# *Kokuten* 黒点 High-Visibility Black Xerographic Background

*Robert J. Nash, Edward. P. Imes, Bruce E. Cray,*
*Marsha A. Butler and Charles G. Dickerson*
*Xerox Corporation, Webster, NY 14580, USA*

## Abstract

On black-and-white xerographic prints, normal-sized, black toner particles in non-image areas (xerographic background) are visible only if present at a high concentration, or if viewed through a magnifying loupe, since fused individual toner particles cannot be resolved by the unaided human eye. As a result, a zero level for visual evaluations may in fact represent a background level of about 200 normal-sized toner particles per $cm^2$. By contrast, isolated, oversized fused black ***kokuten*** background particles (e.g., in the 50 - 80 μm diameter range) are quite visible in non-image areas even at a level of about 2 particles per $cm^2$. Another important difference between normal and ***kokuten*** background particles is their response to xerographic development fields in background areas — normal particles can be markedly suppressed by a reverse-development electrical bias applied to a xerographic development roll, but ***kokuten*** production is unaffected by bias level. As a result, ***kokuten*** background particles represent a copy quality shortfall that cannot be cured by conventional xerographic strategies (e.g., development bias control or background exposure level), so that the minimization of such particles must be centered on improved toner properties.

Since ***kokuten*** particles occur on developed images at a low (but highly visible) concentration, qualitative copy quality evaluations for such particles are most conveniently obtained by a ranking system based on a direct visual comparison between test xerographic prints and standard prints. For quantitative evaluations based on a direct counting of visible particles, xerographic enlargements of test prints enhance the visibility of ***kokuten*** particles, and thereby facilitate particle assays over large background areas.

A range of intrinsic and extrinsic factors in the toner production and xerographic imaging processes can affect the generation of ***kokuten*** background. For example, blending trials on a single test toner indicate that the level of ***kokuten*** background can be altered by changes in blender type and blender settings. Likewise, a comparison of unfused and fused xerographic test prints illustrates the background enhancement effects of fuser roll and paper texture, while tests based on an uncharged photoreceptor reveal that a non-xerographic process, namely mechanical agitation, can eject ***kokuten*** particles from a development housing, and thereby be a significant source of random "noise" in background print tests

## Introduction

The level of xerographic background — toner particles in non-image areas of a print — is an important metric for copy quality [1]. In extreme cases, it can occur in several highly-visible forms — as an overall light gray tone, as dark bands in or across the development process direction, as isolated dark spots, as in-line patterns of streaks, etc. This wide range of appearance is the result of the many possible root causes for background generation, ranging from toner/carrier properties to all of the process subsystems in the xerographic marking process.

From a developer materials viewpoint, a low level of toner charge and wrong-sign polarity are key factors in background development [2-8]. For toners, there can be composition-related issues with respect to charge level, charging rate, charge-admixing rate [9-11], while for carriers, charging problems are normally associated with carrier "aging" effects [12]. Additionally, external factors such as ambient humidity can also affect charging performance, toner flow, etc [13].

With respect to the xerographic development process, a development bias is typically used to suppress background development — for insulative development, a high level of bias will minimize background development [2], while for conductive development, a high bias level can actually increase background development via wrong-sign induction-charging of toner particles in the presence of the electrically-conductive carrier particles [7].

Mechanical forces associated with developer transport/mixing etc. within a development housing can also be a source of eventual background development — an inadequate incorporation of uncharged dispensed toner can produce localized regions of low or wrong-sign toner in a development housing, while overly-aggressive developer mixing can degrade toner and/or carrier charging properties [14].

Localized examples of background development — bands, streaks, and spots — are often related to photoreceptor and/or charging subsystem defects. Non-uniform electrostatic potential may produce bands of visible developed background, while localized charge-deficient micro-regions will produce isolated image spots in the background of discharged-area prints [15]. Similarly, isolated spots centered on background bands across the process direction are characteristic of a transient reduction in development bias via a short-circuit path to the photoreceptor substrate at a pinhole defect. (Characteristically, photoreceptor-based background problems repeat at regular intervals).

The accumulation of a toner film or mini-streaks caused by incomplete photoreceptor cleaning can also produce xerographic background, and this may reflect a non-linear failure mode — an excessive amount of non-transferred toner particles may reduce cleaning performance, which in turn then leads to an increased level of developed background.

The final fusing step in the xerographic marking process can also affect the visibility of developed background particles. For example, the visibility of background toner particles can be enhanced as a result of particle spreading in hard-roll fusing systems [16]. Similarly, xerographic background will be more visible on smooth photo-quality substrates than on conventional office text paper [17,18].

In addition to all of the above modes of typical "toner-sized" background generation, macro-sized spots in background image areas can also create a serious copy quality shortfall, since even low levels of such spots will be highly visible. From a toner viewpoint, oversized particles can be especially troublesome — though difficult to detect in (or remove from) the total toner population, such particles become immediately evident when located in the background areas of developed prints. For black toner, the problem is especially acute [1], since isolated, large black spots (***kokuten***) are highly visible even to an unaided eye. As an example of toner properties on this type of background development, the present report details the effect of the toner additive blending process on the production of oversized toner particles, and on the subsequent generation of ***kokuten*** background spots.

## Experimental

### Toner Materials and Blending Procedures

The base test toner was a black, negative-polarity, wax-containing toner, jetted to an 11-micron mean diameter, and screened at 44 micron. External additives (0.75 wt% of a 16 nm fumed silica and 0.4 wt% of sub-micron fluoropolymer spherical particles) were blended onto the base toner surface, to produce a final functional toner, for use in a blade-cleaned/hard-roll oiless fuser xerographic copier. Several batches of test toner were prepared using the following toner/additive blending schemes.

The test toners were blended in two types of blender: (a) a V-cone blender, where small stainless steel blending balls were used to agitate the toner plus external additives as these powders flowed between the two arms of the mixer during each inversion of the V-shaped mixing chamber; (b) a horizontal, mechanically-agitated fluid-bed mixer, where toner plus external additives were blended via mixing elements mounted on a horizontal high-speed rotating shaft. Two types of mixing protocol were studied: (a) a single-step blend procedure, where the toner and additive particles were blended at their final concentration; (b) a masterbatch procedure, where an initial blend step was used to create an additive-rich blend (e.g., with an additive level ten to twenty times that of the final target value), and a second blend step was used to "dilute" the masterbatched material with additive-free toner in order to create the final target additive level for the total load of toner in the blender.

For the control toner used in the present tests, the external additives were applied using a two-step masterbatch/dilution blending procedure in a production-scale V-cone blender. A control developer was produced from the control toner blended with 100 micron coated ferrite carrier at a toner concentration of 3.5 wt. %.

### Xerographic Print Tests

A commercial low-volume optical copier was used to produce charged-area text prints at about a 5% total image area from a business letter-type input document. Test toners were dispensed into the control developer (a new developer for each test), with development of a small solid-area control image patch being maintained at about 1.2 o.d. For image evaluations, copies were saved at 50 copy intervals throughout a 1000 copy test, and the text-free letterhead area on the test copies was used for the xerographic background and ***kokuten*** particle evaluations.

Since quantitative evaluations of toner xerographic performance can be complicated by machine-to-machine variability with respect to the overall xerographic process and latitude, the following qualitative approach, based on visible comparative evaluations between test and control toners, was used in the present study. Sets of "nominal" and higher quality "benchmark" standard prints were initially selected so as to provide an extended numerical performance rating system based on the following weighted metric:

***kokuten*** *rating* = 0• (*number of copies worse than "nominal"*)
+ 0.5• (*number of copies equal to "nominal"*)
+ 1.0• (*number of prints better than "nominal," but worse than benchmark"*)
+ 1.5• (*number of prints equal to "benchmark"*)

According to this scheme, poor and excellent ***kokuten*** background performance is represented by a rating value of 0 and 31.5, respectively, based on an evaluation of 21 test copies.

For additional diagnostic testing, the background level on the evaluation prints was also assayed in terms of toner particles per unit copy area and toner size. For "normal-sized" background toner particles, x50 photomicrographs were taken of a small area of the copy background area

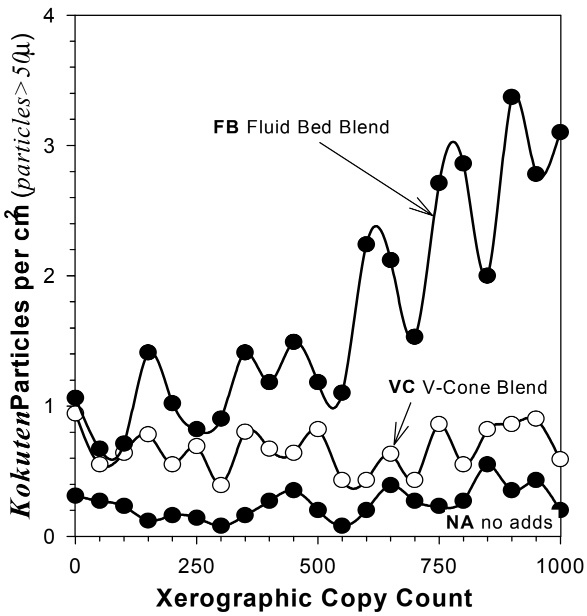


***Figure 1. Kokuten** production vs. copy count for three types of blended toner (common recipe**). FB toner was blended in a** fluid-bed blender; VC toner was blended in a V-Cone blender; NA toner was additive-free, but was processed in a V-Cone blender.*

(0.18cm x 0.23 cm). For the ***kokuten*** particles, however, a large area (50 $cm^2$) of the test print was assayed, in order to capture a statistically significant number of these isolated large particles. Briefly, the procedure was as follows: successive enlarged xerographic copies of an original test print were made at about a 150% magnification, at slightly reduced bias levels (200 volts for copy #1; 250 volts for copy #2, to increase the xerographic enhancement for a background image potential of 120-150 volts), yielding an overall combined optical and xerographic magnification level of x5. As a result, the number density and size of even faintly visible ***kokuten*** particles could be readily obtained from the final enlarged images.

Figure 1 shows the ***kokuten*** results for three types of blended toners. There is an apparent periodicity in the level of ***kokuten*** particles produced by these toners, and this effect will be discussed later. The V-cone-blended toner, **VC** (***kokuten*** rating = 31.5), and the fluid-bed-blended toner **FB** (***kokuten*** rating = 18), were both based on the nominal toner additives composition listed in the Experimental section, while test toner **NA** (***kokuten*** rating = 30) was the additive-free base toner. (Even though external additives were not added to toner NA, this toner was processed in the V-cone blender for the times typically used in the normal masterbatch and dilution steps). Since external additives such as fumed silica serve to reduce the tendency for toner-to-toner sintering (so-called toner "blocking"), the low level of ***kokuten*** particles produced during the print test of the additive-free NA toner indicates that in-situ toner blocking is not the source of ***kokuten***-sized toner particles. However, while toner NA provided an excellent ***kokuten*** performance during a short print test, it cannot be viewed as an effective toner, since external additives are needed to provide a functional level of toner flow, charge level and cleanability to the base toner particles.

Now, as is clear from the results of the toner VC and **FB** print tests, the external toner additive blending process can affect the level of ***kokuten*** performance, even for a single total toner composition. From a series of toner fluid-bed blender trials, a reduction in master batch time and in final blend time was found to match the ***kokuten*** level and overall charge-admixing properties of the V-cone-blended toners. Table 1 lists the ***kokuten*** ratings for various external additive blending schemes on the present toner design, with a simple total blend procedure in a fluid-bed blender (i.e., no preliminary masterbatch step) being particularly ineffective.

**Diagnostic Tests**

While the level of normal xerographic background can be greatly modified via an application of a reverse development bias to a development roll, there was no clear response for developed ***kokuten*** particles when the present print tests were made over a range of biases. To explore this non-xerographic background effect, diagnostic print tests were made on a "poor" toner (chosen so as to accentuate the effects). Figure 2 shows that a "baseline" kokuten level exists even for the extreme non-xerographic case of an uncharged photoreceptor, a result that confirms the lack of a bias effect. Significantly, Figure 2 also shows that a high level of non-xerographic ***kokuten*** background can be triggered simply by the removal/replacement of the

| Toner Blend Type | Masterbatch Blender | Masterbatch Time | Dilution Blender | Dilution Time | ***Kokuten*** Rating |
|---|---|---|---|---|---|
| VC-VC | V-Cone | Standard | V-Cone | Standard | 31.5 |
| VC-FB | V-Cone | Standard | Fluid-Bed | Standard | 22 |
| FB-FB | Fluid-Bed | Standard | Fluid-Bed | Standard | 13 |
| FB | | | Fluid-Bed | x0.3 Standard | 0.5 |
| No Additives | V-Cone | Standard | V-Cone | Standard | 30 |
| FB-FB | Fluid-Bed | x0.5 Standard | Fluid-Bed | x0.2 Standard | 31.5 |

**Table 1. The effect of additive blend procedures on *kokuten* production from a single test toner**

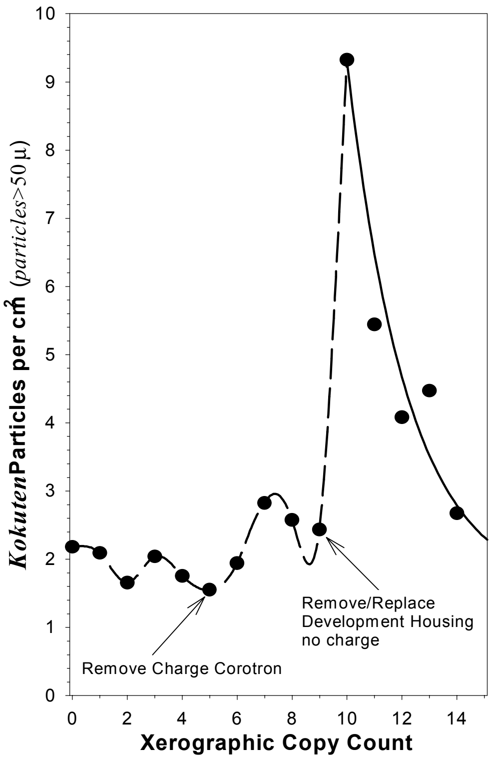


***Figure 2. Kokuten*** *production for a "poor" test toner. To test for non-xerographic effects, the charge corotron was removed, followed by the removal/replacement of the development housing.*

development housing (i.e., a direct mechanical agitation effect). A similar effect was seen when the housing removal/replacement procedure was made in the dark, thus eliminating photoreceptor "light-shock" as a potential mechanism for the background generation. A set of repeated housing removal/replacement tests, Figure 3, suggests a ***kokuten*** particle depletion process at a rate that is proportional to the available population — i.e., in the short-term, ***kokuten*** particles that are "stored" in a development housing can be successively ejected via mechanical agitation. Such a process, of course, is more severe than that expected during normal copy operation, but it does indicate that random mechanical disturbances (such as removal/replacement of a copy paper tray, machine cycling before/after printing, etc.) might create transient increases in the level of ***kokuten*** background particles above any intrinsic steady state value, and might account for the periodic variation in ***kokuten*** production apparent in some of the experimental background data.

During normal copy operation, toner is added (to replace that used to form an image) at a rate of about 30 mg of toner/copy. Since the total amount of toner in the present test developer was about 30 grams, the charging state of the test developer should be unaffected by a normal toner replenishment process. However, the ability of a charged developer to incorporate added uncharged (i.e., dispensed) toner can be an important factor in xerographic background development, and can be tested at a stress level via a deliberate addition of a large aliquot of uncharged toner [7,19]. Normally, such admix tests are made offline in simple small-scale bench tests [10,11,14]; for the present tests, however, in-situ stress admixing was used for both background particle and ***kokuten*** generation, according to the following scheme: 2 grams of test toner were lightly blended with 100 grams of charged developer, and the resultant toner-rich sample was then added to 800 grams of developer in a xerographic development housing. The first ten copies following the stress toner addition were then evaluated for ***kokuten*** and total background performance. Figure 4 shows the ***kokuten*** data for a "bad" fluid-bed toner and for a control toner —as can be seen, the "bad" test toner gives a large initial increase in ***kokuten*** particle count, with a regular decay towards the pre-admix level, while the control toner gives only a small transient increase in ***kokuten*** level. The corresponding total background data, Figure 5, is less well-defined — the control toner shows a large transient in total background, but the data from the test toner are quite scattered at a somewhat lower level. These results illustrate how ***kokuten*** performance (i.e., toners that give fused background spots in the 50 – 80μ range) can overshadow normal background performance (i.e., toners that give fused background spots in the 15 – 20μ range) — in conventional print evaluations, the test toner was judged to be inferior to the control toner, even though its conventional background performance matched that of the control toner.

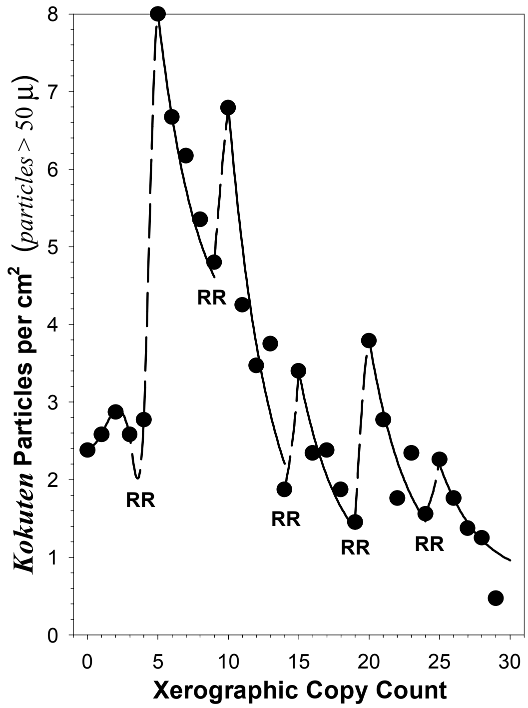


***Figure 3. Kokuten*** *production from a "poor" toner, following repeated removal/replacement of the development housing (at the points marked RR).*

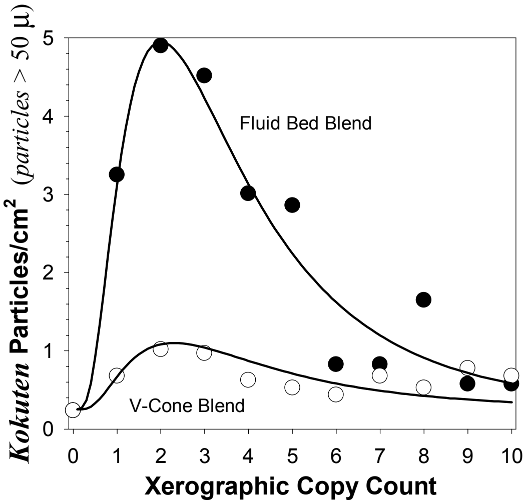


***Figure 4. Kokuten*** *production following a stress addition of toner to a working developer, for toners blended in a fluid-bed and a V-Cone blender*

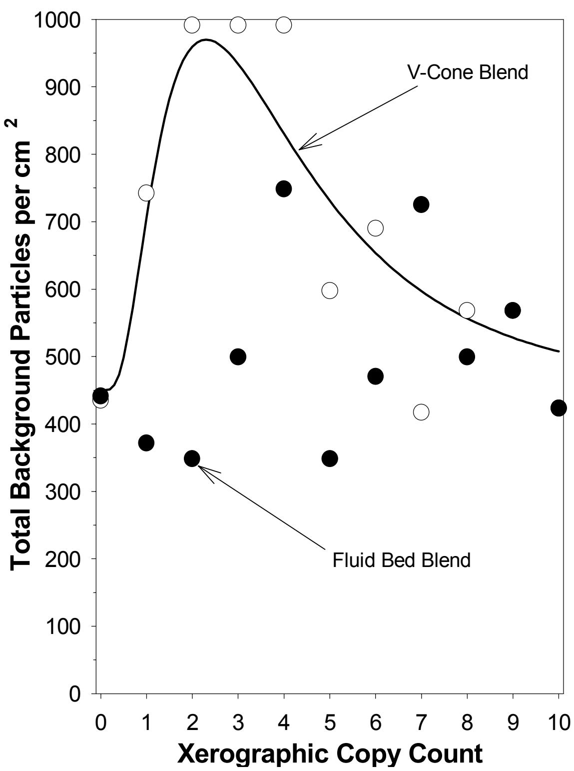


***Figure 5.*** *Total background particle production following a stress addition of toner to a working developer, for toners blended in a fluid-bed and a V-Cone blender.*

Finally, the visibility of ***kokuten*** background particles on fused copies can be undesirably enhanced in the final fusing step. For the present test copier and wax-containing test toners, a hard-roll fusing subsystem was used to provide

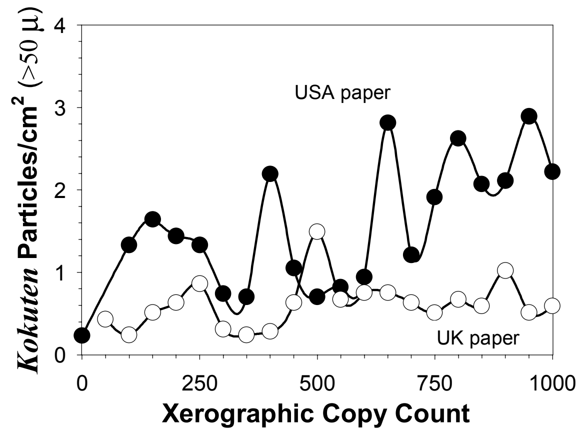


***Figure 6. Kokuten*** *production for a single test toner on two grades of normal copy paper. The UK paper is somewhat rougher than the USA paper.*

the necessary level of toner-to-paper image fix, and release between the fused toner and the oil-free fuser surface. Unfortunately, for large ***kokuten*** background particles, the 200% enhancement in toner diameter created in the hard-roll fusing step greatly increased the visibility of the oversized toner particles. Additionally, as shown in Figure 6, this enhancement process can also be affected by paper substrate texture, even for quite minor differences in the degree of smoothness of regular copy paper.

## Summary and Conclusions

The use of external toner additives is a key enabler in the design of modern, high-performance xerographic toners. Through the use of such additives, important toner functional properties such as flow, RH-stability, charge level and polarity, transfer efficiency, cleanability etc., can be optimized [20]. However, the use of such additives requires an effective blending process as a final step in the toner production process, and the optimization of controlling factors such as blend times, energies, batch size, etc. (especially for multiple additives) requires multiple actual print testing on a wide range of toner design variants [19,21].

While xerographic background problems created by external toner additives are normally associated with factors such as slow charge admixing [7,9], or toner "aging" effects [14], the present results illustrate that the blending process itself, in combination with external additives, can create dysfunctional toner particles in the high end of the toner size distribution. For the present toner design, a gentle blend process with efficient homogenization appears to minimize the production of ***kokuten*** particles — a single-step blend process that poorly incorporated the external additives into the toner batch created the worst level of ***kokuten*** particles. To minimize toner-toner agglomeration, and to maximize the charge-enhancing effect of external additives, a toner blending process must ensure that all toner particles rapidly receive a uniform coating of additives.

Xerographically, oversized ***kokuten*** toner particles, especially in combination with a toner image enhancement created via hard-roll fusing or smooth print substrates, can create an objectionable level of visible xerographic background, even when present at a level of 1% of normal-sized background. It appears that low ***q/m,*** large toner particles [22] that accumulate in development housings under normal operating conditions, can be expelled onto copies simply via mechanical vibrations — this behavior creates randomness in the appearance of ***kokuten*** particles, and thereby complicates even qualitative diagnostic studies of this type of background defect.

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## 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 served an expatriate assignment at Fuji Xerox, Takematsu, Japan, as the Senior Manager, Resident for the Xerox Supplies Development, Manufacturing and Supply Chain Operations organization. He retired from Xerox in 2002, and currently provides a consulting service on a variety of subjects, ranging from xerographic materials to cross-cultural interactions with Japan. In this way, he hopes to remain abreast of two fascinatingly complex and mysterious subjects: triboelectrification and the Japanese language. His research and modeling studies at Xerox were focused on the design and evaluation of xerographic toners, carriers and developers, with especial emphasis on "aging" mechanisms. Starting with the 4th. International NIP Congress in 1988, he has yearly presented the results of his studies at the IS&T NIP Conference. In 1990, he served as Publication Chairman for the 6th. NIP Congress, and in 1992 he was Chairman of the IS&T Honors & Awards Committee. 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.