Analysis of a Blade Cleaning System for Reduction in Wear Rate Variation of the Photoreceptor

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Abstract

A rubber blade cleaning system is widely used in electrophotography process to remove residual toner particles on the photoreceptor surface. In the cleaning process, wear of the photoreceptor is observed by mechanical friction with a rubber cleaning blade. On the other hand, the photoreceptor surface is refreshed by the wear and this prevents image degradation when an aged photoreceptor is used. To obtain both longer life of the photoreceptor and higher image quality, it is important not only to reduce the wear rate of the photoreceptor but also to reduce the variation in the wear rate depending on image forming conditions. In this study, the wear mechanism was investigated from the points of behaviors of a rubber blade, toner particles and additives near cleaning nip. Numerical simulation using FEM (Finite Element Method) structural analysis and DEM (Distinct Element Method) particle motion calculation were used to understand these behaviors. It was clarified that the wear of the photoreceptor mainly was caused by deposited additives released from toner surfaces and that the fluidization of toner particles affects the deposited mass of additives strongly. Based on the results, a remarkable reduction in wear variation was achieved by optimization of cleaning parameters.

Introduction

In a rubber blade cleaning system in electrophotography process, residual toner particles on the photoreceptor are removed by an action of mechanical force applied by a blade after image transfer process. The blade comes in contact with the photoreceptor at a specified normal force and it deforms by the friction force as the photoreceptor rotates. An illustration of a deformed blade is shown in Figure 1. The contact area is called a nip region and the upper stream area is a pre-nip region. In the pre-nip region, toner particles are deposited and they form a "dam."

The blade and deposited toner particles with additives rub the photoreceptor surface and then the worn photoreceptor has to be replaced regularly. The degradation of photoreceptor surface by discharge in charging process is considered to accelerate the wear rate. Reduction in wear rate is important to obtain longer life of the photoreceptor. On the other hand, cleaning process acts another important role to maintain image quality by eliminating deposited materials mechanically that are created in charging process. We investigated the cleaning system to satisfy both conflict requirements focusing on the variation of wear rate. The wear rate depends on not only cleaning parameters but also charging and image forming parameters. By the reduction in the variation of wear rate, a longer photoreceptor life may be achieved without image degradation.

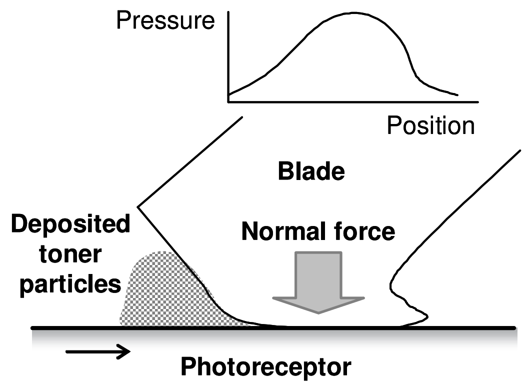

***Figure 1**. Deformed blade and deposited toner particles*

Many wear models have been reported [1, 2]. It is clear that the wear in cleaning process strongly depends on friction force between blade, toner particles, additives and photoreceptor surface, and that the reduction in variation of friction force is effective to reduce wear variation. However, in cleaning process, factors of wear and relation between wear and image forming condition are not well understood. In this study, the mechanism of wear in cleaning process has been investigated by the numerical and experimental analysis of the blade, toner particles and additives, and cleaning parameters have been discussed to reduce wear rate variation.

Wear rate variation

A result of wear rate variation is depicted in Figure 2. Relative wear rate including maximum value and minimum value (equals relatively 1.0) caused by main factors are shown in the figure. The maximum and minimum values differ at approximately 2.5 times affected by the mechanical error, image pattern, environment and other factors. Reduction in wear rate variation is effective to obtain both longer life and stable image quality because the maximum value limits photoreceptor life and the minimum value limits image quality. To reduce friction and wear rate variation, it is obviously effective to reduce both variation of normal force of blade to the photoreceptor and friction coefficient between them. That is, for example, a blade of lower stiffness and a photoreceptor with lower friction coefficient could be countermeasures.

On the other hand, inorganic additives are predicted to have more important role for damage on a resinous photoreceptor surface than a soft rubber blade. Additionally, difference in wear rate between various image patterns is also estimated to be caused by additives rather than blade.

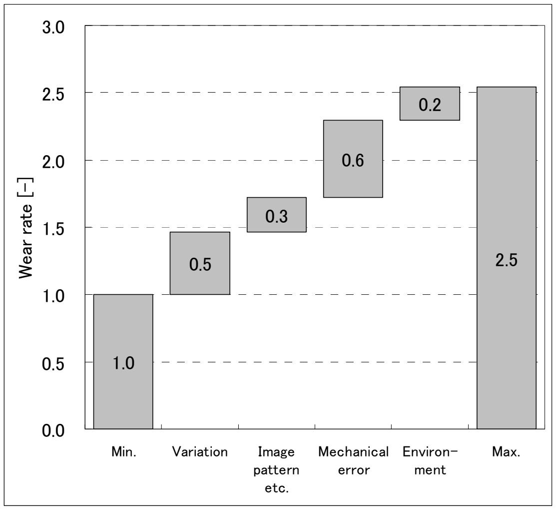

Figure 2*. Variation of wear rate*

Analysis of toner particles and additives

An experimental observation and numerical simulation of the behaviors of toner particles and additives were performed to understand the motion and spatial distribution of toner particles and additives.

Visualization

The experimental setup of observation of toner particles and additives in the pre-nip region of cleaning blade is shown in Figure 3 [3]. A cleaning blade is mounted on a transparent glass drum and the tip of the blade is observed by a high-speed camera.

Observed toner particles and additives are shown in Figure 4. Black region in the lower part of the figure indicates a blade and white horizontal line is additives. Toner particles are located in the upper area of the white line of the additives. The toner particles are transported from the upper side to the lower side with the rotation of drum and form a toner dam. In steady state, although toner particles are transported continuously, deposited toner dam does not grow up. The result suggests that the toner flow circulates from the upper to the lower then toward the direction inside of the figure. As for the additives, they are unevenly distributed in the line shape along the blade edge. It can be estimated that the additives damage the drum surface.

The visualized distribution of toner particles and additives are confirmed in the static observation in Figure 5, where deposited additives in the nearest region to the blade edge and toner particles next to these additives are shown.

Numerical simulation

Numerical simulation of toner particles and additives using Distinct Element Method (DEM) [4, 5] was performed to investigate the motions quantitatively. Prior to the DEM simulation, dynamic deformation analysis of bade was performed to understand the behavior by using a commercially available structural analysis tool with the FEM (Finite Element Method). A deformed profile of the blade is shown in Figure 6. As mentioned in Introduction and Figure 1, the tip of blade extremely deforms due to the contact to the photoreceptor, and the dynamic analysis shows that the tip also vibrates.

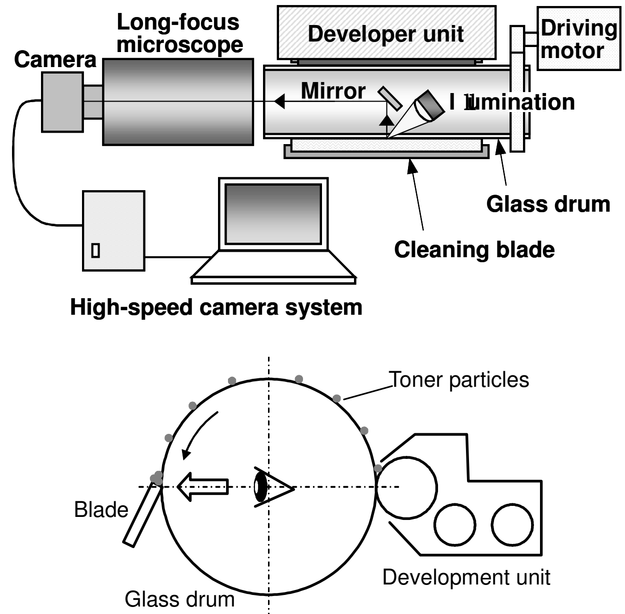

Figure 3*. Experimental setup for observation of toner particles and additives near cleaning nip*

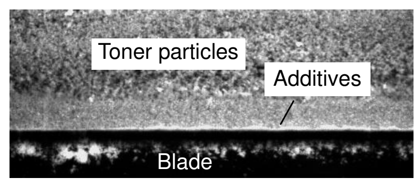

Figure 4*. Observed toner particles and additives*

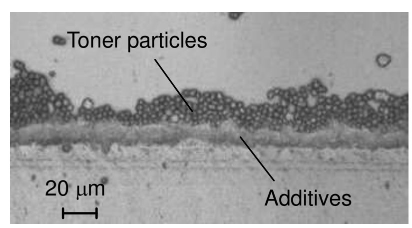

Figure 5*. Deposited toners particles and additives*

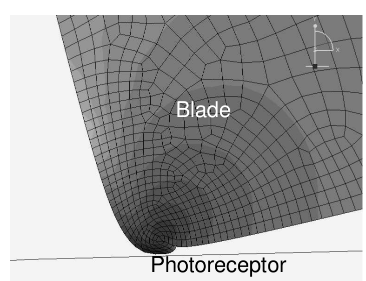

Figure 6*. Simulated deformation of rubber blade*

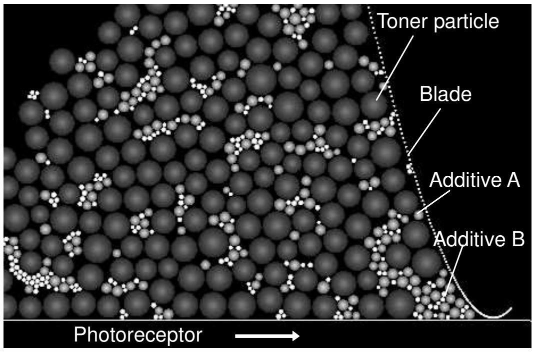

Figure 7*. Simulated result of motions of toner particles and additives*

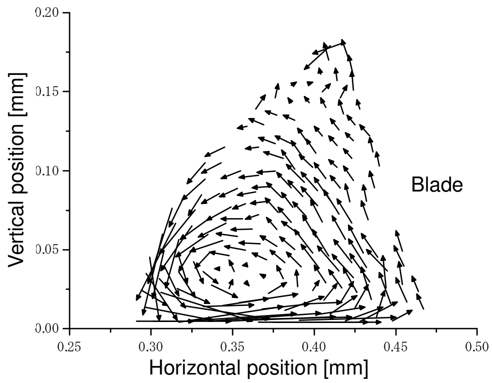

Figure 8*. Velocity vector of toner particles and additives*

In the DEM calculation, toner particles of 10 μm in diameter and two different kinds of additives with 4 and 2 μm in diameters are considered. These particles are set on the photoreceptor wall initially then the wall moves and transports them at 104 mm/s in velocity. A blade is considered as a rigid wall moving sinusoidally in horizontal direction at 3.5 kHz in frequency and 5 μm in amplitude.

A simulated result is shown in Figure 7. The figure depicts deposited toner dam and unevenly distributed additives released from toner particles at the edge of the blade wall. Velocity vectors of particles are plotted in Figure 8. It is clear in the figure that the particles in the dam circulate counter clockwise and the additives at the blade edge wall has almost zero velocity.

Deposition of additives and wear

It appears that the additives deposit on the pre-nip region of blade damage photoreceptor surface. The relation between deposited amount of additives and the wear rate was evaluated. The result is plotted in Figure 9, where the horizontal axis indicate the volume of additives per 1 μm and the vertical axis indicates the relative wear rate. The wear rate is proportional to the volume of additives, that is, the wear rate is controllable if the deposited amount of additives is controlled.

Deposition of additives is considered as a kind of size segregation and is affected by velocities of particles. Numerical result of the relation between velocities of toner particles with additives and deposited amount of additives are shown in Figure 10, where the horizontal axis indicates the average velocity and the vertical axis indicates the time rate of numbers of deposited additives at the blade wall edge. It is shown that the deposition rate is decreased with the increase in average velocity.

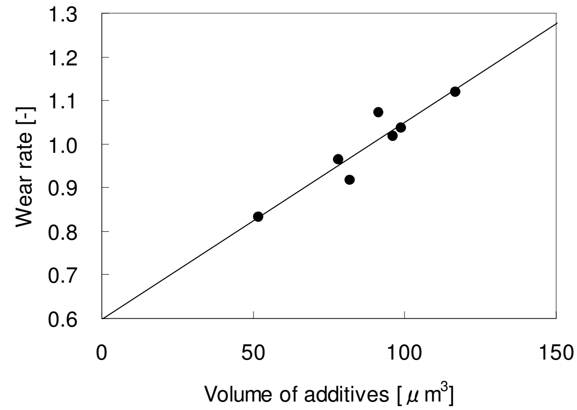

Figure 9*. Relation between wear rate and volume of deposited additives*

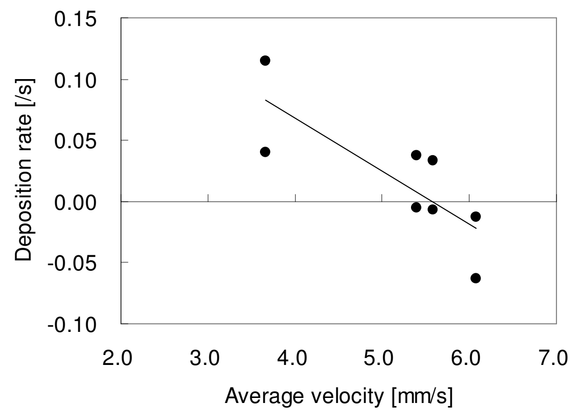

Figure 10*. Relation between deposition rate and average velocity*

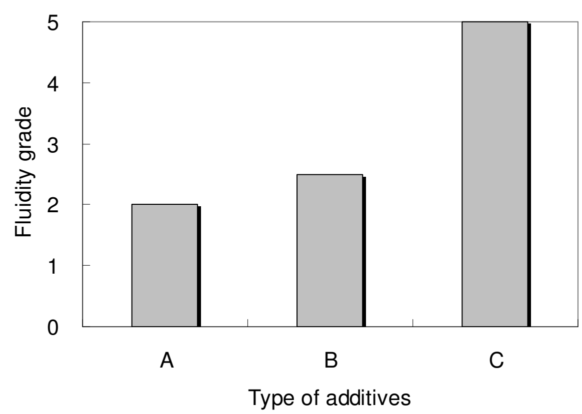

Figure 11*. Fluidity grade of toner particles and additives*

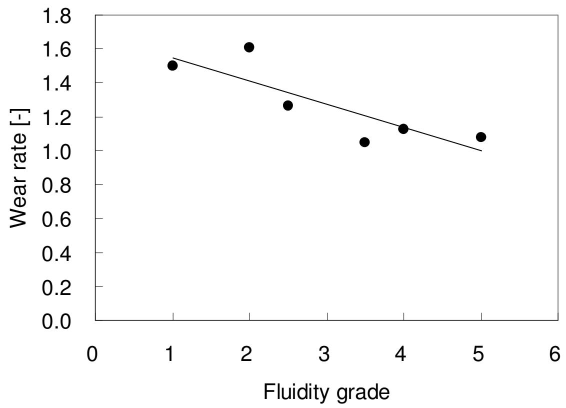

***Figure 12**. Relation between wear rate and fluidity grade of toner particles*

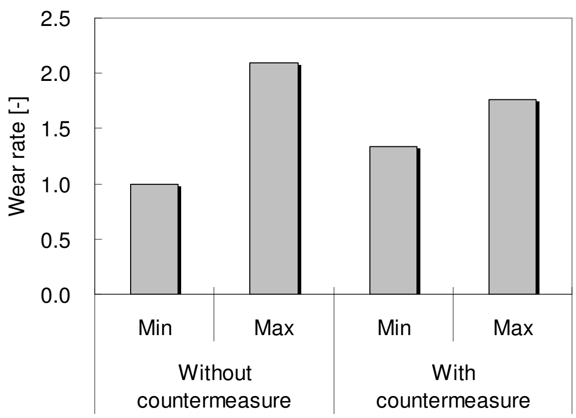

***Figure 13**. Comparison of wear rate with and without countermeasures*

In addition, the fluidity of toner particles is supposed to depend on the type and amount of additives. Qualitatively evaluated fluidity of various types of additives is plotted in Figure 11. Type A does not contain lubricant and Types B and C contain different type of lubricant. It was confirmed that the fluidity is dependent on additives type.

In summary, it is shown that if the type of additives is designed in the point of fluidity, both deposition amounts of additives at the blade edge and the wear rate can be designed appropriately. The evaluated correlation between wear rate and fluidity are plotted in Figure 12.

Reduction in wear rate variation

As a result of the investigation and discussion, the followings are effective for the reduction in wear rate variation:

1. Reduce normal force variation using a low stiffness blade,
2. Reduce friction coefficient by the reduction in surface energy of photoreceptor and/or the engagement of lubricants,
3. Reduce the variation of deposited amount of additives depending on image forming condition by designing type of additives in a point of fluidity.

The effects of these countermeasures were verified using a commercially available product of multi-functional printer. The relative wear rate with and without countermeasures are shown in Figures 13. It is shown that both the maximum wear rate and the variation of wear rate are reduced. In this case with countermeasures, the variation of wear rate was reduced to a half of the case without countermeasures.

Conclusions

In this study, the wear mechanism of photoreceptor was investigated to reduce wear rate variation. Circulation flow of toner dam and deposition of additives in the pre-nip region were clarified by the visualization and numerical simulation of toner particles and additives. The relation between additive types, fluidity and velocities of toner particles, deposited amount of additives and the wear rate were clarified. It was also clarified that the deposited additives serves an important role for wear of photoreceptor.

The countermeasures were discussed and the effects of low stiffness blade, lower friction photoreceptor and additive design were verified experimentally. As a result, remarkable reduction in wear rate variation was achieved.

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Author Biography

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