Gloss Prediction Model for Electro-photographic Printing Based on Image Structures Related to Physical Phenomena in the Image Forming Processes

Kenichi Hamada, Minoru Ohshima, Toru Ogawa, Nobuyuki Nakayama, and Yoshihisa Kitano; Key Technology Laboratory, Fuji Xerox Co., Ltd.; Ashigarakami-gun, Kanagawa, Japan.

Abstract

In developing copiers and printers, it is necessary to design the image gloss according to customers' preferences. In electro-photographic printers, the image gloss depends on the system parameters, such as parameter sets for fusing (pressure, temperature, and dwell time), viscoelastic property of toners, and surface properties of paper. Therefore, it is necessary to develop system models that indicate relations between the image gloss and system parameters.

In this paper, we describe the development of an image gloss prediction model based on image structures that are related to the physical phenomena in the system. We have extracted two characteristic image structures from the analysis of image samples printed by various system parameters. A "micro hollow at the toner boundary" is a boundary dimple among a few toner particles, and a "macro hollow" is a pit composed of a group of toner particles. The "micro hollow at the toner boundary" is formed by a melting phenomenon of the toner particle in the fusing process, and the "macro hollow" is affected by the arrangement of the toner particles in the pre-fusing process. Furthermore, we succeeded in constructing a model that predicts the image gloss based on the sum of the area ratios (occupancy ratio in the surface area) of the two image structures.

Introduction

Image gloss is one of the most important attributes for image quality. The preference for image gloss varies, depending on the customer. In developing copiers and printers, especially production printers, it is necessary to design the image gloss according to customers' preferences. In the case of electro-photographic printers, the image gloss depends on parameters characterizing the electro-photographic system, which we call system parameters, such as parameter sets for fusing (pressure, temperature, and dwell time), viscoelastic property of toners, and surface properties of paper. Therefore, it is possible to design the image gloss of electro-photographic printers according to the customer's preference by clarifying relations between the image gloss and system parameters.

Conventionally, a number of studies have reported that the image gloss is associated with profiles of the image surface. For example, several image gloss prediction models based on the statistical features of the image surface profiles of electro-photographic printers have been proposed [1-2]. With regard to the relationship between system parameters and image gloss, however, a study has proposed an image gloss simulation model based on toner deformation depending on viscoelastic property affected by temperature and frequency in the fusing process [3], but this model is limited to studies on the effects of only a part of the parameters. No studies have been sufficiently conducted based on the physical phenomena in the electro-photographic system. Thus, in the present, it is difficult to design the image gloss of electro-photographic printers.

In this paper, by focusing on the characteristic structures of image surface profiles (image structures) that are related to physical phenomena, we clarified the relationship between physical phenomena and image structures, and the relationship between image structures and image gloss. In the following chapters, we describe the approach for construction of the image gloss prediction model based on the image structures, and the concrete process of construction.

Approaches for construction of a gloss prediction model

A specular gloss is an index of the gloss, defined as the ratio of specular reflection intensity to incident intensity. Specular gloss is determined by the reflection, transmission, scattering, and absorption of light. With regard to the output image of electro-photographic printers, it is known that the reflection on the surface of toners and paper crucially affects the image gloss [4].

Conventionally, several image gloss prediction models based on statistical features of the image surface profiles of electro-photographic prints have been proposed [1-2]. Based on the method of using statistical features, it is difficult to analyze through what kind of physical phenomena the image surface profiles are formed; thus it is difficult to clarify the relation between physical phenomena and image surface profiles.

In this paper, in order to connect the physical phenomena and the image surface profiles, we take an approach to explain image gloss based on the classification of characteristic structures of image surface profiles (image structures). There are several physical phenomena through which the surface profiles are formed, and the characteristics of the image structures are different depending on the physical phenomenon. By classifying the structures, the structures can correspond one-to-one to the physical phenomena.

Based on this approach, we clarified the relation between the physical phenomena and image structures, and the relation between image structures and image gloss based on the following steps.

Step 1: Classification of characteristic structures of image surface profiles (image structures)

Step 2: Specification of the image structures that crucially affect image gloss

Step 3: Investigation of the measurement method for feature values of image structures

Step 4: Investigation of the relation model between the feature values of the image structures and image gloss

It should be noted that the scope of this paper is the gloss of a solid image that is not halftoned.

Construction of the gloss prediction model based on image structures

Classification of the characteristic structures of image surface profiles (image structures)

In order to combine the physical phenomena in the electro-photographic process and image surface profiles, we classified the characteristic structures of the image surface profiles.

According to the measurement principle for specular gloss, it is considered that sizes that range from the wavelength of visible light (400-700nm) to the aperture of the specular gloss meter (several mm) contributes to the specular gloss level. Therefore, we investigated the image surface profiles of this size range. We observed image surface profiles using SEM (Scanning Electron Microscope), as SEM can capture the profiles of this size range.

Samples for observation were prepared by changing output conditions for fusing devices (three products made by Fuji Xerox whose prints have different gloss even if printed on the same type of paper), fusing parameters (fixing member temperature, pressure member temperature, nip pressure, and dwell time) and paper types (existence or non-existence of coat layer, weight), and an orthogonal table was used in order to extract the image structures generated in response to the wide-range space of the system parameters.

As a result, we clarified the image surface profiles and classified them into four kinds of image structures as follows (see Figure 1).

"Micro hollow at the toner boundary": boundary dimple under 10µm among a few toner particles

"Micro hollow at the cross of the paper fiber": dimple of 10-20µm on the cross of the paper fiber

"Macro hollow": Bumpy structure of 50-500µm composed of a group of unmelted toner particles or a mix of toner and exposed paper surface

"Swell": Bumpy structure on the toner image surface with a cycle of 500µm

Specification of image structures that crucially affect image gloss

Next, we specified the image structures that crucially affect image gloss by analyzing the degree of contribution to image gloss of the four kinds of characteristic structures classified in the preceding section.

To analyze the degree of contribution, we executed regression analysis between the specular gloss and the quantity that indicates the unevenness of each image structure. For the quantity, we used the grade value obtained by evaluating SEM-captured images with our naked eyes. We prepared limit samples, by comparing the captured images with the sample images, and we evaluated the grade value in points (in increments of 0.5 points, 9 levels). The higher the point, the larger the surface unevenness.

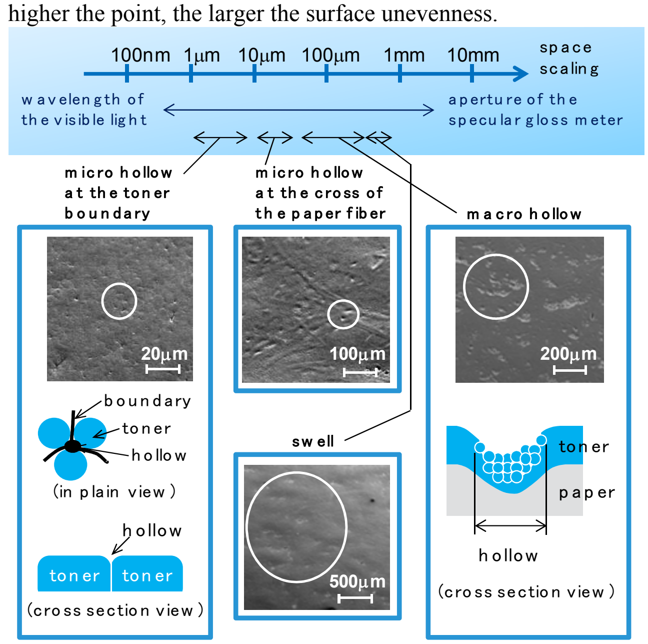


***Figure 1**. Four kinds of image structures*

Figure 2 shows the results of single regression analysis. In all image structures, larger unevenness causes lower image gloss. The results indicate that unevenness causes diffused reflection, which then results in a decrease in specular reflection intensity and then in specular gloss. Additionally, the correlation coefficient between the specular gloss and grade value of the "macro hollow" is markedly high.

Figures 3 (a) and (b) show the results of multiple regression analysis. Figure 3 (a) shows the relation between the predicted value and measured value of the specular gloss. Figure 3 (b) shows the t-value, which indicates the degree of contribution to the specular gloss. We clarified that the specular gloss at an angle of 60 degrees is determined by the four kinds of image structures at a coefficient of determination of 0.69. Furthermore, we clarified that "micro hollow at the toner boundary," "micro hollow at the cross of the paper fiber," and "macro hollow" strongly affect the specular gloss.

The "micro hollow at the cross of the paper fiber," however, has a relatively high correlation coefficient 0.49 with "macro hollow" (see Figure 4). In our observations, we defined "micro hollow at the cross of the paper fiber" and "macro hollow" as different image structures, but in terms of physical phenomena of structure formation, these structures are inferred to be similar. Therefore, we concluded that for construction of the gloss prediction model based on image structures related to the physical phenomena, the image structures that crucially affect image gloss are "micro hollow at the toner boundary" and "macro hollow."

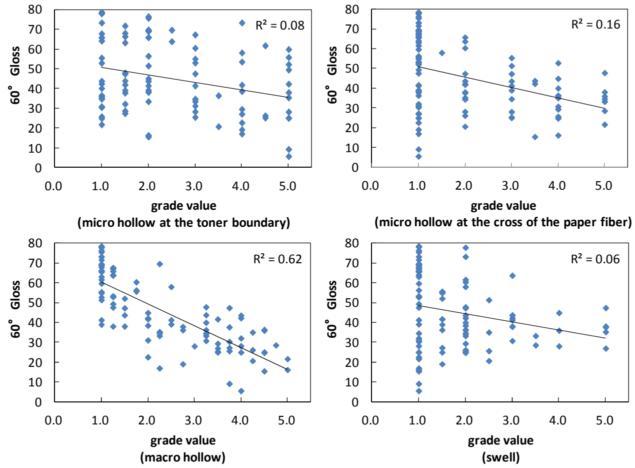
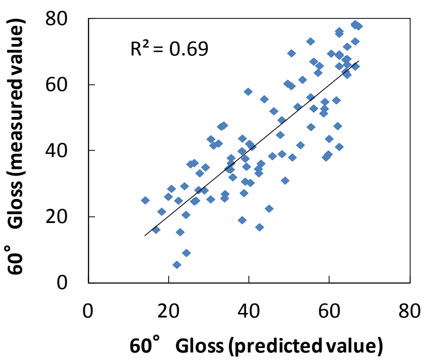
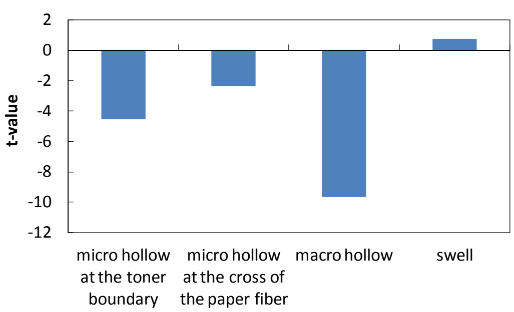


***Figure 2**. Results of single regression analysis*



(a) Relation between predicted values and the measured values of the specular gloss



(b) t-value

***Figure 3**. Results of multiple regression analysis*

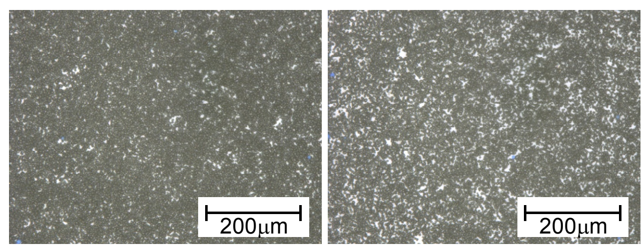
	micro hollow at the toner boundary	micro hollow at the cross of the paper fiber	macro hollow
micro hollow at the toner boundary	1.00		
micro hollow at the cross of the paper fiber	−0.34	1.00	
macro hollow	0.08	0.49	1.00

***Figure 4**. Correlation coefficients among the image structures*

For the two image structures of "micro hollow at the toner boundary" and "macro hollow," which crucially affect image gloss, we considered the physical phenomena that form these structures.

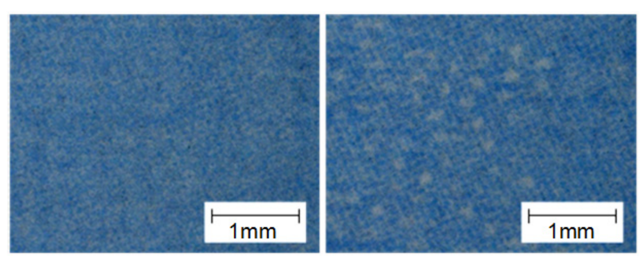
The "micro hollow at the toner boundary" is the boundary dimple under 10μm among a few toner particles. This structure is formed by deformation of the toner particles in the fusing process, and is thus considered to be controlled by the melting phenomenon of each toner particle.

The "macro hollow" is the pit composed of a group of unmelted toner particles or a mix of the toner and exposed paper surface, with a cycle of 50-500μm. This structure is considered to be affected by the physical phenomenon in the pre-fusing process. For example, in the transfer process, non-uniformity of the quantity of transferred toner particles occurs due to fluctuation of electric charge distribution caused by electric discharge, or due to irregularity of the electric field corresponding to the surface unevenness on the paper (see Figure 5) [5-6]. As another example, in the charging process, non-uniformity of the quantity of developed toner particles occurs due to irregularity of the surface potential on the photoreceptor caused by fluctuation of electric discharge (see Figure 6) [7]. The "macro hollow" crucially affects the image gloss; thus, in order to control the image gloss it is considered to be important to control not only the fusing process but also the pre-fusing processes such as charging, exposing, developing, and transferring.



(a) Cast coated paper (b) Matte coated paper

***Figure 5**. Non-uniformity of the quantity of transferred toner particles caused by irregularity of the electric field corresponds to surface unevenness on the paper. The white area indicates the exposed paper surface among toner. (a)Toner transferred on a cast coated paper. (b) Toner transferred on a matte coated paper.*



(a) Bias voltage -1010 V (b) Bias voltage -1210 V

***Figure 6**. Non-uniformity of the quantity of developed toner particles caused by irregularity of the surface potential on the photoreceptor due to fluctuation of electric discharge. The image shows the output image by roller charging with DC voltage. The white area indicates the exposed paper surface among toner [7].*

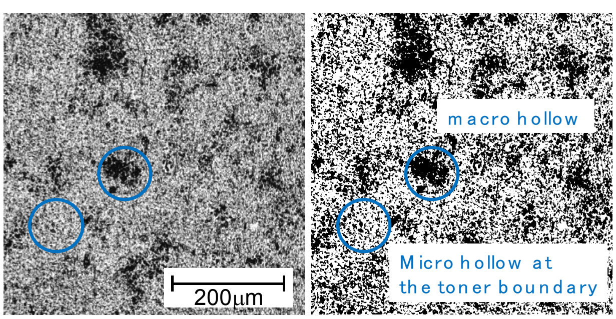
Investigation of the measurement method for feature values of image structures

Next, in preparation for constructing the relation model between the image structures and image gloss, we searched for a measurement method for the feature values of the two image structures "micro hollow at the toner boundary" and "macro hollow," which crucially affect the image gloss.

From the results of the regression analysis in the preceding section, diffused reflection occurs in the area of the two image structures. Thus, it is considered that the larger the area, the weaker the intensity of specular reflection, resulting in a decline of the image gloss. Therefore, we set a hypothesis that the image gloss is determined by the area ratios (occupancy ratio in the surface area) of the two image structures, and investigated the measurement method of the area ratios.

To measure the area ratios, it is suitable to measure the intensity distribution of the specular reflection. In this study, we used a laser scanning confocal microscope to measure the intensity distribution of specular reflection, because it enables us to simultaneously analyze both the intensity distribution of the specular reflection and the surface profiles. By connecting captured images, we managed both a high resolution (0.7μm/pixel, possible to measure the "micro hollow at the toner boundary (under 10μm)" and "macro hollow (50-500μm)") and a wide field of view (2.7mm square, sufficiently wider than the period of the fluctuation cycle of the intensity of the specular reflection), in order to reduce an in-plane variation of the area of the image structures. We extracted the area of the image structures by binarizing captured images with a fixed threshold. We determined the threshold by optimizing the prediction accuracy of the model which predicts the gloss based on the area ratios of the two image structures (see Figure 8).

Figure 7 shows the results. We realized that the two image structures can be captured by imaging the intensity distribution of the specular reflection, and that the area ratios of the structures can be calculated by binarizing the captured image.



(a) Intensity distribution of specular reflection (b) Binarization of (a)

***Figure 7**. Measurement results of the intensity distribution of the specular reflection on the printed image surface*

Investigation of the relation model between the feature values of the image structures and the image gloss

Finally, we verified the suitability of the feature values (area ratios) of the image structures proposed in the preceding section by investigating the relation model between the image structures and specular gloss.

By using the measurement method in the preceding section, we investigated the relation between the area ratios of the image structures and the specular gloss for the output image printed by the electro-photographic printer.

Samples for the investigation were prepared by changing output conditions for fusing devices (five products made by Fuji Xerox whose prints have different gloss even if printed on the same type of paper), fusing parameters (fixing member temperature, pressure member temperature, nip pressure, and dwell time), and toner type (two kinds of diameters and three kinds of viscoelastic properties) as the controllable factors; and toner quantities per area, paper type, and conditions for pre-fusing as noise factors. Thus, the sample space includes not only fluctuations in the fusing process but also those in the pre-fusing process.

Figure 8 shows the results. We succeeded in constructing a model that predicts the gloss based on the sum of the area ratios (occupancy ratio in the surface area) of the two image structures, with a coefficient of determination of 0.94.

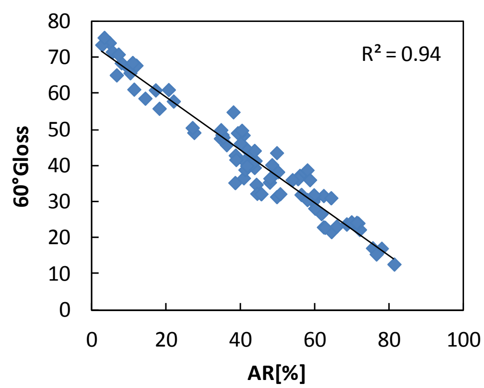


Figure 8. Model that predicts the gloss based on the area ratios of the two image structures. 60° Gloss is the specular gloss at an angle of 60 degrees, and AR is defined as the sum of the area ratio of both the micro hollow and the macro hollow. 60° Gloss = 73.5 – 0.732 x AR.

Summary

In order to design the image gloss when developing electro-photographic copiers and printers, it is necessary to clarify the relation between the system parameters and the image gloss based on physical phenomena in the electro-photographic system.

In this paper, by focusing on the characteristic structures of the image surface profiles (image structures) that are related to the physical phenomena, we clarified the relation between the physical phenomena and the image structures, and the relation between the image structures and image gloss. We hereby obtained a foothold for clarifying the relation between the system parameters and the image gloss.

First, we clarified that the image surface profiles are classified into four kinds of image structures—"micro hollow at the toner boundary," "micro hollow at the cross of the paper fiber," "macro hollow," and "swell." We specified that the image structures that crucially affect the image gloss are "micro hollow at the toner boundary" and "macro hollow." We thus clarified the relation between the image structures and image gloss.

Next, we considered the relation between the physical phenomena and image structures. As a result, we clarified that the "micro hollow at the toner boundary" is controlled by the melting phenomenon of each toner particle, whereas the "macro hollow" is affected by the physical phenomenon in the pre-fusing process. The "macro hollow" crucially affects the image gloss; thus in order to control the image gloss it is important to control not only the fusing process but also pre-fusing processes such as charging, exposing, developing, and transferring.

Finally, we investigated the relation model between the image structures and specular gloss. As a result, we succeeded in constructing a model that predicts the gloss based on the sum of the area ratios of the two image structures with high prediction accuracy.

As a challenge for the future, we are going to clarify the relation between the system parameters and the image gloss by constructing a relation model between the physical phenomena and the image structures. We will thus be able to design the image gloss according to customers' preferences.

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Author Biography

Kenichi Hamada received his MS in applied physics from the Graduate School of Engineering at the University of Tokyo in 2008. He joined Fuji Xerox Co., Ltd. in 2008 and has since been engaged in the development of image structure analysis and fusing technologies of electrophotography.