Use of An Automated Print Quality Evaluation System as a Failure Analysis Tool in Electrophotography

Ming-Kai Tse, David J. Forrest and King Y. She
QEA, Inc.
755 Middlesex Turnpike, Unit 3, Billerica MA 01821 USA
Tel: (978) 528-2034 · Fax: (978) 528-2033
e-mail: info@qea.com
URL: www.qea.com

Paper presented at the IS&T's Eleventh International Congress on Advances in Non-Impact Printing Technologies
October 29-November 3, 1995, Hilton Head, South Carolina

Use of An Automated Print Quality Evaluation System as a Failure Analysis Tool in Electrophotography

Ming-Kai Tse, David J. Forrest and King Y. She
Quality Engineering Associates, Inc.
Burlington, MA 01803 USA

Abstract

An important problem in electrophotography is the diagnosis of process failure. Since an electrophotographic system includes many interacting components, pin-pointing the specific source of a print quality problem is often difficult. In this paper, the use of an automated print quality analysis system, together with strategically designed test prints and a logical analysis methodology for electrophotographic failure analysis will be examined. The image analysis system, using high resolution optics and versatile computer control, is typically applied to print quality metrics such as gray scale, density, line resolution, text reproduction quality, background and satellite particles. A case study on the compatibility of organic photoconducting drums (OPC) and toner used in replaceable toner cartridges will be reported to demonstrate the efficacy of the approach. Design issues for a practical failure diagnosis system will also be discussed.

Introduction

The performance of a printer is determined by its print quality. When a printer fails, its print quality degrades and becomes unacceptable to its user. In laser printers with replaceable toner cartridges, a majority of the problems is due to failure of one or more components in the cartridge. Hence, improving the quality of the toner cartridge and its components is important in eliminating print quality problems in these printers. With the growth of the toner cartridge recycling and remanufacturing industry, the issue of cartridge component quality and compatibility is becoming even more acute as aftermarket or recycled components from multiple suppliers are used in the remanufacturing process. While the quality of individual components may be very high, the mixing-and-matching of components from multiple suppliers will potentially increase the likelihood of print quality problems since the "compatibility" of components has not necessarily been tested or screened vigorously and systematically.

The most common means of evaluating the compatibility of toner cartridge components today is print testing, where many sets of the targets are printed. The printed outputs are usually examined by a trained technician to judge density, image resolution, edge acuity, background, tone reproduction and other print quality factors. In some cases, printed outputs using OEM cartridges are also used to enable a side-by-side comparison. However, making consistent judgments, day after day and time after time, is a tall order. There are simply too many chances for human error, including judgmental differences from one operator to another. Worst of all, the evaluation is adjectival or qualitative, not quantitative. It is expressed in words, not in numbers. To take the inconsistency and subjectivity out of print quality evaluation, an automated image analysis system (IAS-1000, Quality Engineering Associates, Inc.) was assessed as a tool to evaluate print quality. The ultimate goal of this study is to develop a logical methodology for the diagnosis of print quality problems and the identification of the sources of such failures. While the use of image analysis to evaluate print quality is fairly common in the printer and toner manufacturing industries,[1-2] the use of such system to evaluate component "compatibility" does not appear to be a well established approach. For this reason, the main objective of this study is to establish the efficacy of this basic idea. Another objective of this study is, through first hand experience, to identify design factors critical to the deployment of such a system in a production environment.

Experimental Method

The basic design of the image analysis system used in this study is depicted in the schematic in Fig. 1. The system uses a standard CCD camera to capture the printed images. Different combinations of lenses are used to obtain a broad range of magnifications to meet different analysis requirements. For example, the region-of-interest (ROI) is typically up to 4.2mm x 4.2mm for tone reproduction (gray scale) analysis; whereas the pixel size is down to approximately 3 µm for the analysis of resolution, satellite particles and background. The video digitizer uses 8-bit or 256 levels of gray. Two fluorescent lamps are used as the illumination source throughout the study. In a typical test, the test sample is first loaded onto a computer-controlled x-y table with a vacuum holddown. A test script is then executed to automatically scan the specified ROI(s). A broad range of powerful image enhancement, processing and analysis tools are built into the control software to enable a multitude of analysis to be performed on the digitized data. The analysis results are typically exported automatically to another application program such as a spread sheet for further analysis or archival purposes. The most powerful feature in this system is its built-in ability to run C-language scripts, which can automatically execute, in a matter of minutes or less, a complicated test sequence that may take many hours of manual scanning and analysis.

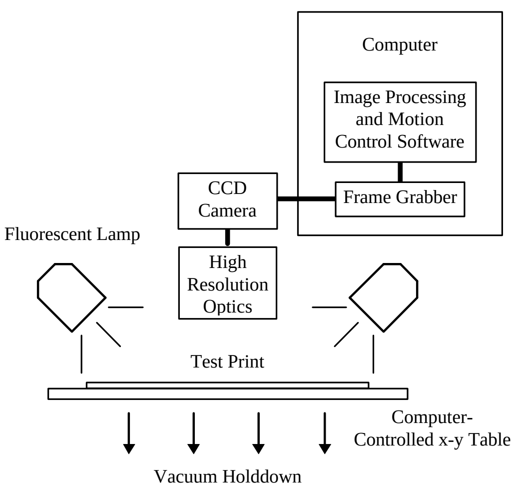

Figure 1. Schematic of the IAS-1000 Automated Image Analysis System

A combination of six new organic photoconducting drums (OPC) used in the Canon EX laser printer cartridge and six types of toner were print tested, producing 36 combinations in total. The OPC used include one OEM and five from different aftermarket suppliers, while all six types of toner are from aftermarket manufacturers. Every print test consists of 10 pages each at the lowest (lightest) and highest (darkest) printer density settings. A carefully designed test target was developed to include: 1) positive (black on white) and negative (white on black) text of various fonts and sizes to evaluate character stroke width, character density, satellite particles and voids; 2) horizontal and vertical line patterns for resolution analysis; and 3) gray scale for tone reproduction analysis. Blank pages were also printed to examine the severity of background.

To gain insight into the relationship between print quality and the characteristics of various toner cartridge components, independent measurements were made on the OPC and the toner. A commercial photoconducting drum test system (PDT-2000, Quality Engineering Associates, Inc.) was used to obtain the photo-induced discharge curves (PIDC). The main electrophotographic properties of the OPC studied were E_{50} (photosensitivity) and charge acceptance. Toner characterization is in progress and the data will be reported when available.

Results

An important advantage of the automated image analysis system is its efficiency in analyzing a large number of prints. With the many test prints from the combination of six OPC and six types of toner in this study, a voluminous quantity of print quality data was obtained by the system in a short time. To enhance the clarity of presentation without losing the essence of the findings, the results from all six OPC but only two types of toner are reported in this paper.

Photo-Induced Discharge Curves (PIDC)

The PIDC for the six OPC are shown in Fig. 2, with a summary of the corresponding E_{50} values in Table 1. As shown, the photosensitivity (E_{50}) of this group of OPC from different manufacturers ranges from 0.13 to 0.19 μJ/cm² - a 46% difference! Intuitively, one would expect a wide range of print characteristics due to the significant differences in photosensitivity. In fact, even a casual visual examination of the test prints would reveal the differences in qualitative terms. The challenge to the analyst is, how different are these prints quantitatively, and what is the relationship between print quality and OPC characteristics? These issues will be examined in more details in the following discussion.

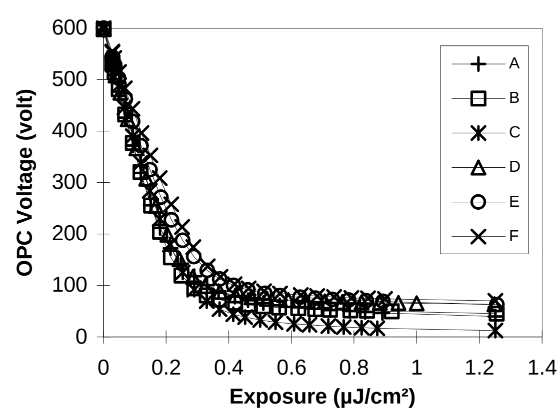

Figure 2. PIDC curves for six new EX OPC

Table 1. E_{50} values for six new EX OPC

OPC	E_{50} (µJ/cm²)
A	0.130
B	0.130
C	0.140
D	0.141
E	0.165
F	0.186

Character Stroke Width and Density

Character stroke width is measured at the vertical stroke of a 14 point Times New Roman character "D". The edge threshold is defined as the 60% transition point from the white background to the darkest location of the stroke.[1] Character density is measured by zooming the region-of-interest (ROI) of the image analysis system in the stroke and analyzing for its "blackness." The results are shown in Fig. 3a for character stroke width and Fig. 4 for character density. For clarity purpose, only the results for low printer density setting are included in both figures, since results from a high printer setting yield similar trends. Figure 3b displays the print with the thinnest stroke width (OPC F, toner B) and the print with the thickest stroke width (OPC A, toner A). The difference is so distinct that even naked eyes would have spotted the variation in qualitative terms. As shown in Fig. 3a and Fig. 4, both character stroke width and character density decrease with increasing E_{50} (i.e., decreasing photosensitivity). Higher photosensitivity in an OPC leads to a broader discharged area as well as a higher contrast potential for a character, and therefore will result in broader and darker strokes. While variations in stroke width and character density are observable for different OPC, the variations appear to be even stronger among different toner. For the two types of toner selected for presentation in Fig. 3a and Fig. 4, the differences in stroke width and density are substantial. Moreover, toner B seems to be more sensitive to variations in E_{50} in character stroke width and density than toner A. In other words, toner A is more "compatible" with a wide range of OPC by these two measures.

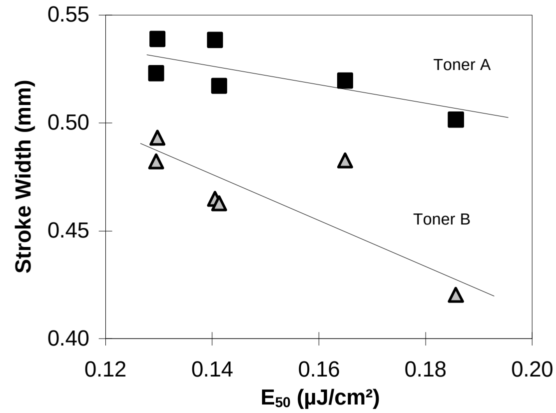

Figure 3a. Dependence of character stroke width on OPC photosensitivity and toner type, print density=1

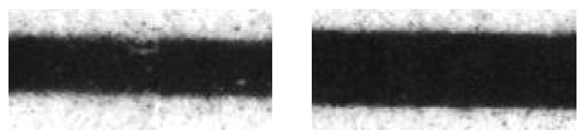

Figure 3b. Contrast between the thinnest stroke width of 0.42mm (OPC F, toner B) and the thickest stroke width of 0.54mm (OPC A, toner A)

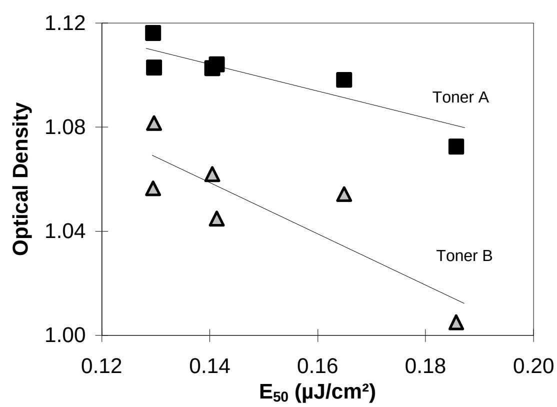

Figure 4. Dependence of character density on OPC photosensitivity and toner type, print density=1

Line Resolution (Modulation)

A 600dpi two-pixel-on-two-pixel-off repeating line pattern on the test print is used to measure the line resolution (modulation) of the OPC/toner combinations studied. The modulation value is expressed by half of the signal range divided by the average signal level:[1]

$$\text{Modulation} = \frac{1/2(\text{peak} - \text{valley})}{1/2(\text{peak} + \text{valley})} \qquad (1)$$

The maximum value of modulation is one (perfectly resolved line-pair) and the minimum is zero (unresolved line-pair). A two-on-two-off pattern was chosen instead of a one-on-one-off pattern because the latter was totally unresolvable by all the toner and OPC studied. The modulation results are shown in Fig. 5a. Again, only the results from one printer density setting are reported for clarity purpose. As shown, the dependence of modulation on OPC photosensitivity is just the opposite to that of character width and density, i.e., the higher the E_{50} (lower photosensitivity), the higher the modulation or the better the resolution. This observation is consistent with the findings on stroke width and character density -- a "faster" OPC produces wider, denser characters as well as lower resolution and vice versa. Again, the toner appears to have a more significant effect on resolution than OPC photosensitivity in this set of data. It should be noted that, although the difference between the sample with the highest and the lowest modulation, printed with toner B, seems very little according to Fig. 5a, even naked eyes can spot the difference between the two readily (Fig. 5b). This proves that human eyes are very sensitive to resolution degradation, and this should be an important factor in evaluating compatibility between different OPC and toner types. Another interesting point is that toner B seems to be less sensitive to variations in E_{50} (more "compatible" with a wide range of OPC) than toner A, which is the complete opposite of what was observed in character stroke width and density as discussed above.

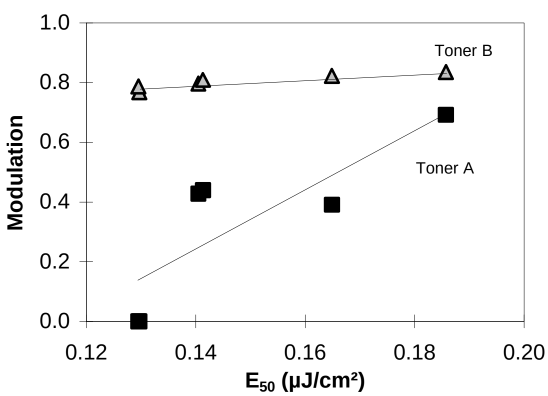

Figure 5a. Dependence of modulation on OPC photosensitivity and toner type

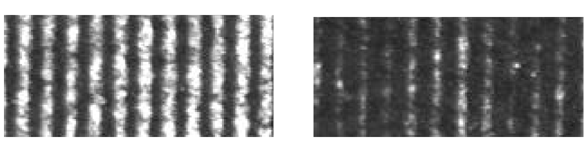

Figure 5b. Contrast between samples with the highest modulation (0.84, OPC F) and the lowest modulation (0.77, OPC A), both printed with toner B

Halftoning and Gray Scale (Tone Reproduction)

A range of gray levels, printed in Postscript, is included in the test target to evaluate the tone reproduction characteristics of the OPC/toner combinations. Generally, the tone reproduction curves (not shown) for all OPC/toner combinations studied tend to be significantly higher than the ideal one-to-one reproduction. Fig. 6a shows a representative portion of the complete tone reproduction curve at an input of 60% gray (optical density ~0.4), plotted against E_{50}. A close examination of Fig. 6a and the tone reproduction curve also suggests that tone reproduction is dependent on OPC photosensitivity -- higher photosensitivity leads to darker gray levels and hence a poorer tone reproduction. However, the toner once again appears to have a more dramatic influence on tone reproduction.

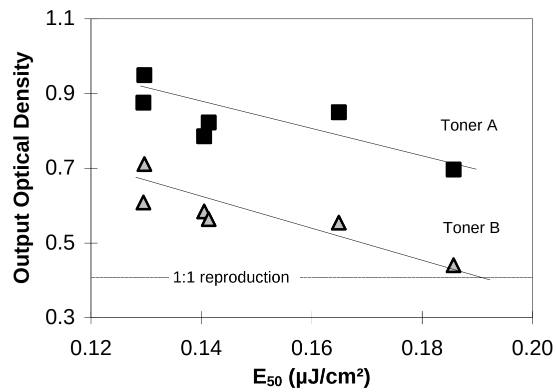

Figure 6a. Dependence of output density on OPC photosensitivity and toner type at 60% gray level

Fig. 6b depicts the output densities of different OPC/toner combinations when the input is fully black (100%). The output density of an OEM OPC printed with OEM toner is also included in the figure as a reference. As shown, the OEM OPC and OEM toner combination seems to do a much better job in reproducing 100% black than any other OPC/toner combination. This is important in the selection of aftermarket OPC and toner combinations.

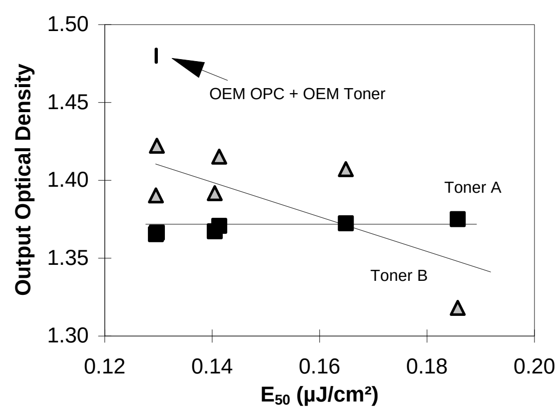

Figure 6b. Comparison between output optical densities of full black of different OPC/toner combination

Although toner A and toner B seem to be equally sensitive to E_{50} variations at 60% gray (Fig. 6a), toner A is much more resilient than toner B at 100% black (Fig. 6b), again striking home the point that toner/OPC compatability should be a major concern in toner cartridge remanufacturing.

Satellite Particle Count and Background on White

Satellite particles are found next to the black and white transitions and are usually a result of the presence of “wrong-sign” toner (e.g., positively charged toner in a discharge-area development, or DAD, system).[3] Background generally refers to toner particles found on solid white areas and is a result of both “wrong-sign” and “right-sign” toner: the latter may occur if the OPC is not charged sufficiently due to a variety of reasons such as a poor primary charge roller charging system or a very worn OPC. In both Fig. 7a (satellite count) and Fig. 8a (background), no definitive dependence on OPC photosensitivity is observed. On the other hand, significant differences in both measurements are observed with the two different types of toner, suggesting that both satellites and background are mostly dominated by the nature of the toner used in the cartridge. Fig. 7b and Fig 8b compare images from samples with low and high satellite particle count and background particle count respectively.

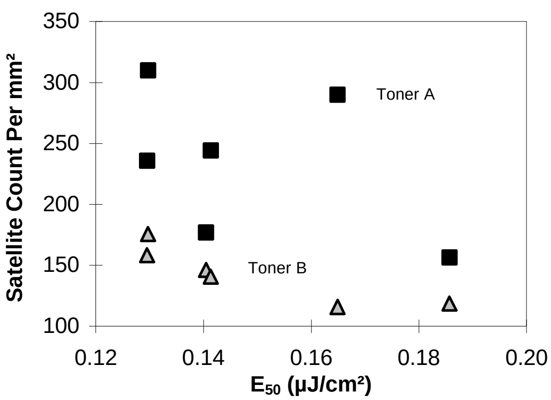

Figure 7a. Satellite particle count

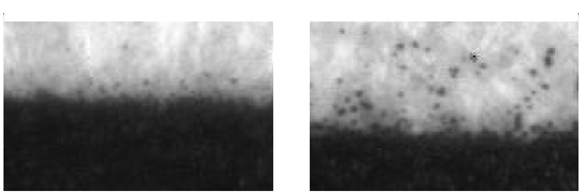

Figure 7b. Comparison between low and high satellite count samples

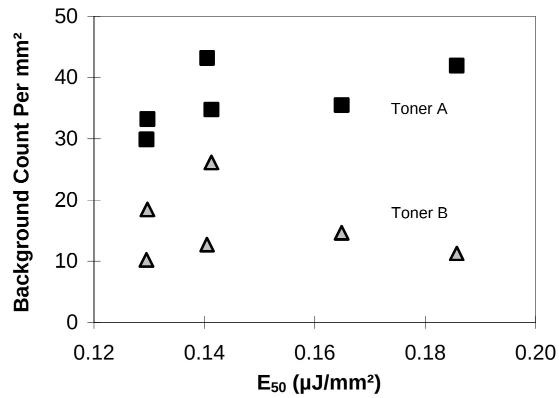

Figure 8a. Background particle count

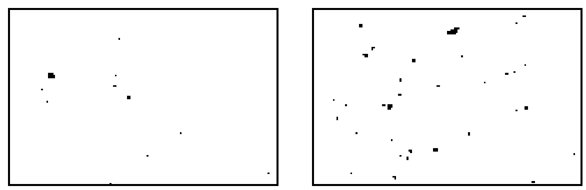

Figure 8b. Comparison between low and high background particle count samples (enhanced images)

Voids in Characters

The results on voids in characters are shown in Fig. 9. Similar to the above observations in satellite particles and background, void count in characters appears to be independent of OPC sensitivity but is dependent on the toner type. This dependence, however, appears to be opposite to the observations in satellite count and background -- toner A has more satellites and background but fewer voids, while toner B has fewer satellites and background but more voids. Evidently, certain characteristics in the toner affect both satellites/background formation and character voids, albeit in an opposite way.

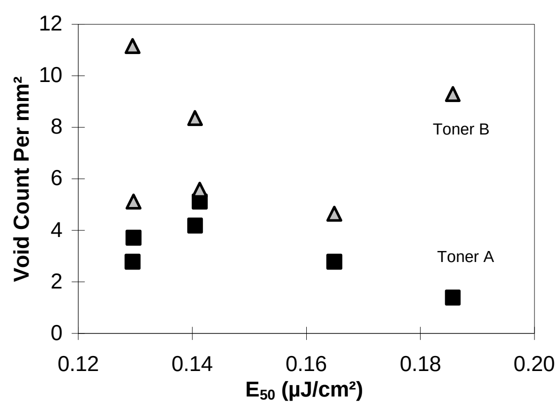

Figure 9. Charcter void count

Summary of Results

Toner seems to play a much more important role than OPC photosensitivity in the print characteristics investigated in this paper. These results are summarized in Table 2. As shown, toner A exhibits high sensitivity to E_{50} variations in certain areas and toner B in other areas. Therefore, there is clearly a trade-off to be made when selecting different OPC/toner combinations.

Table 2. Summary of results (arrows indicate the influence of toner on a particular print characteristic, e.g., toner A induces more satellite particles; sensitivity measures the sensitivity of the toner to variations in OPC photosensitivity, E_{50})

Print Characteristics	**Toner A**		**Toner B**	
Stroke Width	↑	less sensitive	↓	more sensitive
Character Density	↑	less sensitive	↓	more sensitive
Modulation	↓	more sensitive	↑	less sensitive
Density @ 60% Gray	↑	sensitive	↑	sensitive
Density @ 100% Black	< OEM	not sensitive	< OEM	more sensitive
Satellites	↑	not sensitive	↓	not sensitive
Background	↑	not sensitive	↓	not sensitive
Character Voids	↓	not sensitive	↑	not sensitive

Discussion

This study clearly demonstrates the usefulness of an automated image analysis system in examining print quality microscopically, quantitatively, and efficiently. The system enables rapid analysis of a large volume of test prints, which is the key to develop a diagnostic technique for toner cartridge failures. With this tool, a systematic study on the "compatibility" of OPC and toner now becomes a reality.

The test results in this study can be classified into two categories: those that exhibit clear dependence on OPC photosensitivity (e.g. character stroke width, character density, resolution and tone reproduction), and those that do not (e.g. satellite particles, background, and voids in characters). Such an observation can be exploited in developing a rational strategy for differentiating between OPC and toner related problems. Another important observation is that the toner appears to be the stronger determinant of print quality in the range of materials studied. Measurements on toner characteristics will no doubt provide further insight into the reasons behind this observation.

While image analysis provides invaluable information on print quality, it must be emphasized that this provides only part of the picture. An investigation into process failure is more effective if other instrumentation can be applied to characterize the individual components (e.g. the use of an OPC drum test system to obtain the PIDC of an OPC) in order to develop a better understanding of the inter-relationships between component characteristics and print quality as demonstrated in this study.

In the course of this study, several features in the image analysis system stand out as the key factors in determining its success as a production-worthy tool. In particular, its simplicity and efficiency in use, and its flexibility in measuring a wide range of quality metrics. In terms of system design, not only the user-friendliness of the control software is the key, the seemingly mundane issues such as the ease of loading and unloading the test sample, the test sample holddown method, the use of an autofocusing optical system, and the stability of the illuminating light source will all determine the success of the system.

Conclusions

The use of an automated image analysis system to investigate the relationship between toner cartridge component characteristics and print quality is demonstrated. While a comprehensive process failure analysis system awaits further development and refinements, the rudiments of such a system are established in this study. The system utilizes traditional measures of print quality and emphasizes the correlation of these measures with independent characterization of the toner cartridge components.

References

1. J.L. Crawford, C.D. Elzinga, R.Yudico, Print quality measurements for high-speed electrophotographic printers, *IBM J. Res. Develop.*, 276-284, May (1984).
2. J.R. Edinger, Jr., J. Imaging Sci. 31: 177 (1987).
3. L.B. Schein and G. Beardsley, Background development in electrophotography, J. Imaging Tech. 17: 84 (1991).