Centrifugal Measurements of Adhesion Forces of Charged Toner and Polymer Particles

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Abstract

Adhesion forces of a polymer powder to an aluminum substrate were measured by centrifugal method and influence of the particle size and charge on their adhesion forces were examined. An acrylic spherical powder made by polymerization method was used in this study. The diameter of the acrylic powder distributed from 5 to 100 mm and its apparent resistivity was 1.2×10^{12} Ωcm. The acrylic powder was charged by agitating in a polystyrene tube and was classified into several groups based on q/m values by falling in an electric field to estimate the amount of charge of each particle. The adhesion forces of the particles increased by 2 to 3 powers of the particle diameter. However, the adhesion forces spread over 3 to 4 orders of magnitude even for the particles, which seemed to have the same diameter and the same amount of charge. The q/m dependence of the adhesion forces of the particles became stronger with increasing the particle diameter, suggesting that adhesion forces except for electrostatic one became more predominant with decreasing the particle size.

Introduction

Adhesion forces of toners to carrier particles, photoreceptors and papers play an important role in electrophotographic performance. Adhesion forces of toner particles consist of electrostatic force, van der Waals force, surface tension of adsorbed water, etc. Each force is correlated with each other and affected by many factors such as kinds of toners, carriers and photoreceptors, environmental conditions, etc.

Several studies have been made on the adhesion of toners to photoreceptors and carriers, and adhesion mechanism of toner particles have been discussed.[1-4] Most important factors which influence the toner adhesion are toner size and toner charge. We made centrifugal measurements previously on adhesion forces of toner particles, and discussed influence of toner size and toner charge on their adhesion to photoreceptors and carriers.[5,6] It could be said qualitatively that the adhesion forces of toner particles increased with increasing the toner size and the toner charge. The adhesion mechanism of toners is very complicated, however, quantitative understanding has not been obtained. Actually, the adhesion forces of the toner particles spread over several orders of magnitude in our study. One of the reasons for the wide spread of the toner adhesion forces is wide spread of the toner charges.

It is not easy to determine the q/m value of a toner particle, whose adhesion force is determined. In this study, we have tried to determine the adhesion force of a polymer particle to an aluminum substrate, whose q/m value is known by means of classification based on the motion affected by gravity and electric field. First, we describe the experimental procedure for the classification of polymer particles and the adhesion force measurements by the centrifugal method. Then experimental results on the adhesion forces of the polymer particles are given. Finally influence of the q/m value on the adhesion forces of the polymer particles will be discussed.

Experimental

Classification of Particles Based on q/m

An acrylic spherical powder made by polymerization method was used instead of toners in this study. The diameter of the acrylic powder distributes from 5 to 100 μm and its apparent resistivity is 1.2×10^{12} Ωcm.

The powder was put in a polystyrene tube and agitated by rolling to be charged. It should be noted that most acrylic particles were charged negatively by the agitation. Then the charged powder was classified into several groups based on the q/m values by falling in an electric field. Figure 1 shows the apparatus used for the classification of the charged powder. A d.c. electric field of approximately 40 kV/m was formed between a pair of parallel electrodes, and charged particles fell in the electric field from the hopper. Each particle moves depending on its q/m and deposits on each position of the apparatus. Five aluminum substrates were placed as shown in the Figure 1. Acrylic particles of approximately same q/m deposit onto each aluminum substrate. The approximate q/m values of the particles collected at each position from (a) to (e) in Figure 1 are tabulated in Table 1.

Table 1. q/d of the Acrylic Particles and q/m of Particles of 10 μm Collected at Various Positions (Calculated).

Sampling points	q/d (fC/μm)	q/m (10 μm) (μC/g)
a	-0.0259	-0.495
b	-0.0127	-0.246
c	-0.00604	0.115
d	0.00302	0.0577
e	0	0

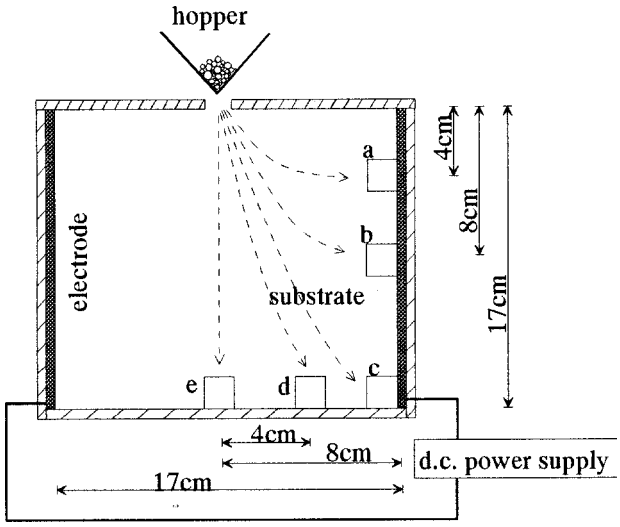

Figure 1. An apparatus for the particle classification.

Centrifugal Measurements of Particle Adhesion Forces

Adhesion forces of the acrylic particles were measured by the centrifugal method using an ultracentrifuge (Hitachi Koki: SCP85H2). An aluminum substrate on which the acrylic particles were deposited and a collecting plate were placed, facing with each other, in a capsule and were mounted in the rotor of the centrifuge. The centrifuge was driven at a rotating frequency for a definite time, and then the surface of the collecting plate was observed by an optical microscope and a TV camera so that the number and the size of the acrylic particles, transferred from the aluminum substrate, were measured by a personal computer. This step was repeated, increasing the rotating frequency. Detailed experimental procedures of the centrifugal measurements were described in a previous paper.[7]

Results and Discussion

Influence of Diameter on the Particle Adhesion Forces

Particle size distributions of the acrylic particles collected at each position from (a) to (e) in Figure 1 are shown in Figure 2. The diameter of the particles collected at all the positions distributes up to 80 μm, but the particles collected at positions (a) and (b) contain more amount of particles of small diameter.

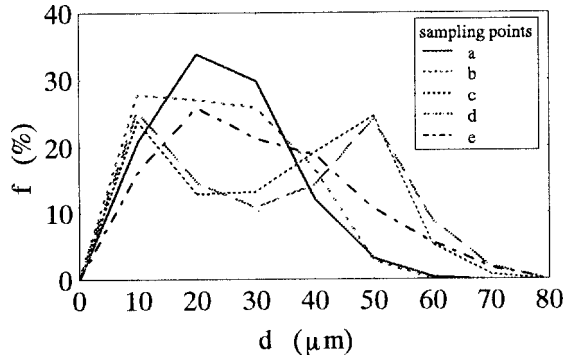

Figure 2. Particle size distribution of the acrylic powder.

Figure 3 shows the particle size dependence of the adhesion forces of the acrylic particles collected at the position (a), which have the largest q/m value among the five sampling positions. A straight line was drawn in Figure 3 by assuming an approximately linear relationship between log (adhesion force) and log (diameter). The adhesion force of the particles collected at the position (a) increased by 2.7 powers of diameter. Lager particles give larger electrostatic forces due to their larger amount of charge and may give larger van der Waals forces.

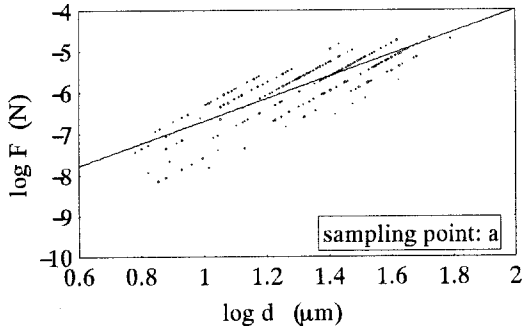

Figure 3. Particle size dependence of the adhesion forces of the acrylic particles collected at the position (a).

Similar relationship on the specimens collected at the positions from (b) to (e), including (a) again, are given in Figure 4.

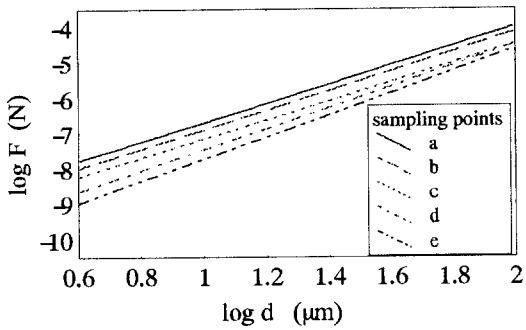

Figure 4. Particle size dependence of the adhesion forces of the acrylic particles collected at various positions.

Influence of q/m on the Particle Adhesion Forces

Figure 5 shows the adhesion force distributions of the acrylic particles collected at various positions. Although the adhesion force distribution shifts in larger direction with increasing q/m, but adhesion forces are widely distributed from 10^{-10} to 10^{-3} N for all the specimens. One of the reasons for the wide spread of the adhesion forces is wide distribution of the particle diameter. In order to avoid the problem of the particle diameter distribution, data of the particles with a definite diameter were taken up from the results of Figure 5.

The adhesion force distributions of the particles of 10 μm in diameter collected at each sampling point are shown in Figure 6. The distributions became narrower comparing with those in Figure 5. However, the adhesion forces spread over 3 to 4 orders of magnitude, even each particle at each sampling position should have the same charge q and the

same mass m (10 μm in diameter). The reason for the spread is ambiguous at this moment, but nonuniform charge distribution on the particle surface and multilayered stacking of the particles may be the reason.

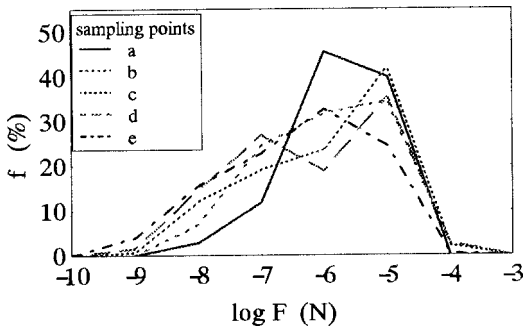

Figure 5. Adhesion force distribution of the acrylic particles collected at various positions.

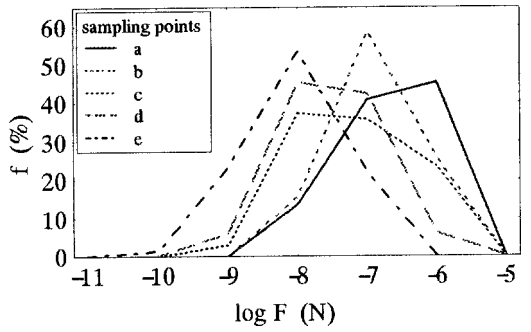

Figure 6. Adhesion force distribution of the acrylic particles of the particle size of 10 μm.

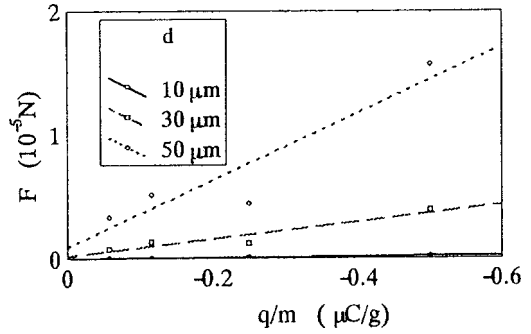

Figure 7. q/m dependence of the adhesion force of the acrylic particles.

Figure 7 shows q/m dependence of the adhesion forces of the acrylic particles for three choices of the diameter. The slope of log (adhesion force) - log (q/m) plots is larger for larger particles. This result suggests that adhesion forces except for electrostatic one become more predominant with decreasing particle diameter.

Conclusions

Adhesion forces of spherical acrylic particles to an aluminum substrate were determined by centrifugal method, and influence of the particle size and charge on their adhesion forces were examined. The following conclusions were obtained.

(1) The adhesion forces of the acrylic particles increased by 2 to 3 powers of the particle diameter.
(2) The adhesion forces spread over 3 to 4 orders of magnitude even for the particles, which seemed to have the same diameter and the same amount of charge.
(3) The q/m dependence of the adhesion forces of the acrylic particles became stronger with increasing diameter, suggesting that adhesion forces except for electrostatic one became more predominant with decreasing the particle size.

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