Visualization Analysis on Melting Deformation of Toner Particles in a Fusing Nip

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Abstract

Image gloss in electrophotographic copiers and printers is closely related to the image structures, which are spatial structures of melted toner layers on media. Therefore, in order to design the image gloss when copiers and printers are developed, it is necessary to clarify relations between the image gloss and the image structures, and relations between the image structures and system parameters. We clarified the relations between the image gloss and the image structures by constructing a relation model between the image gloss and characteristic indices of two image structures that crucially affect the image gloss in our previous report. However, with respect to clarifying the relations between the image structures and the system parameters, analysis on the melting deformation behavior of toner particles is the most important problem to be solved.

In this report we newly developed a visualization measurement method for melting deformation of toner particles in a fusing nip. The method enables us to directly observe the behavior of toner particles in the fusing nip under the condition simulating time variation of temperature and pressure in the actual fusing system.

By using the method, dependences of the deformation behavior of the toners in the fusing nip on the system parameters were analyzed. As a result, it was found that the toner particles are deformed completely in the fusing nip. We also clarified the effect on the deformation of toner particles in the fusing nip caused by temperature of a heating unit and that of a pressurizing unit. Considering the results, it was found that the restoring deformation of the toner after the fusing nip caused by residual stress stored inside the toner particle significantly affects the image structures and image gloss after fusing.

Introduction

Image gloss is one of the most important characteristics for image quality, and the preference for the image gloss varies depending on the customers. Therefore, in the development of copiers and printers, it is required to design the image gloss according to the customers' preferences. In case of the offset printing, controlling surface profiles of the medium or the viscosity of the ink enables us to achieve the desired image gloss because layers of ink of one micrometer is thin in comparison to the surface unevenness of the medium. On the other hand, in case of the electrophotographic printing, it is difficult to design the image gloss by means of controlling the surface profiles of the medium. This is because the layer of toner from a few micrometers to several dozen micrometers is thicker than the surface unevenness of the medium, causing the surface profile of the toner layer to crucially affect the image gloss. The surface profile of the toner layer is determined by the parameters characterizing the electrophotographic system, which we call system parameters, such as the fusing parameter sets (temperature, pressure, and dwell time), the viscoelastic property of toners, the surface property of the medium, and parameters except for fusing. The system parameters strongly affect not only the image gloss but other performances such as the image quality (graininess and so on), productivity, and energy efficiency, which means that it is necessary to control the system parameters for designing the image gloss while ensuring other performances. Therefore it is crucial to clarify the relation between the surface profiles of the toner layer and the system parameters.

In this study we took an approach of clarifying relations between the image gloss and the image structures, which are spatial structures of melted toner layers on media, and relations between the image structures and the system parameters. With regard to clarifying the relations between the image gloss and the image structures, in our previous report we constructed a relation model between the image gloss and characteristic indices of two image structures (the micro hollow at the toner boundary and the macro hollow (see Figure 1)) that crucially affect the image gloss [1]. The micro hollow at the toner boundary is denoted as the "micro hollow" hereinafter. In the report, it is also clarified that the micro hollow is formed mainly by the melting deformation of toner particles in fusing process, and the macro hollow is formed mainly by the effects of pre-fusing processes such as charging and transferring [1]. On the other hand, with respect to clarifying the relations between the image structures and the system parameters, analysis on the melting deformation behavior of toner particles is the most important problem to be solved.

Conventionally a simulation model between the image gloss and toner deformation amount that depends on viscoelastic properties affected by time variation of temperature and pressure in the fusing process has been proposed [2], but this model cannot explain some of crucial phenomena such as the relation between temperature of a pressurizing unit and the image gloss.

When the mechanism of the melting deformation of toner particles in the fusing process is investigated in detail, it is useful to grasp directly the time variation of the deformation in a fusing nip. Conventionally the differences between the input to the fusing nip (the media and the unmelted toners) and the output from it (the media and the melted toners) have been analyzed, but this method enables us only to guess the deformation in the fusing nip, which means that the deformation mechanism cannot be sufficiently verified.

In this report, in order to clarify the melting deformation of toner particles, we developed a visualization measurement method for deformation of toner particles in a fusing nip. The method enables us to directly observe the behavior of toner particles in the fusing nip under the condition simulating time variation of temperature and pressure in the actual fusing system.

By using the method, dependences of the deformation behavior of the toners in the fusing nip on the system parameters were analyzed. The results and consideration are also described in the body of this report.

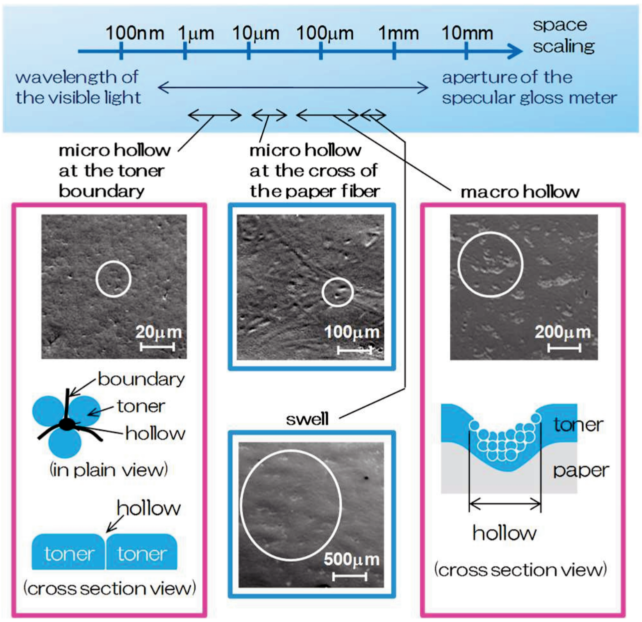

***Figure 1**. Two image structures that crucially affect the image gloss.*

Visualization Measurement Method for Melting Deformation of Toner Particles in a Fusing Nip

Development of a Visualization Measurement Apparatus

Conventionally a study has proposed a visualization measurement method for toner particles in a fusing nip [3], but this method cannot simulate time variation of temperature and pressure in the actual fusing system because the start/end timing of both heating and pressurizing is mismatched due to the configuration that the back of the media contacts with heater all the time, and also because the method has difficulty in high-speed time variation of pressure owing to the linear stepping motor.

In this report, we newly developed a visualization measurement method for the deformation of the toners in the fusing nip. There are two optional approaches to visualize the deformation, one is to observe the deformation from the direction parallel to the facing surface of a heating unit and a pressurizing unit, and the other is to observe the deformation through a transparent heating unit. We adopted the latter approach because with the former approach it is difficult to observe the image structures on the surface of the toner layer that crucially affect the image gloss. In the actual fusing system, which use a roll transport configuration, it is difficult to track the deformation of one focused toner particle with submicron spatial resolution. Thus we developed a visualization measurement apparatus which enables us to directly observe the deformation of toner particles in the fusing nip. In this case, it is required to observe the deformation under the condition simulating time variation of temperature and pressure in the actual fusing system.

First we explain the configuration of the fusing nip in the apparatus (Figure 2). In order to achieve both directly observing the deformation of toner particles and heating them, transparent elements (a glass heater (a glass plate with heat source), a silicon rubber sheet, and a PFA film) are used as the heating unit. A high speed camera with a high frame rate (1000 fps) enables us to capture the deformation behavior. The objective lens and the camera with high spatial resolution (0.95 µm/pixel) make it possible to capture images of the toner particles. We adopt coaxial episcopic illumination for high amount of light and space-saving while eliminating stray light with antireflection coating on the surface of the glass heater. The configurations of the apparatus listed above enable us to observe in the fusing nip in chronological order the deformation of the image structures on the surface of the toner layer which crucially affect the image gloss.

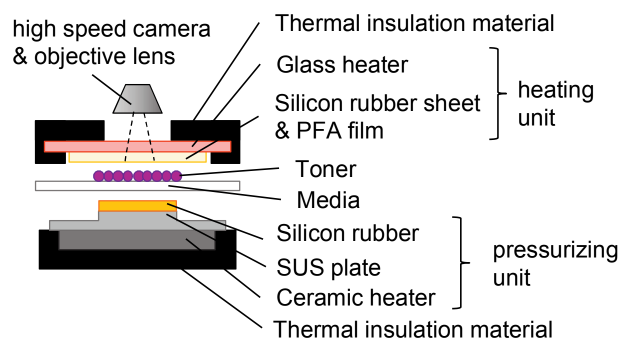

***Figure 2**. Configuration of the fusing nip.*

Next we explain the configuration for controlling time variation of temperature and pressure (Figure 3). In order to simulate the high-speed time variation of pressure (millisecond order) of the actual fusing system, the cam mechanism is used, which presses the movable pressurizing unit to the fixed heating unit. By changing the cam shape and controlling rotational speed of the cam, arbitrary pressure-time profiles can be realized (see Figure 4). The temperature of the heating unit and the pressurizing unit can be controlled independently by using the glass heater and the ceramic heater. In order to match the start/end timing of both heating and pressurizing, the media is constantly maintained at the center position between the surface of the heating unit and that of the pressurizing unit, which means that the heating unit, the media, and the pressurizing unit are simultaneously contact and apart. The above apparatus configurations enable us to simulate time variation of temperature and pressure in the actual fusing system.

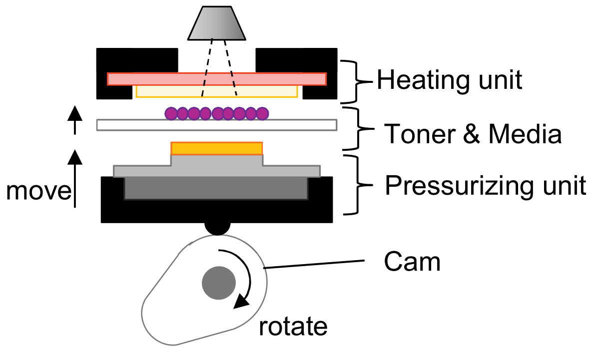

***Figure 3**. Configuration for controlling time variation of temperature and pressure.*

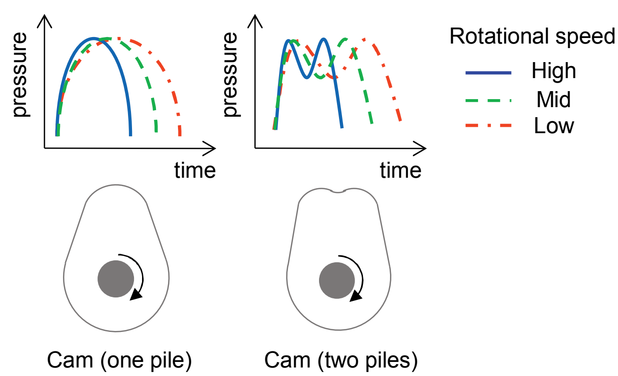

***Figure 4**. Realizing arbitrary pressure-time profiles by changing the cam shape and the rotational speed of the cam.*

Observation of Toner Particles in the Fusing Nip

The toner particles in the fusing nip were observed by using the visualization measurement apparatus. Figure 5 (left) shows the captured image of the surface of the toner layer in the fusing nip. The dark section indicates the contact area between the toner and the PFA film of the surface of the heating unit, whereas the bright section indicates the non-contact area between the toner and the PFA film. The non-contact area is brighter than the contact area because Fresnel reflectance of the incident light from the PFA film to the air is higher than that of the incident light from the PFA film to the toner. Figure 5 (right) shows the image structures after fusing captured by the confocal laser scanning microscope at the same position as Figure 5 (left) and extracted through binarization. It was found that the non-contact area in the fusing nip corresponds to the micro hollow and the macro hollow after fusing. Therefore, by visualizing and measuring the non-contact area in the fusing nip, it is possible to capture the deformation behavior in the fusing nip of the micro hollow and the macro hollow, which are the image structures that crucially affect the image gloss.

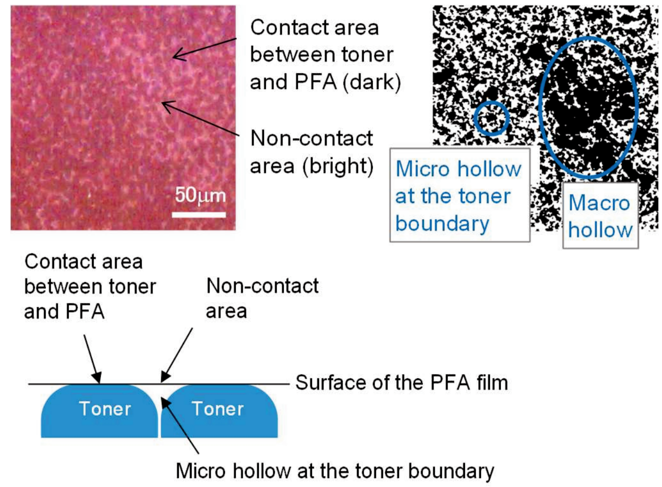

***Figure 5**. Comparison of the distribution between the non-contact area in the fusing nip (left) and the image structures after fusing (right).*

Validation of Reproducibility of the Fusing Process in the Actual Fusing System

In order to validate that the visualization measurement apparatus reproduces the fusing process in the actual fusing system, the deformation amount of the surface toners after fusing in the apparatus and that in the actual fusing system are compared.

Experimental methods are as follows. As the actual fusing system, a roll-to-roll fusing device was used. The time variation of temperature and pressure in the device were simulated in the apparatus. Samples for evaluation were prepared by changing conditions for fusing parameters (heating unit temperature, pressurizing unit temperature, and dwell time) and paper types (weight of coated paper). The levels of the conditions were set by using an orthogonal table in order to cover space of the system parameters.

In addition, an evaluation index of the deformation amount of the toners was considered. In our previous report, it was clarified that the micro hollow is formed by the melting deformation of toner particles in fusing process, and the macro hollow is formed by the effects of pre-fusing processes such as charging and transferring [1]. Therefore it is appropriate to adopt not the macro hollow but the micro hollow as the evaluation target of the deformation amount. Thus a rate of areas of the micro hollow occupying all surface area except for areas of the macro hollows, which we call area ratios of the micro hollow, was used as the evaluation index of the deformation amount.

As a result of the measurements and evaluations, the area ratios of the micro hollow after fusing in the apparatus almost corresponded with those in the actual fusing system, with a coefficient of determination of 0.81 (Figure 6). Thus it was found that the apparatus reproduces the fusing process in the actual fusing system (the roll-to-roll fusing device).

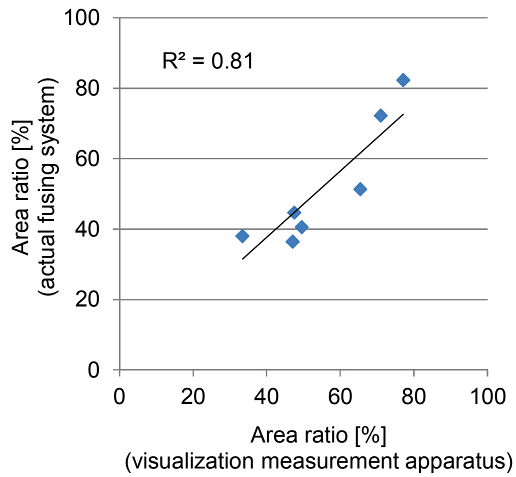

***Figure 6**. Relation between the area ratios of the micro hollow at the toner boundary after fusing in the visualization measurement apparatus and those in the actual fusing system (the roll-to-roll fusing device).*

Analysis on the Toner Deformation Behavior in the Fusing Nip

Dependences of the deformation behavior of the toners in the fusing nip on the temperature of the heating unit and that of the pressurizing unit were analyzed by using the visualization measurement apparatus.

Experimental methods are as follows. The time variation of the deformation amount of surface toners in the fusing nip were analyzed. The temperature of the heating unit was set to 130 °C, 150 °C and 170 °C, and that of the pressurizing unit was set to 40 °C, 80 °C, and 120 °C. The time variation of pressure in the apparatus was set equally to that in the roll-to-roll fusing device. The dwell time was set to 60 milliseconds. In order to mainly evaluate the deformation of the toners, the influence of the macro hollow was mostly excluded by using gloss coated papers as the medium. As the evaluation index of the deformation amount, the area ratios of the non-contact areas between the toner and the PFA film in the fusing nip corresponding to the micro hollow were used.

The dependences of the area ratios of the non-contact areas in the fusing nip on the temperature of the heating unit is showed in Figure 7, and that on the pressurizing unit is showed in Figure 8. In all the conditions, the area ratios decrease to almost 0% within 15 milliseconds from the start timing of the fusing nip. Thus it was found that the toner particles are deformed completely in the fusing nip. In addition, it was found that the temperature of the pressurizing unit has little effect on the deformation of toner particles in the fusing nip, whereas the higher temperature of the fusing unit causes the faster deformation.

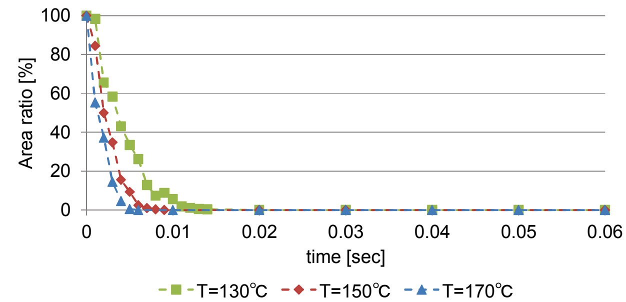

***Figure 7**. Dependences of the area ratios of the non-contact areas in the fusing nip on the temperature of the heating unit.*

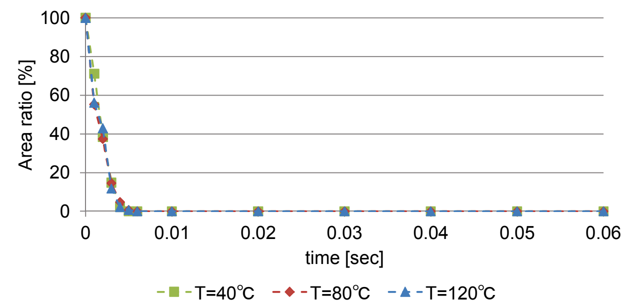

***Figure 8**. Dependences of the area ratios of the non-contact areas in the fusing nip on the temperature of the pressurizing unit.*

Consideration of the Toner Deformation Behavior

We consider the physical mechanism of the toner deformation from the relation between the toner deformation behavior in the fusing nip and the micro hollow after fusing.

From the results in the previous chapter, in spite of the complete deformation of the toner particles in the fusing nip, the micro hollow and the macro hollow were observed after fusing (see Figure 5). In addition, the same results were obtained in all the fusing conditions in Figure 7 and Figure 8. Thus our results showed that the image structures which crucially affect the image gloss are formed by restoring deformation occurring immediately after the fusing nip. Therefore, the main mechanism of the formation process of the micro hollow is considered as the restoring deformation phenomena.

The restoring deformation is considered to be caused by a residual stress stored inside the toner particle, which is a typical property of viscoelastic materials. This suggests that not only the temperature and pressure of the toner in the fusing nip but the cooling condition of the toner immediately after the fusing nip affects the micro hollow.

Figure 9 shows the dependence of the area ratios of the micro hollow after fusing in the visualization measurement apparatus on the temperature of the pressurizing unit (the same experimental condition as Figure 8). The higher temperature of the pressurizing unit causes the smaller deformation amount of the toners after fusing. Since in the fusing nip there is little difference in the toner deformation behavior and the toner particles are deformed completely (see Figure 8), it is inferred that the higher temperature of the pressurizing unit causes the larger restoring deformation amount of the toners after the fusing nip.

In order to explain the difference in the restoring deformation amount depending on the temperature of the pressurizing unit, we analyzed the temperature of the toners in and after the fusing nip. Figure 10 shows calculation simulation of time variation of the toner surface temperature, setting the temperature of the pressurizing unit to 40°C, 80°C, and 120°C. The result demonstrates that the higher temperature of the pressurizing unit causes the higher temperature of the toners after the fusing nip, whereas there is little difference in the toner temperature in the fusing nip.

From these results, it is considered that, in the fusing nip, the conditions of temperature and pressure of the toners are almost equal, which means that the toner deformation behaviors are almost equal, thus the residual stresses stored inside the toner particles are almost equal. It is also considered that, after the fusing nip, the conditions of temperature of the toners are different, which means that the restoring deformation behaviors are different due to the temperature dependence of the viscoelasticity of the toner, thus the restoring deformation is more promoted under the condition of higher temperature of the pressurizing unit.

Consequently, it is clarified that the higher area ratio of the micro hollow depending on the higher temperature of the pressurizing unit is caused by the difference of the restoring deformation amount due to the cooling speed of the toner temperature after the fusing nip.

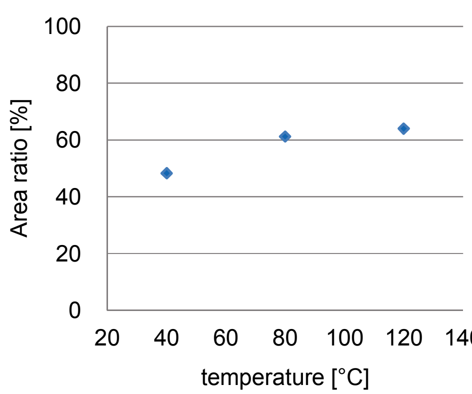

***Figure 9**. Dependence of the area ratios of the micro hollow at the toner boundary after fusing in the visualization measurement apparatus on the temperature of the pressurizing unit.*

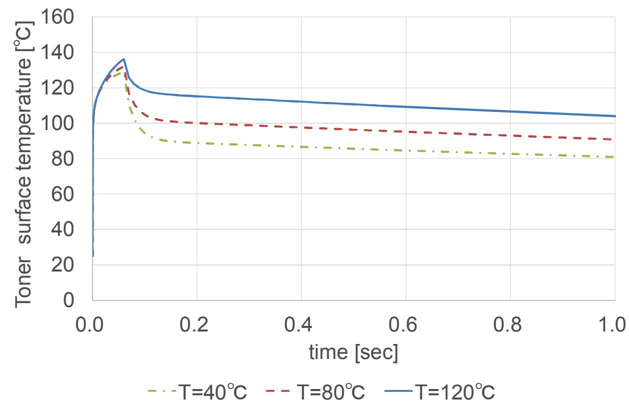

***Figure 10**. Calculation simulation of time variation of the toner surface temperature, setting the temperature of the pressurizing unit to 40°C, 80°C, and 120°C.*

Summary

In order to design the image gloss when copiers and printers are developed, it is necessary to clarify relations between the image gloss and the image structures, which are spatial structures of melted toner layers on media, and relations between the image structures and system parameters. Analysis on the melting deformation behavior of toner particles is the most important problem to be solved with respect to clarifying the relations of the latter.

In this report we newly developed a visualization measurement method for melting deformation of toner particles in a fusing nip. We successfully observed the behavior of toner particles in the fusing nip under the conditions of time variation of temperature and pressure, which simulated conditions in actual fusing system.

We analyzed the dependences of the deformation of the toners in the fusing nip on the system parameters with the method. Our results showed that toner particles are deformed completely in the fusing nip. In addition, we clarified the effect on the deformation of toner particles in the fusing nip by temperature of a heating unit and that of a pressurizing unit. Considering the results, we clarified that the dominant physical phenomenon determining the image gloss is the restoring deformation of the toner after the fusing nip caused by residual stress stored inside the toner particle, which is a typical property of viscoelastic materials.

As a challenge for the future, we plan to proceed with the analysis on the relation between the image structures and the system parameters in detail by using the visualization measurement method. We will thus make it possible to design the image gloss according to customers' preferences.

References

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[3] M. Kouno, et al. Japan Patent P2006-349742A (28, December, 2006).

Author Biography

Kenichi Hamada received his Master of Science in applied physics from the Graduate School of Engineering, 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.