Tribocharging of Toner Particle in Two-Component Developer

Youichi Nakamura, Yasuyuki Suzuki, Yutaka Terao,
Jun Tanabe and Taro Sekine
Nippon Institute of Technology
Minami-saitama, Saitama 345 –8501 Japan

Abstract

The effects of toner components and their size on the property of tribocharging of toner are important to evaluate the electrophotographic developer. However, characterization of electric charge and size of toner has been separately done by several conventional methods. We have made a step of development in a simultaneous data processing to evaluate electric charge and size of each toner particle and their relationship by a laser Doppler velocimeter. Size dependence of charge to mass ratio *q/m* for individual toner particles in addition to electric charge quantity *q* is visualized by the method on the instrument. Through the statistical data processing, experimental study on tribocharging between polyester toner particles and ferrite binder carrier or polymer coated ferrite carrier beads in two-component developer is done. From the experimental results the *n*-th power dependence of diameter on tribocharge in the two-component developer system of polyester toner and ferrite binder carrier is 2.35 for the particles without silica coating, and the value is 2.02 for the particles without silica coating in the system of polyester toner and polymer coated ferrite carrier. Some physical approaches on tribocharging mechanism between toner and carrier are described to explain the discrepancies based on the second power dependence of diameter using the surface state theory.

Introduction

Study on tribocharging of toner particles in two-component developer is important to evaluate the electrophotographic properties of toner. Measurements of charge quantity on toner have been done by various methods and theoretical approaches on the mechanism of tribocharging of toner particles with carrier beads have been proposed. We have also reported the results of particle size dependence of tribo-electric charge on toner particle by a laser-based instrument, the Electrical Single Particle Aerodynamic Relaxation Time (E-SPART) analyzer[1,2].

As this method enables us simultaneous measurement of the aerodynamic diameter *d* and the electric charge to diameter ratio *q/d* on each toner particle, the data set of *d* and *q* for a single particle is obtained. This has an advantage over other methods in view of comparing macroscopically and also microscopically the ordinary quantities such as charge to diameter ratio *q/d*, and charge to mass ratio *q/m* for some amount of toner with the calculated values from the data sets over thousands of particles by a data processing with a computer.

In two-component electrophotographic developer, tribocharging of toner particles is generated by contacting with magnetic carrier beads. It is therefore appropriate to understand the mechanisms governing tribocharging and the limitation factor of maximum charge quantity on toner particle. Recently the surface state theory of Lee[3] appears to correctly describe the behaviour of toner charging and it has been advanced by L. B. Schein and M. LaHa[4] and E. Gutman and G. Hartmann[5]. In the theory the charge exchange per unit area on the surfaces of toner and carrier is based. Some of the experimental results by the blow-off method,[4] and the charge spectrograph method[6,7] have been examined and discussed by the theory.

The aim in this study is to demonstrate the visualization of size dependence of charge to mass ratio *q/m* for individual toner particles in addition to electric charge quantity reported previously, and the experimental results are also examined in the surface state theory.

Experimental

Measurement of particle size and charge of individual toner particles was performed by an E-SPART instrument with the data processing by a personal computer. The aerodynamic diameter and the electric charge to aerodynamic diameter ratio *q/d* on each particle can be obtained by detecting a phase shift of the modified movement by acoustic vibration of a fixed frequency of 1 kHz and by measuring the drift velocity due to a superimposed DC electric field.[1,8] The drift velocity is proportional to *q/d* with a coefficient determined by each experimental condition. Calibration of aerodynamic diameter was carried out with Latex Microspheres of polystyrene of 3.09µm.

The negative toner samples made of polyester with or without coating silica on the surface were prepared to analyze the size dependence of tribo-electric charge *q* and charge to mass ratio *q/m* in two-component developer .

Each sample has five specimens, classified by their diameter from 4µm to 9µm. As carrier sample, the two kinds of type, polymer coated carrier and ferrite binder carrier were prepared.

Results and Discussion

In Figure 1 – Figure 4, toner size dependence on charge to mass ratio *q/m* is shown in combination with polymer coated ferrite carrier. Toner concentration C_t was 5*wt%* in the two component developers. From the experimental results, *q/m* value was shown to increase with decrease of particle size, while the level on *q/m* for toners with silica coating was higher than that for without silica coating : the mean value of *q/m* for the individual particles with silica coating was -34.2μC/g at a mean diameter of 6.2μm and that without silica coating was -21.8μC/g at 6.2μm. As shown in Figures 3 and 4, toner size dependence on *q/m* had a tendency of $d^{-1.5}$ rather than d^{-1}, where *d* is aerodynamic diameter. Toner concentration *Ct* dependence on mass to charge ratio *m/q* was shown for toners without silica coating in a specimen having a mean diameter of 9.2μm in combination with polymer coated ferrite carrier in Figure 5. The mass to charge ratio *m/q* increased linearly with the toner concentration *Ct*. This result is consistent with the prediction from the surface state theory[4]. A size dependence of *q/m* at 3*wt%* of *Ct* in the developer was also shown in Figure 6. The results showed a similar tendency with that at 5*wt%* of *Ct*. Size dependence on the electric charge *q* of toner without silica coating was shown for polymer coated ferrite carrier in Figure 7 and for ferrite binder carrier in Figure 8. The level of electric charge for toners with polymer coated ferrite carrier beads in Figure 7 was slightly larger than that with ferrite binder carrier in Figure 8. From a gradient of the regression line size dependence of electric charge of toner particle can be derived as *n*-value in d^n. The *n*-value with polymer coated ferrite carrier was 2.02 and that with ferrite binder carrier was 2.35.

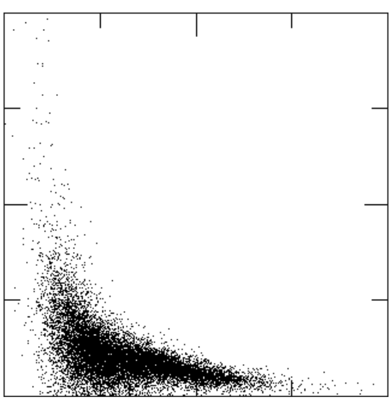

Figure 1. Size dependence on the charge to mass ratio q/m of polymer toner particles without silica coating. (Carrier: polymer coated ferrite carrier, Ct: 5wt%)

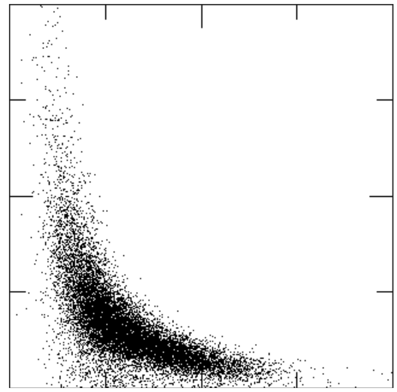

Figure 2. Size dependence on the charge to mass ratio q/m of polymer toner particles with silica coating. (Carrier: polymer coated ferrite carrer, Ct: 5wt%)

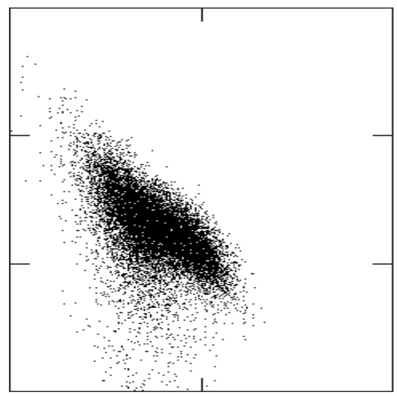

Figure 3. Size dependence on the charge to mass ratio q/m of polyester toner particles without silica coating in log-log scale. (Carrier: polymer coated ferrite carrer, Ct: 5wt%)

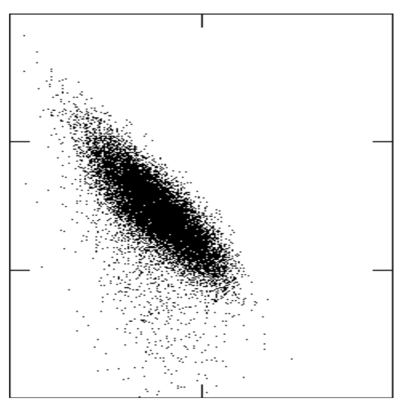

Figure 4. Size dependence on the charge to mass ratio q/m of polyester toner particles with silica coating in log-log scale. (Carrier: polymer coated ferrite carrer, Ct: 5wt%)

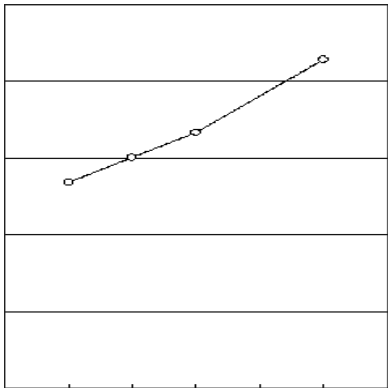

Figure 5. Toner concentration Ct dependence on mass to charge ratio m/q for polyester toner without silica coating. (Carrier: polymer coated ferrite carrer, mean diameter: 9.2 μm)

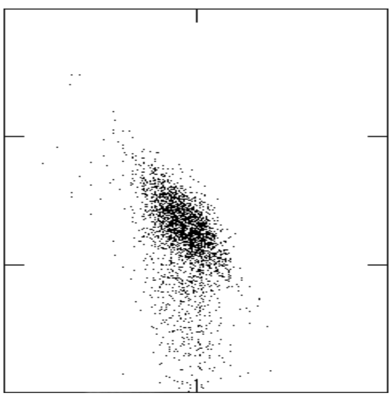

Figure 6. Size dependence on the charge to mass ratio q/m of polyester toner particles without silica coating in log-log scale. (Carrier: polymer coated ferrite carrer, Ct: 3wt%, meam diameter: 9.2μm)

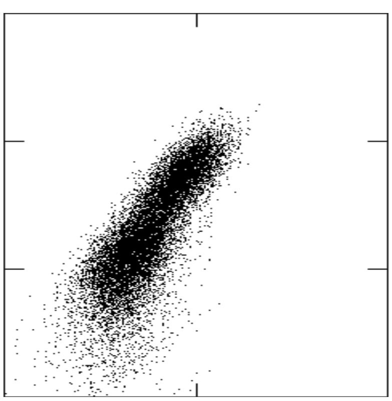

Figure 7. Size dependence on the electric charge of polyester toner without silica coating. (Carrier: polymer coated ferrite carrer, Ct: 5wt%)

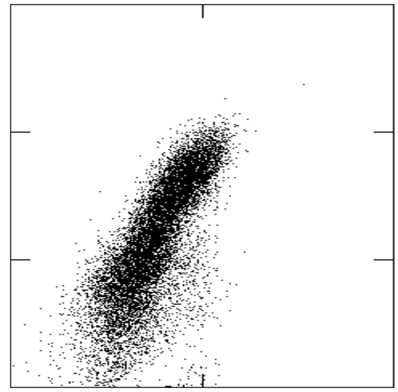

Figure 8. Size dependence on the electric charge of polyester toner without silica coating. (Carrier: ferrite binder carrer, Ct: 5wt%)

From the surface state theory[9)] electric charge quantity to mass ratio q/m is expressed in Eq. (1) , as

$$q/m = 3e\Delta\phi \,/\, [RCt\rho c/Nc + r\rho t/Nt\,]. \qquad (1)$$

Here,

- Nc: number of charge states on carrier per unit energy per unit area
- Nt: number of charge states on toner per unit energy per unit area
- e: electronic charge
- $\Delta\phi$: energy difference between the charge state on toner and the state on carrier
- R: radius of carrier
- r: radius of toner
- ρc: density of mass for carrier beads
- ρt: density of mass for toner particles
- Ct: toner concentration in weight
- m: mass of toner particle

When m is replaced by $4/3\pi\rho t\; r^3$, charge quantity q is can be expressed in Eq (2), as

$$q = 4\pi e\Delta\phi r^3/[RCt(\rho c/\rho t) \,/\, Nc + r/Nt] \qquad (2)$$

From Eq (2) it is shown that electric charge q can be approximately proportional to r^2 in low density limit, $Nt << Nc$, and in larger size region of toner particle when the second term becomes dominant in denominator:

$$q \simeq 4\pi e\Delta\phi Nt\, r^2 \qquad (3)$$

On the other hand, electric charge q tends to be approximately proportional to r^3 in high density limit and in smaller size region of toner particle when the first term becomes dominant:

$$q \simeq [4\pi e\Delta\,\phi\,\rho t\; Nc \,/\, (\rho cRCt)]\; r^3 \qquad (4)$$

However, it is also suggested that q has a certain n-th power dependence more than second of d in the intermediate condition, where n belongs in the region from 2 to 3. In the case of ferrite binder carrier, the lower level on the electric charge means that Nc for ferrite binder carrier is smaller than that for polymer coated ferrite carrier. This suggests that the intermediate condition can be more easily satisfied in the case of ferrite binder carrier.

Therefore, the higher power dependence of toner diameter d on the electric charge, $n = 2.35$, can be explained by the surface state theory. The upper value of electric charge q is expected to be limited by discharge in atmosphere. The size dependence of the value was described previously in terms of the breakdown electric field[2)]. Especially for toners with silica coating, the experimental results agreed with the expect value.

Summary

1. Size dependence of charge to mass ratio q/m for individual toner particles in addition to electric charge quantity q was visualized by a modified E-SPART analyzing method with a computer aided data processing.
2. For tribocharging, electric charge of toner depends on the n-th power of diameter: n is 2.35 for the polyester toner particles without silica coating in combination of ferrite binder carrier, while n is 2.02 for the ones in combination of polymer coated ferrite carrier.
3. A higher power dependence of toner size on electric charge was suggested to be expected by the surface state theory on tribocharging mechanism.

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Biography

Youichi Nakamura received his B.S in Applied Physics from the Waseda University in Tokyo in 1966, and his M. S and Doctor of Science from the Tokyo Metropolitan University in 1968 and 1973, respectively. He joined in R&D Div. of Semiconductor LSI Works of Hitachi Co., Ltd. in 1971. Since 1987 he has carried out on research in the field of electrical and physical evaluation for electrophotographic materials at Nippon Institute of Technology.