Effects of Particle Size and Atmosphere on Tribocharging of Polymer Powders

Takeshi Hasegawa, Manabu Takeuchi
Department of Electrical and Electric Engineering, Ibaraki University
Nakanarusawa, Hitachi, 316-8511 Japan

Abstract

Control of tribocharging characteristics of toners plays an important role in electrophotography. The maximum toner charge may be restricted by the dielectric breakdown of atmosphere gas. In order to clarify this idea, the influences of particle size and atmosphere on the tribocharging characteristics of spherical toners and acrylic powders were examined in this study. The agitation of toner and acrylic powders with copper shots and blow-off measurements were carried out in a shielded box, in which dry air, argon or helium was filled at various pressures. It was found that the tribocharge, Q/M, of the toner and acrylic particles depended on their particle size, the atmosphere gas and its pressure. The tribocharge of toner particles was larger than that of the acrylic particles at the same particle size, which may be attributable to the CCA contained in the toner particles. The tribocharge of toner and acrylic particles increased with an increase in the pressure of atmosphere gas, which suggested that the maximum charge of particles was influenced by the dielectric breakdown of the atmosphere gas. Factors affecting the maximum charge of toner and acrylic particles will be discussed [1].

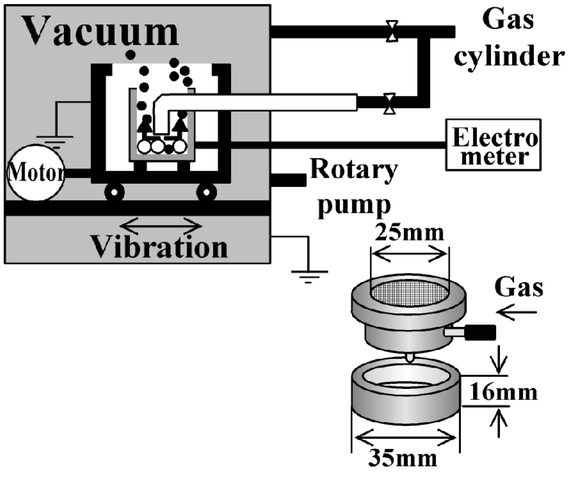


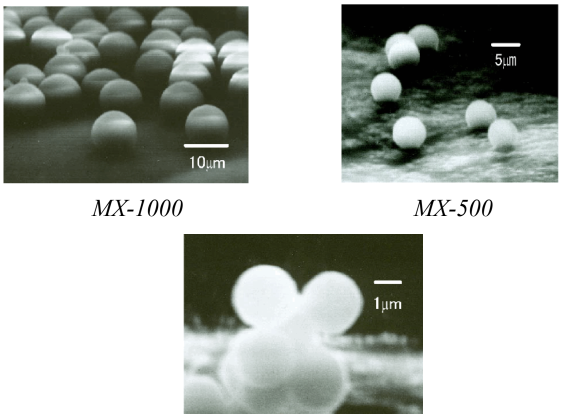
Figure 1. Apparatus for Q/M measurements by blow-off method in a shielded box and Faraday cage.

Introduction

Electrophotography is based on control of charged toner particles by electric fields. For that purpose, control of charge on toner particles is very important. Toner particles are tribocharged in most electrophotography systems. Tribocharging characteristics of polymer particles including toner particles are influenced by many factors such as chemical composition of particles, particle size, resistivity, etc. In addition to these fundamental properties of particles, tribocharging conditions also influence charging characteristics of particles.

From a different point of view, the question, what factors limit the maximum charge of toner particles, is important. Some workers say that the maximum charge of toner particles is limited by dielectric breakdown of atmosphere gas. On the other hand, other scientists reported that small particles can sustain more charge than the critical one which causes the dielectric breakdown of the atmosphere gas [2].

In this study, the influence of particle size and atmosphere on the tribocharging characteristics of the particles was examined by measuring the tribocharge, Q/M, by means of blow-off method, and factors which limit the maximum charge of particles are discussed.

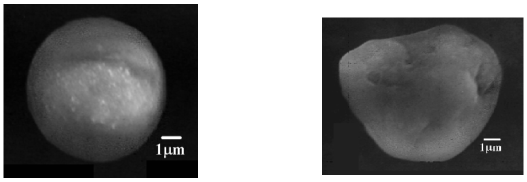


MX-1000

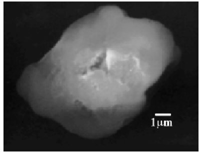
MX-500

MX-300

Figure 2. SEM images for three kinds of spherical acrylic powders.



Spherical toner *Quasi-spherical toner*



Irregular toner

Figure 3. SEM images for three kinds of spherical toner particles.

Measurements of Q/M

Three kinds of acrylic powders and three kinds of toners were used in this study, whose fundamental properties are shown in Table 1. All the acrylic powders were spherical and their average particle sizes were 10µm (MX-1000), 5µm (MX-500) and 3µm (MX-300). The particle size distribution is considerably sharp for all the acrylic powders. One toner was spherical (6.38µm), another quasi-spherical (5.48µm), and the other irregular (5.73µm). The particle size distribution was not so sharp for all the toners. The spherical toner was prepared by polymerization method. The irregular toner was prepared by pulverizing method starting from the spherical toner. The quasi-spherical toner was prepared by mechanical treatment of the irregular toner.

Copper shots were used as rubbing media for tribocharging of the particles. Characteristics of the copper shots are shown in Table 2.

In order to study influence of atmosphere gases on the tribocharging of particles, all the tribocharging measurements were carried out in a shielded box. Agitation of a specimen powder with the copper shots for tribocharging was carried out in the shielded box, and blow-off measurements were also performed in the same box. Figure 1 displays a schematic layout of the experimental apparatus for tribocharging and blow-off measurements.

A mixture of a powder and the copper shots were charged in a Faraday cage, which was vibrated by a motor, and rubbed with each other for tribocharging, and then blow-off measurement was carried out. The Faraday cage was made of aluminum. The upper lid of the Faraday cage was made of a metallic mesh, through which the specimen powder was blew-off, and the copper shots remained in the cage. The experimental procedure was composed of the following three steps. A powder and copper shots were placed in the Faraday cage at the first step. At the following step, the mixture of powder and copper shots was agitated by vibrating the Faraday cage for 3 minutes. Finally, tribocharge of the powder was measured by blowing-off the powder from the mixture. Dry air, argon and helium were used as the atmosphere gas, and their pressure was changed from 1.33 to 1013 hPa.

Table 1. Fundamental characteristics of polymer powders and toners.

	Mean particle size	Main resin	Shape
Acrylic powder (MX-1000)	**10µm**	**Acrylic**	**Spherical**
Acrylic powder (MX-500)	**5µm**		
Acrylic powder (MX-300)	**3µm**		
Toner (spherical)	**6.3µm**	**Polystyrene**	**Spherical**
Toner (quasi-spherical)	**5.4µm**		**Quasi-spherical**
Toner (irregular)	**5.7µm**		**Irregular**

Electric Field Strength for Dielectric Breakdown

Acceleration of charged particle and repetition of ionization by collision cause a dielectric breakdown of the atmosphere gas, which may limit the sustainable charge of a polymer particle or a toner particle. Electric field strength at the surface of a charged spherical particle is given by the following equation

$$E = \frac{Q}{4\pi\varepsilon_0 r^2} \tag{1}$$

where Q is particle charge, e_0 is dielectric constant of vacuum and r is particle radius. When the electric field in the vicinity of a charged particle exceeds the critical value for dielectric breakdown, the breakdown of the atmosphere gas occurs, which may limit Q/M of particles. Therefor, $Q_{\max}$, the sustainable maximum surface charge density of particles, is expressed in the following form.

$$\sigma = \varepsilon_0 E_{bd} \tag{2}$$

Minimum electric field strength for dielectric breakdown, E_{bd}, is expressed by a function of only pressure of gas. For example, E_{bd} of air at 1013hPa (atmospheric pressure) is 3.0×10^6V/m. The value of E_{bd} decreases with a decrease in atmosphere gas pressure. This phenomenon is known as Paschen's law. The values of E_{bd} are larger in the order of dry air, argon and helium at a pressure. Sustainable maximum surface charge densities, σ, calculated by eq. (2) are given in Table 2.

Table 2. Theoretical values for sustainable maximum charge density in various atmosphere gases.

	In dry air	In argon	In helium
Charge density	**26.9µC/m²**	**7.8µC/m²**	**4.3µC/m²**

Results and Discussion

All the acrylic powders used in this study were charged positively with the copper shots. While all the toners were charged negatively. Dependence of measured Q/M for the acrylic powders on gas pressure in dry air, argon and helium are shown in Figures 3, 4 and 5, respectively.

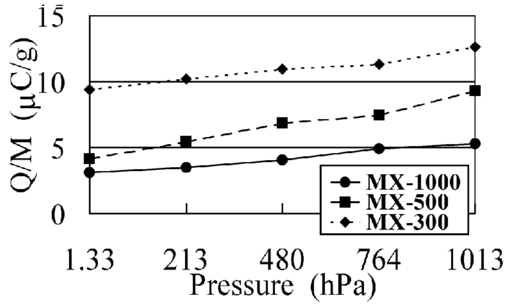


Figure 4. Pressure dependence of tribocharge Q/M with copper shot for three kinds of acrylic powders in dry air.

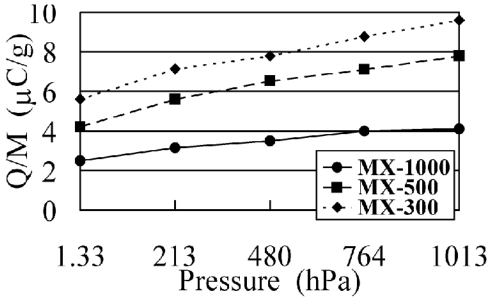


Figure 5. Pressure dependence of tribocharge Q/M with copper shot for three kinds of acrylic powders in argon.

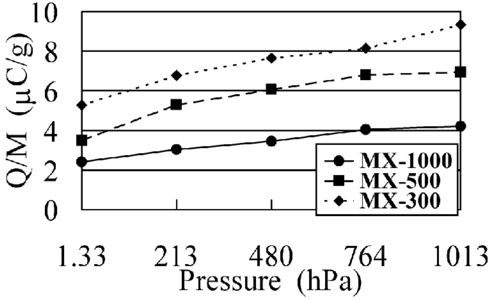


Figure 6. Pressure dependence of tribocharge Q/M with copper shot for three kinds of acrylic powders in helium.

The tribocharge Q/M of acrylic powders increased with increasing gas pressure regardless of gases. These results seem to follow Paschen's law and suggest that the maximum tribocharge of particles is influenced by the dielectric breakdown of the atmosphere gas.

All the three kinds of toners used in this study also showed similar pressure dependence of Q/M to the acrylic powders as shown in Figures 7,8 and 9. The Q/M values were larger than the values of acrylic powders for all the toners regardless of atmosphere gases as shown in Table 3.

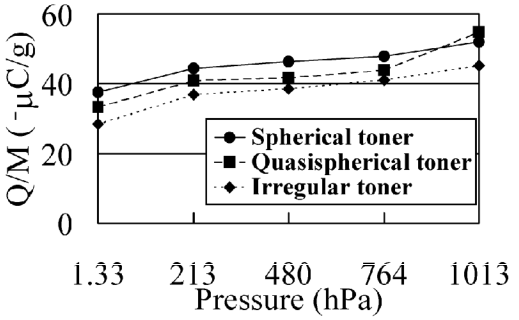


Figure 7. Pressure dependence of tribocharge Q/M with copper shots for three kinds of toners in dry air.

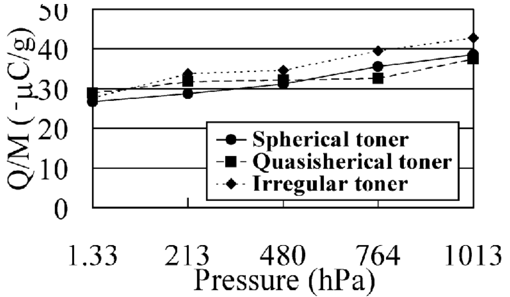


Figure 8. Pressure dependence of tribocharge Q/M with copper shots for three kinds of toners in argon.

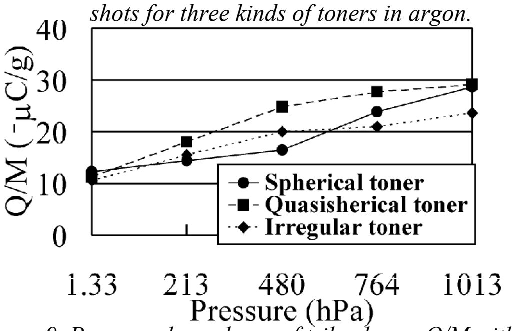


Figure 9. Pressure dependence of tribocharge Q/M with copper shots for three kinds of toners in helium.

Table 3. Comparison of experimental values of tribocharge for acrylic powders and toners in dry air, argon and helium at 1013hPa.

	In dry air	In argon	In helium
Acrylic powder (MX-1000)	**5.2μC/g**	**4.3μC/g**	**4.2μC/g**
Acrylic powder (MX-500)	**9.3μC/g**	**7.8μC/g**	**6.9μC/g**
Acrylic powder (MX-300)	**12.6μC/g**	**10.1μC/g**	**9.3μC/g**
Toner (spherical)	**52.0μC/g**	**38.6μC/g**	**28.7μC/g**
Toner (quasi-spherical)	**54.9μC/g**	**37.4μC/g**	**29.1μC/g**
Toner (irregular)	**45.2μC/g**	**42.8μC/g**	**23.6μC/g**

If the tribocharge of a particle depends on only electric field strength for the dielectric breakdown of the atmosphere gas, the surface charge density of a particle should be equal to the values in Table 1 regardless of particle size. In order to check whether experimental tribocharge density is larger than the theoretical value or less, the surface charge densities are plotted for three kinds of acrylic powders in Figures 10. The experimental Q/M values are fairly less than the theoretical value in dry air for all the acrylic powders. This result suggests that the rubbing of the acrylic powder with copper shots may not strong enough for the maximum charging which causes a dielectric discharge. The experimental surface charge density, Q/A, are also less than the theoretical value in argon. However, the experimental Q/A values are larger than the theoretical value for all the acrylic powders. The maximum sustainable charge may be limited by the dielectric breakdown of atmosphere gas in this case. The larger amount of surface charge density than the theoretical value may be explained by the fact that the acceleration field is not broad enough for dielectric breakdown for small particles. In other words, the electric field strength decays so rapidly with distance from the particle surface in a small particle that the acceleration of charged particles is not sufficient for causing dielectric discharge.

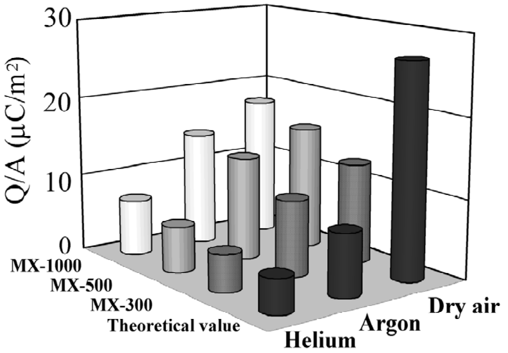


Figure 10. Comparison of experimental and theoretical values of maximum surface charge density for acrylic particles in various atmosphere.

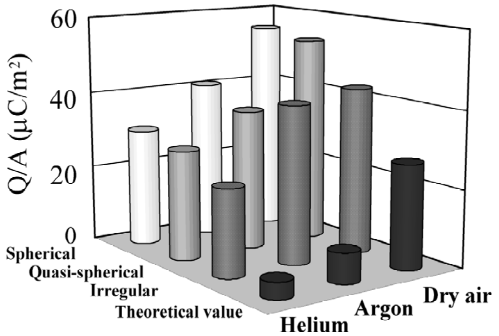


Figure 11. Comparison of experimental and theoretical values of maximum surface charge density for toners in various atmosphere.

In the case of toners, the experimental Q/A values are larger than the theoretical value for all the toners in all the atmosphere gases as shown in Figure 11. Because the toner particles contain CCA, they are more easily tribocharged than the acrylic particles. The maximum tribocharge can be considered to be limited by the dielectric discharge in the toners used in this study. The lager Q/M values than the theoretical one may also be attributable to a small particle size of toners.

Conclusion

Influence of particle size and atmosphere gas on the tribocharge, Q/M, was studied for acrylic powders and toners, and the following results were obtained.

(1) The magnitude of Q/M of acrylic powders and toners decreases in the order of in dry air, argon and helium.
(2) Q/M of the acrylic powders and toners increased with an increase in atmosphere pressure.
(3) Experimental values of Q/A were larger than the theoretical value for acrylic powders in helium.
(4) Experimental values of Q/A were larger than the theoretical value for all the toners in all the atmosphere gases.
(5) The larger surface charge density than the theoretical value may be explained by the fact that the acceleration field is not broad enough for dielectric breakdown for small particles.

References

1. Takeshi Hasegawa, Manabu Takeuchi, Proc. Japan Hardcopy 2000, pg. 49, (2000) [in Japanese]
2. Peterson J.W., J. Appl. Phys., **907**, pg. 25, (1954).

Biography

Takeshi Hasegawa received his B.E. in Department of Electrical and Electronic Engineering from Ibaraki University, Japan in 1999. He is now working for his M.E. at the same university. His main focus has been tribocharging of polymer powders in various atmospheres to clarify factors affecting the Q/M of polymer powders.

E-mail : nm9626@hcs.ipc.ibaraki.ac.jp