

# Triboelectric Charging of Some Toner Materials

*Hiroshi Kokado, Masaaki Takahashi and Katsuyoshi Hoshino*  
*Department of Imaging Science, Chiba University, Chiba, Japan*

## Abstract

An apparatus for triboelectric charging was designed and constructed. It allowed us to measure charging behavior of sample films dynamically under controlled atmospheres. Using the apparatus, dependences of charging characteristic on humidity was investigated for some toner components. The charging behavior was greatly dependent on humidity, and the dependence was a function of the material used. The effect of film thickness and molecular weight of the sample materials on triboelectric charging are also described.

## Introduction

Contact-triboelectric charging phenomena have found an extensive application in the preparation of electrophotographic developers. However, the charging mechanism of insulators such as toners and resins has not been well understood. Information on the mechanism should be accumulated for getting high-quality toner images and consequently for designing toner materials. Therefore, it is necessary to investigate charging characteristics of toner materials and discuss them from a scientific point of view.

It is known that the contact-triboelectric charging of materials is greatly influenced by the atmospheric condition (humidity, surrounding gases, gas pressure, etc.).<sup>1,2</sup> Based on these facts, we designed and constructed an apparatus for triboelectric charging that allowed *in situ* measurements of surface potential of sample films under controlled atmospheric conditions.<sup>3</sup> In this paper, we report the dynamic triboelectric charging behavior of toner and resin films when they are charged by contact with iron carrier beads under controlled atmospheres.

## Experimental

### The Apparatus for Triboelectric Charging

A schematic illustration of our apparatus for triboelectric charging is shown in Figure 1. The apparatus consists of a cylindrical holder (~760 mm $\phi$ ) on the rim of which a sample film (30 mm  $\times$  50 mm) is mounted, a magnet roll (~16 mm $\phi$ ) with a sleeve covered with carrier beads and a cam. The holder and the magnet roll are rotated independently with separate motors. A gap formed between the holder and the magnet roll is controlled using the cam. This apparatus was set in a glass chamber and triboelectric charging measurements were conducted under various humidities and gas pressures. Surface potential was measured with a Model 555P-1 probe attached to surface potential meter TREK Co., Model 344). Relative humidity was monitored with a hygrometer (VAISALA Co., Model HMP134Y).

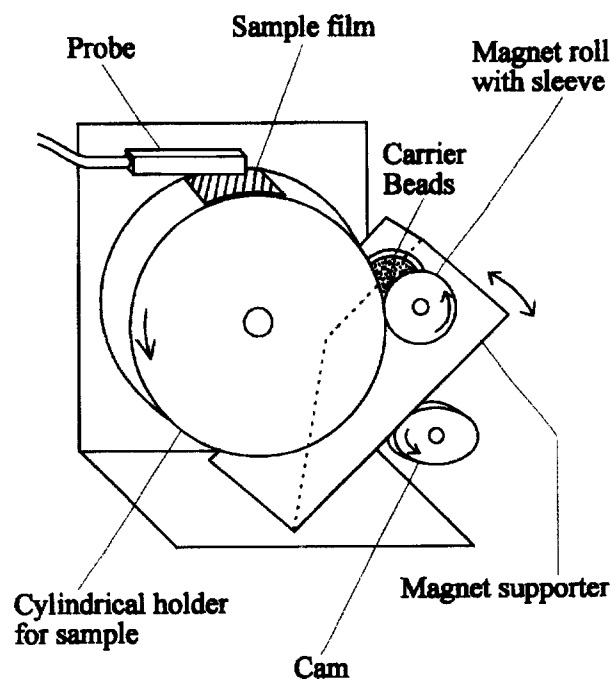


Figure 1. The apparatus for triboelectric charging.

### Sample Films

Sample films for triboelectric charging were prepared on an aluminum substrate by spin-coating a toluene solution of poly(styrene-co-butadiene) (St-BD), poly(styrene-co-butylmethacrylate) (St-BMA) polystyrene(Mw:  $1 \times 10^4$ ,  $6 \times 10^4$ ,  $2 \times 10^5$ ) and polyester denatured by styrene acryl resin (PESA). Toner films were prepared by wire-bar coating of a toluene dispersion of toner powders for minus charging (Sharp. Co). These polymer and toner films were annealed at 60°C for 3h and 1h, respectively, before use. Iron powder (no coated with polymers) was used as carrier beads. Its shape was roughly spherical and the diameter was about 110 $\mu$ m on the average. The amount of carrier beads to be employed was optimized (in our case, about 6.5 grams) from the viewpoint of reproducibility.

## Results and Discussion

### Dependence of Triboelectric Charging on Relative Humidity

The effect of relative humidity (RH) on triboelectric charging was investigated for polymer and toner films. Figure 2 shows plots of surface potential vs. relative humidity for poly(St-BMA)(O), poly(St-BD)( $\bullet$ ), polystyrene( $\Delta$ ),

and toner films)(▲), Surface potentials were measured 30 minutes after triboelectric charging set in. All the measurements were carried out under a nitrogen atmosphere. Surface potentials increased with the humidity. This suggests that the sample films employed are liable to be charged triboelectrically in the presence of water.<sup>4</sup> For the polymer films, the surface potentials at 80% RH were slightly lower than those at 60% RH, while the surface potential increased linearly with RH for the toner film. This may be because excessive water molecules on the toner film surface are absorbed by carbon black in the toner and surface resistance of the film does not diminish.

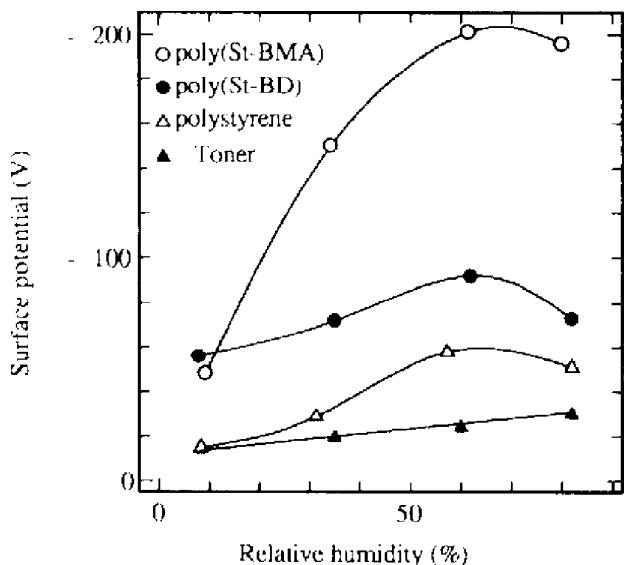


Figure 2. Dependence of surface potentials of toner and polymer films on relative humidity.

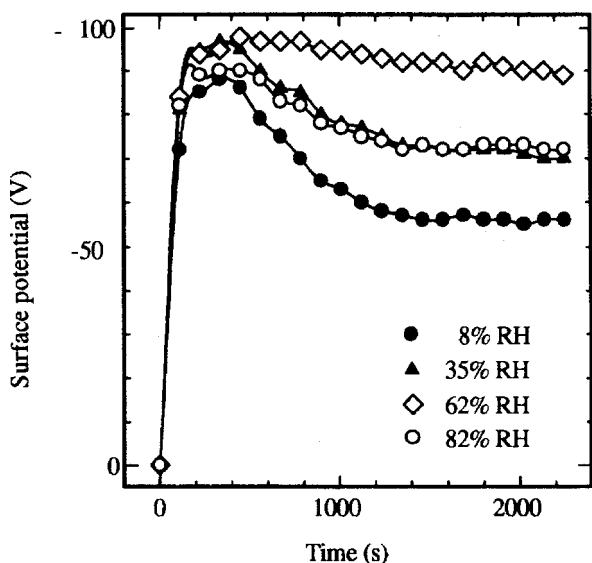


Figure 3. Dependence of triboelectric charging of poly(St-BD) films on relative humidity.

Figure 3 shows a plot of surface potential vs. triboelectric charging time for the St-BD film under the same nitrogen atmosphere. Relative humidity was varied from

8% RH to 82% RH. The abscissa in Fig. 3 is not the net contact-triboelectric charging time but measuring time: the former may be about one 100th of the latter. The steep rise of surface potential to a maximum, and its subsequent fall to a steady value, were observed for the St-BD film. The steady value was largest at 60% RH.

The charging characteristics described above can be explained if it is assumed that two sites for plus and minus charging coexist on the St-BD film and their humidity dependence differs from each other: surface potential at the minus charging site does not increase above 60% RH, whereas that at the plus charging site increases with the relative humidity.

### Ambipolar Triboelectric Charging

Figure 4 shows the dependence of charging characteristics of the PESA film on relative humidity under the same nitrogen atmosphere. The charging behaviors are greatly dependent on the humidity, and the polarity of surface potential changed from plus to minus as relative humidity increased from 7% RH to 81% RH. These behaviors can also be explained by the assumption of ambipolar properties of charging surface of the film.

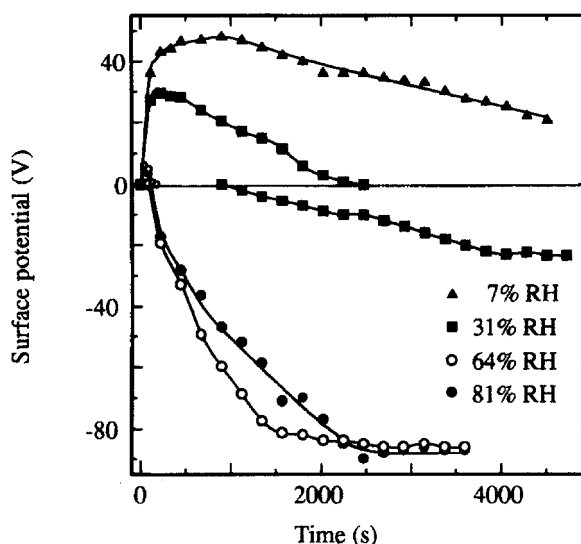


Figure 4. Dependence of triboelectric charging of polyester denatured by styrene acryl resin films on relative humidity.

It was observed that the film exhibited the ambipolar behavior above ca. 30% RH. For example, look at the curve for RH; 31%, measuring time; 1000~2500 s. The surface potential measured in this study corresponds to the mean over a small area under the probe (diameter: 2.5 mm). In the PESA film, plus charged areas and minus charged areas are distributed in the same film. The plus charging sites that are less sensitive to the humidity are faster in accepting positive charges from the carrier surface. So at the very early period of tribo-charging (0~1000 s), the potential of areas that encountered the most frequent contacts to carriers was recorded. The polarity was plus. Between 1000 s and 2500 s, the negative charging starts to exhibit the effect, but because of the non-uniformity of charging, both the most positive areas and the most negative areas contribute to the result of measurements. The bivalent data in this time

region represent the most positive and the most negative among a wide distribution of the potential. After that, all the surface of film were negatively charged though the non-uniformity still existed.

### Relationship Between Film Thickness and Relative Humidity

An interesting effect of film thickness on charging characteristics was investigated. Polystyrene films (Mw:  $2 \times 10^5$ ) were charged triboelectrically and saturated surface potential was plotted as a function of film thickness at three relative humidities (Fig. 5). At a low humidity (<10% RH), surface potential increased linearly with film thickness, indicating that charges distributed on the film surface. On the other hand, the plots at higher humidities showed a knee at about  $6\mu\text{m}$  where the slope changed. This is probably because charges can penetrate into the bulk of the film to the depth of  $\sim 6\mu\text{m}$ .

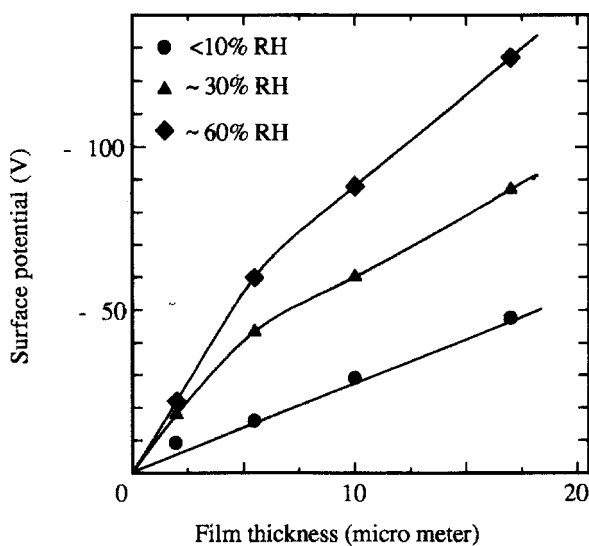


Figure 5. Relationship between the saturated surface potential of polystyrene film and the film thickness under relative humidity of <10%, ~30% and ~60%.

### Effect of Molecular Weight on Triboelectric Charging

The effect of molecular weight (Mw) on triboelectric charging was examined using polystyrene films (Mw:  $1 \times 10^4$ ,  $6 \times 10^4$ ,  $2 \times 10^5$ ). Charging measurements were performed at <10% RH and ~60% RH. Figure 6 and 7 show the triboelectric charging behaviors at <10% RH and ~60% RH, respectively. It was revealed from these figures that 1) initial charging rate increased with increasing Mw, 2) saturated surface potential decreased with an increase in Mw, 3) surface potential for higher molecular-weight film reached saturated value more rapidly, and 4) charging ability of the films is enhanced with increasing humidity independently of Mw. The difference in affinity of the films for water molecules may account for the experimental facts 1) ~ 4), but the evidence to support the present thesis is not conclusive.

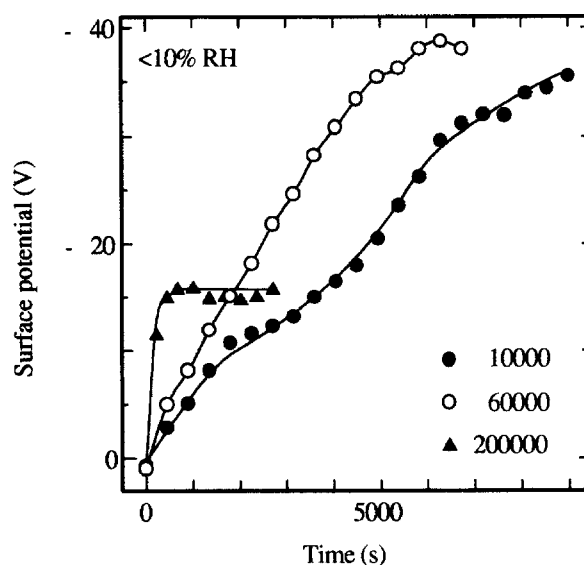


Figure 6. Effect of molecular weight on triboelectric charging of polystyrene films at below 10% RH.

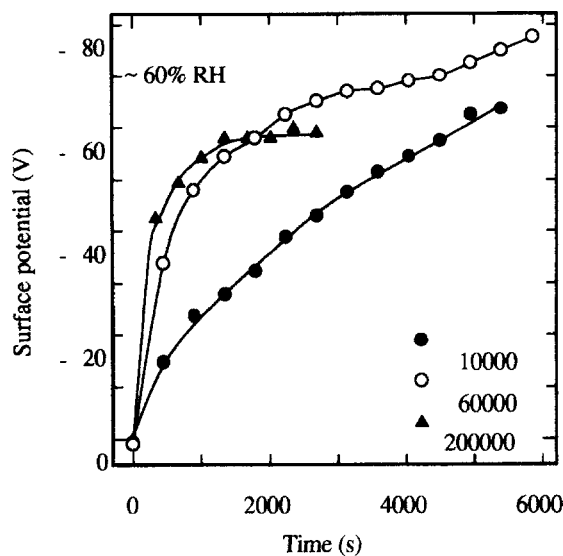


Figure 7. Effect of molecular weight on triboelectric charging of polystyrene films at about 60% RH.

### Conclusion

We designed and constructed an apparatus for triboelectric charging that allowed *in situ* measurements of surface potential of polymer and toner films under controlled atmospheric conditions. Conclusions obtained from the study are summarized as follows.

1. The dependence of charging ability on humidity was different from material to material.
2. For the materials in which plus charging and minus charging sites coexist, complicating features were observed in their charging characteristics. This may be due to difference in the effect of humidity on the two sites.
3. Water molecules in the atmosphere affected not only the film surface but also the film bulk, and increased the charging ability.

4. In triboelectric charging of a polymer film, charging rate and saturated value of surface potential were greatly dependent on molecular weight of the polymer.

### References

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