Quantification of Toner Aging in Two Component Development Systems

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Abstract

Xerographic toners are typically blended with additives for adhesion control in development and transfer processes. 10-100 nanometer size additives on toner surface are used to space toners away from the electrode surfaces which lower the adhesion forces. However, in a developer housing, additives get buried into the toner over time due to the repeated mechanical stresses encountered. This is referred to as toner aging. Aged toners can have significantly higher adhesion forces and often perform poorly in development and transfer. In this paper, we will discuss models for estimating the surface additive coverage distribution on toners in the developer housing and its impact of development and transfer performance.

Introduction

In electrophotography, charged toner particles are moved from one surface to another by applying electrostatic fields where the resulting electrostatic forces on the toners are used to overcome the surface adhesion forces. For instance during the development process, toners are moved from the carrier surface to the photoconductor surface and during the transfer process the toners are moved from the photoconductor surface to the paper surface. Control of adhesion of toner particles is critical to achieving stable image quality in the electrophotographic process. To this end nanometer size additives are added to the toners. These additives, typically 10-100 nanometer silica particles, adhere preferentially to edges and holes on the toner surfaces.[1] The effect of the silica additives on toner adhesion has been studied extensively in the past. Iimura et. al.[2] have shown experimentally using a centrifuge that the adhesion forces of tribocharged toners decreases exponentially with increasing surface additive coverage. They used the charge patch model to propose that increasing surface additive coverage on toners increases the total charged area on the toner particles, resulting in a more uniformly charged toner. Gady el. al.[3] have shown a rapid decrease in the applied voltage required to achieve 90% transfer efficiency with increasing silica content in toners. They suggest that additives might act as asperities that prevent intimate contact between surfaces.

In a typical two-component development housing (see for example Schein[4]), toners and carriers are mixed in the sump at a specified ratio known as the toner concentration. This mixture is picked up by a developer roll, metered using a trim bar to achieve a uniform thickness and transported to the development zone where the toners are presented to the image on the photoconductor. Toner and carrier particles are repeatedly subject mechanical stresses during the mixing, trimming and development processes. Computer simulations have been used to study the motion of carrier particles around the developer roll (see for example Ref. 5). Simulations suggest that regions of high stress in the housing are at the trim bar. The amount of stress on the developer material depends on the strength of the trim pole magnets, the speed of the developer roll and the trim bar gap.

The loss in functionality of developer material due to the repeated mechanical stresses over time is referred to as aging. The decline of developer conductivity with age of the developer and its impact of development performance of conductive magnetic brush systems has been studied by Nash et.al.[6] Another aspect of developer aging is toner impaction on carrier surfaces which affects the tribocharging characteristics of the toner.[7] Trickle[8] has been used to extend the developer life by adding small amounts of fresh carrier with the toner dispense. In all of the above mentioned studies, the focus of aging is the state of the carrier surface over time. However the effect of the mechanical stresses on the toner surfaces, may be equally important. We refer to this as toner aging. Figure 1 below shows photomicrographs of two toner particles, one fresh and the other aged for 60 minutes in a developer housing. The fresh toner has significant surface additive coverage, whereas the aged toner has almost no additives on the surface. Chemical analysis reveals that the additives are buried beneath the surface in the aged toner. Due to the significant dependence of the adhesion forces on the surface additive coverage as discussed previously, one would expect fresh toners and aged toners to perform differently during development and transfer, and this has been observed experimentally as well.

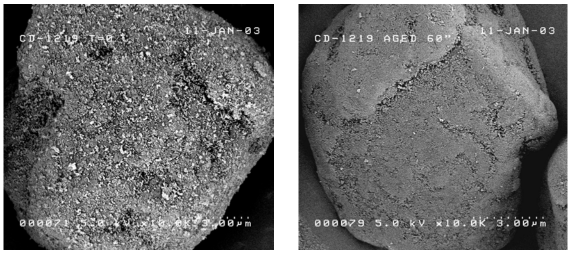

Figure 1. Photomicrograph for fresh toner on the left and 60 minutes aged toner on the right

The surface additive coverage on the toners in a development housing is a distribution that depends on the area coverage of the images that have been run through it. For high area coverage print jobs a significant fraction of toners are likely to be "fresh" and have a high surface additive coverage. Conversely, for low area coverage print jobs, a significant fraction of toners are likely to be "aged" and have a low surface additive coverage. In general, the toners in the developer sump will have a distribution of surface additive coverage, and the development and transfer performances will depend on this distribution. In this paper, we will discuss how the distribution of surface additive coverage on toners can be modeled. This distribution can be used to obtain the average surface additive state of the toners in the developer sump which can be related to the development and transfer performance.

Modeling the Surface Additive State of Toners

Figure 2 shows a schematic of mass balance in a developer housing. M_s is the sump developer mass, M_t is the sump toner mass = $M_s TC/(1+TC)$, where TC is the toner concentration in the sump. D_t is the dispense rate and C_t is the throughput rate. R_w is the trickle waste. Let TC_0 be the toner concentration in the replenisher.

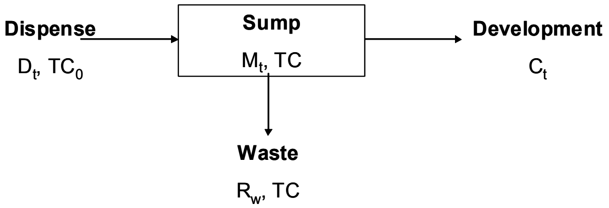

Figure 2. Schematic of mass balance in a developer housing

The toner mass balance (neglecting toner emissions and bead carry out etc..) may be written as:

$$M_t(t+dt) = M_t(t) + (D_t \frac{TC_0}{1+TC_0} - C_t - R_w \frac{TC}{1+TC})dt \quad (1)$$

Let $g_s(\tau,t)$ be the age distribution of toners in the sump, i.e. the fraction of toners with residence time τ at time t. Thus,

$$\sum_{\tau=0}^{t} g_s(\tau,t) = 1, \text{ and } g_s(\tau,t) = 0 \text{ for } \tau > t. \quad (2)$$

The evolution of the age distribution can be written as:

$$\begin{aligned} M_t(t+dt)g_s(\tau+dt,t+dt) &= \left(M_t(t) - R_w \frac{TC}{1+TC}\right)g_s(\tau,t) \\ &\quad - C_t g_d(\tau,t) \\ M_t(t+dt)g_s(0,t+dt) &= D_t \frac{TC_0}{1+TC_0} \end{aligned} \quad (3)$$

Here g_d is the age distribution of the developed toners on the photoconductor.

Next we consider the surface additive state on the toners. Let $N_f(\tau,t)$ represent the number of additives on a toner of age τ at time t. A normalized value of N_f=1 represents the number of additives on toners in fresh developer. Let $g_{sa}(\tau_1,\tau,t)$ be the fraction of $N_f(\tau,t)$ that have been resident of the toner for time τ_1 ($\tau_1 \leq \tau$). Thus $\Sigma_{\tau 1}\, g_{sa}(\tau_1,\tau,t)=1$. Also, let p_a be the fraction of free additives in dispense. For simplicity, we assume that these free additives are instantly blended and uniformly distributed among the developer surfaces in the sump (both carrier and toner). Then we may write the evolution of the surface additive state as follows:

$$\begin{aligned} N_f(\tau+dt,t+dt) &= N_f(\tau,t) + p_0 \\ g_{sa}(\tau_1+dt,\tau+dt,t+dt) &= \frac{N_f(\tau,t)}{N_f(\tau+dt,t+dt)} g_{sa}(\tau_1,\tau,t) \\ g_{sa}(0,\tau+dt,t+dt) &= \frac{p_0}{N_f(\tau+dt,t+dt)} \\ g_{sa}(0,0,t+dt) &= 1 \end{aligned} \quad (4)$$

Here:

$$p_0 = \frac{1}{M_t} p_a D_t \frac{TC_0}{1+TC_0} dt \frac{1}{1 + \frac{1}{TC}\frac{\rho_t}{\rho_c}\frac{D_t}{D_c}}$$

is the amount of fresh additives added to incumbent toners. D_t and D_c are toner and carrier diameters, respectively, ρ_t and ρ_c are the toner and carrier mass densities, respectively.

Figure 3 shows a typical plot of toner cohesivity with age which can be fit to an exponential. The increase in cohesivity with age is believed caused by a decrease in the surface additive coverage due to additive burial. Let T_b be the exponential time constant for additive burial. Then the surface additive state of a toner with residence time τ at time t may be written as:

$$P_s(\tau,t) = \sum_{\tau_1=0}^{\tau} e^{-\tau_1/T_b} g_{sa}(\tau_1,\tau,t) \quad (5)$$

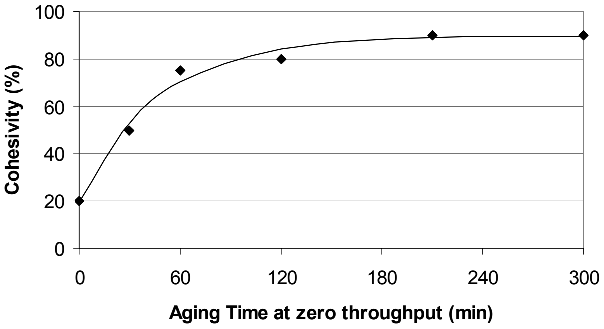

Figure 3. Toner cohesivity versus age

After some simplification, the evolution of the surface additive state of the toner $P_s(\tau,t)$ may be written as:

$$\begin{aligned} P_s(\tau+dt,t+dt) &= p_0 + e^{-dt/T_b} P_s(\tau,t) \\ P_s(0,t+dt) &= (1-p_a) + p_0 \end{aligned} \quad (6)$$

The first term above the effect of free additives from the dispenser and the second term is the effect of additive burial. Finally, we can define the normalized developability (γ_s) as the average surface additive state of the toners in the sump and normalized transferability as the average additive state of the developed toners on the photoconductor:

$$\begin{aligned} \gamma_s(t) &= \sum_{\tau=0}^{t} P_s(\tau,t) g_s(\tau,t) \\ \gamma_d(t) &= \sum_{\tau=0}^{t} P_s(\tau,t) g_d(\tau,t) \end{aligned} \tag{7}$$

One might expect the development and transfer performance to be dependent on γ_s and γ_d, respectively. These in turn depend on the additive burial process and the dispense history which largely depends on the customer image. We can also specify the average age for toners in the sump and the photoconductor as:

$$\bar{\tau}_s = \sum_{\tau=0}^{t} \tau g_s(\tau,t), \quad \bar{\tau}_d = \sum_{\tau=0}^{t} \tau g_d(\tau,t), \tag{8}$$

To complete the description of the model given by Eqs.1-8, we need to specify how the age distribution of developed toners $g_d(\tau,t)$ is determined. This depends on the development probability (P_d) of sump toners. Let us consider two cases:

(a) Uniform development probability for all toners (P_d=1):

$$g_d(\tau,t) = g_s(\tau,t)$$

(b) Development probability of toners given by their surface additive state (P_d=P_s):

$$g_d(\tau.t) = \frac{1}{\gamma_s(t)} g_s(\tau,t) P_s(\tau,t).$$

Note that cases (a) and (b) are somewhat analogous to the "Equilibrium" theory and "Field Stripping" theory in Schein's[4] discussion of the theories of development.

Simulation Results

Consider a developer sump with mass M_s= 3500 gm at a TC=4% (toner mass $M_t \approx 135$ gm). The replenisher toner concentration TC_0 =200% and fraction of free additives in the replenisher p_a=0.25. The additive burial time constant T_b= 45 minutes (from Figure 3). We will assume that the sump TC is maintained constant and excess mass is trickled out. One can identify three regimes of behavior depending on the throughput rate (C_t): (a) Low Area Coverage (LAC) where $M_t/C_t >> T_b$, (b) Nominal Area Coverage (NAC) where $M_t/C_t \approx T_b$, and (c) High Area Coverage (HAC) where $M_t/C_t << T_b$. Note that M_t/C_t is a crude estimate of the toner residence time in the sump. For the example here, we will choose C_t=1 gm/min, 3gm/min and 15 gm/min to represent the LAC, NAC and HAC regimes, respectively. The simulations are run for 300 minutes starting with an initial sump of fresh toner, i.e. $g_s(0,0)$=1, $P_s(0,0)$=1. For the example here, we assume that the development probability with age is given by the surface additive state of toners in the sump (P_d=P_s).

Figures 4-7 show plots of average age of toners (τ_s, τ_d) , sump toner age distribution at 300 minutes, toner surface additive distribution at 300 minutes (P_s) and evolution developability (γ_s) and transferability (γ_d) over time, respectively. Age distribution in the sump (Figure 5) shows significant fraction of aged toners for the LAC case. This is reflected in the high average toner age (Figure 4). The average toner age on the photoconductor (PC) is lower because we assume that toners with higher surface additive coverage (i.e. fresh toners) are preferentially developed. The surface additive state distribution with age (Figure 6) shows the impact of free additives for the HAC case.

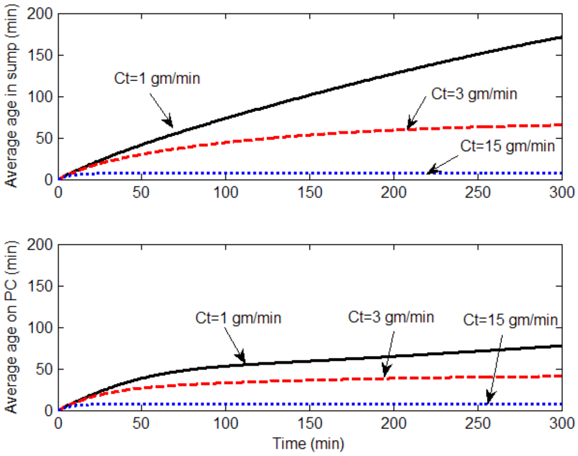

Figure 4. Average toner age in the sump (top) and photoconductor (bottom) for various values of C_t.

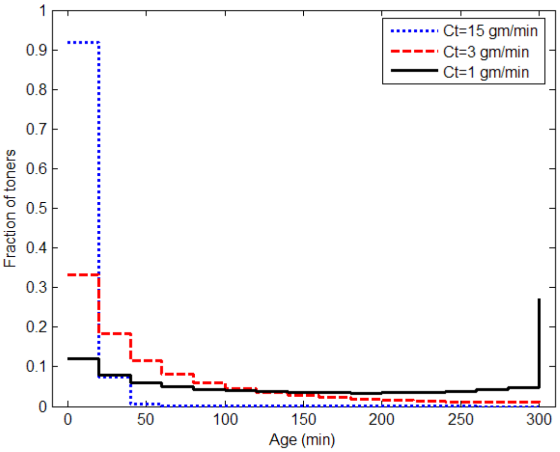

Figure 5. Sump toner age distribution at 300 minutes.

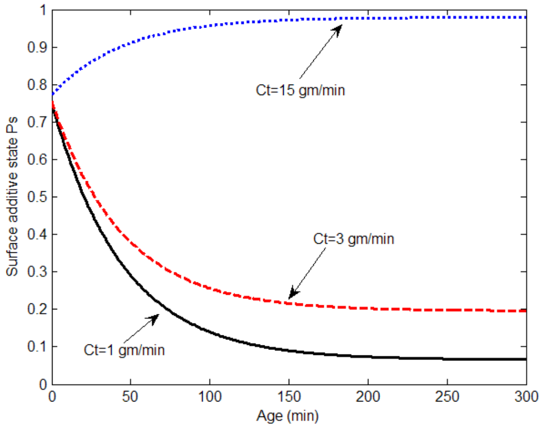

Figure 6. Surface additive state distribution at 300 minutes

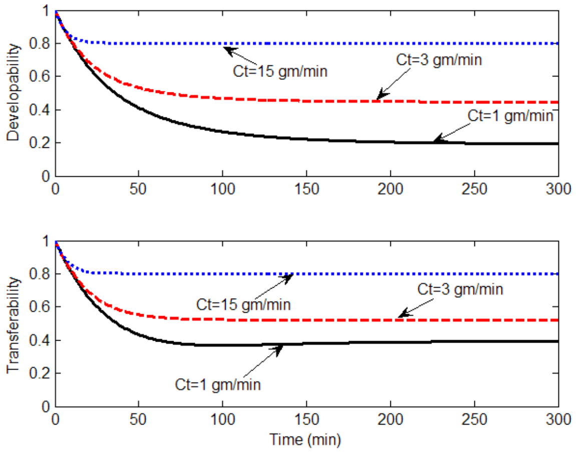

Figure 7. Evolution of normalized surface additive states for toners in the sump (top) and photoconductor (bottom)

Conclusion

In this paper we discussed how the distribution of additive burial states on toner surfaces can be modeled. These distributions define the average surface additive state of toners which can be related to the toner adhesion properties and therefore to development and transfer performance. The models can be used to understand how image quality might be impacted by various customer jobs.

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Author Biography

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