Relationship between Tribocharge and Contact Potential Difference in Toner-Carrier Systems

Masahide Yamaoka, Manabu Takeuchi
Department of Electrical and Electronic Engineering, Ibaraki University
Nakanarusawa, Hitachi, Japan

Abstract

Relationship between tribocharge Q/M of an acrylic powder and contact potential difference of metal beads, with which the polymer was tribocharged, was examined. First a contact potential measuring system for powdered materials was fabricated, which was based on Kelvin method. Tribocharge of the acrylic powder was measured by blow-off method. Metals beads of gold, silver, copper, etc. were employed as the rubbing medium. It was found that the contact potential difference of metal beads was influenced by their surface oxidation. The contact potential difference of metals had a linear relationship with their work function. The Q/M of acrylic powder has a close relationship with contact potential difference of metals qualitatively, but quantitative agreement between Q/M of acrylic powder and contact potential difference was not obtained.

Introduction

In recent years, technologies using electrostatic charging of powders, for example electrophotography and powder coating, are widely used. Those technologies utilize electrostatic forces ingeniously. Therefore, it is important to control the charge of powders for high performance.

Usually photoreceptor and toner are charged by corona discharge and tribocharging, respectively, in electro-photography. The corona charging of a photoreceptor is usually controlled by the applied voltage to the corona electrode. Toner particles are tribocharged by friction with carrier beads and a doctor blade in dual-component and mono-component developers, respectively. However, many factors, such as particle size of toner, atmospheric condition, etc., influence tribocharging of toner particles, and it is not so easy to control tribocharge of toners.

It is well known that contact potential difference between two materials also influences their tribocharging. Ionization potential, a similar concept to the contact potential difference, is often used when arguing about tribocharging of electrophotographic developers.

We studied influence of contact potential difference of rubbing medium on tribocharging of polymer powders as well as work function. For that purpose, we made an apparatus for measuring contact potential difference of powdered materials. First, this paper describes outline of the apparatus briefly. Then experimental results of measurements of contact potential difference are given for a polymer powder and several kinds of metal beads. Finally, influence of contact potential difference and work function on tribocharge of the polymer powder with metal beads will be discussed.

Experimental

Contact Potential Difference Measurements

The schematic drawing of an apparatus for contact potential difference measurement is shown in figure 1. This measuring system is based on Kelvin method. The system consists of an upper vibrating electrode, a sample layer with a thickness of 1mm, a lower electrode, a variable DC power supply and an electrometer for measuring the unsteady current. The upper and lower electrodes are made of gold for prevention of oxidation of the electrodes. The diameters of upper reference electrode and lower electrode are 20 mm and 33 mm, respectively. The vibration frequency and amplitude are 3 Hz and 3 mm, respectively. The principal of the contact potential difference measurement is as follows: Let us suppose some contact potential difference between the sample and the upper electrode in figure 1. When the upper electrode vibrates at a certain frequency, the capacitance between upper electrode and sample fluctuates. Unsteady current is happened to flow to the measuring circuit by the fluctuation of capacitance. The bias voltage supplied to the upper electrode from the variable DC power supply is tuned to minimize the unsteady current. The apparent contact potential difference between the upper electrode and the sample is equal to the bias voltage, when the unsteady current due to the vibration of upper electrode is reduced to a minimum.

Since the upper electrode is made of gold, contact potential difference of a specimen to gold is obtained by the measurement in this study.

Blow-off Measurements

The schematic drawing of an apparatus for measurements of tribocharge between a polymer powder and metal beads is shown in figure 2. This measuring system is based on the blow-off method. A Faraday-cage, made of aluminum, which vibrates with a motor, is installed in a vacuum chamber. The Faraday-cage is connected to an external electrometer for tribocharge measurements. The frequency and amplitude of vibration of the Faraday-cage is 3 Hz and 30 mm, respectively. The agitation of specimen was carried out in vacuum,[1] and the blowing-off was made by using dry-air with a pressure of 6 kg/cm^2.

An acrylic powder was used as an ideal powder in this study, which was spherical and whose diameter was 8 µm. Beads of gold, silver, copper, titanium, tin and zinc were used for the rubbing medium, whose diameters were 1 to 3 mm.

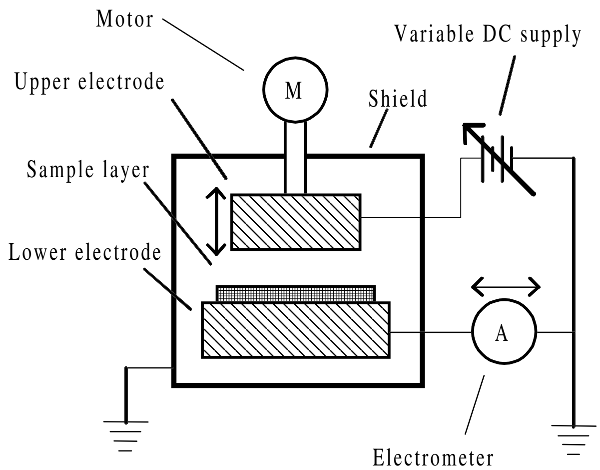

Figure 1. Schematic drawing of an apparatus for contact potential differenced measurement.

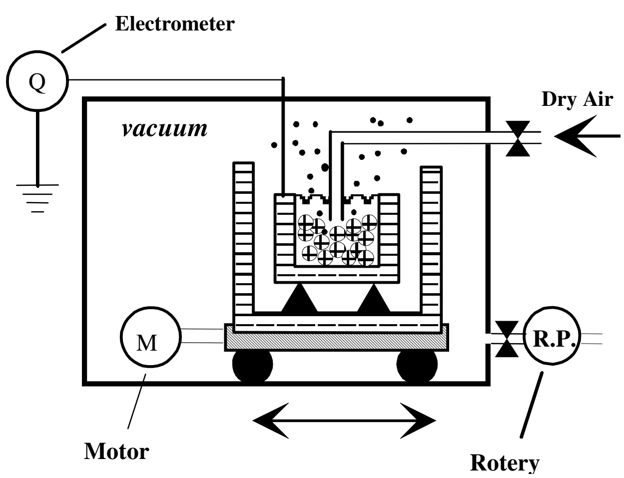

Figure 2. Schematic drawing of an apparatus for measurements of tribocharge between a polymer powder and metal beads.

Results and Discussion

Relationship Between Contact Potential Difference and Work Function of Metals

The work functions against contact potential difference to gold are plotted in figure 3 for metal plates, corresponding to the metal beads mentioned above. The contact potential difference of metals to gold has a linear relationship with their work function, which were measured by photoelectron method.

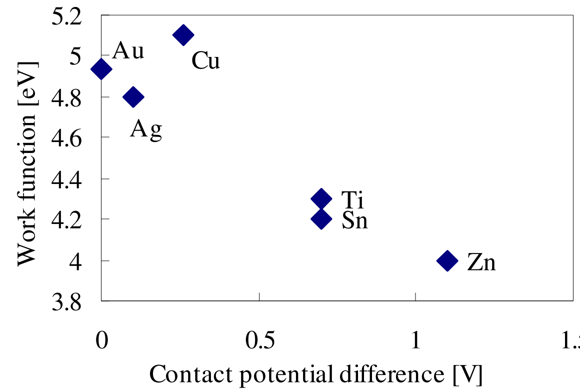

Figure 3. The work functions against contact potential difference to gold.

Contact Potential Difference and Ionization Potential of Acrylic Powder

Since the contact potential difference and ionization potential of the acrylic powder may be influenced by its charging, the charge on the acrylic powder was eliminated by two methods, by using a de-ionizer, and charge elimination by using methanol. The contact potential difference and ionization potential of the acrylic powder are tabulated for three treatments of the specimen in table 1. Since the untreated specimen has some charge before the measurement, the value of contact potential difference may have some error. The treatments by both methanol and the de-ionizer reduce the charge on the specimen. Since the former may give anther error by adsorption of methanol, the data obtained by using the de-ionizer are employed in this paper for further discussion, which will be more consistent with other measurements.

Table 1. The Contact Potential Differences and Ionization Potentials of the Acrylic Powder.

	Contact Potential Difference [V]	Ionization Potential [eV]
Untreated	0.49	4.29
Methanol	0.80	4.18
De-ionizer	1.60	4.25

Relationship between Q/M and Contact Potential Difference and Work Function

The Q/M of the acrylic powder are plotted against contact potential difference and work function of metal beads in figures 4 and 5, respectively. It seems that the contact potential difference has a closer relationship with Q/M than work function. Actually the correlation coefficient between Q/M of the acrylic powder and contact potential difference and work function of metal beads are -0.89 and 0.61, respectively.

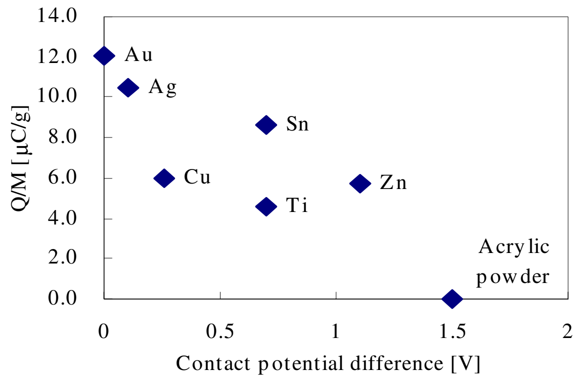

Figure 4. Relationship between Q/M of acrylic powder and contact potential differences of metal beads.

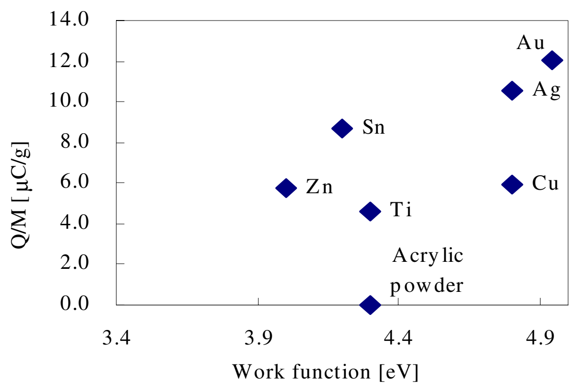

Figure 5. Relationship between Q/M of acrylic powder and work functions of metal beads.

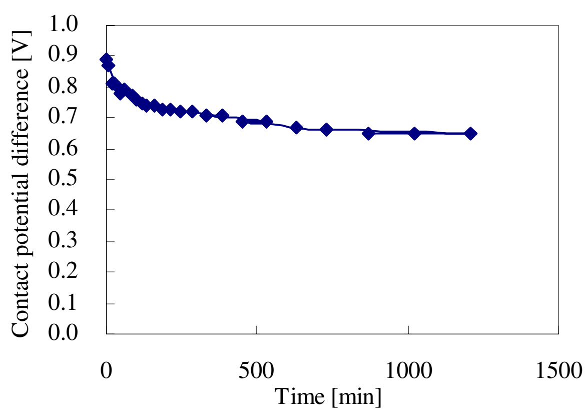

Figure 6. The influence of surface oxide of Ti *on its contact potential difference with time after polishing with sandpaper.*

Effect of Polishing on Contact Potential Difference and Work Function of Metals

In order to check the influence of surface oxide of metals on contact potential difference and work function, their change with time after polishing with sandpaper was monitored.[2] One of the results is shown for titanium in figure 6. The polishing of titanium increased its contact potential difference, suggesting the fact that some surface oxide was removed. However, the contact potential difference decreased again when being exposed to air, suggesting surface oxidation. Similar results were obtained for other all metals as shown in figure 7.

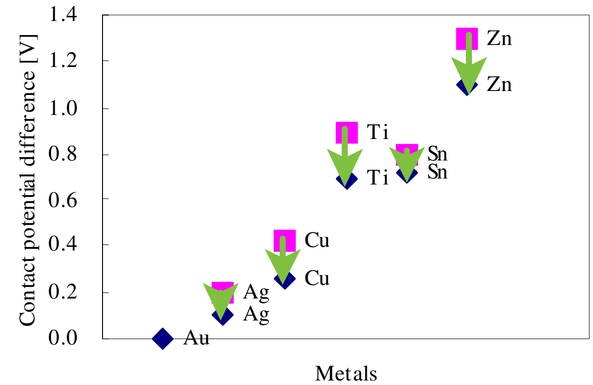

Figure 7. The influence of surface oxide of several metals on contact potential difference with time after polishing for all metal beads used in this study.

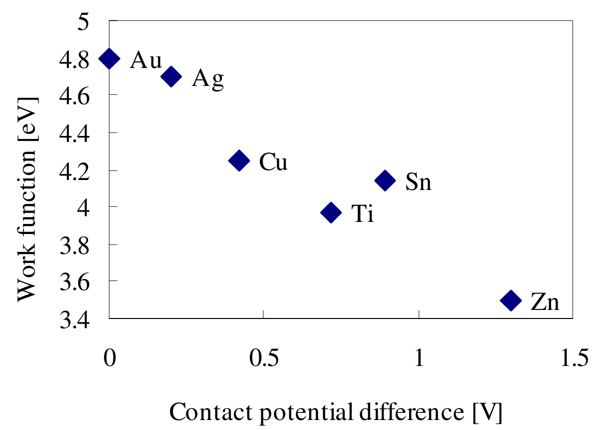

Figure 8. Relationship between work functions and contact potential differences of metal beads after polishing.

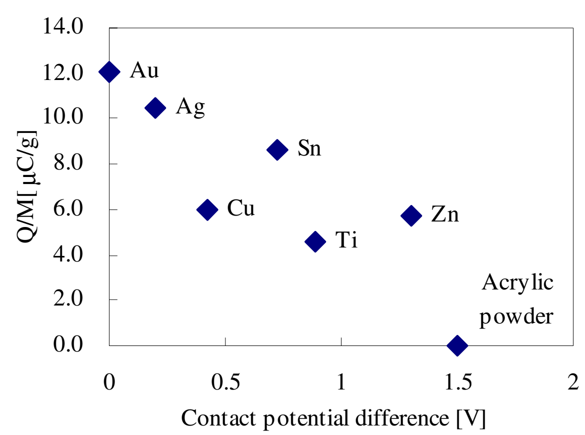

Figure 9. Relationship between Q/M of acrylic powder and contact potential difference of metal beads after polishing.

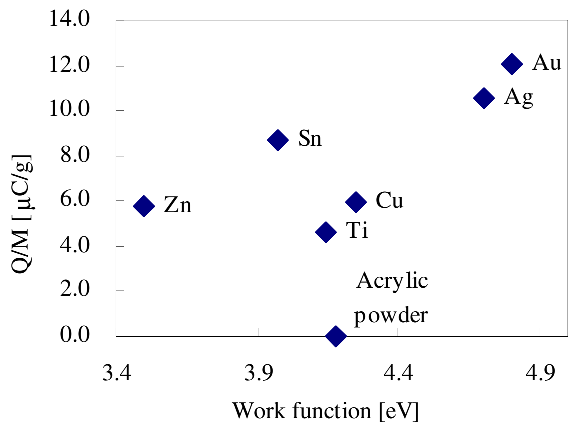

Figure 10. Relationship between Q/M of acrylic powder and work functions of metal beads after polishing.

Similar results to figures 3, 4 and 5, when using polished metals, are shown in figures 8, 9 and 10, respectively. Similar relationships were obtained again between Q/M of acrylic powder and contact potential difference and work function of metals. The polishing made the correlation between Q/M of acrylic powder and contact potential difference of metals much closer. The correlation coefficient changed from –0.89 to –0.93 by the polishing. These results may be attributable to the fact that some surface oxide of metal beads is removed during agitation with the polymer powder in the Faraday-cage.

Factors Determining Q/M of Powder

If dielectric breakdown of air limits the maximum charge of the acrylic particle, it will be 5.4 fC for the particle of the diameter of 8 •m. Since all the values of Q on a particle obtained in this study were less than this value, it should be noted that the maximum charge of a particle is determined by other factors except for the dielectric breakdown of air. For example, the charge Q on a particle of 8 μm rubbed with gold was 3 fC.

The estimation of the charge on a particle due to the contact potential difference is not easy, because it depends on the situation of the particle and its surrounding condition. Roughly speaking, however, the experimental value of Q on a particle was larger than an estimation value based on contact potential difference. The reason is ambiguous right now.

Conclusions

A contact potential difference measuring system was fabricated and contact potential differences of an acrylic powder and several kinds of metal beads were measured. The following results were obtained.

1. The values of contact potential difference of metals are affected by their surface states.
2. The contact potential difference of metals has a linear relationship with their work function.
3. The Q/M of acrylic powder has a close relationship with contact potential difference of metals qualitatively, but quantitative agreement between Q/M and contact potential difference was not obtained.

References

1. Richard P. N. Veregin, David Powell, Carl P. Tripp, Maria N. V. McDougall, Margaret Mahon, *J. Imaging Sci. Technol.*, **41**, 192 (1997)
2. A. R. Akande, J. A. Adedoyin, *J. Electrostatics*, **51/52**, 105 (2001)

Biography

Masahide Yamaoka received his B. Eng. in Electrical and Electronic Engineering from Ibaraki University in 2000. He is now working for M. Eng. at the same university. He is studying factors affecting toner charging, such as contact potential difference, ionization potential, etc.