Journal of Imaging Science and Technology® 52(1): 010504–010504-10, 2008.

Comparative Studies of Gloss Development in Electrophotography and Offset Printing

Yoshihisa Kitano
Fuji Xerox Co. Ltd., 2274 Hongo, Ebina-shi, Kanagawa 243-0494, Japan
E-mail: kitano.yoshihisa@fujixerox.co.jp

Toshiharu Enomae▲ and Akira Isogai
The University of Tokyo, Yayoi 1-1-1, Bunkyo-ku, Tokyo 113-8657, Japan

Abstract. *Gloss development is known to be different in offset printing and electrophotography. Gloss is also known to be determined by the topography, namely the three-dimensional profile, of the printed surface. This study aims to shed light on the difference between surface topography formation processes in offset printing and electrophotography. Our observations showed that in offset printing, printed surface topography forms through the following process: Upon ink transfer, the ink surface is uneven due to inhomogeneous ink layer splits. This unevenness is leveled out over time. Ink flows along the paper surface and the ink vehicle penetrates into the paper, thus yielding a printed surface topography consistent with the original paper surface topography. In electrophotography, printed surface topography was shown to form through the following process: Before fusing, roughness distribution along the unfused surface is characteristically similar to that of the paper surface. Pressure and heat applied upon fusing cause the toner to spread sideward, thus yielding a printed surface that is different from the original paper surface topography; more specifically, the printed surface becomes smoother than the paper surface. We then incorporated into electrophotography the processes which in offset printing appear relevant to formation of a printed surface topography that follows paper surface topography. This method of electrophotography produced a printed surface topography and print gloss more consistent with the paper surface topography. © 2008 Society for Imaging Science and Technology.*
[DOI: 10.2352/J.ImagingSci.Technol.(2008)52:1(010504)]

INTRODUCTION

In recent years, many high-speed, high-image quality color printers have been commercialized.[1–3] These printers allow easier and faster printing, and can also readily respond to digitalization in the printing workflow. Because of these features, these printers are used in the printing market as short-run printers. However, print gloss of electrophotographic outputs have been known to be less consistent with the gloss of the paper used, as compared to the print gloss of offset printing outputs.[4] In other words, electrophotography produces high print gloss even on low-gloss matte-coated paper, which results in a texture quite different from offset printing products and thus may give an unnatural impression. It is desirable, therefore, that print gloss change according to the paper gloss in electrophotographic outputs, as it does in offset printing outputs, so that the prints appear more natural.

In offset printing, studies have been carried out mainly on the mechanisms of gloss development on high-gloss paper. When ink is transferred to paper, topographical unevenness, called split patterns, forms on the ink surface. One study, for example, shows that some of these split patterns persist on the printed surface even after the ink dries, and this is known to affect print gloss.[5] Furthermore, changing the ink vehicle absorbency of the coated paper by altering its surface and internal structure has also been found to affect print gloss.[6] Another study shows, through cross-sectional observations of printed samples, that the amount of ink absorbed in the paper affects printed surface topography formation.[7] Little has been clarified, however, about the mechanisms of gloss development when offset printing is performed on low-gloss paper.

With respect to electrophotography, several studies have been conducted in an attempt to develop fusing technologies that provide high print gloss levels.[8] One study demonstrated that the amount of toner transferred to paper has a significant influence on printed surface topography.[9] In another study, print gloss was reported to be made uniform using a clear toner.[10] Another study showed through cross-sectional observations how the height and uniformity of the toner layer in electrophotographic outputs are different from the those of the ink layer in offset printing outputs.[11] Very few attempts have been made, however, to study how print gloss changes according to paper gloss in electrophotography.

In previous studies, we demonstrated how the topographies, namely the three-dimensional profiles, of paper and printed surfaces differ in offset printing and electrophotography. One of these studies quantitatively analyzes the relationship between the topography of the surface of coated paper and that of its printed surface at the same location, using Pearson's correlation coefficient.[4] Four kinds of coated paper, each possessing a different gloss level, were used. In offset printing, the correlation coefficient was high for every kind of coated paper except cast-coated paper. In electrophotography, however, the correlation coefficient was low for

▲IS&T Member.

Received May 21, 2007; accepted for publication Sep. 2, 2007; published online Jan. 15, 2008.
1062-3701/2008/52(1)/010504/10/$20.00.

all four kinds of paper. These results imply that in order for print gloss to change according to paper gloss, printed surface topography should follow paper surface topography.

This study aims to shed light on gloss development mechanisms in offset printing, and how these mechanisms are different from those in electrophotography. To do this, we examined the processes of printed surface topography formation in offset printing and electrophotography. Through these observations, we were able to identify the processes in offset printing that can be assumed to be responsible for obtaining printed surface topography similar to paper surface topography. We incorporated these processes into electrophotography, and analyzed the effects.

All experiments in this study were carried out using matte-coated paper, whose surface topography was expected to have a significant influence on the formation of the printed surface topography. Prints of single-color, solid images were used as printed samples. In offset printing, these images were produced using solvent-based sheet-fed ink. For electrophotographic printing, ground polyester toner and a two roll fusing device were used.

EXPERIMENTAL DETAILS

Printing Trials

For both offset and electrophotographic printing commercial matte-coated paper (Oji Paper, Tokyo, OK matte coat) of a basis weight of 127.5 g/m^2 was used.

Offset printing was performed using a universal printability tester (KRK, Tokyo, MPT6000), and dampening water was not applied. For ink kneading, aluminum rolls, 62 mm in diameter and 40 mm in width, covered with multiple layers of rubber (adding up to a total thickness of 2 mm) like those in sheet-fed offset printing presses, were used. The printing speed was 2.8 m/s, and the linear printing pressure was 11.8 kN/m (printing pressure is customarily expressed in nip load per roll width, or linear pressure [kN/m], because the area of contact between the roll and the paper cannot be measured). The ink kneading temperature was 25°C and the ambient temperature was 20°C–25°C. The ink used in the printing trials was a solvent-based sheet-fed ink (Toyo Ink Manufacturing, Tokyo, TK high-unity MZ); the color of the ink was cyan. These conditions, including ink type, were selected based on those employed in common sheet-fed offset printing presses. The amount of ink supplied to the kneader was 0.1 mL, which is the amount required to reproduce Japan Color 2001[12] standards. Consequently, 1.2 g/m^2 of ink was transferred to the matte-coated paper to cover the entire surface. When the same amount of ink was used to print on cast-coated paper, the height of the ink layer after drying was approximately 0.8 μm.

The image formation processes in offset printing were simulated under these conditions. In these simulations, ink is first fed onto the ink kneading roll. After the ink is sufficiently kneaded, it is then transferred to the paper. As the ink contacts and transfers to the paper, it forms ink filaments, which in turn cause splits in the ink layer on the paper. The low molecular weight components of the ink penetrate into the paper; the components remaining on the paper surface dry and harden through evaporation and oxidative polymerization.[13]

Electrophotographic printing was performed using a color laser printer (Fuji Xerox, Tokyo, DC1250). This printer has a hot roll fusing system with two fuser rolls, heated by halogen lamps inside the rolls. The rolls, made of aluminum, are each 60 mm in diameter and 350 mm in length, and covered with an 8 mm layer of silicone rubber. As standard printing conditions, the printing speed was set to 130 mm/s, the fusing load to 1275 N, and the fusing temperature to 160°C. The toner used in the printing trials was a cyan toner, made of polyester ground into particles of an average size of 6.5 μm. The amount of toner was adjusted so that the average height of the toner layer was approximately 4.0 μm when printing was performed on cast-coated paper.

For both printing methods, commercial matte-coated paper (Oji Paper, Tokyo, OK matte coat) of a basis weight of 127.5 g/m^2 was used.

In the experiment for examining the relationship between paper surface topography and lightness of offset printed samples, solidified samples of ink layers at various stages during gloss change were prepared. These samples were obtained by immersing offset printing outputs in liquid nitrogen, each after a given time period following printing, and then drying them for two days in a freeze dryer (Tokyo Rikakikai, Tokyo, EYELA FDU-830).

In the experiment for examining the relationship between fusing parameters in electrophotography and the resulting printed surface topography, the load and temperature were considered variable fusing parameters. One of these two parameters was changed at a time, while the other parameter was maintained at the standard level mentioned above. Printed samples were obtained for three values of each parameter. The values employed were as follows: Fusing loads of 981 N, 1275 N (standard level), and 1569 N; and fusing temperatures of 150°C, 160°C (standard level), and 170°C.

In the experiment which incorporates into electrophotography the processes of surface topography formation in offset printing, printed samples were heated in an oven at 160°C for 30 s so that the toner on the paper regained its viscoelasticity. The fusing load was 981 N, and the fusing temperature was 150°C; both parameters set to be lower than the standard values.

Printed Sample Characterization

The paper surface and its printed surface at the same location were examined using a laser microscope, VK-8500 (Keyence, Osaka). Using VK-8500, both three-dimensional profiles and color images of the surfaces can be simultaneously obtained; the latter obtained using a charge coupled device (CCD) camera built into the microscope. VK-8500 converts the three-dimensional profiles to present them as grayscale images, in which the elevated areas appear lighter in color, and the lower areas appear darker. The samples were observed with a sampling pitch of 0.02 μm in the height direction.

The specular gloss of the paper and printed samples at 60° was measured using a gloss meter (Nippon Denshoku, Tokyo, VG2000). The gloss was observed continuously using an analog output, starting from 5 s after paper passed through the ink kneading rolls in offset printing, and from 5 s after paper passed the fuser rolls in electrophotographic printing.

Another laser microscope, VF-7500 (Keyence, Osaka), was used for continuous observation of offset printing processes and printed surfaces. This microscope was connected to a video camera, and video images (optical microscope images) of the sample surface were recorded throughout the length of the printing process. Still images were taken from these video images at selected times, and fed to computers. The pixel-based white spot area ratios and reflected light profiles of these images were obtained using image processing software, Image-Pro Plus (Media Cybernetics; Washington, DC).

To examine the relationship between paper surface topography and lightness images of offset printing samples prepared using the same paper, samples were observed using VK-8500. In obtaining, as RGB data, color images of the print samples, we maintained the intensity of illumination constant for all print samples. The RGB data were assumed to be sRGB, and converted to $L^*a^*b^*$ images.

Pearson's correlation coefficients for quantifying the similarity between paper surface topographies and the surface topographies of printed samples prepared using the same paper were calculated based on five sampling points, using Image-Pro Plus. The average of these values was then obtained to be presented as the final correlation coefficient value.

To examine the level of influence that paper surface topography has on printed surface topography, radially averaged power spectra (RAPS)[14] were obtained from five sample locations on the topographical images of the paper surface. After printing had been carried out on that same paper, RAPS were obtained from corresponding locations on the topographical images of the printed surface as well. These RAPS values were compared using the gain defined by the following transfer function:

$$Gain(dB) = 20\log\left(\frac{\text{RAPS(Printed surface topography)}}{\text{RAPS(Paper surface topography)}}\right). \tag{1}$$

If the gain is 0 dB, the surface topographies before and after printing are completely identical. A gain value greater than 0 dB indicates that the printed surface is rougher than the paper surface; a gain value less than 0 dB indicates that the printed surface is smoother than the paper surface. The gain values for the five sample points were averaged to obtain the final gain value.

RESULTS AND DISCUSSION

Surface Topography and Gloss Dynamics for Matte-Coated Paper

Topographies of the paper surface, and of the surface of printed samples created under standard printing conditions, were observed using VK-8500. The topographical images obtained are shown in Figure 1, in the form of grayscale and three-dimensional profile images. In offset printing, the paper surface topography is shown to have a significant influence on the printed surface topography. In electrophotography, low-frequency, long wavelength roughness is preserved on the printed surface. High-frequency, short wavelength roughness, however, is hidden by the toner, causing the printed surface to be considerably smoother than the paper surface.

Figure 2 shows changes in print gloss, or the gloss dynamics, immediately after offset or electrophotographic printing was performed on matte-coated paper. In offset printing, the gloss changed with time; it increased for approximately 10 s immediately after printing and subsequently decreased for several minutes. In other words, the printed surface topography continued to change throughout the length of this time period. In electrophotography, on the other hand, the gloss did not change with time. These results show that in offset printing, the printed surface topography develops over a period of time after the ink has been transferred onto the paper; while in electrophotography, the printed surface topography is established upon fusing, in the fusing nip.

Mechanisms of Gloss Development in Offset Printing

To clarify the mechanisms of gloss development in offset printing, the changes in surface topography during gloss increase and during gloss decrease were examined.[15,16]

Printed surface during print gloss increase

The printed surface immediately after ink transfer was observed using VF-7500. The light source for the microscope was placed so that the direction of light was perpendicular to the surface of the printed sample. As shown in Figure 3, many white spots were visible throughout the surface, indicating that the printed surface was very uneven. This uneven topography is caused by splits in the ink layer, produced upon nip exit.[5,6,17]

Figure 4 shows how the white spot area ratio (the ratio of the total area occupied by white spots to the total surface area) and print gloss changed with time. The white spot area ratio decreased for the initial several tens of seconds, reflecting the decrease in topographical unevenness, after which the white spot area ratio barely changed. Print gloss, on the other hand, increased, also for the initial several tens of seconds. The print gloss then reached a peak value, after which it decreased for several hundreds of seconds. The time during which the white spot area ratio decreased coincides with that during which print gloss increased. This suggests that as the solvent ink layer was leveled out, topography of the printed surface became less uneven, leading to the increase in print gloss.

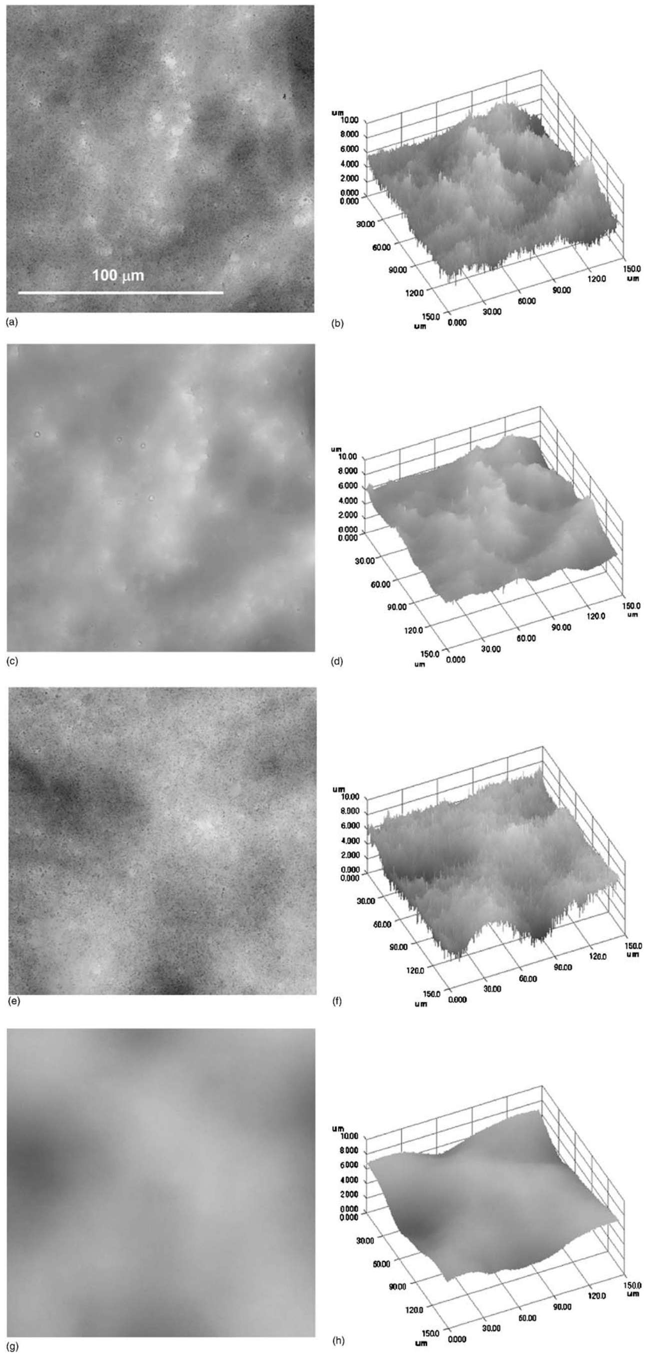


Figure 1. Topographical grayscale images and three-dimensional profiles, of printed and unprinted paper surfaces. In the grayscale images, the elevated areas appear lighter in color, and the lower areas darker. (a)–(d) show data obtained from offset printing samples; (e)–(h) are from electrophotographic printing samples printed under standard printing conditions. The data were obtained by assigning height scale of 10 μm to 256 levels of gray. (a) Topographical grayscale image of paper surface, before offset printing; (b) three-dimensional profile of (a); (c) topographical grayscale image of printed surface, after offset printing was performed on (a); (d) three-dimensional profile of (c); (e) topographical grayscale image of paper surface, before electrophotographic printing; (f) three-dimensional profile of (e); (g) topographical grayscale image of printed surface, after electrophotographic printing was performed on (e); (h) three-dimensional profile of (g).

Printed surface topography during print gloss decrease

To examine the process of print gloss decrease, still images of the printed surface, 30 and 180 s after ink transfer, were

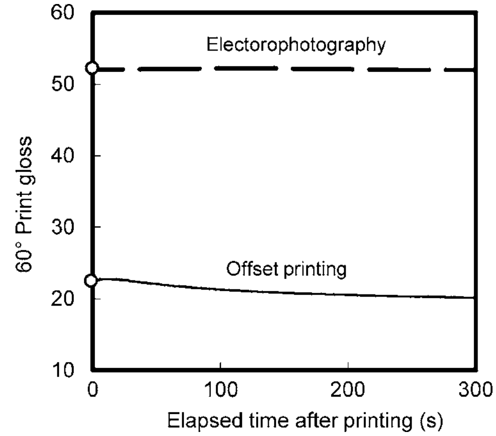


Figure 2. Dynamic print gloss, for electrophotography and offset printing, on matte-coated paper. Data were obtained from 5 s after paper passed through fuser nip/ink kneading rolls, respectively.

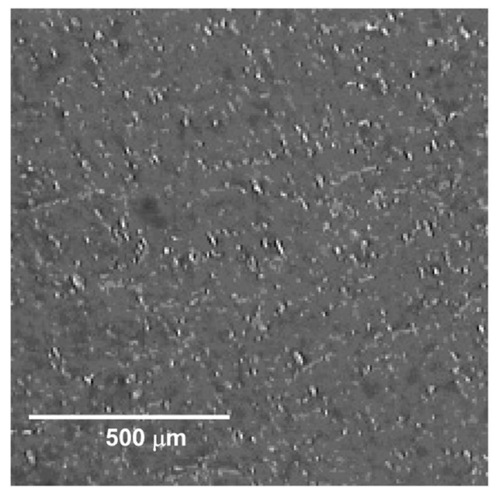


Figure 3. Surface image of offset printing output, immediately after ink transfer.

obtained from video images recorded using VF-7500. The light source for the microscope was placed so that the direction of light was as close to parallel to the sample surface plane as possible. The magnification of VF-7500 was adjusted so as to reduce the influence of the diffused light entering the ink layer, while allowing a sufficient amount of light reflected from the surface to be taken in. If the direction of light from the light source is unchanged, and the influence of diffused light is reduced, topography can be roughly assessed from the reflected light profiles.[18] The reflected light profiles of the still images, shown in Figure 5, indicate the presence of roughness with wavelengths of several micrometers. Furthermore, a significant increase in high-frequency roughness is indicated in the reflected light profiles of the surface 180 s after ink transfer [Fig. 5(b)].

The paper surface and printed surface were also observed using a scanning electron microscope, as shown in Figure 6. As can be seen in Fig. 6(a), pigments, a few μm in size and made of such substances as calcium carbonate, are found throughout the paper surface. Figure 6(b) shows that

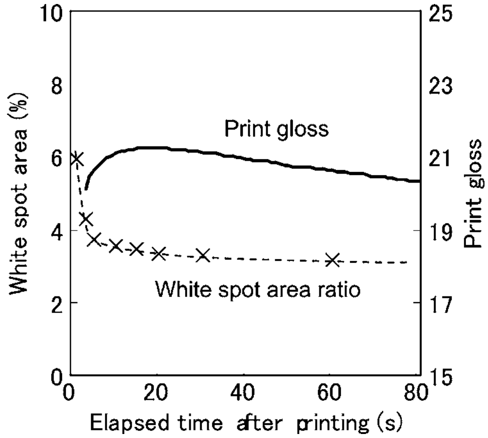


Figure 4. Dynamic print gloss and changes in white spot area ratio, when offset printing is performed on matte-coated paper.

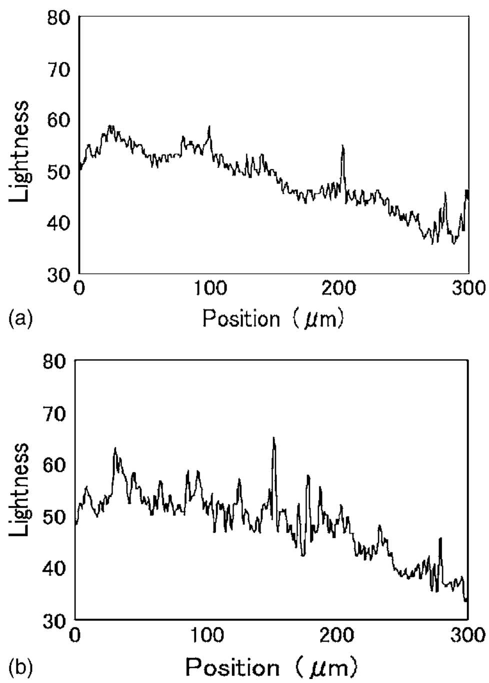


Figure 5. Reflected light profiles of offset printing outputs, 30 s (a) and 180 s (b) after printing.

the profiles of these pigments remain clearly visible in some areas of the printed surface. The profiles of the pigments, initially hidden by the ink layer, presumably became distinct as the ink film became thinner with the penetration of the ink vehicle, so distinct that they could be detected as high-frequency roughness in the reflected light profile analysis.

Relationship between printed surface topography and ink distribution

Paper roughness may cause ink flow, which in turn can lead to uneven ink distribution. The thickness of the ink layer is known to correlate strongly with color density, according to the Kubelka–Munk theory[19–21] In other words, the concave areas with more ink are expected to appear densely colored, and the convex areas with less ink are expected to appear lighter. The assumed driving force for ink flow that wets the

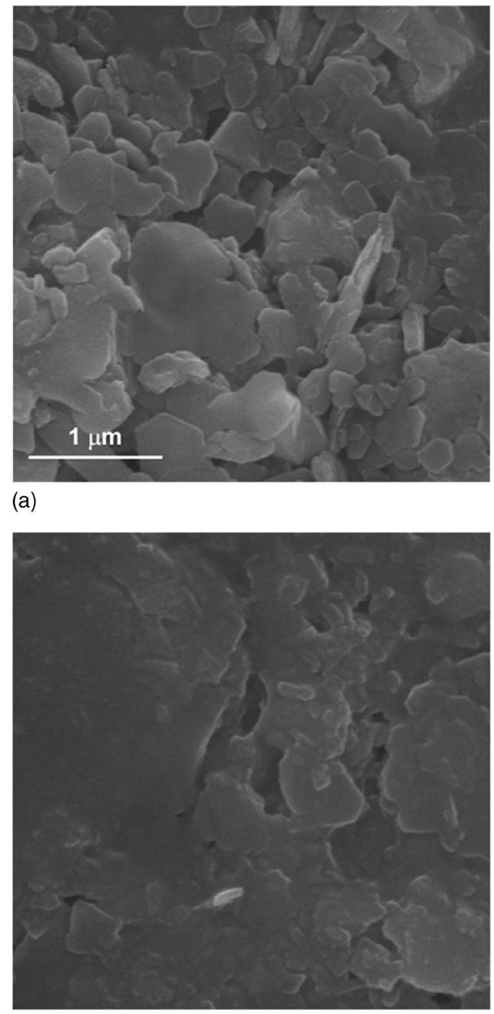


Figure 6. Scanning electron micrographs of paper (a) and printed (b) surfaces, in offset printing.

surfaces of the concave areas is the surface tension of the ink, rather than gravity. With these assumptions, we observed how the relationship between the paper surface topography and the lightness ($L^*a^*b^*$) images of the printed surface changed over time, and a quantitative analysis was carried out, as follows. The correlation coefficient between the topographical grayscale images of the paper surface and the lightness images of the printed sample prepared using the same paper, both obtained using VK-8500, was calculated. Eight sample locations were chosen per sheet, and the correlation coefficient between each of these locations on the topographical grayscale images of the paper surface and its corresponding location on the lightness image of the printed sample was calculated. The average of these coefficients for the eight sample points was obtained to be presented as the final coefficient. Correlation coefficients were calculated for given time intervals after printing, and the results are shown in Figure 7. Although no correlation between the paper surface topography and the lightness images was apparent immediately after ink transfer, the correlation coefficient increased with time. These results imply that ink flows

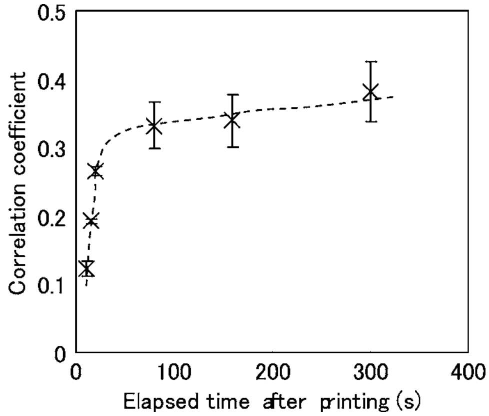


Figure 7. Change in correlation coefficient between locations on topographical grayscale images of the paper surface and corresponding locations on lightness images of offset printing samples.

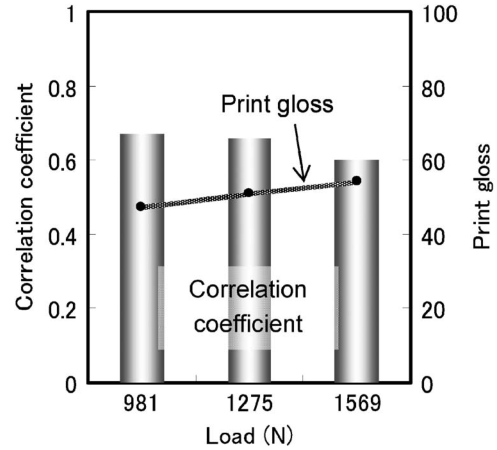


Figure 8. Effect of nip load in electrophotographic printing.

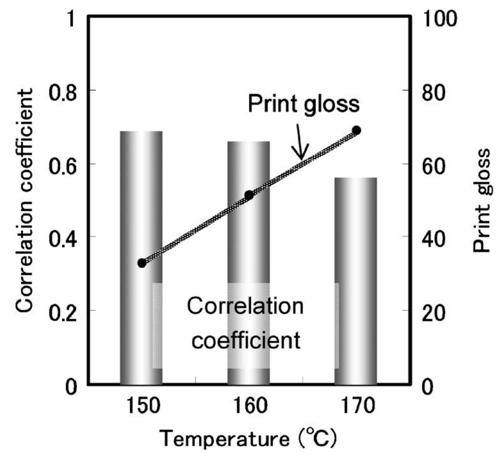


Figure 9. Effect of nip temperature in electrophotographic printing.

according to the paper surface topography, and in time accumulates in the concave areas of the paper surface, thus making those areas appear darker.

Process of printed surface topography formation in offset printing

The above results suggest that in offset printing, using solvent ink on matte-coated paper, printed surface topography is formed, and thus gloss is determined, through the process described below:

When ink is transferred to paper, the printed surface topography is uneven, due to inhomogeneous ink layer splits. This unevenness disappears over the initial several tens of seconds following ink transfer. Concurrently, the ink flows along the paper surface, and the printed surface becomes smoother than the paper surface.

During the next several hundred seconds, the ink vehicle penetrates the paper, causing the printed surface topography to gradually become more similar to the paper surface topography. In other words, the roughness that was previously hidden by the ink layer becomes apparent and prominent as a result of ink vehicle penetration.

Mechanisms of Gloss Development in Electrophotography

To clarify the mechanisms of gloss development in electrophotography, we examined the effect of fusing parameters, namely the load and temperature of the nip, on the relationship between the paper and printed surface topographies.[22]

Relationship between nip load and printed surface topography

The surface topography of paper and that of printed samples produced with different nip loads were observed using VK-8500, and the correlation coefficients between the topographical images of the paper and printed surfaces were calculated. As shown in Figure 8, the correlation coefficient decreased as the nip load increased. Figure 8 also shows the relationship between the nip load and print gloss. Print gloss, on the other hand, increased as the nip load increased. These results show that print gloss and the level of influence that paper surface topography has on the printed surface topography change with the nip load.

Relationship between nip temperature and printed surface topography

The surface topography of paper and that of printed samples produced with different nip temperatures were observed using VK-8500, and the correlation coefficients between the topographical images of the paper and printed surfaces were calculated. As shown in Figure 9, the correlation coefficient decreased as the nip temperature increased. Figure 9 also shows the relationship between the nip temperature and print gloss. Print gloss, on the other hand, increased as the nip temperature increased. These results show that print gloss and the level of influence that paper surface topography has on the printed surface topography change with the nip temperature.

Relationship between paper surface topography and unfused surface topography

The results for all fusing parameter values indicate the following: The less the fusing energy applied to the toner, the more influence paper surface topography has on the printed surface topography. This implies that the unfused surface topography follows, to a certain extent, the paper surface topography, and the printed surface topography becomes different from the paper surface topography when heat and

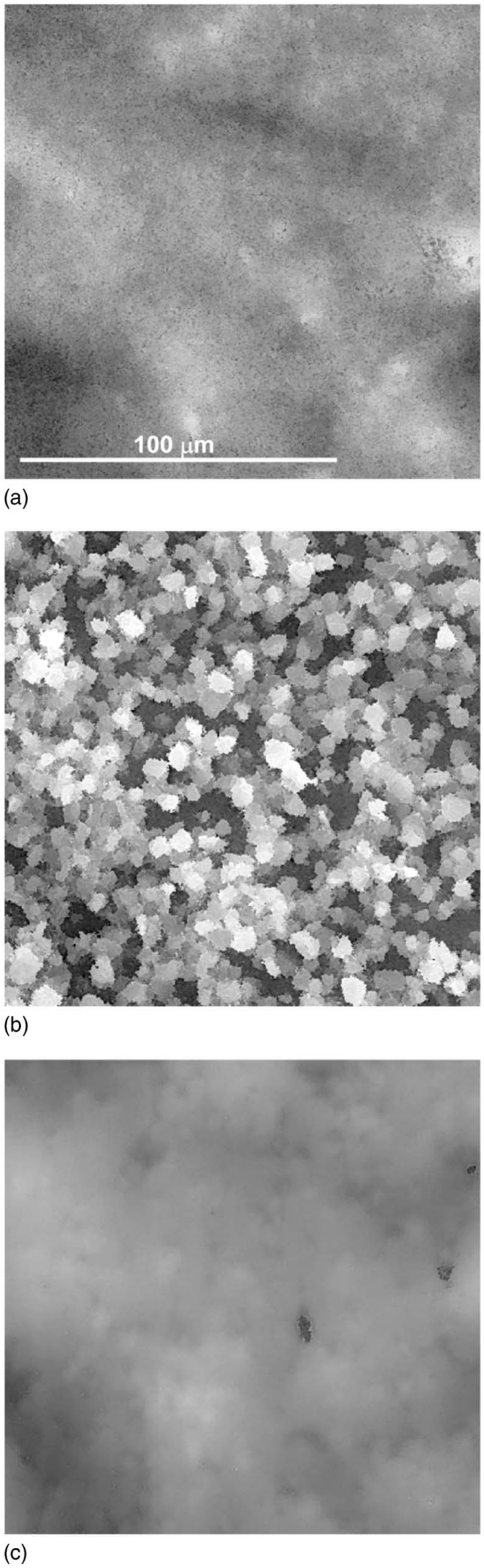


Figure 10. Topographical grayscale images of paper, unfused, and printed surfaces in electrophotographic printing. The data were obtained by assigning height scale of 20 μm to 256 levels of gray. In these grayscale images, the elevated areas appear lighter in color, and the lower areas darker.[22] (a) Topographical grayscale image of paper surface; (b) topographical grayscale image of unfused surface; (c) topographical grayscale image of printed surface.

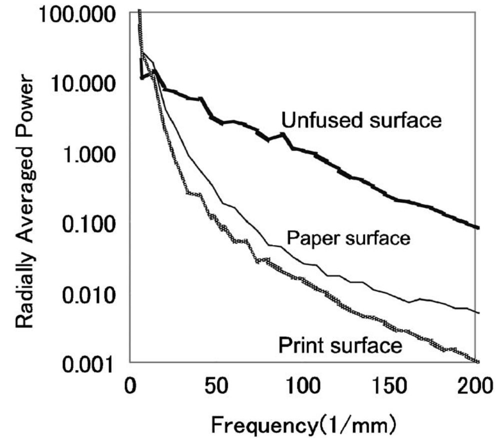


Figure 11. Frequency characteristics of surface topographies.

pressure are applied. With this assumption, the relationship between the paper surface topography and the unfused surface topography was examined.

Paper surface topography, unfused surface topography, and printed surface topography were observed using VK-8500; the images obtained are shown in Figure 10. The unfused surface was covered with toner particles larger than those covering the printed surface. Two-dimensional Fourier transform was carried out for the above three types of surface images. Using RAPS, it was examined whether any distinctive frequencies existed, other than those corresponding to the toner particle size. Although the transfer function may seem to enable a more direct comparison between the surface topographies, the function was not used in this case, for toner particles on the unfused surface would obviously interfere with the output parameter of the function (the dividend of the transfer function, derived from the unfused/printed surface topography).

The results of the frequency analysis are shown in Figure 11. If the difference between the slopes of the curve preceding and following a point exceeded a given threshold, the point was deemed a "point of inflection." In Fig. 11, no distinctive peaks can be observed, but a number of such points of inflection are present. The frequencies corresponding to these points are shown in Table I. In the high-frequency range, no such frequencies are shared between the three surface types. This is because on unfused/printed surfaces, reproduction of paper surface roughness smaller than the toner diameter is difficult, for the toner would cover up and conceal such roughness. In the low-frequency region, however, the paper and unfused surfaces have some frequencies in common, whereas none are observed between the paper and the printed surfaces. This experiment was repeated several times, and similar results were obtained for all trials.

From the above results in frequency comparison, together with the observations on the relationship between the energy applied to the toner and the level of influence paper surface topography has on printed surface topography, the mechanisms of gloss development in electrophotography, under the conditions of the present study, can be character-

Table I. Distinctive frequencies (points of inflection in Fig. 11) in surface topography.

Paper surface (1/mm)	Unfused surface (1/mm)	Printed surface (1/mm)
13.5	13.5	13.5
	26.9	26.9
40.4	40.4	
		53.8
60.6	60.6	
		67.3
74.0	74.0	
		80.7
87.5	87.5	
107.7		
	114.4	
121.2		
134.6	134.6	
		154.8
168.2		
181.7		
		188.4
195.2		

ized as follows. The influence of the paper surface is maintained, to a certain extent, on the unfused surface topography. The heat and pressure applied upon fusing cause the toner to spread sideward.[23] The toner layer is leveled out, and the printed surface topography becomes different from the paper surface topography; more specifically, it becomes smoother. It should be noted, however, that these observations may be affected by various factors; such as the conditions under which the toner is transferred to paper, toner viscosity, fusing conditions, fuser configuration, and so forth.

Process of printed surface topography formation in electrophotography

The above results suggest that in electrophotographic printing on matte-coated paper, using methods within the scope of this study, the printed surface topography is formed through the process described below:

When the toner on the surface has not yet been fused, the distribution of low-frequency roughness (i.e. roughness on a scale greater than toner particle size) along the unfused surface is characteristically similar to that of the paper surface. The pressure and heat applied upon fusing cause the toner to flow sideward and coalesce, thereby yielding a toner layer surface topography that is different from that of the paper surface topography. The degree of change in the toner surface topography is dependent on the amount of pressure and heat applied, and also the viscosity of the melted toner. The printed surface topography thus becomes smoother than the paper surface topography.

Incorporating Offset Printing Surface Topography Formation Processes in Electrophotographic Printing

Processes in printed surface topography formation

The above results suggest that in offset printing, a printed surface topography that follows the paper surface topography is created, mainly due to the following processes:

Process 1: Topographical unevenness of the printed surface, caused by ink layer splits produced upon ink transfer, is smoothed out. In other words, the influence of the ink layer is reduced.

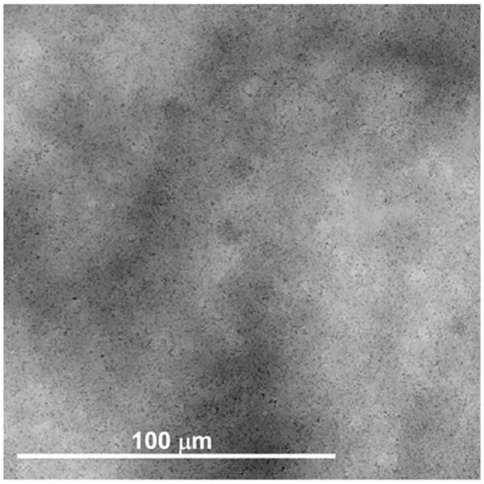
Process 2: Ink flows along the paper, and the ink vehicle penetrates the paper. This is possible because the ink is mobile even after it is transferred to the paper.

With the assumption that incorporating these processes in electrophotographic printing would yield a printed surface topography more consistent with the paper surface topography, the following steps were taken. With regard to Process 1, the influence of the toner layer was to be reduced; in other words, the toner was to be "smoothed out." To do this without exerting too much energy on the paper surface, so as to maintain the influence of paper surface topography, a low fuser nip temperature and a low fuser nip load were applied. With regard to Process 2, the toner viscosity was kept low to maintain toner mobility on the paper surface and thus facilitate changes in surface topography. Furthermore, one known difference between the printed surface topographies of offset printing outputs and electrophotography outputs lies in the height of the ink and toner layers. Namely, the height of the toner layer is known to be greater than that of the ink layer.[11] Therefore, the amount of toner was adjusted so that the height of the toner layer was approximately 2.0 μm when printing was performed on cast-coated paper, for this was the minimum height for which no voids were left in the printed images.

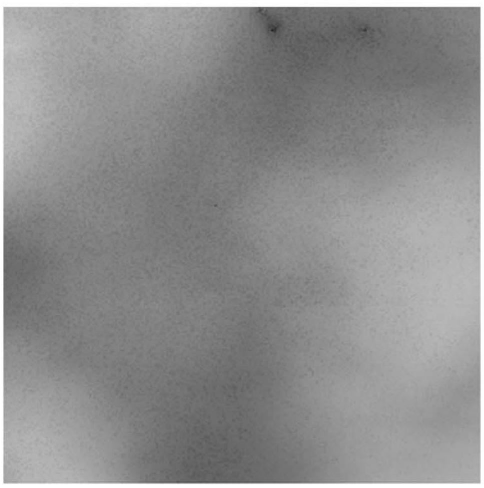
Printed surface topography resulting from electrophotographic printing that incorporates processes in offset printing surface topography formation

The paper surface and the printed surface resulting from performing the above method of electrophotographic printing on that same paper (i.e. with surface topography formation processes of offset printing incorporated, hereon referred to as *altered form of electrophotography*) were observed using VK-8500. Topographical grayscale images of the surfaces were obtained, and are presented in Figure 12.

Table II shows the correlation coefficients between topographical images of the paper and printed surfaces, and also print gloss levels, for outputs produced by the three methods of printing: Offset printing, conventional electrophotography, and altered form of electrophotography. Transfer function calculations for each printing method, with the paper and printed surface topographies as the input and output, respectively, are presented in the graph shown in Figure 13. Table II shows that the altered form of electrophotography produces outputs with reduced gloss and printed surface topographies more strongly correlated with the paper surface topography, when compared to conventional electrophotography. Furthermore, in Fig. 13, the



(a)



(b)

Figure 12. Topographical grayscale images of paper surface and printed surface of output produced by electrophotography incorporating offset printing processes. The data were obtained by assigning height scale of 10 μm to 256 levels of gray. In these grayscale images, the elevated areas appear lighter in color, and the lower areas darker. (a) Topographical grayscale image of paper surface; (b) topographical grayscale image of printed surface.

Table II. Comparison of print gloss and correlation coefficients between paper and printed surface topographies.

	Print gloss	Correlation coefficient
Offset printing	19.1	0.88
Conventional Electrophotography	51.3	0.66
Electrophotography incorporating processes in offset printing	44.2	0.78

transfer function curve for the altered form of electrophotography is shown to be closer to the curve for offset printing, compared to that for conventional electrophotography.

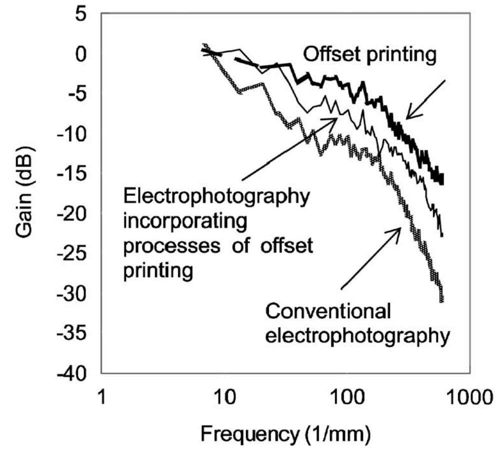


Figure 13. Comparison of transfer function calculations.

In other words, the gain value for each frequency value in the altered form of electrophotography shifts closer to that of offset printing. These results collectively indicate that when the aforementioned processes are incorporated into electrophotography, the surface topography and gloss of the outputs become more consistent with those of the original paper.

CONCLUSION

This study demonstrates the difference between printed surface topography formation processes in offset printing and those in electrophotography, when using matte-coated paper.

In offset printing, printed surface topography can be assumed to form through the following process: The ink is transferred to the paper, and ink layer splits cause topographical unevenness on the printed surface. This unevenness is smoothed out during the initial several tens of seconds following ink transfer. The ink flows along the paper surface, and the printed surface becomes smoother than the paper surface. For the next several hundreds of seconds, the ink vehicle penetrates the paper, causing the printed surface to gradually become more similar to the paper surface. In other words, the roughness initially hidden by the ink layer becomes apparent as a result of ink vehicle penetration.

In electrophotography, the printed surface topography can be assumed to form through the following process: When the toner on the surface has not yet been fused, the distribution of low-frequency roughness (i.e. roughness on a scale greater than toner particle size) along the unfused surface is characteristically similar to that of the paper surface. The pressure and heat applied upon fusing cause the toner to flow sideward and coalesce, thereby yielding a toner layer surface topography that is different from the paper surface topography. More specifically, the printed surface becomes smoother than the paper surface. The degree of difference between the paper and printed surfaces is dependent on the amount of pressure and heat applied, and also the viscosity of the melted toner.

The printed surface topography formation processes in offset printing seemingly responsible for producing a printed surface topography that follows the paper surface topography were incorporated into electrophotographic printing in rudimentary fashion. This altered form of electrophotography produced outputs with surface topographies and gloss more consistent with those of the original paper, compared to outputs produced by conventional electrophotography.

The results obtained from this study may well change according to such factors as toner characteristics, fusing conditions, and fuser configurations. However, this study can still open the door to a new technology for achieving, in electrophotography, gloss development similar to that in offset printing. It is our intention, therefore, to proceed with further research on toner characteristics, fuser configuration, etc., based on the results of this study.

REFERENCES

[1] J. Takagi, "On-demand full color digital xerography printing system—Color DocuTech 60," J. Imaging Soc. Japan **40**, 145 (2001).

[2] T. Shibutani, "Single path duplex electrophotographic printer," J. Imaging Soc. Japan **40**, 150 (2001).

[3] M. Anzai, "Overview on plateless digital printing methods," J. Imaging Soc. Japan **40**, 140 (2001).

[4] Y. Kitano, T. Enomae, and A. Isogai, "Analysis of printed surface topography in electrophotography and offset printing," J. Imaging Soc. Japan **44**, 450 (2005).

[5] T. Enomae, M. Teramoto, F. Onabe, S. Hayano, H. Naito, K. Takano, and K. Kamada, "Mechanisms of print gloss development," *Proc Intl. Printing and Graphic Arts Conference* (TAGA, Atlanta, GA, 2001) pp. 1–8.

[6] Y. Arai and K. Nojima, "Coating structure of cast coated paper for obtaining high print gloss," *Proc. 64th Pulp and Paper Research Conference* (TAPPI, Tokyo, 1997) pp. 47–55.

[7] H. Uchimura, Y. Ozaki, S. Maruyama, and A. Sawatari, "Observation of the printing ink transferred and penetrated into the paper," J. Printing Sci. and Technol.**39**, 48 (2002).

[8] J. C. Briggs, J. Cavanaugh, M.-K. Tse, and D. A. Telep, "The effect of fusing on gloss in electrophotography," *Proc. IS&T's NIP14* (IS&T, Springfield, VA, 1998) pp. 456–461.

[9] T. Pettersson and A. Fogden, "Leveling during toner fusing: Effects of surface roughness and gloss of printed paper," J. Imaging Sci. Technol. **50**, 202 (2006).

[10] O. Ide and M. Kurimoto, "Image quality improvement with surface structure modification in xerography," J. Imaging Soc. Japan **38**, 103 (1999).

[11] M. Kurimoto and F. Watanabe, "Cross-sectional observation of color hardcopy images," J. Imaging Soc. Japan **35**, 131 (1996).

[12] M. Kaji, S. Otake, and Y. Azuma, "Colorimetric characteristics of process color prints produced under the japan color conditions: Conversion trials from $L^*a^*b^*$ values to CMY dot percent values" *Recent Progress in Color Management and Communications* (IS&T, Springfield, VA, 1998) pp. 62–67.

[13] The Japanese Society of Printing Science and Technology, *Insatsu Kougaku Binran* [Handbook of Printing Technology] (Gihodo Shuppan, Tokyo, Japan, 1983).

[14] R. Ulichney, *Digital Halftoning* (MIT Press, Cambridge, MA, 1988).

[15] Y. Kitano, T. Enomae, and A. Isogai, "Mechanisms of gloss development with matte-coated paper in offset printing," J. Printing Sci. and Technol.**42**, 105 (2005).

[16] Y. Kitano, T. Enomae, and A. Isogai, "Mechanisms of gloss development with matte-coated paper in offset printing (2:) Post-printing micro-dynamics of ink film," J. Printing Sci. and Technol.**43**, 346 (2006).

[17] S. Hayano, K. Takano, K. Kamada, M. Teramoto, T. Enomae, and F. Onabe, "Structural analysis of coated layer (II)," TAPPI J. **53**, 1015 (1999).

[18] Y. Osawa, *Image Processing* (CG-ARTS, Tokyo, 1997).

[19] M. Nonaka and F. Hiraishi, "Application of Kubelka-Munk Analysis to Ink Layer," J. Printing Sci. and Technol.**21**, 7 (1983).

[20] Y.-H. Zang and J. S. Aspler, "The effect of surface binder content on print density and ink receptivity of coated paper," J. Pulp Pap. Sci. **24**, 141 (1998).

[21] P. Lepoutre, J. H. DeGrace, and P. J. Mangin, "Printability of coated papers: Influence of coating absorbency," TAPPI J. **62**, 33 (1979).

[22] Y. Kitano, T. Enomae, and A. Isogai, "Mechanisms of gloss development with matte-coated paper in electrophotography," J. Imaging Soc. Japan **45**, 504 (2006).

[23] K. Horie and K. Maruyama, "What is the high quality image in electrophotography," J. Imaging Soc. Japan **26**, 48 (1987).