

Surface Treatment and Its Effects on Toner Adhesion, Cohesion, Transfer, and Image Quality

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Abstract

By treating the surface of toner particles with submicrometer particulate addenda, it has been possible to reduce the size of the toner from approximately 12 μm to 8μm. Presumably, this is because the particulates separate the toner particles from the photoconductor, thereby facilitating transfer. However, in the area of digital electrophotography, where images frequently comprise half-tone dots, the cohesiveness of the toner stacks may affect the final image quality. This paper discusses the effect on transfer of surface treated toners, with the surface treatment concentration varying between 0 and 2% by weight of toner. In essence, it was found that, while transfer efficiency increased with increasing silica concentration, resolution decreased and dot structure after transfer was degraded. Toner adhesion measurements, performed using an ultracentrifuge, were found to correlate well with the transfer efficiency measurements and suggest that the observed transfer behavior may be interpreted in terms of toner-to-photoconductor adhesion and interparticle cohesion effects.

Introduction

It is well established that the adhesion properties of toner particles affect transfer.[1-3] Numerous methods have been employed to reduce toner-to-photoconductor adhesion in order to both improve transfer and facilitate cleaning. For example, surface treatments such as zinc stearate and Teflon have been demonstrated to significantly reduce toner adhesion.[4,5] In two component developer systems, addition of third-component particulate addenda to the toners have shown marked effects on toner adhesion and improved the toner flow as well.[5,6] Third-component addenda such as silica are a particularly efficient means to reduce toner adhesion both to itself and to photoconductors.[7] Indeed, the use of particulate addenda has enabled the mean volume weighted average diameter of toner particles in commercially available electrophotography to decrease from about 12 μm to approximately 8.5 μm over the past few years. The mechanism is primarily the ability of the surface treatments to control the surface forces that would otherwise overwhelm the electrostatic forces driving transfer for the smaller particle sizes.

In recent years, third-component particulate addenda, such as silica, have been appended to toner particles to reduce and control adhesion and thereby improve flow and transfer. Although the mechanism is not fully understood, it has been shown that particles having diameters in the range of tens of nanometers located on the surface of the toner particles affects the adhesive forces to non-toner surfaces and the cohesive forces between toner particles.[8] The mechanism is (presumably by the particulate addenda) serving as asperities that reduce adhesion by roughening the surface, preventing intimate contact between the toner and the adherent surface or other toner particles.

Experiment

In this study, the transfer efficiency, dot structure, and resolution of electrostatically transferred images were determined for a series of nominal 8.5 μm volume averaged diameter ground toner particles. In addition, the force needed to remove the particles from a photoconductor was measured using a Beckman LM 70 ultracentrifuge.

Two series of toners were used in this study. The first consisted of a ground polyester with between 0% and 2% Aerosil R972 (produced by DeGussa, Inc., http:\\www.degussa.com) silica particles, by weight, added to the surface of the toner particles. These particles have an average diameter, as reported by DeGussa, of approximately 16 nm although SEM micrographs show agglomerates in the range of 60 nm. The second series was quite similar except the toner particles also contained a silicone release agent. The volume-weighted average diameter of the toner, as determined using a Coulter Multisizer, was approximately 8.6 μm for the toner without the silicone additive and approximately 8.1 μm for the silicone-containing toner.

Transfer efficiency was measured using transmission densitometry for toned optical densities on the photoconductor between 0.1 and 1.0. The average transmission efficiency over the range of optical densities was determined as a function of voltage applied to the transfer roller. The conducting layer of the photoconductor was grounded and the maximum transfer voltage applied was 2500 volts. The transfer efficiency increased with applied transfer voltage over the entire 0-2500 volt range. The voltage, $V_{90\%}$, at which the average transfer efficiency exceeded 90% was then determined for each series of toners containing the various levels of silica mentioned above.

The adhesion of the toner particles to the photoconductor was determined by developing low density patches and removing the toner in an ultracentrifuge capable of spinning at 70,000 rpm. The procedure is as follows. The initial number of particles on the photoconductor was established by counting, using suitable image analysis software. Next, the photoconductor was placed in the centrifuge and spun at the desired speed. The sample was removed and the remaining particles on the photoconductor were counted. This process was repeated for a series of speeds. Centrifugation was performed in a low vacuum of approximately 10^{-3} Torr. The initial coverage was 0.5 density as measured in transmission corresponding to a 50-60% surface coverage by the particles.

Results

The applied voltage, $V_{90\%}$, for which the transfer efficiency exceeds 90%, as a function of silica concentration, is shown in Fig. 1 for the toners with and without the silicone additive. As can be seen, the voltage necessary for 90% transfer drops rapidly with increasing silica concentration for both toners. However, the effect levels off for silica concentrations of more than 0.5% with the effect for 1% and 2% silica only incrementally larger than that at 0.5%. Moreover, it can be seen that the use of a silicone additive in conjunction with the silica not only does not result in a further reduction in the voltage needed for 90% transfer, but actually reduced the effect of the silica treatment applied without the silicone additive. The silicone additive may be acting as a liquid bridge that actually reduces the efficiency of the silica in separating the toner from the surface. Further studies are needed to understand this issue in more detail.

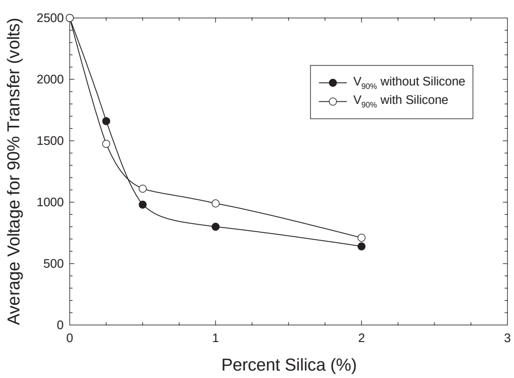
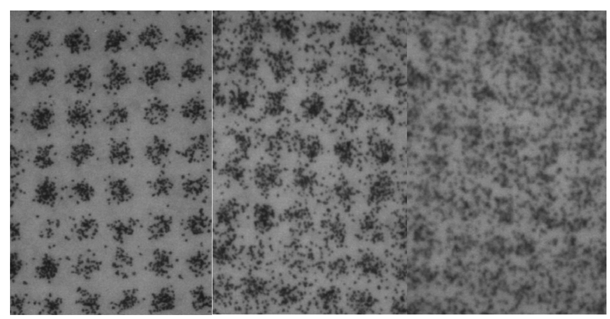


Figure 1. Comparison in transfer performance for silica treated toner with and without silicone additive.

From the data thus far presented, it may appear that the process of transferring toner can be made more robust, although perhaps reaching a point of diminishing returns, simply by increasing the concentration of silica on the toner particles. However, this is not quite correct. Transfer is not just the removal of toner from a photoconductor accompanied by a deposition of the toner on a receiver. Rather, it is that process with the additional constraint that image disruption must be minimized. Image disruption was characterized in this study by microscopically examining the halftone dot pattern and resolution chart before and after transfer.

In this study the effect of the silica concentration on image disruption was determined by qualitatively examining the structure of the halftone dots and measuring the resolution in line pairs per millimeter before and after transferring the image using a 1500 volt transfer bias. Before transfer, a resolution between 14, respectively. Resolution also tends to decrease with increasing silica concentration. This effect is shown in and 16 line pairs per millimeter was obtained. Moreover, the dots were well formed, exhibited minimal satellite formation, and, in general, appeared to reproduce the test target quite well. However, it was found that after transfer, the dots were disrupted, with the amount of disruption and the number of satellites increasing monotonically with increasing silica concentration. This effect is shown in Figs. 2A-2C for the silicone-containing toner with 0, 0.5, and 2.0% silica Fig. 3, for toners both without and with the silicone additive. The reduction in resolution is more severe for the toner system containing the silicone adhesion additive.



A *B* *C*

Figure 2 A-C. Progressive degradation in dot integrity with increasing silica concentration (0.0%, 0.5%, and 2.0%)

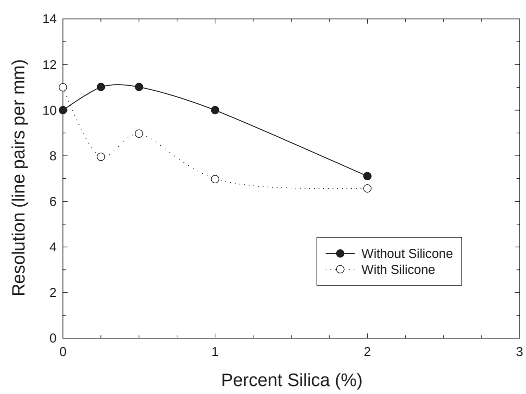


Figure 3. Effect of silicone additive on image resolution.

Figure 4 shows the percent of the toner (without silicone) removed from the photoconductor as a function of the mean applied force produced by different centrifuge speeds. Data for three silica concentrations of 0%, 1%, and 2% are shown. The highest force corresponds to 70,000 rpm.

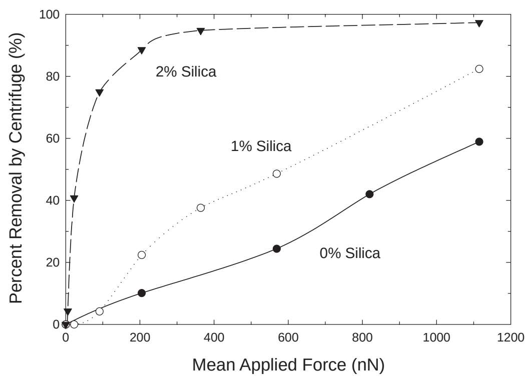


Figure 4. Percent removed silica concentration series from a photoconductor using centrifuge detachment.

The mean applied forces reported above were calculated by assuming that the particles were spherical polyester toner with a radius of 4 μm and a mass density of 1.2 g/cm^3. The removal force, P_S, estimated at the 50% removal point, was determined to be 970 nN, 580 nN, and 39 nN for the 0%, 1%, and 2% silica-coated toner particles, respectively.

Analysis

As shown in the previous section, transfer efficiency improves with increasing silica concentration while dot integrity and resolution are both degraded. Moreover, the force needed to detach the toner from the photoconductor also decreases with increasing silica concentration.

Let us first assume that the uncoated toner particles are spheres with a radius of approximately 4 μm. The particle removal force, F_S, can be calculated from JKR theory. Assuming a reasonable value of w_A = 0.05 J/m^2, the particle removal force is estimated to be 943 nN. In light of the approximations made, this value is in reasonable agreement with the experimentally obtained value of 970 nN.

Estimates of the electrostatic contribution to particle adhesion are not as simple to make, owing to polarization and charge distribution effects. Although details of this problem are presented elsewhere, these issues will be examined briefly.[9,10] Using the values of charge to mass reported earlier, (37 ± 3 μC/g, ρ = 1.2 g/cm^3), it is then calculated that F_I would be in the range of 20 to 40 nN for the present toner particles. This range in force is less than the measured force needed for detachment shown in Fig. 4.

Using a parallel plate capacitor approximation, one finds that this charge density would result in an electric field of approximately 2.1 × 10^8 V/m. This would clearly exceed the Paschen limit in air and would result in dielectric breakdown as the toner particle approached the photoconductor during development.[11,12]

The percent of the surface coverage of the toner by the silica can be estimated by assuming both the toner and silica are spherical. For the purpose of this calculation, assume the weight fraction of the silica is 1%. The primary particle size of the silica is 16 nm diameter but it is clustered into particles of 60 nm average diameter, also assumed to be spherical. Using ρ = 1.75 g/cm^3 as the mass density of the silica and ρ = 1.2 g/cm^3 as the mass density of the toner, and knowing that the toner has a mean diameter of 8 μm, the fraction of the surface area of the toner covered by silica clusters is 25%. For 2% silica by weight, the area coverage calculated is 50%. These estimates are consistent with SEM micrographs of the toner.

Assuming that the work of adhesion for silica to photoconductor remains at w_A = 0.05 J/m^2, upon substitution it is found that F_S' ≈ 70 nN. The experimentally obtained value of F_S' was approximately 51 nN. In view of the approximations made, the experimentally obtained value is in reasonable agreement with that estimated. It is interesting to note that these values are also close to the estimated contributions of the electrostatic image charges to the total force of adhesion, suggesting that, at this level of silica treatment, both van der Waals and electrostatic interactions are significant factors in determining the total force holding the toner to the photoconductor. The applied electrostatic field needed to effect separation of the toner from the photoconductor was estimated to be in the range of 3 to 6 × 10^6 V/m, which is readily obtainable. Accordingly, transfer efficiency should be quite good in the presence of the silica particles in agreement with the experimental observations.

The detachment force for the toner particles containing 1% silica was determined by the centrifuge experiments to be approximately 580 nN, or about an order of magnitude larger than the estimated image charge contributions. In this case, the detachment field was calculated to be approximately 4.9 × 10^7 V/m, ignoring polarization effects. This result suggests that transfer of the toner across an air gap would not be feasible even with this level of silica present. Rather, it is necessary for the receiver to contact the toner, thereby supplementing the electrostatic transfer forces with surface forces.

Conclusions

It was found that the transfer efficiency of an electrophotographic toner increases with an increasing concentration of nanometer-size silica particles on the surface of the toner. However, accompanying the improved transfer efficiency is a loss of resolution and a decrease in dot integrity. These results track with a decrease in the adhesion of the toner to the photoconductor, as measured with an ultracentrifuge. The size of the removal forces measured appear consistent with estimates that assume van der Waals interactions, but, in general, appear too large to be attributed to electrostatic interactions alone. As the concentration of silica approaches 2%, the contributions of the van der Waals and the electrostatic forces become comparable in magnitude.

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Biography

Barrett Gady obtained his undergraduate degree in physics at Rochester Institute of Technology in 1990. Upon graduating, he spent a year performing UHV surface science work at Argonne National Laboratories. He entered the graduate program at Purdue University and obtained his Master’s and Doctorate degrees in experimental condensed matter physics. His thesis work involved the study of the forces governing small particle adhesion using atomic force microscope techniques. In 1996, he joined the electrophotographic research group at Eastman Kodak Company. His current interest include toner transfer and color electrophotographic systems engineering.

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