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Original Research Paper

Microscale gap breakdown induced by toner triboelectrification

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ABSTRACT

Microscale gap discharge-relaxation around toner particles during triboelectrification was investigated. Single toner layers of their thickness 10–20 μm were pinched and rubbed by two flat stainless steel electrodes between which various voltage differences were added. We found that sliding the upper electrodes enhanced successive voltage droppings between the electrodes due to gas discharge, even under 5 V of the applied potential difference which is far smaller than that allowed by Paschen's criteria in the atmospheric condition. This suggested that the electric field formed by the triboelectrified particles enhanced the inter-electrode avalanche. The measured charge amounts on the toner particles were too small to explain breakdowns with assuming traditional Paschen's criteria. For further investigation, measurement of the breakdown curve between the stainless steel electrodes was conducted. The obtained curve showed the existence gap discharge in the microscale gap range, which is out of the Paschen's criteria, and rather followed so-called modified Paschen's curve. It was suggested that discharge-relaxation between the toner and the electrodes occurred in the microscale gap region, which prevents charge accumulation in the toner layer.

1. Introduction

It has been repeatedly pointed out that the standard theories of contact electrification based on work function difference as the driving force of charge transfer [1–3] failed to estimate order of charge amount of dielectric particles [2–6]. In the 1990s, one of the authors argued that charge on a single particle generated by contact electrification is enough to cause breakdown in the air, and proposed a 'charge relaxation model [5,6]' to predict the final charge amount on insulating particles. In the model, the Paschen's curve [7] was applied to determine the breakdown voltage, as well as to determine the residual charge. In series of impact experiments with single dielectric particles as relatively large as 1 mm in diameter, the model predicted equilibrium charge densities, in the range of 10^{-5}–10^{-4} C/m^2, fairly correctly [6]. As regards smaller particles less than 10 μm, the verification of the model has been difficult due to the difficulty in measurements; nevertheless their discharging behavior is both important theoretically and industrially.

Theoretically, it can be said that smaller particles can sustain larger surface charge density considering the field strength around charged particles. When we assume the traditional Paschen's curve as the criteria of the discharge-relaxation, the maximum charge density on the 10-μm-diam sphere is estimated to be approximately 10^{-3} C/m^2 [6]. Whereas, the typical observed maximum charge densities on this size of particles seldom exceed 10^{-4} C/m^2. Recently, however, several studies [8–10] have focused on a failure of Paschen's curve, that is, as the gap distance below the minimum-giving distance of Paschen's, the breakdown voltage continues to decrease, which enables microscale gap breakdown. It is our concern how the relaxation process will be discussed when we consider the possibility of microscale gap breakdown.

From an industrial viewpoint, one of the important applications of powder charging is in the field of electrophotographic printers. Toner particles, less than 10 μm in diameter, are electrified by friction in a mass rather than by one-by-one impact. In a mono-component system, they are pinched and rubbed between conductive blades and rollers, whilst in two-component system they are mixed with 'carrier' particles. It is crucial to know the possibility of discharge-relaxation under these conditions, because it determines the final charge, affecting the picture quality.

In this work, to clarify the possibility of discharge relaxation from triboelectrified toner, we used a similar configuration to

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mono-component system as our experimental rig. In the experiments, two flat stainless steel electrodes pinched a toner layer, and voltage droppings between the electrodes were observed with rubbing the toner layer. To discuss the results, the breakdown curve between stainless steel in the air was measured. From these, we investigated the possibility of microscale gap discharge-relaxation of triboelectrified toner.

2. Experiments

2.1. Breakdowns between toner layers

Fig. 1 shows a schematic illustration of the experimental apparatus. Two electrodes were stainless steel columnar ingots with their bottom and top surfaces lap-polished. The diameters of the upper and the lower electrode were 50 mm and 100 mm respectively. A resin handle was attached to the top surface of the upper electrode to move it by hand. A portion of commercial spherical toner particles (©BROTHER positive type and negative type chemical toner of the average size 6 μm in diameter) with its mass 10–20 mg was dispersed on the center of the lower electrodes, and then covered by the upper electrode with its mass 200 g. The upper electrode was moved horizontally on the dispersed toner roundly by hand for a toner layer forming. The distance of the electrodes was roughly estimated as 10–20 μm. This was calculated from the measured capacitance of around 1–2 nF, with an assumption of parallel electrodes filled in part with a material with same volume of the total toner and its permittivity.

The positive electric potential was applied to the upper electrode, using a MATSUSADA PL-650 DC power supply with a current regulating resistance (100 Ω ~20 MΩ) inserted. The lower electrodes were grounded. Generated voltage droppings between the two electrodes were observed under following conditions.

2.1.1. Static conditions (spontaneous voltage-droppings)

In static conditions, the upper electrode was fixed (no motion) during measurements. The electric potential of more than 450 V was applied to the upper electrode using the power supply with a resistance of 20 MΩ inserted. Spontaneous voltage-dropping events between the electrodes were recorded by a TEKTRONIX DPO5104 Digital oscilloscope with an input impedance of 40 MΩ. The upper electrode potential was increased until the oscilloscope acquired the voltage-dropping events.

2.1.2. Dynamic conditions (forced voltage-droppings)

Potential of less than 300 V, with which spontaneous voltage droppings never occurred in the static conditions, was applied to the upper electrodes with a resistance of 20 MΩ inserted, then the electrodes was moved horizontally by hand, with velocity of approximately 1 cm/s. The voltage was recorded by the digital oscilloscope.

The frequencies of the voltage dropping events while the electrodes moving were measured. In this case the current regulation resistance was replaced with smaller ones (0.1–1 kΩ) to obtain an enough fast voltage recover rate. In the measurements, the upper electrode was slid a few millimeters horizontally by hand, and voltage-dropping events were acquired with their occurrence time attached by using the special function called a FastFrame mode of TECTRONIX DPO5104, with which the oscilloscope can acquire and memory all the triggered event separately with fine time resolution for each with a 500 ns window.

The tribocharge amounts on toner were measured. The samples were rubbed between the electrodes during 1 min, until the charge amounts on toner were saturated, with a 0.1–1 kΩ resistance inserted for various applied voltage. After rubbing samples, the upper electrode was removed upwards with the electric potential maintained. It could be noted that the almost all toner sample adhered to the electrode of opposite polarity to the toner charge type. (The positive type toner adhered to the negative biased lower electrode, the negative type to the positive biased upper.) The toner was then aspirated into a Faraday cage of a TREK HS212HS Q/M meter from both the electrodes, and their total charge amounts and the mass were measured by using the Q/M meter and a SATORIUS precision weighing instrument respectively.

2.2. Microscale gap discharge between metals

Several experimental studies on microscale gap breakdown [8–10] have been already conducted, though the results largely depended on the electrode material. In this study we measured a breakdown curve between two stainless electrodes in atmospheric condition by using a newly developed simple technique.

Fig. 2 shows a schematic illustration of the experimental rig. The most distinctive characteristic of the method was that the breakdown voltage measurement began at the state that the cathode and the anode were in contact. The cathode was the stainless steel sphere of 1/4 inch in diameter, which was grounded. A positive electric potential of 300 V was applied to the stainless steel plane, using the DC power supply with a high power resistance of 10 kΩ inserted. At the beginning of the measurement, since the anode and the cathode were in contact, all the supplied potential difference was impressed between both ends of the resistance. When the measurement began, the anode was separated from the cathode by hand with a velocity approximately 1 cm/s. While separating the two electrodes, the digital oscilloscope recorded the voltage rise events occurred at the anode, with their occurrence time attached.

3. Results

3.1. Inter-toner-layer breakdown

In the static conditions, i.e. when the electrodes in Fig. 1 were not moved, fairly high potentials were needed to cause breakdowns. Fig. 3 shows the observed waveform of a single breakdown

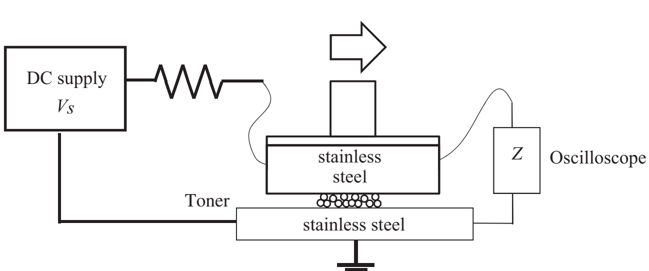

Fig. 1. A schematic illustration of experimental apparatus for observing voltage dropping through a toner layer during triboelectrification.

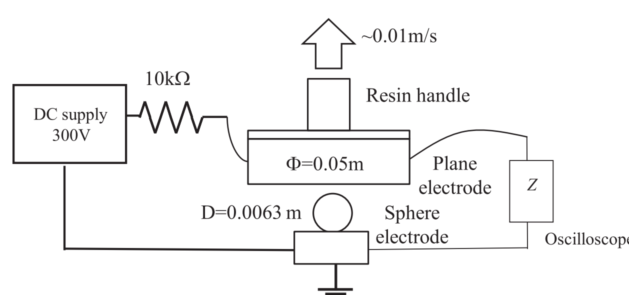

Fig. 2. A schematic figure of the experimental apparatus measuring breakdown voltage characteristics in the microscale gap region.