

The Effect of Fusing on Gloss in Electrophotography

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Abstract

In dry toner electrophotography, hot-roll fusing is the method most commonly used to fix the toner to the media. In hot-roll fusing, the combined effects of time, temperature and pressure determine the fusing quality with respect to the degree of toner fixing and gloss level. Acceptable fusing quality can only be achieved when the process parameters are within the fusing latitude, or “fusing window.” In this paper, the effect of the fusing process parameters on gloss is studied experimentally using a computer-controlled hot-roll test apparatus. The roles of media and coating are also examined for insight into the mechanisms of gloss development. The importance of lubrication, fuser roller design, and other practical considerations for minimizing hot-offset and extending the fusing window are also touched on.

Introduction

The rapid growth of digital photography has created increasing demands on the consumables market to produce glossy, electrophotographic dry toner images on opaque substrates. To meet these demands, however, a significant technical problem in color electrophotography — namely, differential gloss — remains to be better understood.^{1,2,3} Differential gloss refers to the varying levels of gloss in different areas of a halftone image. The presence of differential gloss in digital photographic images is considered aesthetically unpleasing and not up to the traditional “photo-quality” standard long established by silver halide imaging.

The primary purpose of this paper is to study the impact of media design and fusing conditions on gloss development. It is well known that even fusing systems designed specifically to produce glossy images often produce images exhibiting non-uniform gloss. From this

observation, it would appear that not all the elements within such images have equal gloss-producing capabilities. To be able to minimize and ultimately eliminate differential gloss, it is important to understand the mechanisms underlying its formation and the image elements in halftone images that control it. In this investigation, using two substrates with different coatings and a set of commercially available polyester-based color toners, we explore the relationship between specific image building blocks and gloss. We evaluate the effectiveness of a “toner receiver layer” for enhancing gloss uniformity. We also attempt to understand the “cost” of gloss by monitoring quality attributes that may be adversely affected when high gloss levels are achieved.

The development of gloss in color electrophotography is a process involving complex interactions between the toner, the substrate, and the fusing method. To optimize the fusing process in general, and to fully assess the gloss potential of a given substrate/printer system in particular, investigative tools must be developed to facilitate the development process. The common practice of performing a fusing study in a printer or copier is both cumbersome and limited in flexibility. What is needed for fusing technology and material development is a general-purpose test bed that affords the investigator a high level of flexibility in controlling the process and material parameters.

Experimental Method

The experimental study was set up to look at four aspects of gloss development:

- 1) The effect of fusing temperatures
- 2) The effect of toner coverage
- 3) The effect of paper type
- 4) The trade-off, if any, between high gloss and other image quality attributes

Fusing

To conduct the fusing experiments in a controlled way, we decided to separate image generation and image transfer to the paper from the actual fusing process. Image generation and transfer were accomplished with a commercially available high-resolution color laser printer with the OEM polyester CMYK toner set. The fusing section of the printer was modified to achieve only minimal fixing of the toner to the paper. The minimal fix allowed for easy handling of the paper in the subsequent fusing experiments.

To perform the fusing experiments, a commercially available toner fusing test system (QEA TFS-1000) was used. The TFS-1000 allows independent adjustment of fuser pressure, temperature, paper feed rate, and lubrication of the fuser roller. The design of the system and its application to determining fusing latitude and the effects of media thickness on fusing have been reported previously.^{4,5}

A significant advantage of the TFS-1000 over a modified printer as a fusing tool is that it greatly increases the range of fusing conditions that can be examined. Another important advantage of this system is that all the critical process parameters are accessible to the user, making it possible to perform a comprehensive parametric study that would be impossible or impractical with a printer.

Capitalizing on these capabilities, a preliminary experiment was performed with the TFS-1000 to quickly determine a range of process conditions for producing reasonable gloss with the toners and papers used. The results of this experiment determined that the following conditions would be used in the rest of the study: 10 psi air cylinder pressure, 3 ppm (pages per minute) paper feed rate, and a fusing temperature between 100°C and 130°C. With this fusing system, the applied pressure and chosen feed rate result in an average nip pressure of 0.4 MPa, a nip width of 6 mm, and a residence time of 430 ms.

Paper

In designing the experiments, two questions guided our selection of materials: 1) how critical is the gloss of the substrate to the gloss of the finished print, and 2) can differential gloss be minimized or eliminated by the use of specially formulated coatings. With these questions in mind, the following two media were chosen for this study:

- 1) "Uncoated" paper stock. This is a highly calendered, 100 lb. glossy paper with a 6:1 pigment (CaCO_3) to binder ratio. This paper was chosen as a typical glossy laser printer substrate.
- 2) "Coated" paper stock. This is the same as the "uncoated" paper stock, but with an additional phenoxy/polyol receiver-layer coating. This paper was selected to get a better understanding of the effect of the so-called "toner receiver layer." This layer is

thought by some in the industry to reduce differential gloss.

Image Quality Measurement

A test target developed for this study contained a set of cyan, magenta, yellow, and black step density wedges generated through halftone dot screening. The area of each step was 40×15 mm. The gloss in these areas was measured with a BYK-Gardner 4630 glossmeter.

The test target also contained a series of fine lines in both horizontal and vertical orientations. The lines were $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$ point wide ($44 \mu\text{m}$, $88 \mu\text{m}$, and $176 \mu\text{m}$, respectively), printed in cyan, magenta, yellow, and black. These lines were included to examine the effect of the fusing process on line quality, including line width, blurriness and edge quality. Line quality was measured with an automated print quality analysis system (QEA IAS-1000). Using the same system, the optical densities of the color patches were also obtained.

Results and Discussion

Gloss on Samples with Minimal Fusing

The gloss of the samples minimally fused with the modified printer was measured as a benchmark for the main experiment. The results are shown in Figure 1.

In this figure, the measured gloss decreases as the gray level or toner coverage increases. Since the samples were only minimally fused, we concluded that at low gray levels, gloss is controlled primarily by the substrate and that at higher gray levels, the under-fused, non-glossy toner covering the substrate reduces the contribution of the substrate to gloss. That the gloss of the substrate is an important contributing factor to the overall gloss of the image is further demonstrated by the main fusing experiment described below.

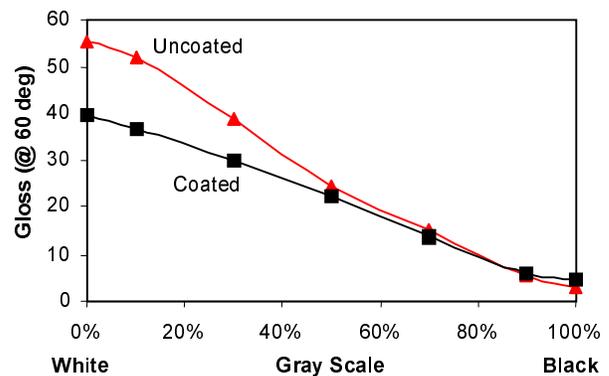


Figure 1: Gloss versus gray scale for under-fused paper samples. (Data is the average of all CMYK measurements)

Effect of Gray Level on Gloss of Fused Samples

In the main experiment, the under-fused samples were subjected to further fusing under controlled conditions in

the TFS-1000 Toner Fusing Test System. After further fusing, the gloss on the test targets underwent significant change, as shown in Figure 2. Comparing these results with the data in Figure 1, one unexpected difference is that the gloss levels are reversed for the uncoated and coated samples: the uncoated paper decreases in glossiness from 55 to 43 gloss units, and the coated paper increases from 40 to 54. This is probably due to the difference in the papers' response to the lubricating oil on the fuser rollers.

The data in Figure 2 can be viewed in two parts. On the left-hand side of the graph, gloss decreases with increasing gray levels, a behavior very similar to the results shown in Figure 1 for the under-fused samples. At gray levels below the mid-tones, fusing temperature has no noticeable effect on gloss in either coated or uncoated papers, suggesting that the gloss is controlled by the gloss of the paper substrate. For the coated paper, gloss decreases quite substantially (close to 50%) as gray levels increase from 0% to the mid-tones. Compared to the uncoated paper, gloss levels in the coated paper are higher but also more dependent on gray level, as shown by the steeper rate of gloss reduction in these samples. In the uncoated paper, gloss drops significantly, though not as steeply as in the coated paper.

On the right-hand side of the graph, gloss increases with increasing gray levels, suggesting that a different mechanism is at work in this range. The effects of fusing temperature and paper coating here are contrary to the observations at low gray levels. First, the gloss is substantially higher at the higher fusing temperature (124°C), indicating that at this temperature there must be appreciable melting and coalescing of the toner, forming a more or less continuous, flat surface with a specularly reflective surface.

Second, comparing the "uncoated" and "coated" results in Figure 2, it can be concluded that the differential gloss, which amounts to approximately 15-25 gloss units, is very similar in these two paper types. The presence of the "toner receiver layer" in the coated paper did not achieve the intended uniformity of gloss and conferred no apparent benefit as compared with the uncoated paper.

Mechanistically, we can summarize the dependence of gloss on gray scale as follows. At very low gray levels, or low levels of toner coverage, gloss is controlled by the gloss on the paper, as long as this gloss is not degraded by the fusing process. More specifically, we can describe gloss development in this range as coating controlled. At very high gray levels and at a sufficiently high fusing temperature, gloss is controlled by the melting, coalescence, flow and smoothing of the toner, which forms a specularly reflective surface. Therefore, we will generally describe the gloss development in this range as fusing-controlled, with a whole host of parameters such as the physical properties of the toner, the surface roughness of the paper substrate, the smoothness of the fuser roller, and the pressure at the nip all

affecting the resultant gloss level. In the mid-tones (about 45% to 65% gray), it appears that neither media gloss nor toner gloss has an appreciable effect. In this range, it is evident that there is a sufficient quantity of toner to block the reflectance of the media, but insufficient toner to produce continuous and complete coverage of the surface. This range is characterized by significant light scattering and reduced gloss.

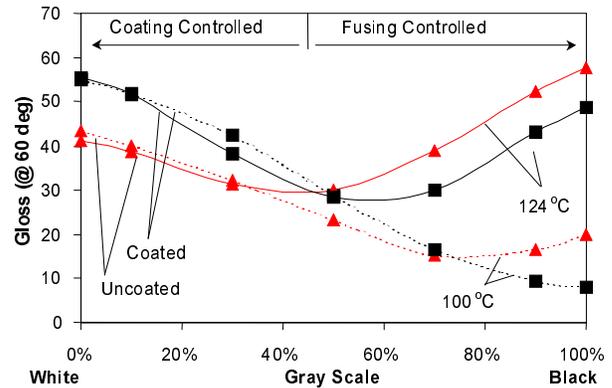


Figure 2: Gloss versus gray scale value after fusing. (Data is the average of all CMYK measurements)

Effect of Fusing Temperature on Gloss

The data in Figure 2 can be graphed differently, as shown in Figure 3, to develop an understanding of the effect of fusing temperature on gloss. In Figure 3, we see that the gloss in white areas is unaffected by fusing temperature and is controlled by the media type. At the mid-tones (50% gray), gloss is only slightly affected by fusing temperature and there is little difference between the two media types. At a high gray level (100%), the gloss increases to a maximum of about 60 gloss units as the temperature rises above 120°C. The uncoated paper reaches its maximum gloss at a slightly lower temperature (120°C) than the coated paper (128°C). A possible explanation of this will be discussed below.

Image Quality: Line Width

Does achieving high gloss cause degradation of other image quality attributes? In an attempt to answer this question, line quality and solid-fill optical density were measured on the samples studied in the main fusing experiments. The results are shown in Figures 4 and 5.

We looked first at how line width might be affected by high gloss. Figure 4 shows line width gain as a function of fusing temperature. Line width gain is defined here as the difference between the line width requested in the input file and the actual line width on the print. The data in Figure 4 show the average line width gains for several colors (CMK), all line widths ($\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$ point), and both horizontal and vertical lines. Yellow lines were not measured due to difficulties in getting reliable thresholding in the line width measurement.

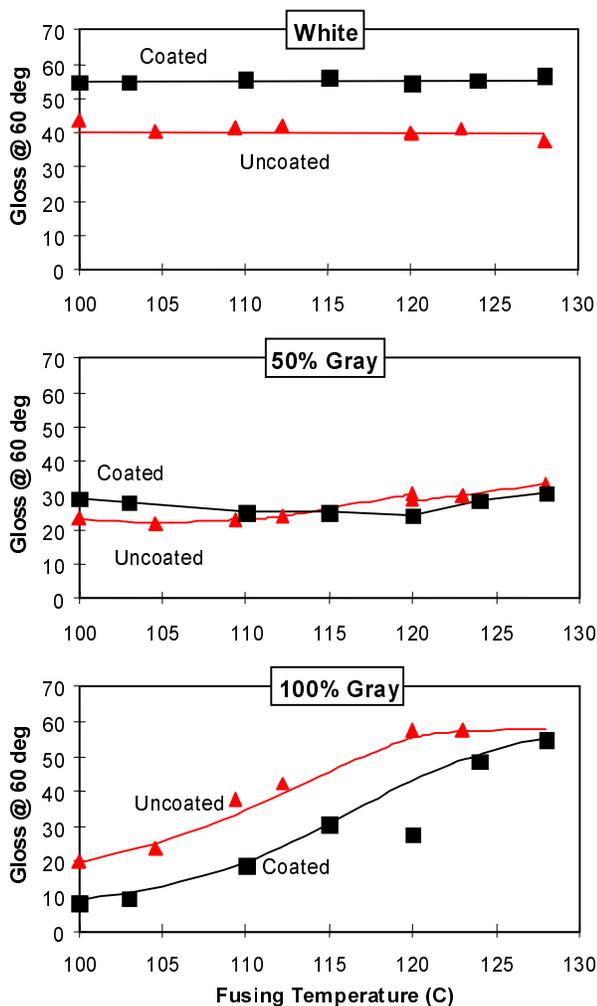


Figure 3: Gloss as a function of fusing temperature. Data is the average of CMYK.

Prior to fusing, the line width gain averaged 47 μm for the uncoated and 53 μm for the coated under-fused samples. This 6 μm difference between the uncoated and coated samples and similar differences in blurriness and edge raggedness (ISO-13660 defined⁶) indicate some influence of media type in the transfer process prior to fusing.

After fusing, the line width gain increased. At 128°C, the average line width gain reached 63 μm for the uncoated paper (a 34% increase over the level prior to fusing) and 76 μm for the coated paper (a 43% increase). Although lines of all colors studied became wider as fusing temperature increased, black lines exhibited the greatest increase. Additionally, wider lines had larger width gains than narrower lines. The gain in line width with fusing temperature is a critical issue because it basically translates into a loss of resolution.

The increase in line width after fusing is simply a consequence of the heating and melting of the toner, which cause it to flow. Some of the toner undoubtedly flows into the paper fibers, but some of it spreads along the surface of the paper causing the lines to grow in width.

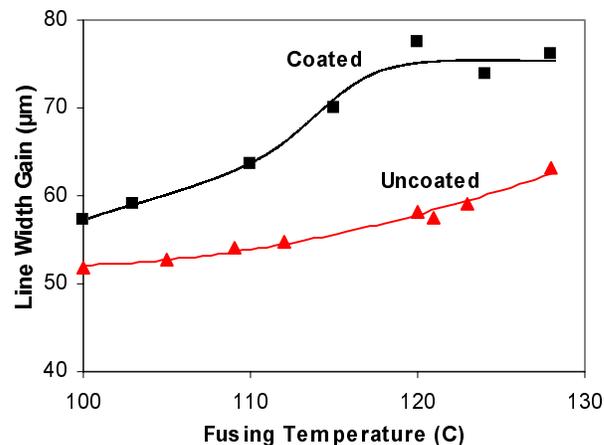


Figure 4: Line width gain as a function of temperature. Data is the average of black, magenta, and cyan; 1/8, 1/4, 1/2 point; and both horizontal and vertical lines

Image Quality: Optical Density

We also looked at how optical density of solid fills might be affected by high gloss. These results are shown in Figure 5. As fusing temperature increased, the optical density of the solid-fill area also increased. The optical density ultimately reached a level of about 2.4, which is very high for electrophotographic printing. The uncoated samples reached this density at about 120°C, while the coated samples reached the same density at 128°C. This is very similar to the gloss measurement data in the lower part of Figure 3. It is not too surprising that the two are related, because in measuring optical density, the diffused light reflected off the surface enters into the calculation as does the specular reflection from the same surface in measuring gloss. As the toner surface becomes increasingly smooth with increasing fusing temperature, the optical density increases (due to lower diffuse reflection) and the gloss increases (due to higher specular reflection).

Effect of Paper Type

Focusing on the differences between the “uncoated” and “coated” media, we observed that:

- 1) The line width gain was higher on the coated paper, even in the under-fused condition
- 2) The line raggedness and blurriness were also worse on the coated paper, even in the under-fused condition
- 3) Higher fuser temperatures were required to achieve maximum gloss and optical density levels on the coated paper.

Clearly one difference between the two papers is the additional energy that is needed to soften the coating. This is one possible explanation of the higher fusing temperature needed to achieve high gloss and optical density on the coated paper. However, it is not clear how this same

reasoning could explain the poorer line quality observed in the under-fused conditions on the coated paper.

To better understand the source of these differences, particle size and distribution analyses were performed on unfused coated and uncoated samples using the IAS-1000 Print Quality Analysis System. A typical result of these analyses is shown in Figure 6. In general, the particle analysis showed a greater number of large particles and a less uniform distribution of particles on the coated samples. This may explain why the lines are wider and more ragged on the coated media. It may also explain why the coated paper requires a higher fusing temperature to achieve maximum gloss and optical density. If the toner is less uniformly distributed on the coated media, it may take a higher fusing temperature to cause the toner to flow and form a smooth and highly reflective surface.

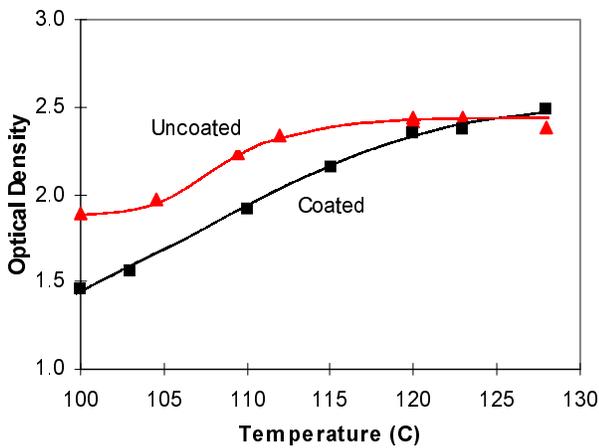


Figure 5: Optical density as a function of temperature. Data is for black area. The cyan, magenta, and yellow areas do not exhibit a significant increase in optical density with fusing temperature.

But why should there be more toner and less uniform distribution on the coated paper? After all, the samples were printed with the same printer. The answer may come from the difference in the electrical properties of the two paper types. The surface potential decay curves obtained using the ECD technique⁷ and shown in Figure 7 indicate that there is a clear difference in the dielectric relaxation properties of the two media types. The coated paper exhibits lower potential decay rate than the uncoated paper, resulting in a higher field across the media during electrostatic charging, more efficient toner transfer, and more toner deposited on the media surface. Although this explanation is somewhat speculative, it would account for the differences observed between the two paper types.

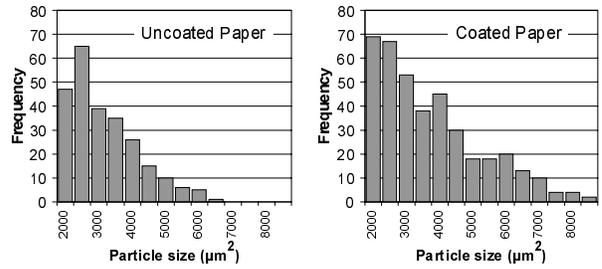


Figure 6: Particle size measurement shows the coated paper to have more large particles and hence less uniformity. Data is for 10% gray areas on unfused samples

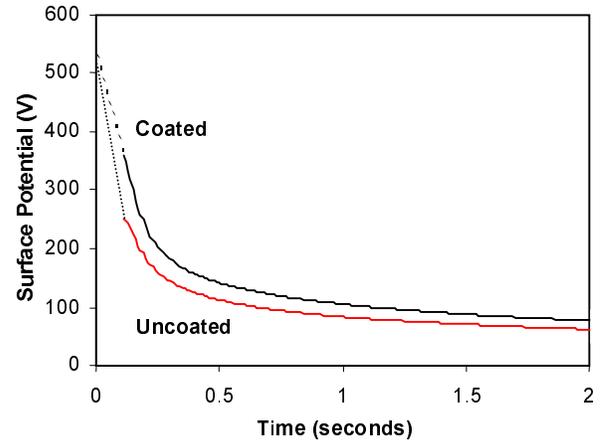


Figure 7: Surface potential decay measurement on two paper samples

Conclusions

This study has offered new insight into the mechanisms of gloss and differential gloss development, processes involving complex interactions between the media, toner, fusing system, and process conditions. The main observations of the study include:

- 1) Gloss at low gray levels (low toner coverage) is controlled predominantly by the substrate. As gray levels increase from zero to about 50%, gloss decreases. In this range, the rate of decrease in gloss as gray levels rise is independent of fusing temperature, but dependent on the coating on the media.
- 2) Gloss at high gray levels is controlled predominantly by the fusing of the toner. As gray levels increase from about 50% to 100%, gloss increases. In this range, the rate of increase in gloss as gray levels rise is strongly dependent on fusing temperature, but much less so on the media coating.
- 3) The specific “toner receiver layer” studied in this work did not show any significant advantage over the “uncoated” media surface with respect to overall gloss level or reduction in differential gloss.
- 4) There is a penalty for high gloss. Our data on line width, edge raggedness, and blurriness suggest that as fusing temperature is raised to increase gloss, basic

image quality attributes such as line quality may degrade. This trade-off between gloss and other attributes must be considered in developing photo-quality images in electrophotographic printing.

- 5) Preliminary data based on image analysis and measurement of dielectric relaxation characteristics suggest that the process of image transfer to the media is also critical to gloss development. The transfer process controls the manner in which the toner is distributed on the paper and is an important factor in optimizing gloss and minimizing differential gloss.
- 6) The experience gained in this work clearly highlights the value of a stand-alone toner fusing test system for R&D on toner and media, and for the design of fusing systems. The test system used not only provides the means for experimenting with a broad range of process variables, it also allows a critical mass of data to be gathered systematically and efficiently.

Future Work

Although the test system was designed to accept a wide range of fuser rollers, availability issues prevented us from using the same fuser rollers in the toner fusing test system as in the printer that generated the under-fused samples. Ideally, the same roller types should be used so that the test results can be applied directly and without ambiguity. This will be the subject of future investigation.

Additional work will also focus on the effect of different halftoning algorithms on gloss, further quantifying the loss of resolution with fuser temperature, and an expanded look at the effect of fuser pressure and residence time on gloss.

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Biography

Dr. John C. Briggs joined QEA in January 1998. He is responsible for new product development and pre-sales customer support. Previously at Iomega Corporation, he was a key contributor to the design and development of the Zip™ drive. Dr. Briggs holds two patents and has several patents pending. Between 1986 and 1991, he received his BS, MS, and Ph.D degrees in Mechanical Engineering from the Massachusetts Institute of Technology. His research focused primarily on non-destructive testing and acoustic emission measurements.