Tribo-charging Between Toners and Carrier Bead Surfaces

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Abstract

The tribo-charging behavior between toner particles and carrier beads were studied by measuring the Q/M and Q/D spectra of toner mixing with ferrite carriers. Initially, toners without extraparticulates were used. The Q/M values after tribo-interaction were found to always increase with mixing time, but it saturated when a critical time was reached. The saturation value of Q/M decreased with the toner concentration. The wrong-sign toner population also decreased with mixing time. When extraparticulates were added into the toner before mixing, the charging characteristic changed completely. The Q/M data were strongly dependent with the selection of extraparticulates, indicating that the tribo-charging process between the carrier and toner was overwhelmingly a surface interaction phenomenon. In addition, we found that smaller toner particles always contained lower charge per particle (q_p) which followed a linear dependence with the square of the particle diameter.

Introduction

Tribo-charging[1,2] between insulator surfaces is very important for electro-photographic processes[3-7]. Although tribo-charging phenomena had been observed thousands years ago, the actual physical events behind charge generation are still obscure. The suitable modeling of the tribo-charging between toner and carrier is also still under investigation[3-7]. The tribo-charging between toner and carrier, however, was complicated with the presence of extraparticulates added in significant quantity in toner to facilitate the flow properties. Our aims here, therefore, is to first separate the effect of the extraparticulates from the toner-carrier tribo-charging behavior. Carefully studying the charging behavior with Q/M and Q/D measurements hopefully may unveil the basic principles behind this important but perplexing charging phenomenon.

Experimental Procedures

The toner used throughout the whole experiment are the extraparticulate free SX compatible toner kindly supplied by the Trends Tone Company. the average diameter of the toner particles was around 13.0 µm. The true density and apparent density were 1.5 and 0.53 g/cm^3 respectively. The carrier beads (Powder Tech; F141-1030) were acrylate coated ferrite particles with the diameter around 82 µm. The true density and apparent density were 5.5 and 2.6 g/cm^3 respectively. The three types extraparticulates used here were high purity (99.8%) amorphous fumed silica surface treated to yield hydrophobic surface properties: R805; R504 from Degussa and T720 from Cabot.

To study the tribocharging behavior of toner, the extraparticulate-free SX-compatible toner was blended with carrier beads by a fixed weight fraction before putting in a roller mixer for tribo-charging. The roller mixer turned 200 rpm, and the mixing lasted for a fixed length of time, ranging from 1 minute to 1000 minutes. For the study of the extraparticulate effect on toner charging, a fixed amount of extraparticulate was blended into toner by a V-blender before tribocharged with the carrier. After mixing in the roller mixer, the tribocharged toner was analyzed by Q/M and Q/D meter to measure the tribocharges on toner.

A Q/M meter (Epping GMBH; Q/M meter type 05) was used to measure the average toner charge normalized to toner weight after mixing with carrier beads. The charge distribution was obtained by using the Q /D meter (Epping GMBH) with which toner population versus Q/D, where D is the diameter of toner particle diameter, was measured by optically detecting the optical density profile versus flight length of the toner laminar flow between two charged parallel plates. A SEM (JEOL; JSM 5200) was used to examine the toner, carrier, and the extraparticulate before and after tribocharging.

Results

Effect of Mixing Time

The tribocharges generated from toner-carrier contacts was first measured by Q/M as a function of mixing time between toner and carrier. The Q/M values between the SX-compatible toner and the carrier beads was negative. The negative charge increased with the mixing time initially, but the rate decreased as the mixing time increased, finally the Q/M value leveling off to a saturated limit. This behavior was observed for the various toner concentrations (Ct) from 2.5% to 30%, as shown in Figure 1.

The charge generation from toner-carrier tribo-actions was further analyzed by Q/D meter where the charges of the toner particle were measured as Q/D, viz. charges normalized to the particle diameter, in a distribution of the relative population over the measured Q/D range. Generally, the Q/D spectrum (population versus Q/D value) of the charged toner appeared to be a symmetric distribution with Q/D, insensitive to the toner charging time and the toner concentration. However, the Q/D value corresponding to the central peak of the symmetric distribution moved to the more negative direction as the mixing time increased. The increase of the negative charges slowed as the mixing time increased and eventually approached to zero, demonstrating a similar behavior to that of the Q/M data.

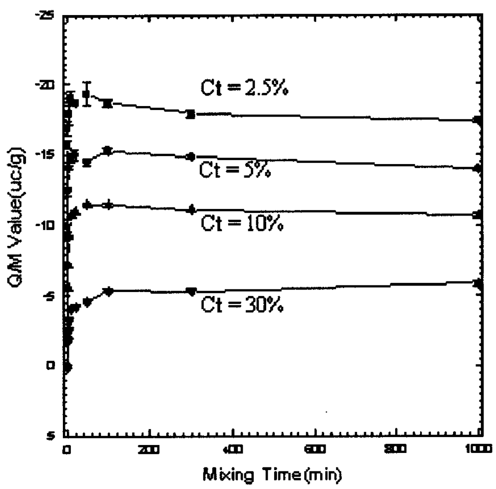


Figure 1. Toner tribocharge Q/M versus mixing time for various toner concentration C_ts.

The wrong sign toner (WST), defined as the toner population that possess the opposite sign of charge to that held by the majority of the toner, was found to decrease with mixing time when the charge distribution shown in Figure 2 moved afar from the neutral zero charge point.

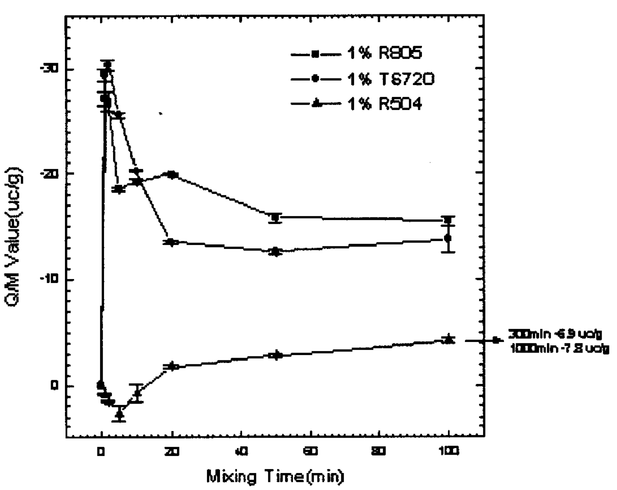


Figure 2. Tribocharges of toner blended with extraparticulates versus mixing time.

Effect of Toner Concentration

As shown clearly in Figure 1, the tribo-charges decreased with the toner concentration C_t independent of the mixing time. Closely examining the data indicated that the saturation time for the tribocharge to reach the level-off Q/M value increased with C_t. The same behavior was also observed in the Q/D data.

The wrong sing toner (WST), however, was found to increase with toner concentration.

Effect of Toner Particle Size

The tribo-charge of the toner can be further examined in such a way that the relative toner population versus charge q can be obtained for the various size components in the toner. The toner was sub-grouped into 8 components according to the particle size, and for each group the charge distributions q versus particle size was obtained. It is clearly seen that the larger particles generally hold greater amount of charges and the charge distribution spread over a larger q range. A plot of the q value corresponding to the peak population, q_{max}, versus the square of the mean particle diameter shows excellent fit to a straight line for the entire charge range. This behavior indicates that the charges generated during tribo-actions and collected at the toner is proportional to the surface area of each particles.

Effect of Extraparticulates

Effect of Extraparticulate Concentration C_e

Addition of extraparticulates introduced an overwhelming effect on the tribocharging behavior of the toner. The Q/M value could either increase or decrease, depending on the type of extraparticulates, as the extraparticulate concentration C_e increased when the toner concentration C_t and mixing time were fixed. For example, in the case of TS720, the Q/M became more negative as C_e increased, from -14 μc/g at $C_e = 0$ to nearly -28 μc/g for $C_e = 2\%$. For C_e higher than 2%, the Q/M remained almost constant. Similar behavior was observed for R805 but the saturation Q/M value was lower, approximately -18μc/g, and the threshold C_e for constant Q/M was much lower, at approximately 0.2%. On the other hand, the extraparticulate R504 introduced opposite effect on the Q/M, i.e. the Q/M became more positive as the concentration of R504 increased, from -14 μc/g at $C_e = 0$ to nearly +5 μc/g for $C_e = 2\%$, after which the Q/M value was independent with C_e. From this result, it is evident that the added extraparticulates could over-ride the original tribo-charging characteristic of the toner and impart the intrinsic charging properties into the system. Although the three extraparticulates were all high purity fume silica, apparent the different surface treatment and the geometry of the fine particles resulted in drastically different charging characteristics.

As the extraparticulate concentration increased, the distribution of toner population over Q/D was also found to be sharper, indicative of a more uniform charging characteristics among the toner particles. Furthermore, the wrong sign toner decreased significantly with increasing C_e.

Effect of Mixing Time

The effect of mixing time was shown in Figure 2 for the toners blended with the three different extrapartic-ulates. All three curves seemed to follow a similar trend that the tribo-charge increased quickly in the beginning but subsequently decreased to a level-off value. This general trend is again similar to that of the extraparticulate free toner. However, there is a subtle difference to be noted. For R805 and TS720 which imparted negative charge to the toner, the Q/M decreased to a value close to extraparticulate free saturation Q/M value around -14 μc/g. For the positive-chargeimparting R508, however, the Q/M decreased continuously to become negative for longer mixing time. This behavior indicated the change of charging characteristic of the extra-particulate modified toner during mixing. As will be discussed further later, this variation of behavior with time was due to the loss of extraparticulates from the toner surfaces to the carrier bead surfaces.

Similarly to the Q/M data, the Q/D spectra of the extraparticulate-added toner charged with the carrier beads also shifted quickly with mixing time in the beginning but slowed to a saturated distribution for longer mixing time.

Effect of Toner Concentration C_t

At low extraparticulate concentration (C_e< 0.2%), the effect of toner concentration C_t on charging of the extraparticulate-added toner is similar to that without the extraparticulates, that is, as C_t increased the level-off value of Q/M increased continuously. However, at higher extraparticulate concentrations (C_e> 1%), the effect of C_t became more complicated. For R504 fumed silica, for which positive charging was the intrinsic tribo-charging, the Q/M value after fixed length of mixing increased initially to higher positive charges as the toner concentration increased. The Q/M value then decreased, leveling to zero charging as C_t increased up to 50%. This behavior will be discussed later in this paper.

Discussions

Toner-carrier Charging

During the process of mixing, the toner particles constantly impact and contact the surfaces of the carrier beads and other toner particles to provide opportunities of charge transfer between surfaces. The driving force for charge transfer between two insulators was postulated to be due to the difference of local work function of the two contacting surfaces. That is, electron would transfer from the surface where the work function is smaller to that with higher work function. Under the appropriate condition, the carrier beads should provide a constant source or sink for the electron transfer to or from the toner particles according to the work function of the carrier coating. Since the difference in the work functions of two contacting toner particles was in average to be zero, the tribo-contacts between toner particles effectively generates no net charge change. Consequently, as the mixing time increase, the average charge on the toner particle increased due to the contacts with carrier beads.

However, due to the electrostatic repulsive force between charges of the same sign, it became more difficult to transfer electron to a surface which is negatively charged. At the same time, the difference in work function between the two contacting surfaces will decrease with charge transfer. These two effects combined to result in the eventual halt of any further charge transfer. This is exactly what had been observed in the previous section that the charge, Q/M or Q/D, increased with mixing time but eventually became constant as the mixing time exceeded certain threshold values.

Although the contacts between toner particles in average produced no net charge change, they could generate wrong sign toner as shown in the Q/D spectra due to the fluctuation of surface properties of toner particles. It is well known that toner was made of polymer resin combined with various ingredients to give the proper magnetic, triboelectric, adhesive, as well as flow properties. The distribution of these ingredients was by no means to be perfectly uniform, the "work function" varied from one local spot to another. Therefore, although the net change in charge was zero, charge transfer between toner particles was possible, creating the wrong sign toner (WST).

Since the wrong sign toner was generated from the toner-toner contact due to the fluctuation of surface properties, it increased with the toner concentration and decreased as the uniformity of the toner surface increased when extraparticulates were added and adsorbed on the toner particles. However, as the mixing time increased, the WST could come in contact with the carrier surface which had even higher electron work function, the WST eventually would become right sign charged, and therefore the population of WST decreased with mixing time.

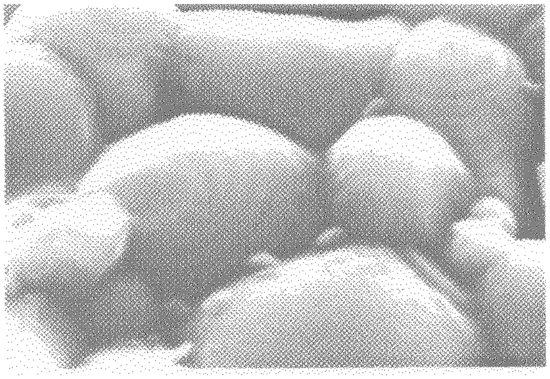
Moreover, when the toner concentration increased, the relative number of carrier beads decreased, so did the amount of electrons that could be transferred onto the toner surfaces. In addition, the relative number of toner particles increased at the same time, therefore the available electrons transferred from carrier to each toner particle decreased with toner concentration.

Due to the fact that tribocharging between toner and carrier is essentially a surface contact phenomenon, larger toner particles could therefore accumulate greater charges as the number of the surface states on the toner surface increased in average with the surface area.

Effect of Extraparticulates

It had been reported before[8] that the added extraparticulates usually adsorb onto the toner surfaces. In fact, it is a common practice to surface treat the hydrophilic fumed silica with silanes or silicone fluids in order to make the fine particles more hydrophobic, hence more capable to adsorb better to the toner surfaces to yield improved flow properties. Since the tribocharging between toner and carrier is primarily a surface interaction, as evidently shown in our data, it is of no surprise that the addition of extraparticulates could change the tribo-charging behavior completely. The modified final charging characteristics were results of surface contact electrification between the carrier beads and the extraparticulates, if the extraparticulate concentration C_e exceeds the monolayer coverage. This is evident from the Q/M data versus C_e for the three different extraparticulates tested in this report. Therefore, extraparticulates can be used as the so-called external charge control agent since carefully tailored extraparticulate can impart the desired charging properties to the toner-carrier systems.

However, the adsorption of the extraparticulates to the toner surfaces is not permanent. The fine particulates could fall off the toner surfaces and cause a return to the behavior of the extraparticulate free toner, as shown in Figure 2. In many cases, moreover, the extraparticulates could be transferred during the tribocharging to the oppositely charged carrier surfaces, causing contamination of the carrier. This effect is shown in Figure 3 where the SEM micrographs of the rolled carrier beads showing the coverage of the fine particulates. The contamination of the carrier would cause the subsequent charging ineffective, leading to problems of toner development.



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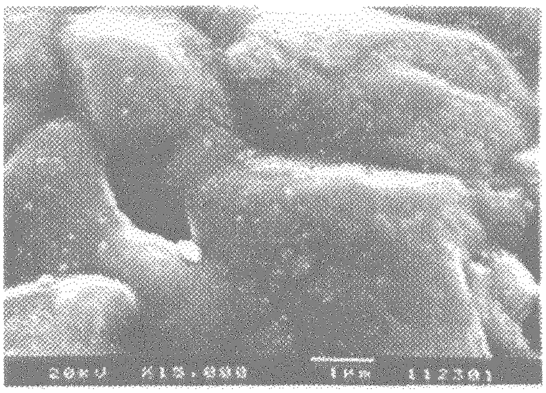

b.

Figure 3. The SEM micrographs of carrier: a) mixed with extraparticulate-free toner, and b) mixed with extraparticulate-added toner.

The coverage of the high purity extraparticulates, however, makes the surface properties of the toner particles more uniform. The increase in uniformity resulted in the decrease of wrong sign toners which were generated due to toner surface heterogeneity during contacts between toner particles.

Conclusions

It therefore can be concluded that:

1. The electric charges, either measured in Q/M values or Q/D distributions, of the toner tribo-mixed with carrier beads is dependent on the mixing time. The charges increase quickly in the beginning but later saturated to an equilibrium value as the tribo-time becomes larger than the threshold value.

2. The electric charge from toner-carrier contact electrification decreased with the toner concentration C_t. The charging rate also decreased with the toner concentration C_t.

3. The electric charges accumulated on the toner particles during contact with carrier beads increased linearly with the surface of the toner particles.

4. The wrong sign toners decreased with mixing time, but increased with the toner concentration. The wrong sign toner is possibly generated by contact between toner surfaces that have different surface work functions due to fluctuation of surface properties of the toner materials.

5. The addition of extraparticulates in toner can completely change the charging behavior of the toner. Evidence showed that this is due to the surface coverage of the toner particles by the fine particulates.

6. The extraparticulates, however, may fall off the toner surfaces, causing a return to the original toner charging behavior. In some cases, the transfer of the extraparticulates to the carrier beads can result in contamination that significantly reduces the effectiveness of the development system.

7. The wrong sign toner decreased with increasing extraparticulate concentration, probably due to the increase of uniformity of the toner surfaces covered with the high purity extraparticulates.

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