The Effect of External Toner Additives on the Aging of Conductive Developers

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Abstract

While conductive carrier particles are a necessary component of a CMB developer, other developer components can also strongly affect the overall conductive performance. For example, since toner particles are insulative, the conductivity of a toned CMB developer will always be lower than that of the base carrier particles; in general, the conductivity of toned carrier particles (i.e., a conductive developer) will be an exponentially declining function of the toner concentration, leading to an eventual insulative failure state at high toner concentrations. A second important property of conductive developers is the so-called breakdown voltage, i.e., the voltage at which the developer conducts a large current (e.g., 0.1 mA). The breakdown voltage value is typically an increasing function of the toner concentration; ideally, a conductive developer will combine a high level of conductivity with a high breakdown voltage value. Film-forming external toner additives tend to reduce the influence of toner concentration on developer conductivity. Indeed, during extended use, developer conductivity can be maintained or even increased through the use of film-forming additives. However, such additives may also reduce the breakdown voltage of an aged conductive developer, and for such cases, the failure mode will be electrical shorting if a high bias is applied across the development brush. This report illustrates the varying effects of toner external additives on the aging performance of conductive developers, using experimental data taken on a range of model conductive developers based on a single conductive carrier.

Introduction

In a conductive, two-component magnetic brush developer (CMB), the carrier beads provide electrically conductive pathways through the entire development brush. As a result, the development field is concentrated at the brush tips, thus producing highly efficient xerographic image development coupled with a strong level of background suppression.[1,2]

To be xerographically functional, a CMB developer must remain conductive over a range of toner concentrations, and in general the conductivity of a toned developer, σ_c, will decline exponentially with increasing toner concentration, C, with a sensitivity governed by toner and carrier size, shape, density and surface chemistry [3,4,5]. Long-term carrier aging effects such as the permanent accumulation of toner (so-called toner impaction or scumming) on the surface of conductive carrier beads will make a CMB developer increasingly sensitive to toner concentration.[6,7]

A second significant conductive property of a CMB developer is the so-called breakdown voltage value V_B, i.e., the applied d.c. voltage at which the developer brush conducts a high current, e.g., 0.1 mA. The breakdown voltage of a CMB developer is generally an increasing function of the toner concentration, so that a low toner concentration may be a failure (high current flow) condition for electrical breakdown. (In xerographic applications, where the development roll is electrically biased with respect to a grounded photoreceptor substrate, a low breakdown voltage value may create a bias short-circuit, e.g., via conductive defects in the photoreceptor, or to adjacent conductive components in the development housing. Xerographic systems based on a high development bias will be especially affected by developers with low values of V_B). As with developer conductivity, the breakdown voltage value of a CMB developer is a function of toner and carrier physical properties, and can also be affected by overall developer aging effects such as toner film accumulation and carrier coating loss.

Though present at relatively low levels in a typical toner design, external additives may also affect the conductive properties of a CMB developer, as evident through additive-driven changes in the conductivity:C sensitivity factor [3,5] and in the V_B value. Besides time-zero properties, external additives may also affect the conductive aging process of CMB developers, and the present report details illustrative examples of this long-term effect.

Experimental

Materials

CMB Carrier

Rough, water-atomized iron powder, air-oxidized to produce a core breakdown voltage of about 300 volts. Partially solution-coated with about 1.5 wt% PMMA to give a carrier VB of about 600 volts.

Test Toners

Toner S — polystyrene/n-butylmethacrylate binder with about 10 wt% carbon black; size-classified to remove fines. Toner P — linear polyester binder with about 12 wt% carbon black; non-classified.

External Additives

(i) 16 nm hydrophobic fumed silica; (ii) sub-micron, spherical fluoropolymer powder; (iii) zinc stearate powder.

Test Procedures

Test developers were aged in a single development roll aging fixture[8] at a constant solid-area density. At regular aging intervals, 50 ml samples of developer were removed for conductivity measurements in a magnetic brush cell.[3-5] Normally, the conductivity value was calculated based on the conduction current at 200 volts d.c.; for highly conductive or insulative samples, the test measurements were extrapolated to 200 volts. Measurements were made on developer samples, and on de-toned carrier samples. At time-zero and at the end-of-test, developer conductivity properties were scanned over a range of toner concentrations, so that their sensitivity to toner concentration could be assessed.

Results

TEST 1: Toner S with 0.35 wt% Submicron, Spherical Fluoropolymer Powder and 0.8 wt% 16 nm Fumed Silica as External Additives

For this toner, the triboelectric charging properties showed only a small decline with developer age, with a xerographic setpoint at an average value of -22 μC/g @ 1.25 wt%. Though the de-toned carrier breakdown potential declined about 40% with developer age, the breakdown potential for the developer toned at the run condition remained high in the 600 - 700 volt range, Figure 1.

Similarly, the de-toned carrier conductivity remained high at about 10^{-8} $ohm.cm^{-1}$ throughout the aging test, while the toned developer conductivity was 2 to 3 orders less conductive, Figure 2. Diagnostic bench tests over a range of toner concentration, (inset plots in Figs. 1 and 2), indicate that the breakdown voltage and the conductivity of the developer became more sensitive to toner concentration with age, with the aged developer being essentially insulative at toner concentrations above about 1.5 wt%. (The run-time conductivity and breakdown data for the de-toned carrier samples reflect carrier aging effects alone, whereas the aging data for the toned developer samples are additionally affected by toner concentration effects. As a result, the toned developer data reflect variations in the operational toner concentration during the aging test, and are thus somewhat erratic).

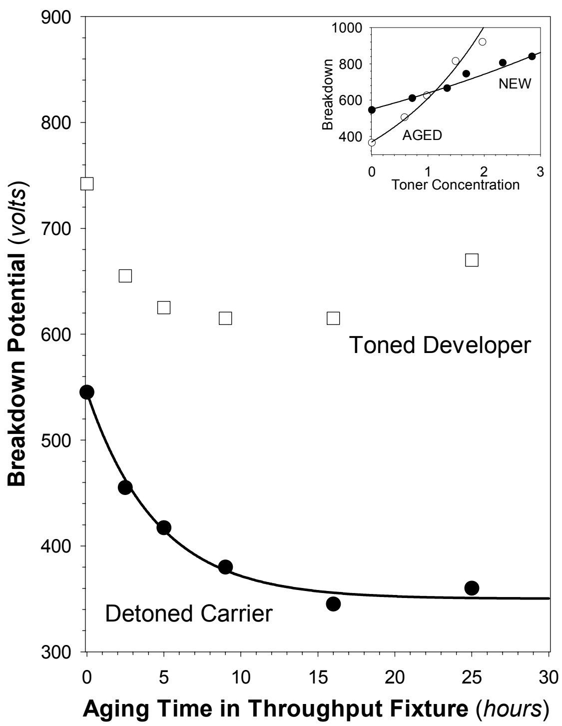

Figure 1. Breakdown potential for developer and carrier with toner S plus fluoropolymer additive.

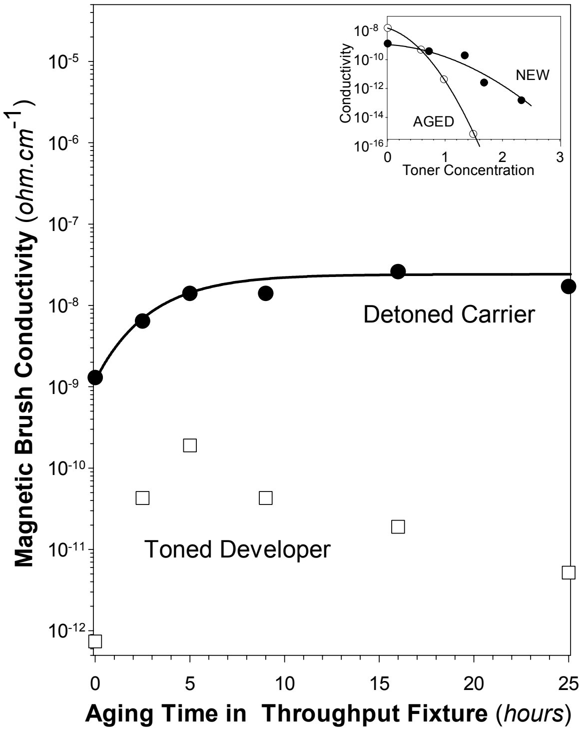

Figure 2. Conductivity for developer and carrier with toner S plus fluoropolymer additive.

From a breakdown voltage viewpoint, the toned developer performance was quite satisfactory throughout the aging test; the developer conductivity data, however, indicate a steady decline to an eventual insulative failure condition.

TEST 2: Toner S with 0.35 wt% Powdered Zinc Stearate and 0.65 wt% 16 nm Fumed Silica as External Additives

In this test, the triboelectric charging properties also showed only a small decline with developer age, with a xerographic setpoint at an average value of -25 μC/g @ 1.35 wt%. From a conductivity viewpoint, however, the new set of external additives produced a major change in the developer aging response. Both the detoned carrier breakdown potential and the toned developer breakdown potential decreased sharply with age, falling in both cases to just below 100 volts, Figure 3.

Likewise, the conductivity data, Figure 4, indicate an aging response to a highly conductive state, even for the toned developer. The diagnostic tests taken over a range of toner concentrations, (inset plots in Figs. 3 and 4), show that breakdown voltage and the conductivity of the developer both have a minor sensitivity to toner concentration with age, and that developer aging leads to a decreased sensitivity.

From a developer conductivity viewpoint, the toned developer performance was at a high level throughout the aging test; the breakdown voltage data, however, indicate a rapid decline to a bias shorting level.

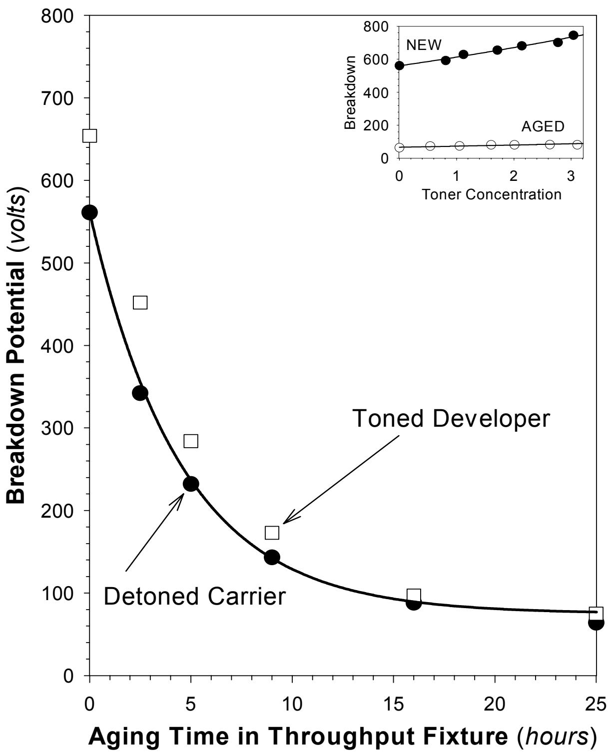

Figure 3. Breakdown potential for developer and carrier with toner S plus zinc stearate additive.

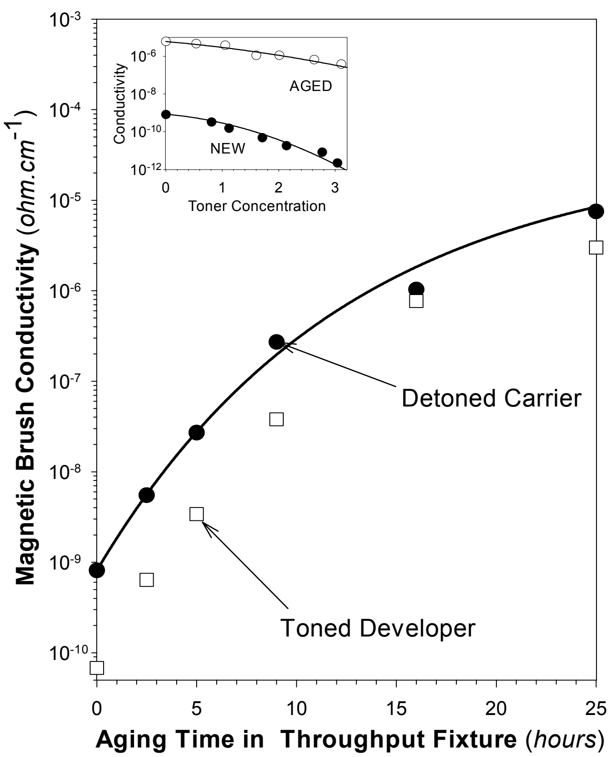

Figure 4. Conductivity for developer and carrier with toner S plus zinc stearate additive

TEST 3: Toner P with 0.35 wt% powdered zinc stearate and 0.65 wt% 16 nm fumed silica as external additives.

In this test, the triboelectric charging properties of the non-classified, polyester-based toner also showed only a small decline with developer age, with a xerographic setpoint at an average value of -35 μC/g @ 1.30 wt%. While the de-toned breakdown voltage data show a decline to an aged plateau value of 200 volts, the breakdown voltage data at the operational toner concentration show satisfactory performance with age at a range of 400 to 600 volts, Figure 5.

The conductivity data, Figure 6, show only a one order of magnitude enhancement for both the de-toned and toned developer, in contrast to the four orders of magnitude increase given by stearated toner S in test 2. The diagnostic tests taken over a range of toner concentrations, (inset plots in Figs. 5 and 6), show that the breakdown voltage and the conductivity of the developer in test 3 both have a medium sensitivity to toner concentration with age, and that developer aging leads to a slightly increased sensitivity.

From both a developer conductivity and breakdown voltage viewpoint, the toned developer performance in test 3 was satisfactory throughout the aging test.

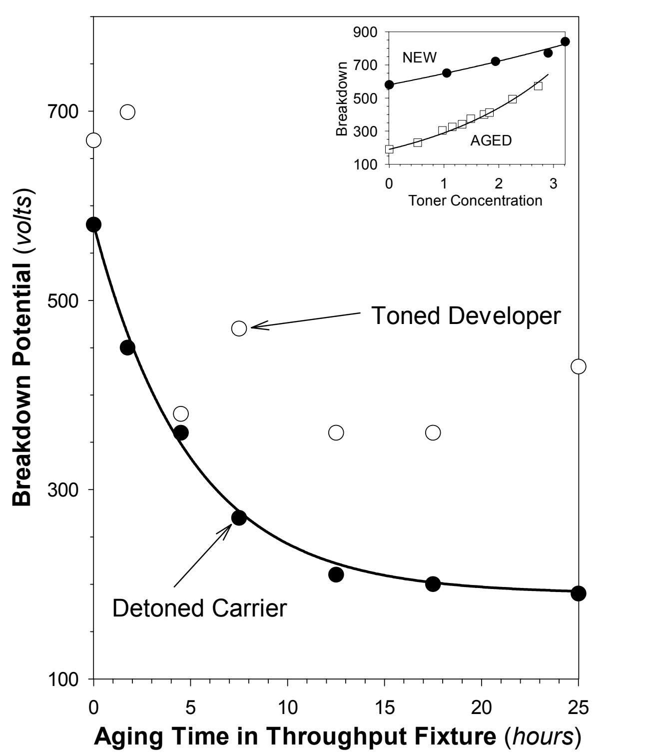

Figure 5. Breakdown potential for developer and carrier with toner P plus zinc stearate additive.

Discussion

While the base carrier used in the present studies was surface-treated (via air-oxidation of the core followed by a partial coating of PMMA) to produce a time-zero, untoned breakdown potential of almost 600 volts, the experimental data taken during the aging tests show an exponential decline in the V_B value of the de-toned carrier samples, with the largest declines being in tests 2 and 3. Wet chemical tests on the detoned carrier samples indicate an age-induced increase in metallic, conductive surface regions — for the carrier samples from test 2 (stearate-based, size-classified toner), the exposed high conductivity area increased from 35% to 70% of the total carrier area. It appears that a combination of surface abrasion and particle attrition can lower the breakdown potential of the de-toned carrier beads with age, and from the data of tests 2 and 3 this effect is most pronounced for the case of a stearated toner. As shown in past studies, stearate enhances the packing of carrier beads over that seen with additive-free toners or toners based on additives such as silica or fluoropolymers.[3,5] In general, such increased packing enhances toned developer conductivity, but for the present test carrier the increased packing evidently also increased the tendency for carrier abrasion.

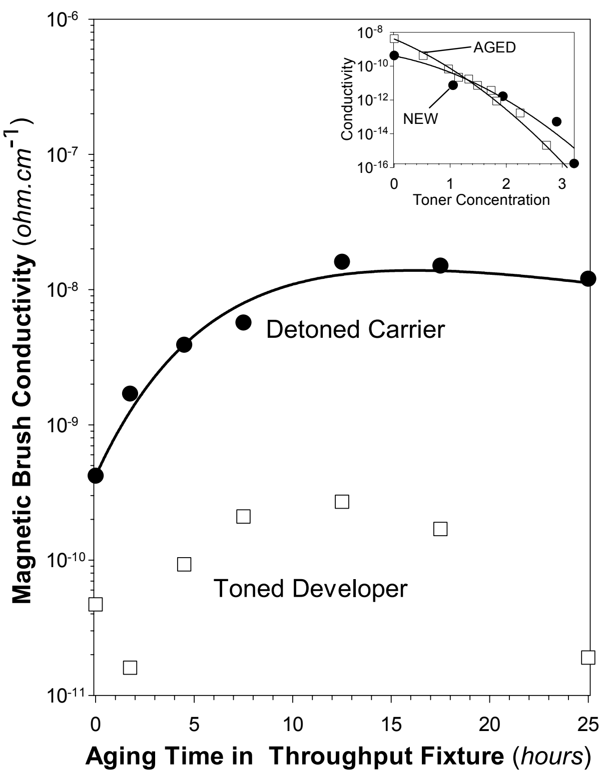

Figure 6.Conductivity for developer and carrier with toner P plus zinc stearate additive.

The stearated toner in test 2 also leads to a greatly enhanced de-toned carrier conductivity with age — there is a monotonic increase over four orders of magnitude, whereas the stearate-free version of the test toner (as used in test 1) gives only a single order of magnitude increase, as does the stearated polyester toner used in test 3. The toned developer conductivity aging behavior shown in test 2 is also noteworthy — a monotonic increase over four orders of magnitude, whereas the toners in tests 1 and 3 give only a single order of magnitude increase.

While the differences between the results from tests 1 and 2 reflect the effect of toner external additives on carrier packing, the stable results seen in test 3 apparently reflect a balancing of conductivity-enhancing and conductivity-depressing effects. In this regard, toner impaction data, Figure 7, taken on the aged carriers from the three tests clearly illustrate the latter effect.

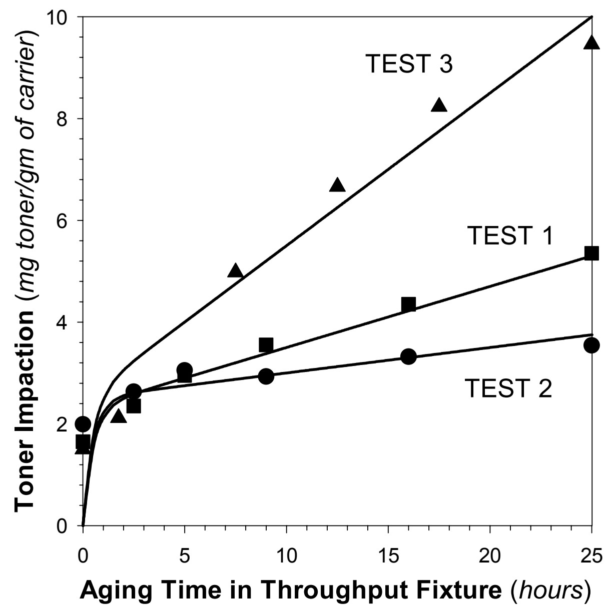

Figure 7. Toner impaction data for the developers aged in tests 1-3.

The stearated, size-classified S toner gives a low rate of toner impaction (reaches 3.5 mg of toner/gm of carrier after 25 hours of aging); the stearate-free version of toner S gives a fourfold increase in impaction rate (reaches 5.4 mg of toner/gm of carrier after 25 hours of aging); the non-classified toner P gives an ninefold increase in impaction rate (reaches almost 10 mg of toner/gm of carrier after 25 hours of aging). These large differences in toner impaction behavior reflect contributions from additive types, toner size and base resin.[8]

In summary, the three aging tests show how a range of intrinsic and extrinsic toner properties can affect the conductive performance of a single carrier type. The aging data reinforce the view that the conductive properties and performance of a conductive developer, especially as a function of age, can be affected by all components in the developer design. Therefore, for complex conductive developer designs based on reduced toner size and multicomponent external additives, optimized performance will require a careful minimization of multiple aging mechanisms.

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Author Biography

Robert Nash received his Ph.D. in Physical Chemistry from the University of Bristol, England. He joined the Xerox Corporation in 1970. From 1998 until the end of 2000 he was an expatriate at Fuji Xerox, Takematsu, Japan. He now consults on topics from xerographic materials to cross-cultural interactions with Japan. In 1999, he was named as a Fellow of the IS&T, and in 2002 he received, jointly with John Bickmore, IS&T's Chester Carlson Award.