Satellite Formation in Transfer Gaps

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Abstract

Toned electrophotographic images often exhibit toner satellites around alphanumeric characters and halftone dots. Among the electrophotographic subsystems, transfer is believed to be a frequent and even dominant source of such image artifacts. This paper reports on toner adhesion, detachment, and disruption as determined using a laboratory ultracentrifuge and an electrostatic detachment cell (ESD). The simplicity of this apparatus helps isolate factors contributing to satellite formation such as toner particle size, surface treatment, transfer gap (pre-nip or post-nip) and transfer electric field. Measurements have confirmed that surface-treatment can decrease adhesion and/or cohesion and increase the number, but not the spatial extent, of laterally displaced toners after gap-jumping. Results from both the ultracentrifuge and the ESD show that, even for highly surface-treated toner, only a small fraction of toner is removed by the normally-directed electrostatic forces encountered during transfer from photoconductor to paper. In contrast, relatively weak tangential forces cause toner to move laterally; suggesting an additional mechanism for satellite formation that need not involve gap jumping.

Introduction

The electrophotographic copier/printer state-of-the-art has been advancing steadily toward smaller toner particles to achieve higher image quality. A simultaneous trend has been to use toner surface-treatments (such as fumed silica and titania) to maintain transfer efficiency, improve charge stability, and extend developer life. These benefits of surface-treatment are well established, but a drawback is increased satellites (stray toner particles near characters or other toned features) and related image disruptions during transfer.[1]

The mechanisms underlying the image disruptions during transfer are not fully understood, but it is plausible that the formation and increase in satellites with increasing level of surface treatment occurs due to the decrease in van der Waals forces. Once contact (toner-toner and/or toner-film) is broken, Coulombic repulsion between particles and the applied electric field can then cause the particles to scatter, even perhaps within a nip if it is not tight enough. By controlling the charge on the toner and the type and amount of surface treatment, it might be possible to optimize the surface treatment of the toner for a given transfer configuration. From a hardware design point of view, it might be possible to optimize transfer electromechanical parameters such as roller diameter, nip width, resistivity, bias strategy, preconditioning, etc.

Experimental Approach

Toned images were produced on a photoconductor using a magnetic brush and a two-component developer. The weight percentages of the silica/titania surface-treatments ranged from zero to 0.50/1.0 and 1.00/0.35 (%silica/%titania). For the various tests the toned images included bias-developed solid areas, optically exposed images of uniform halftones and text.

The fundamental determination of toner-toner cohesive force and toner-film adhesive force was done in the Beckman Ultracentrifuge, model L8-70M, 6.45 cm radius rotor, capable of 70,000 rpm (producing centrifugal force up to roughly 350,000 g). Generally, samples for the centrifuge were oriented so that the removal force was normal to the film, but some tests were done with the samples rotated 90 degrees or 180 degrees, so that the centrifugal force was tangential or embedding, respectively. For removal force directed normal to the surface, the toner percent removed increases gradually with increasing force, while for tangential removal force there is a much sharper, relatively low, force threshold for complete removal.

The simple stationary geometry of the electrostatic detachment cell facilitated evaluation of the roles of gap and electric field on satellite formation. Nominal gaps were limited to a minimum of 3 mil, allowing reasonable tolerance for the imperfect flatness of the polished stainless steel support block and receiver electrodes. To extend the range of electric field without air breakdown, the apparatus was operated in a chamber that could be evacuated to low vacuum or operated under a controlled atmosphere such as SF_6 gas. Transfer biases sustainable without dielectric breakdown were generally up to 1600 V for a nominal 3-mil gap, and 2000 V for a 5-mil gap. Corresponding maximum electric fields in the gap were 19.0 and 14.8 V/µm, respectively, after accounting for the nominal thickness and relative permittivity of the photoconductor. These maximum fields are almost double those sustainable at the same gaps in normal atmosphere. However, fields of these magnitudes can be encountered during biased-roller transfer, including in the pre-nip and post-nip regions.

Image Analysis

Samples for the ultracentrifuge were generally prepared by bias-developing toner for uniform solid-area coverage. For samples comprising less than a monolayer of toner coverage, the amount of residual toner after centrifugation was determined on an area-coverage basis, averaged over three distinct fields of view in the microscope. For more than a monolayer of toner coverage, the centrifugal removal of toner was determined by removing the residual toner from the photoconductor with clear tape and measuring the transmission density using the X-Rite model 310 densitometer, again averaged over three fields of view.

Photoconductor samples for the ESD had toned halftone patterns, at a nominal 5% percent tint and 30 dots/inch. The corresponding nominal dot diameter of about 200 µm is comparable to the width of a fine character strokewidth. The low % tint corresponds to relatively isolated dots, a situation with minimal neighboring-dot electrostatic repulsion, and amenable to theoretical electrostatic analysis. Even under the influence of the maximum obtainable fields, only a small portion (usually less than a monolayer) of toner jumped the gap. The toner area coverage was measured and tabulated within concentric circular areas centered on a dot using an Omnicon 3500 II Image Analyzer. This was repeated for three dots on each sample. In a subsequent calculation the toner coverage was determined as a function of radial distance, over a range from less than the dot radius to the midpoint between dots.

Other PC film samples for the ESD had toned 12-point Times Roman "N" characters for satellite GS measurements.[2] Again, usually only a small fraction of the toner jumped across the cell gap, even with the highest sustainable electric fields. In order to distinguish toner associated with the original character from satellites, a mask of the ideal "N" was registered over the partially transferred character. Toners having spilled between the vertical character strokes outside the mask area were counted and converted to the conventional satellite (GS) metric. GS data were averaged from two "N" characters on each sample. Satellites around the residual "N" on the photoconductor were determined similarly.

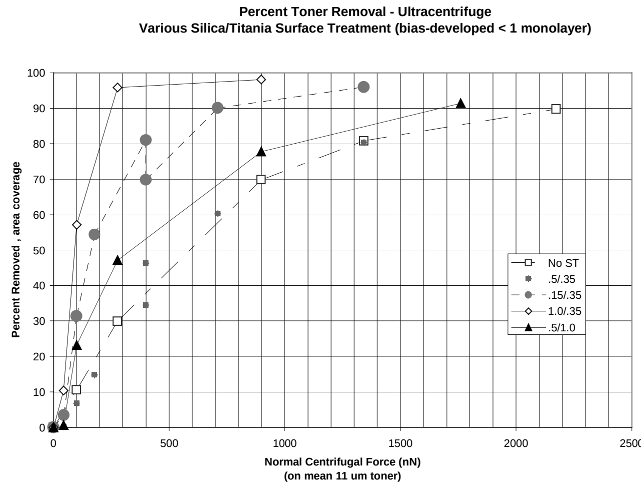

Figure 1. Ultracentrifuge removal of toner with various surface-treatments.

Ultracentrifuge Experimental Results

Basic adhesive (or cohesive in the case of multiple-layer toner stacks) force of toner on film is summarized in Fig. 1 for a variety of surface treatments. The general trend is a gradual increase in toner removal with increasing normal centrifugal force. This indicates a wide distribution of forces on the toner particles of a given type, perhaps related to particle-to-particle size and shape variability, contact variability, and surface-treatment nonuniformity. Toner charge may also be highly variable and nonuniform, although the removal forces for most of the toners are of such a magnitude that surface forces are probably dominant, rather than electrostatic forces.

Another general trend apparent in Fig. 1 is that the normal removal force required decreases for high surface-treatments (except for the 0.5/0.35 surface-treatment, which for unknown reason does not fit the pattern). This is consistent with earlier results reported for color polyester toners.[1] For the 0.15/0.35 surface, the 50% removal force is about 160 nN, compared to 560 nN for the untreated toner. For the 1.0/0.35 surface treatment, the 50% removal force is only about 90 nN.

The toner stack height appears to be a significant factor in removal force (Figs. 2 and 3). For the untreated toner, short stacks (bias-developed delV = 40 V for < 1 monolayer) require more removal force than tall stacks. For the highly surface-treated toner the removal force is

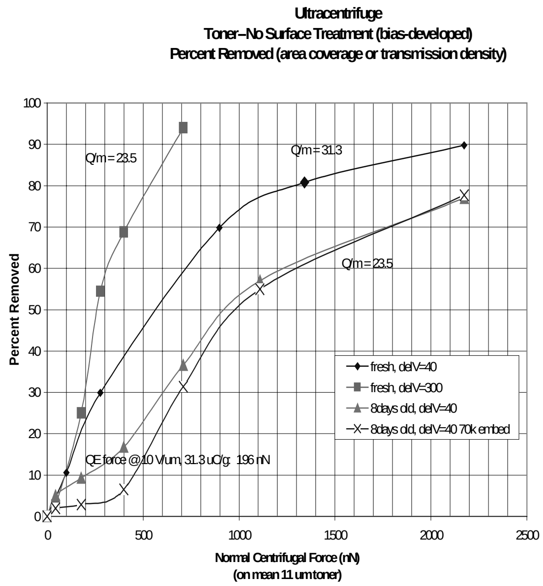

Figure 2. Ultracentrifuge removal of untreated DHV1 toner, fresh and aged, low-density and high-density.

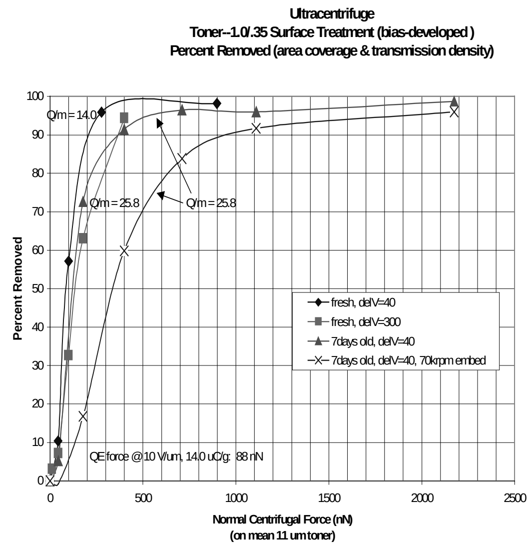

Figure 3. Ultracentrifuge removal of highly treated (1.0/0.35) DHV1 toner, fresh and aged, low-density and high-density.

less for all density levels, but the tall stacks require more removal force than the short stacks. A possible interpretation in terms of adhesion/cohesion would be that the surface-treatment in this case is more effective in reducing toner-film adhesion than in reducing toner-toner cohesion.

Figures 2 and 3 also show the effect on low toner-coverage (<1 monolayer) samples of several days aging before centrifuging. The removal force is increased for both the untreated toner and the 1.0/0.35 surface-treated toner. A gradual plastic deformation at the toner-film interface, increasing the contact area and surface force, is visualized as a possible explanation. To further exaggerate the possible plastic deformation, some aged toned samples were oriented in the Ultracentrifuge to embed the toner (at 70,000 rpm), rather than remove it, prior to centrifugal removal. For the untreated toner this resulted in a significant increase in the threshold removal force for the lightly adhering toners, but little change in the removal force required for more tightly adhering toner particles. For the 1.0/0.35 surface-treated toner the centrifugally embedded toner required higher removal force over the full range of percent removed.

Except for the results noted in Figs. 2 and 3, all results reported here are for detachments made between ½ hour and 3 hours after toning the samples, to avoid aging. Short-time aging effects remain an open question.

. Ultracentrifuge runs with toned film samples oriented for tangential removal force showed a fairly sharp threshold for complete removal at a relatively low removal force. For the %0.15 silica / %0.35 titania treated 11 µm toner the transition from 0 to 100% removal was accomplished in the range of 44 to 177 nN (10 to 20 krpm).

Highly surface-treated (1.3% silica) polyester cyan toner on an organic photoconductor was abruptly and completely removed at ~10 nN tangential force (15 krpm), almost 2 orders-of-magnitude less than the 50% removal force normal to the surface (Fig. 4).

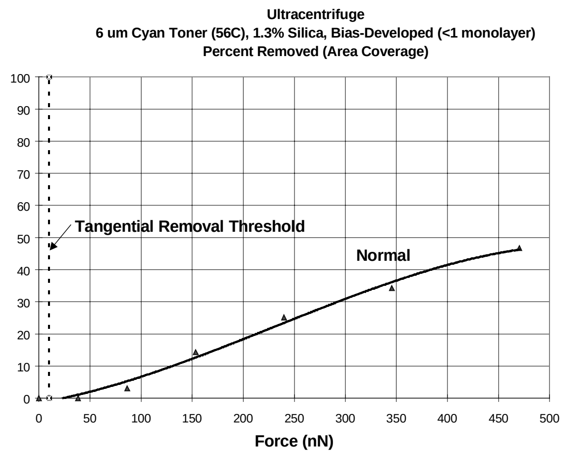

Figure 4. Ultracentrifuge removal of highly treated (1.3% silica) 6 μm cyan toner—normal and tangential

Electrostatic Detachment (ESD) Cell Results

For toner, with Q/m in the range of 10-30 uC/g, the calculated maximum electrostatic (Q times E) force obtainable in the ESD in SF_6, with E = 19 V/μm, is 119 to 358 nN. This is not sufficient to approach complete removal as determined in the ultracentrifuge, except for the highly surface-treated toner (Figure 1). Accordingly, it was no surprise that transfer was usually far from complete in the ESD. The solid area residuals showed that the toner tends to detach in clumps and expose the bare film surface in a random pattern, then disperse laterally before reaching the steel receiver. These patterns suggest a predominance of toner-film adhesion failure over toner-toner cohesion failure. The aged samples did not transfer as well as the fresh samples, consistent with the ultracentrifuge results.

The halftone dot transfers preserved a recognizable dot pattern at the 30 dot/inch pitch, but the toner particles were dispersed over a diameter roughly double the ~222 μm diameter of the toned dots.

The distribution of transferred toner was evaluated in terms of receiver area coverage as a function of radial distance from the ideal halftone dot center. For comparable transfer fields, the surface-treated toners generally showed higher transfer efficiency (i.e., % coverage). This is consistent with easier removal of surface-treated toners in the ultracentrifuge. For the highest silica surface-treatment (1.0/0.35 pph silica/titania), significant transfer was obtained at an electric field of only 5.9 V/μm, a field strength too small for significant transfer of untreated toner.

Transfer coverage begins falling off within the ideal dot radius, and significant satellite coverage extends about 135 μ beyond the ideal dot radius. There must be a significant lateral component in toner trajectories to result in this spatial dispersion on the receiver. The transfer efficiency increases strongly with transfer field. For the surface-treated toners, the 3-mil gap yields a more sharply defined transferred dot than the 5-mil gap, for comparable electric field. The radial extent of the satellites is on the order of 250 μm from the dot center, regardless of gap, field, or surface-treatment. The full-width/half-max extent of coverage is also essentially invariant.

Conclusion

The effect of surface-treatment in reducing toner adhesion and cohesion has been confirmed and quantified for a range of silica/titania surface treatments on 11 μm polystyrene toner. The centrifugal 50% removal force for the 1.0% silica / 0.35% titania treated toner was reduced by 6x, compared to the untreated toner, for low densities. In the ESD the role of surface-treatment in increasing gap jumping (with a lateral dispersion on the receiver) at a given field has also been quantified. The ESD results confirm the strong dependence of toner gap jumping efficiency on electric field. In agreement with theoretical calculations, small toned features were observed to have a larger percentage of spreading during gap jumping. The ESD results do not reveal a strong dependence of spatial extent of satellites on gap, field, or surface-treatment. The ultracentrifuge and ESD results show prominent toner clumping, nonuniformity, and a wide distribution of apparent particle adhesive/cohesive force.

The fragility and instability of toned images on photoconductive film was demonstrated by disruption of toned images in several ways. Image disruption following a simple finger flick or peeling from tape highlighted the importance of careful toned film (and paper) handling (in the lab and in copier/printers), especially for highly surface-treated toners. The relative ease of tangential removal of toner from film was quantified in the ultracentrifuge. In the ESD, satellite formation was observed on some residual images as well as on the receiver. A time dependence of toner adhesion/cohesion was found on a time scale of a few days.

References

1. B. Gady, D. J. Quesnel, D. S. Rimai, S. Leone, and P. Alexandrovich, *J. Imag. Sci. Technol*. **43**, 288 (1999).
2. R. P. Dooley and R. Shaw, *J. Appl. Photogr. Eng.* **5**, 190 (1979).

Biography

Robert D. Fields received a Ph.D. degree in Chemical Engineering from Cornell University in 1973. He is an Associate Scientist at Heidelberg Digital. For the majority of his career he has been involved in process development and manufacturing of electrophotographic toners and developers. Most recently he was the Program Manager for Kodak's new toner manufacturing facility in England. He is the holder of several patents in the area of toner formulations. Currently he is working on commercialization of materials for electrophotographic digital printers. He is a member of the IS&T.