Charged Particle Adhesion Internal to and External to an Electrostatic Field

Julie G. Whitney; Lexmark International; Lexington, KY/USA

Abstract

Toner adhesion to a polyimide film substrate has been measured both inside and outside of an electrostatic field. Toner removal outside of an electrostatic field was done with a blow-off tool described previously. In-field measurements were done with a parallel plate device where the top plate was held at a known voltage and the lower plate grounded. Toner samples were as-transferred to a polyimide intermediate transfer belt. Charged parallel plates have a propensity to experience low-field breakdown, as charges are highly mobile on the plate surface. To address that issue a thin insulation layer between the two plates was used. In-field and out-of-field toner removal responds differently to toner charge. A hypothesis of image dipole cancellation with electric field is proposed.

Introduction

Measuring toner adhesion to different substrates is an important part of electrophotographic printer system development. Multiple methods have been used with the most studied being ultra-centrifuge removal and atomic force microscopy. [1-7] Analysis of toner adhesion distributions as a function of variables like environment have demonstrated a much more complex relationship between charge and adhesion than had previously been recognized. [8-10] Separating these variables requires being able to test toner adhesion in an electric field as well as outside of it. We have developed two techniques that can be used in combination to help decouple effects of van der Waals and electrostatic forces adhering small charged particles like toner to substrates. The two methods are an air blow-off tool that removes particles mechanically, outside of an electrostatic field; and a parallel plate fixture that removes particles electrostatically. These two tools can produce results from the same sample, and both will give a distribution of percentage removal with increasing force.

Toner Measurement Tools:

The air-pulse blow-off tool measures the adhesion force for a sample of toner as it has been developed or transferred onto an intermediate transfer belt or a photoconductor surface. [8] The advantages of this tool are its ability to measure adhesion of a toner sample from inside an actual printer system, its ability to return a distribution of removal forces for a toner sample, and its ability to respond to toner samples that have both dispersive force adhesion and charge based adhesion. The air blow-off tool has demonstrated that toner adhesion is a function of environment as well as toner type, asperity coverage and charge. Measurements taken with this system also correlate well with published values obtained from other measurement methods. Typical toner adhesion from an extra-field removal process is about 30nN to 400nN, with higher adhesion forces noted for toner with no external particle asperities. [1,3,4,11,12]

In order to measure toner removal in an electric field a charged parallel plate toner removal tool has been designed and built. The tool utilizes two parallel plates, the lower one at ground and the upper one at a controllable DC voltage, to create a field. The plates can be precisely controlled to come together to specified distances as well as to do a timed drop, dwell, and rise cycle. The lower plate has a designed-in vacuum chuck that allows a transfer belt to be held securely without any clip or adhesive that might change the stack height. The parallel plate tool also takes samples of toner from inside an actual printer system where dispersive force adhesion and charge based adhesion are intertwined.

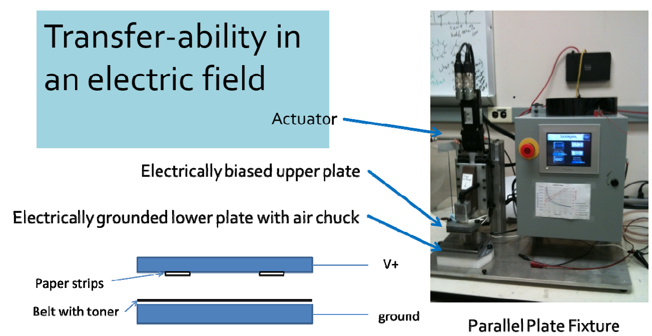

Figure 1: *Parallel plate fixture removes toner from an intermediate transfer belt to strips of smooth paper using an electrostatic field.*

An issue that biased conductive plates have in field based removal is that there is nothing to stop electrical charge from concentrating on any piece of dust or other field concentration feature. As has been described in the literature [13] this causes a parallel plate fixture to poorly reproduce the fields associated with transfer or development because Paschen breakdown occurs in the tool at a much lower voltage than in the printer system. In order to create a more representative system the top plate was fitted with two symmetrical strips of paper attached by conductive tape. In this manner the interface between the two plates now became a sandwich of conductive tape, ultra smooth gloss paper, toner and transfer belt. This configuration allowed toner to be transferred from the sample to the paper as happens in a transfer nip in an electrophotographic printer. The fields and appearance of the toner in the test also now correlate well with measured values from printer systems. The actual field present across the toner was determined from the voltage drop across the gap created by insulative material. Toner removal reaches a maximum around

5E06 V/m and breakdown occurs by 8E06 V/m with exact values depending on the toner type and charge. This matches well with theoretical predictions of transfer fields given by one-dimensional analytical models. The appearance of breakdown on the samples looks like the print defects actually seen from breakdown in a printer system. The toner changes sign and remains on the donor substrate in a fairly uniform layer, increasing in density as the voltage increases. Figure 2 shows this response for two milled toners tested in the parallel plate fixture. The amount of toner moved was measured by measuring the optical density of the toner which left the transfer belt donor and ended up on the smooth paper acceptor.

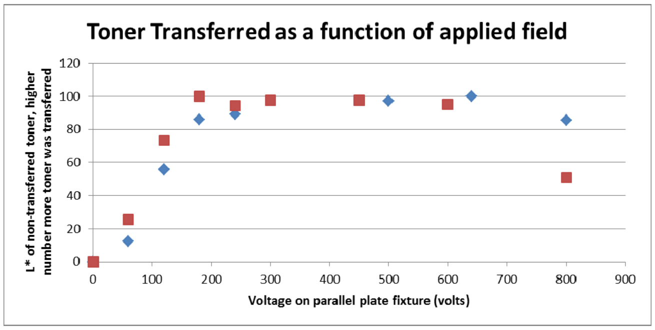

Figure 2: Toner removal on the parallel plate fixture for two different milled toner samples, as a funtion of the applied field. As with transfer the percentage of toner that is moved by the field increases, is flat for a large operating range, and then decreases as Paschen breakdown changes the sign of the toner.

Experimental Results

Electric removal force is found by measuring the normalized toner removal at different field levels. The removal force is the Lorentz force, F=QE, where Q is the charge on the toner and E is the electric field. The average toner charge is found for the sample using a Keithley electrometer coupled with a Faraday cage and the size distribution of the sample can be determined using a Mastersizer III. Samples are generated by stopping an electrophotograpic printer in the middle of a print job using special control software. The samples are then taken from the printed toner on the transfer belt. A half tone sample is used to give maximum sensitivity for both the parallel plate fixture and the mechanical adhesion blow-off tool. Two printed areas in close proximity on the transfer belt can then be tested for their response to electrostatic removal and to mechanical removal.

In order to separate charge related effects from van der Waals responses, a series of measurements were taken with the same toner/printer system and different transfer voltages on downstream color stations. This method has been described previously to generate a series of toner samples with the charge on the toner being the only variable between them. [8,9] For each voltage level, a series of electric field measurements can be made. The toner removed can be measured a variety of ways, depending on the color of the toner and substrate. For black toner on a black substrate, a strip of adhesive tape can be used to remove the toner left on the substrate and then transfer that to white or other contrasting substrates. The quantification of toner on the adhesive tape can be measured by a color meter or by analysis of microphotographs of the sample though simple particle counting algorithms.

A set of test toners was generated which had the same base particle material and different levels of standard external asperities made primarily of silica spheres. High levels of additives resulted in a low contact area between the toner particle and the polyimide transfer belt. Low levels of additive resulted in high contact areas between particles and the transfer belt. Van der Waals forces increase with increasing contact area. Each sample was then generated at different charge levels resulting in a matrix of mechanical adhesion and electrostatic charge.

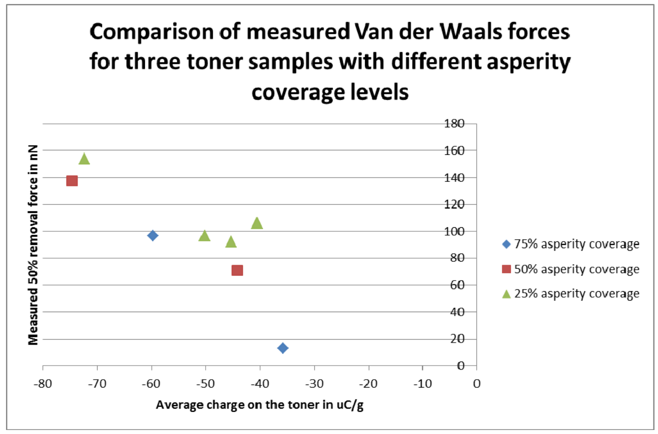

Figure 3: Mechanical removal of toner samples with different asperity coverage as a function of induced toner charge. As expected at any given charge, the higher the percent coverage, the lower the force required for 50% removal. Higher force is required for higher % removal.

The samples were taken from a 20% half tone layer of the toner transferred onto an intermediate belt and stopped prior to reaching a nip designed to transfer the toner to paper. Each sample was tested for mechanical adhesion using the blow off fixture and for adhesion inside of a field using the parallel plate fixture. Figure 4 shows the results of that experiment.

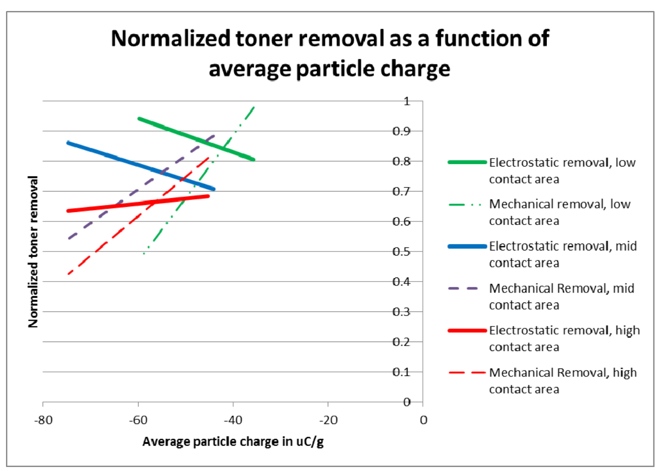

Figure 4: Normalized toner removal at a constant mechanical force of about 250nN (60%-80% removal) and a constant electrical field of -2.4E6 V/m as a function of toner charge and additive coverage.

As toner charge became more negative the amount of toner removed mechanically from the blow-off tool decreased. The estimated removal force was about 250nN, a level exceeding what a transfer force due to an electrostatic field should be able to apply. Conversely, as the toner charge became more negative the amount of toner removed with a given electrostatic field increased. The field used was -2.4E6 V/m. For a -60μC/g particle of 6 μm diameter that would represent a Lorentz force of about 20nN, significantly lower than the measured van der Waals force. Removal of toner inside of an electrostatic field better represents the physical mechanisms of development and transfer. This data suggests that increasing toner charge could improve these processes. Additional work on actual printer systems confirmed that for the same toner sample, moderate increases in toner charge increased transfer efficiency. The data also suggests that toner which is mechanically adhered in excess of 250nN, can be transferred with a field which should only be exerting a few 10's of nN.

Discussion:

We have previously demonstrated that it is possible to have dispersion force measurements which can result in adhesion forces for charged particles exceeding several hundred nano-Newtons. [10] A calculation of forces as they exist based on uneven charge and charge location on the surface of toner yield the magnitude of adhesion values measured by multiple external-field techniques. We have also proposed that applying an electric field to toner on a dielectric substrate will allow for a removal force that is lower than the removal force for the same toner outside of an electric field. [11] The reason for this difference is that the electric field needed to remove toner cancels the image dipole in the base substrate. If this hypothesis is correct then increasing toner charge without increasing contact area or surface energies of the toner should increase the Lorentz force and decrease the image force. The result would be a predicted increase in the percentage of toner removed as toner charge increases. Experimental results using the parallel plate fixture have supported this assertion. As toner charge increases, the ability of an electric field to move the toner also increases. This finding correlates well with in-printer tests showing that increasing charge improved transfer efficiency.

Removal of toner from a substrate outside an electric field should not have the benefit of the mitigation of the image dipole in the substrate. In the non-field case, the adhesion of the toner to a substrate should increase with increasing average toner charge. This part of the hypothesis was tested with the adhesion blow-off tool. As predicted, increasing average toner charge decreases the normalized amount of toner removed at all force levels.

The difference in removal response to charge with applied electric field supports the hypothesis of cancellation of the image dipole. It also explains why toner removal forces in transfer are generally in the 10's of nano-Newtons where the removal force reported in the literature would require forces an order of magnitude greater. The difference between in-field and out of field removal has consequences for electrophotographic printer design. Certain processes, such as cleaning, rely on the system's ability to remove toner outside of an electric field. For these systems, toner charge will be as significant an obstacle as van der Waals attractions. Other processes, such as development and transfer, are aided by higher charge on the toner. For these systems an increase in uniform toner charge will enhance the process. It should be noted that a layer of highly charged toner will require a larger field to overcome the internal field in the toner, however once that is accomplished the ultimate efficiency of the process will be enhanced.

Conclusion:

Adhesion measurements for charged toner on a polymer belt substrate have been made for removal both inside and outside of an electrostatic field. Measurements inside a field were made using a charged parallel plate device. This fixture was modified to include an insulative material layer in order to replicate the structure of an electrophotographic printer nip. Electric field was determined from the thickness of the insulative separation layer and the voltage drop across it. The result of the field, in terms of toner transferred mimics the same field in a printer system. Measurements outside of a field were made using an air blow-off tool. Test samples demonstrated that as toner charge increased, toner removal inside of an electric field improved in efficiency, while toner removal outside an electric field decreased in efficiency. These findings support the hypothesis of negation of the image dipole inside an electrostatic field, and therefore the reduced adhesion force for charged particles inside that field.

References

[1] M.C. Dejesus, D.S. Rimai, E. Stelter, T.N. Tombs, D.S. Weiss, "Adhesion of Silica-Coated Toner Particles to Bisphenol-A Polycarbonate Films" Journal of Imaging Science and Technology, 52(1) 2008 p. 01503-1

[2] H. Stotzel, H.J. Schmidt, D. Auerbach, B. Makin, D. Dastoori, H. Bach "Adhesion Measurements for Electrostatic Powder Coatings" Journal of Electrostatics 40&41 (1997) 253-258

[3] M.H. Lee, J. Ayala "Adhesion of Toner to Photoconductor" Journal of Imaging Technology 11: 279-284 (1985)

[4] B. Gady, D.J. Quesnel, D.S. Rimai, S. Leone, P. Alexander, "Particle Adhesion and Removal in Electrophotography" Journal of Adhesion Science and Technology, Vol 17, No 7 pp 917-942 (2003)

[5] H. Mizes, M. Ott, E. Eklund, D. Hays "Small Particle Adhesion: Measurement and Control" Colloids and Surfaces A: Physicochemical and Engineering Aspects 165 (2000) 11-23

[6] H. Kawamoto "Manipulation of Single Particles by Utilizing Electrostatic Force" Journal of Electrostatics (2009) doi:10.1016/jelestat.2009.07.002

[7] E.A.Eklund, W.H. Wayman, L.J. Brillson, D.A. Hays "Toner Adhesion Physics: Measurements of Toner/Substrate Contact Area" IS&T's Tenth International Congress on Advances in Non-Impact Printing Technologies (1994) 145

[8] J.G. Whitney and B.A. Kemp, "Toner Adhesion Measurement" Imaging Science and Technology NIP 26, 227 (2010)

[9] J.G. Whitney "Toner Charge and Environmental Interactions with Toner Adhesion" Imaging Science and Technology NIP 27 136 (2011)

[10] Kemp, BA and Whitney, JG; "Nonlinear nature of micro-particle detachment by an applied static field," Applied Physics Letters, Vol. 102, Issue 14, 141605 (2013)

[11] D.S. Rimai, D.S. Weiss and D.J. Quesnel " Particle Adhesion and Removal in Electrophotography" Journal of Adhesion Science and Technology, Vol. 17 no 7 pp. 917-942 (2003)

[12] D.S. Rimai, D.J. Quesnel, L.P. DeMejo, M.T. Regan "Toner to Photoconductor Adhesion" Journal of Imaging Science and Technology, Vol. 45 No. 2 (2001)

[13] R. Hoffman “Modeling and Simulation of an Electrostatic Image Transfer” Technische Universitat Munchen,(2003)
[14] J.G. Whitney “Toner/Transfer Member Adhesion Response to Environment – Induced Material Property Changes, and Their Impact on Transfer Fields” Imaging Science and Technology NIP 28 (2012)

Author Biography

Julie Gordon Whitney is Transfer Physicist at Lexmark International. Whitney received her BS in Mechanical Engineering from Purdue University (1982), MS from Indiana State University (1986) and Ph.D. in from the University of Cincinnati (1992).

