure 2. Size dependence of the adhesion force for the non-tribocharged toner.

The relationship between the average adhesion forces of the non-tribocharged toner and the surface coverage is shown in figure 3. It is found that the average adhesion forces rapidly decrease with increasing the surface coverage, and saturate at about 25 % coverage.

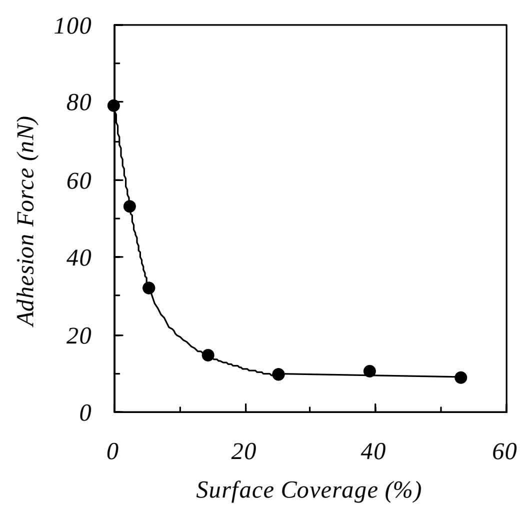

Figure 3. Relationship between the average adhesion force and the toner surface coverage for the non-tribocharged toner.

This result is discussed using the contact model illustrated in figure 4. The contact between a toner particle with the additive and a photoconductor can be classified into two cases, (1) toner surface contacts a photoconductor illustrated in figure 4-(a), (2) additives on toner surface contact a photoconductor illustrated in figure 4-(b). The diameter of a toner particle is larger than the diameter of an additive. Since van der Waals force is proportional to particle diameter, van der Waals force between a toner surface and a photoconductor is larger than van der Waals force between an additive and a photoconductor. In the case of lower surface coverage, the average of van der Waals force must be large because there are many toner particles like figure 4-(a) on a photoconductor. On the other hand, when the number of toner particles like figure 4-(a) decreases with increasing the surface coverage, the average of van der Waals force tends to decrease. It is considered that the non-electrostatic adhesion force at higher surface coverage is determined by van der Waals force between additives and a photoconductor.

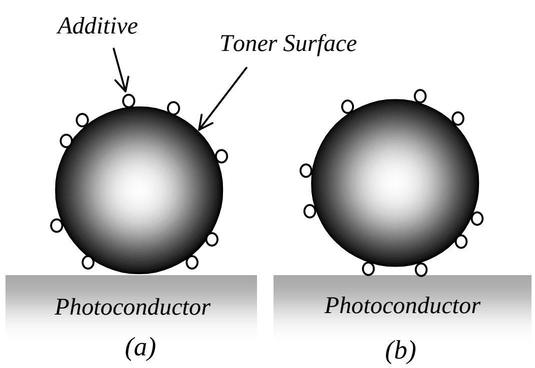

Figure 4. The contact models between a toner particle with additives and a photoconductor; (a) toner surface contacts a photoconductor, (b) additives contact a photoconductor

Electrostatic Adhesion Force

Adhesion forces between the toner, which was charged by mixing with polymer coated carrier beads, and the photoconductor are measured for each toner samples. The toner charge to mass ratios Q/M are measured by the blow-off method and controlled by the toner concentration.

Figure 5 shows the dependence of the average adhesion force on $(Q/M)^2$ for each toner samples. The average adhesion force increase in proportion to $(Q/M)^2$, and the slope γ decreases with increasing the surface coverage. Figure 6 shows the relationship between γ and the surface coverage. It is found that γ decreases exponentially with increasing the surface coverage. Thus, at the same Q/M, the electrostatic adhesion forces decrease exponentially with increasing the surface coverage.

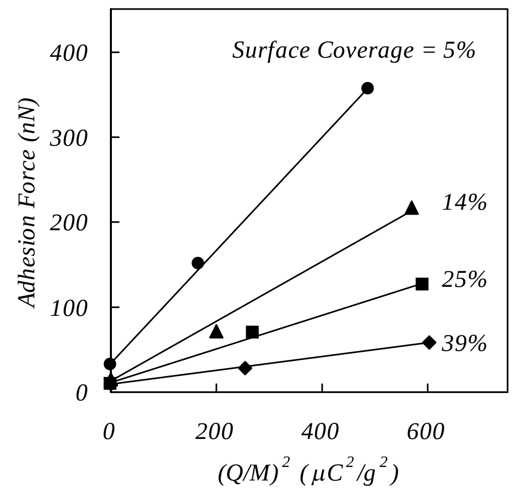

Figure 5. Dependence of the average adhesion force on the square of toner charge to mass ratio, $(Q/M)^2$.

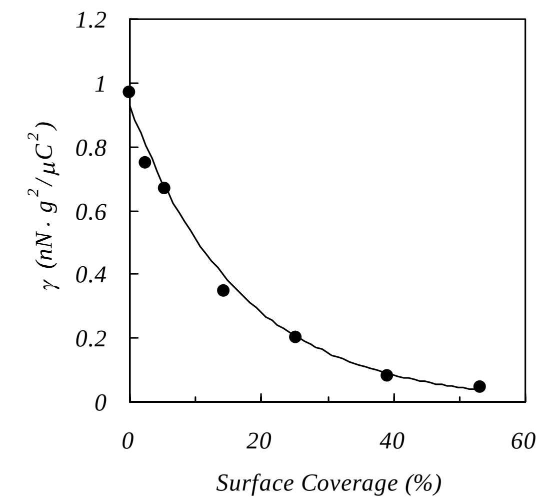

Figure 6. Slope between the average adhesion force and $(Q/M)^2$, γ plotted against the toner surface coverage.

To explain these results, the electrostatic image force of a uniformly charged spherical particle is estimated. For D = 9 μm and Q/M = -20 μC/g, the electrostatic image force[7] is calculated to be approximately 7 nN. On the other hand, the electrostatic adhesion forces for Q/M = -20 μC/g, which are obtained from γ in figure 6, range from 17 to 388 nN. Accordingly, the electrostatic image force of the uniformly charged particle does not explain the magnitude of the measured electrostatic adhesion forces and the change of the electrostatic adhesion force by the additive.

The charge patch model[8, 9], which is the electrostatic adhesion force model for a particle with non-uniform charge distribution, is discussed next. In this model, the electrostatic adhesion force between a toner and a photoconductor, say Fe, can be expressed as follows[9]:

$$Fe = \xi q^2 f / 2\varepsilon_0 A_t \quad (2)$$

where $\xi = (\varepsilon'-1)/(\varepsilon'+1)$; ε' is the relative dielectric constant of the photoconductor, ε_0 is the dielectric constant of free space, q is the total charge on the toner particle, A_t is the total charged area on the toner particle, f is the ratio of the charged area in contact with the photoconductor to the total charged area on the toner particle. From equation (2), even if the total charges of toner particles are equal, the electrostatic adhesion force changes depending on A_t. Thus, it is considered that the change of electrostatic adhesion force by the additive can be explained by the change of A_t. The measured values of electrostatic adhesion force decrease with increasing the surface coverage. Then, it is assumed that A_t increases with increasing the surface coverage because the electrostatic adhesion force is inversely proportional to A_t. The values of A_t are estimated from equation (2) and the measured values of electrostatic adhesion force. Then the ratios of A_t to S (the surface area of the spherical particle with the toner particle diameter) are calculated. For D = 9 μm and Q/M = -20 μC/g, A_t/S is 0.6% for the toner sample without the additive, and 13% for the toner sample that the surface coverage is 53%. A_t of a toner particle without the additive will be small, because the surface charges concentrate at the region which have high chargeability, such as CCA (charge control agent). When a toner particle with the additive are mixed with carrier beads, both the toner surface and the additive on the toner surface will be charged. Therefore, A_t of the toner particle will increase with increasing the surface coverage because the total area of the charged additive on the toner particle increases at the same time.

Comparison of Non-Electrostatic Adhesion Force and Electrostatic Adhesion Force

Figure 7 shows the relationship between the average adhesion force and the surface coverage for the non-tribocharged toner and the tribocharged toner (Q/M = -20 μC/g). The adhesion forces of the tribocharged toner (Q/M = -20 μC/g) are about 3 to 10 times as large as that of the non-tribocharged toner. Therefore, the contribution of the electrostatic adhesion force to the adhesion force is larger than that of non-electrostatic adhesion force.

Conclusion

The relationship between non-electrostatic or electrostatic adhesion force of toner and the toner surface coverage by the additive are obtained using the centrifugal method. From the series of experiments, the toner surface treatment by the additive changes the van der Waals force of the toner and the charge distribution on the toner surface. To be more exact, the surface charge distribution of one toner particle will be necessarily measured.

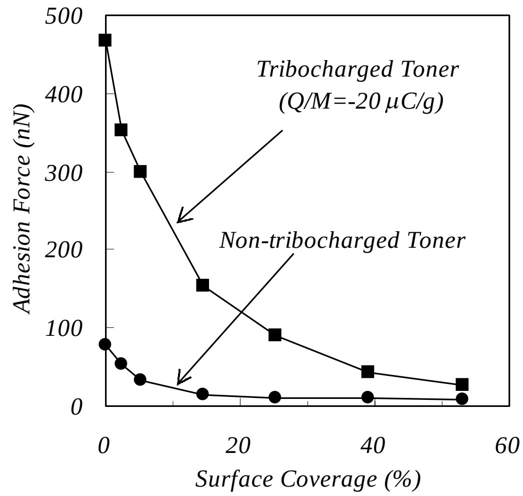

Figure 7. Relationship between the average adhesion force and the toner surface coverage for the non-tribocharged toner and the tribocharged toner.

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Biography

Haruo Iimura received his M.S. degree in physics from Tsukuba University and joined Ricoh in 1985. Recently he belongs to Imaging Technology Division in Ricoh. His present research interest includes measurement of the dominant force of toner movement in electrophotographic process. He is a member of the physical society of Japan.